THE CTA PROJECT

Vladimir V Vassiliev, University of California Los Angeles (for the CTA Consortium)
CTA DESIGN (BASELINE)

CTA is next generation ground-based gamma-ray observatory

CTA Southern site

**Location:** Paranal grounds in the area of Cerro Armazones, Chile

**CTA-S Configuration:** 4 LSTs, 25 DC(SC)-MSTs, ~70 SC(DC)-SSTs

**Note:** Site is near the existing Paranal observatory, under management by European Southern Observatory (ESO)

**Second Option:** Aar farm, Namibia

CTA Northern site (CTA-N)

**Location:** Observatorio del Roque de los Muchachos
La Palma, Canary Islands, Spain

**CTA-N Configuration:** 4 LSTs, 15 DC(SC)-MSTs

**Note:** Existing observatory, under management by Instituto de Astrofisica de Canarias (IAC)
Site of LST prototype & existing MAGIC telescopes

**Second Option:** San Pedro Martir Observatory, Mexico
A few nanosecond flash of UV-optical Cherenkov light produced by air-showers is focused by telescope optical system onto fast multichannel cameras.

Imaging Atmospheric Cherenkov Technique
Energies down to 20 GeV → Cosmology++

Energy Resolution
≈10% → lines, features

Sensitivity & Collection Area
×10 → all topics

Field of View
≈8° → surveys, extended objects

Angular Resolution
Few arcminute → morphology

Energies up to 300 TeV → Pevatrons

Rapid Slewing
20 seconds → transients

Excess [Bin]

Time from GRB [sec]

40 60 80

60 40 20 0

z=4.3, E=30GeV, 0.1 sec time bin

Energies up to 300 TeV → Pevatrons

CTA Cherenkov Telescope Array

Slide from CTA CDR Presentation by J. Hinton
CTA PERFORMANCE (SIMULATIONS)

Highlights
10 x improved sensitivity;
8 deg FoV combined with arcmin-scale angular resolution for efficient surveys and study of extended sources;
<10% Energy resolution to resolve spectral features.
CTA IN NUMBERS

CTA is an observatory with the projected lifetime of 30 years with the initial anticipated commitment of partners to operate it for 10 years;

CTA baseline concept includes two sites one in the south (CTA-S) and one in the north (CTA-N) with the total number of telescopes exceeding 100;

CTA is being developed by the CTA consortium (CTAC) comprising from ~1300 scientists from ~180 institutions in 32 countries, which contribute ~420 FTEs;

CTA construction cost estimate is €297M + 1480 FTE-years ~ €400M;

CTA operations cost estimated to be €20M/year;
All CTA data and associated tools will be fully open after a proprietary period (~1 year);
Relative time allocation between KPSs and GO Program is under discussion;
Products delivered to a user: FITS data files, FERMI-like analysis tools, etc.

Extract from “CTA Science Case”:

Over the lifetime of CTA the majority of the available observation time at both of the CTA sites will be open time, awarded by an independent Time Allocation Committee to Guest Observer proposers from CTA member countries, based on the scientific merit. The remaining time consists of Director’s Discretionary time and, in the first decade of operations, a 40-50% share used by the CTA Consortium to deliver a Core Program consisting of a number of Key Science Projects (KSPs).
Excellent science case and the production of legacy data-sets of high scientific value to the wider community;

Clear added value of achieving science goals as KSP rather than a part of GO program, e.g. very large observing time needed, potentially systematics limited data set requiring CTAC expertise, or needed coherent approach across multiple pointings.
The priority for the CTA dark matter program is to indirectly discover the nature of dark matter with a positive observations complementary to the searches of DM at LHC and direct DM detection experiments.

The publication of limits following non-observations would certainly happen but in planning the CTA observational strategy the priority of discovery of thermal relic, WIMP, with the “natural” velocity averaged cross-section of $3 \times 10^{-26}$ cm$^3$s$^{-1}$ drives the program.

The balance between the strength of expected DM annihilation signal, its uncertainty and the strength of the astrophysical backgrounds drives the prioritization of targets.
<table>
<thead>
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<th>Year</th>
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<tbody>
<tr>
<td>Galactic halo</td>
<td>175 h</td>
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<td>Segue 1 (or best) dSph</td>
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- **First 3 years**
  - The principal target is the Galactic Center Halo (most intense diffuse emission regions removed);
  - Best dSph as “cleaner” environment for cross-checks and verification (if hint of strong signal).

- **Next 7 years**
  - If there is detection in GC halo data set (525h)
    - Strong signal: continue with GC halo in parallel with best dSph to provide robust detection.
    - Weak signal: focus on GC halo to increase data set until systematic errors can be kept under control.
  - In no detection in GC halo data set
    - Focus observations on the best target at that time to produce legacy limits.

