THE “FUTURE” OF GAMMA-RAY ASTRONOMY

Patrizia Caraveo
INAF
INAF IS VERY ACTIVE IN GAMMA-RAY SPACE ASTRONOMY

Integral Swift Agile Fermi (MAGIC)
Rossi prizes

Geminga
G.F.Bignami & J.Halpern

1975

Cos-b
Exosat

BEPPO-SAX
XMM-Newton
Integral
Swift
Agile
Fermi

1993
1998
2007
2011
2012

1998

2007

2011

2012

tomorrow:

CTA
GAMMA-RAYS AS THE MISSING LINK

- photons - ground and space telescopes
- Cosmic rays
- neutrinos
- Gravitationl waves

E’ la somma che fa il totale
WHAT ABOUT THE FUTURE?

WHY IS INAF INVESTING IN CHERENKOV TELESCOPES?
The challenge of ground based $\gamma$-ray astronomy
Of Cherenkov light produced by air-showers into ns-sensitive cameras.
How to do better with IACT arrays?

- **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 gammas
    - ✓ Improved angular resolution
    - ✓ Improved background rejection power

→ More telescopes!
Major IACT Instruments

VERITAS Arizona, USA 1800 m asl
4 telescopes of 12m diameter
fully operational from fall 2007

MAGIC Canary Islands 2200 m asl
2 x 17m telescopes. Magic I in operation since
Oct 2003, Magic II first light shown at ICRC09

HESS Namibia 1800 m asl
HESS I: 4 telescopes of 12m diameter
HESS II: 28 m diameter
~200 TeV sources
tevcat.uchicago.edu/
Each object is a cosmic particle accelerator...
cherenkov telescope array
Science-optimization under budget constraints:

- **Low-energy γ**
  - High γ-ray rate, low light yield
  - Require small ground area, large mirror

- **High-energy γ**
  - Low γ-rate, high light yield
  - Require large ground area, small mirror

HOW?

- Few large telescopes for lowest energies
- ~km² array of medium-sized telescopes
- 4 LSTs
- ~25 MSTs plus ~24 SCTs extension
- Large 7 km² array of small telescopes
- ~70 SSTs
Theme 1: Cosmic Particle Acceleration
- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Theme 2: Probing Extreme Environments
- Processes close to neutron stars and black holes?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

Theme 3: Physics Frontiers – beyond the SM
- 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?
STRONG LINK BETWEEN NEUTRINOS AND GAMMA-RAYS
New emission model
Rendering of the southern Array
WHO? CTA CONSORTIUM
SPOKESPERSON WERNER HOFMANN (HEIDELBERG)
CO-SPOKESPERSON RENÉ ONG (UCLA)

May 2018

32 countries
94 parties
207 institutes
1473 members (508 FTE)
## Consortium status

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<th>Country</th>
<th>Members</th>
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### FTE evolution

**Breakdown:**
- Scientists: 901 (296 FTE)
- Engineers: 254 (121 FTE)
- Students: 231 (63 FTE)
- Administration: 23 (5 FTE)

Chair Consortium Board

Jürgen Knödlseder
WHERE? CTA SITES

- Argentina
- Chile
- La Palma

Chile - ESO
FINAL LAYOUT – SOUTHERN AND NORTHERN SIDE

North site
4 large LST
15 medium MST

Type:

- 23-m LST
- 12-m MST
- 4-m SST

North Reference Site Layout

Circles:
- 400 m
- 800 m
- 1200 m

4 LSTs, 25 MSTs, 70 SSTs
$5 \sigma$

50 hours
Science
with the
Cherenkov
Telescope
Array

published as an open access e-book by World Scientific
— *International Journal of Modern Physics D, Gravitation; Astrophysics and Cosmology*
Where are we?

