Cherenkov Telescope Array: Overview & Galactic Science

COSPAR 2018 (Pasadena, CA, USA)
Session E1.5: Origin of Cosmic Rays

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¹See https://www.cta-observatory.org/consortium_authors/authors_2018_07.html
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2005-2018: VHE Astronomy Comes of Age

• Dominant expectation (pre-1990)
  – Will find the “cosmic ray” accelerators – probably SNRs

• Reality (2018)
  – Astonishing variety of VHE \( \dagger \) emitters
    • Within the Milky Way
      – Supernova remnants
      – Bombarded molecular clouds
      – Stellar binaries - colliding wind & X-ray
      – Massive stellar clusters
      – Pulsars and pulsar wind nebulae
      – Supermassive black hole Sgr A* 
      – Diffuse & extended emission
    • Extragalactic
      – Starburst galaxies
      – MW satellites
      – Radio galaxies
      – Flat-spectrum radio quasars
      – ‘BL Lac’ objects
      – Gamma-ray Bursts

\( \dagger \) 50 GeV – 50 TeV
Imaging Atm. Cherenkov Technique

Atm. Cherenkov showers:
- V. large light pool ~250 m diameter
- Rapid time structure ~ 5 ns
- Fully calorimetric
- Fine angular structure (< 1’)

Imaging technique:
- Excellent shower reconstruction
- Large background rejection

Well-demonstrated by current instruments: H.E.S.S., MAGIC, & VERITAS

But we have not reached limit of the technique!

Further improved by:
- More views of shower
- Higher resolution images
- Wider field-of-view
Larger area → More contained events, more images

Light pool radius
$R \approx 100-150m$
≈ typical telescope Spacing

Sweet spot for best triggering & reconstruction...
most showers miss it!

✓ Larger detection Area
✓ More Images per shower
✓ Better γ-ray reconstruction
✓ Lower energy threshold
Planning for the Future

What do we know, based on current instruments?

Great scientific potential exists in the VHE domain
- Frontier astrophysics & important connections to particle physics

Imaging Cherenkov technique is very powerful
- Have not yet reached its full potential → large telescope array

Exciting science in both Hemispheres
- Argues for an array in both S and N

Open Observatory gives substantial reward
- Open data/access, MWL connections to get the best science

International partnerships required by scale/scope
- Challenges associated with putting pieces together (i.e. funding streams, communities, etc.)
The Consortium developed CTA and will construct the bulk of the CTA hardware through in-kind contributions.

June 2018

31 Countries
204 Institutes
1461 Members (503 FTE)
CTA Main Scientific Themes

Cosmic Particle Acceleration
- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Probing Extreme Environments
- Processes close to neutron stars and black holes
- Processes in relativistic jets, winds and explosions
- Exploring cosmic voids

Physics frontiers – beyond the Standard Model
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high-energy photons?
- Do axion-like particles exist?
FOCUS FOR THIS SESSION: ORIGIN OF COSMIC RAYS

**Cosmic Particle Acceleration**
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CTA Sites

CTA-North
La Palma (Spain)

La Palma, SPAIN

+30

CTA-South
ESO/Paranal (Chile)

Paranal, CHILE


detector units
650 m, 140 km east

detector units
1400 m, 500 km south

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CTA Design (S array)

Science Optimization under budget constraints

**Low energies**
- Energy threshold 20-30 GeV
- 23 m diameter
- 4 telescopes
  *(LST’s)*

**Medium energies**
- 100 GeV – 10 TeV
- 9.7 to 12 m diameter
- 25 telescopes
  *(MST’s/SCTs)*

**High energies**
- Up to > 300 TeV
- 10 km² eff. area @ 10 TeV
- 4m diameter
- 70 telescopes
  *(SST’s)*
Telescope Types

See also
https://www.cta-observatory.org/
Flux Sensitivity

Major sensitivity improvement & wider energy range
Angular & Energy Resolutions

Important for resolving morphology of Galactic sources

Important for spectral precision
Galactic Discovery Reach

Survey speed: x300 faster than current instruments

Current Galactic VHE sources (with distance estimates)

- HESS
- VERITAS
- CTA
CTA Science Program

- Open observatory
- Proposals for Guest Observer Programme – essential for major community involvement
- All data on public archive after proprietary period (typically 1 year)
- ~40% time in Key Science Projects (KSPs), carried out by CTA Consortium

KSP Programme described in *Science with CTA* document arXiv:1709.07997
(soon to be published as a book)
Key Science Projects (KSPs)

- Dark Matter Programme
- Transients (Extragalactic CRs)
- Galaxy Clusters
- Star Forming Systems
- ExGal Survey
- ExGalactic CRs
- AGN
- Galactic Centre
- Galactic Plane Survey
- LMC Survey
- PeVatrons
- KSPs most relevant for this session
Galactic Plane Survey

- First very high sensitivity survey at TeV energies
- Full-plane survey at arc-minute angular resolution
- Expect (many) 100’s of new sources, especially PWNe, SNRs and binaries → population studies (origin of CR’s)
- Great potential for discovery of new phenomena
- Detailed view of diffuse $\gamma$-ray emission

(10 years) - energy > 125 GeV
- wealth of VHE diffuse emission & sources, including the only known PeVatron
- giant particle outflow (Fermi bubbles)
- ideal region for dark matter searches
PeVatron Search

- What sources accelerate hadrons to the knee?
  - SNRs are standard paradigm, but only a handful provide strong evidence for hadron acceleration so far, and only up to ~ 10 TeV.

- Search for PeVatrons (beyond the GC) via the > 100 TeV spectrum
  - Use GPS as finder and follow-up 5 brightest sources with no cut-off
  - Electrons’ emission suppressed above 100 TeV (Klein-Nishina)
  - MWL information critical for identification
Star Forming Systems

**Key Questions:**

- What is the impact of CRs on the ISM and how do they propagate?
- What is the relation between star formation (SF) and particle acceleration in systems of all scales?

Motivated by connections seen in FIR, GeV γ-rays and, now TeV γ-rays.

Methodology: deep observations of a set of characteristic objects at different scales.
- **2017-8**: Hosting agreements, site preparations start
- **2019**: Start of construction
- Construction period of ~6 years
- Initial science with partial arrays possible before construction end
VHE $\gamma$-ray astronomy is now a major research field

Great scientific potential and the power of the atmospheric Cherenkov technique $\rightarrow$ CTA

Cherenkov Telescope Array (CTA)*

Outstanding sensitivity & resolution over wide energy range
Far-reaching key science program
Open observatory with all data released to public

Probing CR origin with CTA

- Galactic plane survey (GPS): first v. high sensitivity, high angular resolution survey at very high energies
- Galactic Centre: rich region imaged by CTA at arc-min resolution
- PeVatron search: directly identify sources producing hadronic particles at PeV energies
- Star forming systems: connection between SF and particle acceleration

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