*in case of detection at GC, large $\sigma$

| Segue 1 (or best) dSph | 150 h | 150 h | 150 h | 150 h | 150 h | 150 h | 150 h |   |   |   |
| Galactic halo | 100 h | 100 h | 100 h | 100 h | 100 h | 100 h | 100 h |   |   |   |

*in case of detection at GC, small $\sigma$

| Galactic halo | 100 h | 100 h | 100 h | 100 h | 100 h | 100 h | 100 h |   |   |   |

*in case of no detection at GC

| Best Target | 100 h | 100 h | 100 h | 100 h | 100 h | 100 h | 100 h |   |   |   |
Deep 525 h exposure in the inner 5° around Sgr A*;

Extended 300 h survey of 10°x10° region;

Produce CTA legacy data set for large range of scientific topics, which include
- GC and GC DM halo
- Understand “backgrounds” pin down VHE sources and map diffuse emission
  - Astrophysics of SNRs (multiple sources, e.g. G1.9, …)
  - Astrophysics of PWNe and Pulsars
  - Extended objects such as Central Radio lobes (central ±1°) and arc features.
Thermal DM

Thermal value of the annihilation cross-section is within CTA reach; for the first time array of IACT will be able to probe predicted WIMP parameter space.

There is significant impact of Galactic diffuse emission on the detectability of leptonic annihilation modes (through IC).
The observing strategy is based on the detection of the gradient in the rings (1° - 5°; width 1°) centered on GC with the strip |b| < 0.3° removed. Cored profiles generate weaker limits and typically large systematics.

Systematic errors have dramatic effect particularly on the detectability of the hadronic channels.
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 \( O(\alpha) \).

Owing to improved energy resolution CTA is ideally suited for search of DM annihilation spectral features, line and VIB (arguably “smoking gun” for WIMPs), in the signal from GC region.
A large number of DM sub-halos are predicted to populate the Milky Way DM halo; Dwarf spheroidal galaxies, DM clumps (no significant baryonic matter), which could potentially be detected in CTA surveys.

Dwarf galaxies (about 20 known) have long been targets favored by IACTs for indirect DM searches due to:
- Arguably most DM-dominated systems in the Universe;
- Lowest astrophysical backgrounds due to conventional VHE physics.

No VHE detection has been reported so far.
DWARF SPHEROIDAL GALAXIES
CTA SENSITIVITY

New ultra-faint dSphs discovered in DES survey in the Southern hemisphere, e.g. Reticulum II, and more such discoveries are anticipated with the start of LSST operation.

Best dSph targets for CTA will be selected on the latest knowledge prior to the observations.

dSph’s J-factor controversies:
• Possible anisotropy in the velocity dispersions;
• Possible contamination from foreground Milky Way stars (Segue I’s J-factor is particularly questionable Bonnivard, Maurin, Walker arXiv: 1506.08209)
CTA contribution to DM research (Summary)

CTA has good prospects to probe for the first time WIMP models with thermal relic cross-section and masses above 200 GeV;

Together with Fermi CTA will be able to exclude thermal WIMPs within the mass range from a few GeV up to a few tens of TeV.

For heavy WIMPs (>TeV) CTA will provide unique observational data to probe parameter space not reachable by any other experiments planned today.

CTA is complementary instrument to LHC and direct DM searches probing some non-overlapping regions of DM particle parameter space.

If DM is detected by CTA, it will also be possible to explore some properties of DM particle through the study of annihilation channels, etc.

Control of systematics in deep observations of GC halo and dSph(s) is critical for the success of these studies and will require full knowledge of the instrumentation (hence CTA KSP)

Better understanding of J factors is essential for interpretation of observational data and derivation of limits.
**Distant past:** Many ideas and simulations, multitudes of reviews (ESFRI, PASAG, NWNH, P5,..), lots of positive recommendations (in US NWNH ranked it 4th), formation of world-wide international consortium.

**Resent past:** Science performance and preliminary requirement review, Technical design report and review, Selection of Sites (S&N), CDR, CTA science case, STAC reviews, Construction of prototypes of CTA telescopes, establishment of CTA Observatory gGmbH to manage construction.

**Nearest future:** Site negotiations, founding agreement, formulation of in-kind contributions for construction, pre-production reviews, initial site infrastructure construction.
CTA LARGE SIZE TELESCOPE (LST)

OS: Prime focus, parabolic, segmented, active control.
Aperture: 23 m
Collecting area: 350 m²
Focal Length: 28 m
Mirror segment size: 1.5 m

Camera Ø: 2.3 m
Photosensor: PMT
Field of View: 4.5°
Pixel size: 0.1°

Structure: Carbon-fiber for 20 s repositioning

Prototype: construction started October, 2016 at CTA-N (La Palma); to be 1st LST.

Installation: 4 LSTs (N) + 4 LSTs (S)
CTA MEDIUM SIZE TELESCOPES (MSTs)

CTA DC-MST:
- OS: Prime focus, Davies-Cotton (DC), spherical
- M1 segmented; Aperture: 12 m
- Collecting area: 100 m²
- Focal Length: 16 m
- Mirror segment size: 1.2 m
- Camera Ø: 2.4 m
- Photosensor: PMT
- Field of View: 8°
- Pixel size: 0.18°
- Number of pixels: 1800

Prototype: Telescope structure and partially populated mirror are constructed near Berlin

CTA SC-MST:
- OS: Two-mirror, Schwarzschild-Couder (SC), aspheric, both M1 and M2 segmented;
- Aperture: 9.66 m
- Collecting area: 50 m²
- Focal Length: 5.59 m
- Mirror segment size: 1.0 m
- Camera Ø: 0.78 m
- Photosensor: SiPM
- Field of View: 8°
- Pixel size: 0.067°
- Number of pixels: 11,328

Prototype: Is under construction at FLWO in Southern Arizona.

SC-MST was proposed by the CTA-US in 2006

Installation: 25 MSTs (S) [10 DC-MSTs +15 MSTs] + 15 MSTs (N)
Both DC-MST and SC-MST use the same positioning system developed by DESY

If SC-MSTs are implemented in CTA baseline configuration they will operate nearly at the limit of IACT technology and provide the highest angular resolution.
PSCT UNDER CONSTRUCTION AT FLWO

OSS pre-assembly

M2 ½ OSS assembled

Camera frame

FEE Module

Backplane PCB

Tracking control

M1 mirror panel module assembly

pSCT assembly began at FLWO

M2 mirror panel prototypes
pSCT project is funded through MRI program of National Science Foundation.

CTA SMALL SIZE TELESCOPES (SSTs)

SST-1M
Krakow, Poland
OS: DC
Photosensor: G-APD
FoV: 9 deg
Area: 6.5 m²

SST-2M ASTRI
Mt. Etna, Italy
OS: SC
Photosensor: SiPM
FoV: 9.6 deg
Area: 6 m²

SST-2M GCT
Meudon, France
OS: SC
Photosensor: SiPM
FoV: 9 deg
Area: 6.8 m²

Demonstrated performance of the SC Optical system

Demonstrated first camera Cherenkov image in SC Optical system

Total of 70 SSTs to be installed at CTA-S
CTA-US GOALS

• Contribute to the implementation of the CTA baseline MST arrays (core energy range from sub-100 GeV to above 10 TeV);

• Complete MRI pSCT project, verify performance and undergo CTA pre-production review;

• Lead completion of the baseline MST array(s) in S or N with 15 SCTs in collaboration with international partners to significantly improve angular resolution, point source sensitivity and survey speed;

• Secure $25M construction funding shared by NSF-AST (MSIP, 2017?) and NSF-PHY;

• Support CTA operations at a commensurate level (~7%) per year for 10 years, starting ~2023;

• Secure participation of the CTA-US in CTA KSPs;

• Secure participation of the US scientific community in the CTA Open Time program.
CTA – BREAKTHROUGH SCIENCE WITHIN REACH

CTA science motivations as compelling as ever (e.g. probes natural WIMP cross-section in DM parameter space not reached by other experiments);

CTA is a single world wide effort with strong international participation;

CTA project has matured and is now on a clear trajectory for construction;

U.S. participation even at relatively small level comparing to the total CTA cost is critical for the implementation of the CTA baseline MST arrays;

U.S. is bringing to CTA years of expertise and innovation in the field to maximize scientific return of this next generation instrument;

U.S. access to the premier ground-based gamma-ray observatory of the decade through KSPs and GO programs – an opportunity not to miss!
WIMP DARK MATTER

- Weakly Interacting Massive Particles (WIMPs)
  - The weak interaction mass scale and ordinary gauge couplings give right relic DM density without fine-tuning

\[ \Omega_{\text{DM}} h^2 = \frac{3 \times 10^{-27} \text{ cm}^3 \text{s}^{-1}}{\langle \sigma v \rangle} \quad \langle \sigma v \rangle_W \sim \frac{\alpha^2}{m_{\text{WIMP}}^2} \sim 3 \times 10^{-26} \text{ cm}^3 \text{s}^{-1} \]

- Mass scale O(GeV)-O(TeV), makes them cold dark matter
- Provides benchmark for indirect detection: thermally-produced WIMPs

- WIMP candidates from a variety of BSM theories: SUSY, Extra-dimensions, ...

Roszkowski et al., arXiv:1405.4289
GAMMA-RAYS FROM DM ANNIHILATION

- Can reveal the abundance and distribution of DM
- Do not suffer from propagation effects at Galactic scale
- Characteristic features may be present in the spectrum at these energies
CTA TIME ALLOCATION MODEL

Best effort
Priority on commissioning

“Guaranteed” minimum performance
Observatory-mode operation

Science Verification
Early science

KSPs
GO Program

Deployment status
Time: First Ten Years

Relative time allocation between KPSs and GO Program is under discussion; All CTA data will be fully open after a proprietary period.