TECHNICAL DESIGN & PROTOTYPING
LARGE TELESCOPE (LST)

- Optimized for Energies < 100 GeV
- 23 m diameter
- 389 m² dish area
- 28 m focal length
- 1.5 m mirror facets
- 4.5° field of view
- 0.1° pixels
- Camera Ø over 2 m
- Carbon-fibre structure for 20 s positioning
- Active mirror control
- 4 LST on South site
- 4 LST on North site
- Prototype 1st telescope
LST 1
Medium Size Telescope
Optimized for 100 GeV - 10 TeV Range

- 12 m diameter
- 100 m² dish area
- 16 m focal length
- 1.2 m mirror facets
- 8° field of view
- 0.18° pixels (~2000 pixels)
- Camera Ø over 1.5 m
- Active mirror control

25 MST on South site
15 MST on North site

MST Prototype in Berlin
Small Size Telescope (SST-1M)
Optimize for Energy range above 10 TeV

- Davies-Cotton Design
- 4m diameter single mirror
- $f/D = 1.4$
- SiPM camera with new hexagonal sensor

SST-1M Prototype in Krakow
Dual-Mirror Design

- Cost-Effective small telescopes with compact camera
- Higher-performance telescopes with big FoV

- Reduce plate size
- Reduce PSF
- Uniform PSF across FoV
SST-GATE
SST-ASTRI
end-to-end prototype
Telescopes

SST harmonization → ASTRI-like
The prototype is placed at 1725 m. on the Etna volcano @ INAF-Catania mountain station in Serra La Nave.
Why ASTRI?

ASTRI
Astrofisica con Specchi a Tecnologia Replicante Italiana

*Astrophysics with Mirrors via Italian Replication Technology*
(No mirrors, no party!)

Name given by Nanni Bignami:
ASTRI first light
Polaris
Serra la Nave, May 28th 2015
First optical validation of a Schwarzschild Couder telescope: the ASTRI SST-2M Cherenkov telescope

E. Giro¹,², R. Canestrari³, G. Sironi³, E. Antolini³, P. Conconi², C.E. Fermino⁴, C. Gargano⁵, G. Rodeghiero¹,⁶, F. Russo⁷, S. Scuderi⁸, G. Tosti³, V. Vassilev⁹, and G. Pareschi²

### Table

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SiPM pixel linear dimension: 7 mm $\rightarrow$ 11.2 arcmin
25th of May 2017

First Cherenkov light with the ASTRI camera

Press Release

CTA Prototype Telescope, ASTRI, Achieves First Light

During the nights of 25 and 26 May, the camera of the ASTRI telescope prototype (picture on the left) recorded its first ever Cherenkov light while undergoing testing at the astronomical site of Serra da Neve (Mount Neve) in Itacolomi managed by INAF-Catania. This comes not long after its optical validation was achieved in November 2016 (see story here). This accomplishment was the first optical demonstration for astronomical telescopes using the novel Schwarzschild-Couder mirror design. The ASTRI telescope is a proposed Small-Size Telescope design for the Cherenkov Telescope Array (CTA).

Although the camera was not fully configured, the ASTRI team was still able to capture its first Cherenkov light and produce beautiful images of the showers generated by cosmic rays in the Earth's atmosphere. The image below shows one of the events captured by the team. This information will allow scientists to reconstruct the direction of gamma-ray photons emitted from celestial sources (indicated by the yellow line on the image on the left). The camera is based on novel 54x4 small pixel sensors (7 mm x 7 mm) and LUTRON ASICs pixel-finder front-end electronics. The camera was specifically designed to fit on the dual mirror ASTRI telescopes for covering a large field of view of 10° x 10°.
ASTRI Prototype: Testing the camera

- Runs in December, January, May, February & March bad weather
- Technical calibrations (lots) and scientific observations (very few up to now) on going
Run January 2018

- Implemented at level of front end electronics
- Data taken in parallel to science data
Gli “ASTRI”
di Horn
L’astronomo che ha progettato il Futuro

10th of November 2018
Dedication of ASTRI prototype telescope to Guido Horn D’Arturo → ASTRI – HORN telescope
Horn d’Arturo: Italian-Jewish astronomer, inventor of the “segmented” astronomical mirrors
First detection of a Gamma Ray Source with a IACT dual-mirror telescope!!!

Energy threshold ~ 3.5 TeV
LETTER TO THE EDITOR

First detection of the Crab Nebula at TeV energies with a Cherenkov telescope in dual-mirror Schwarzschild-Couder configuration: the ASTRI-Horn telescope

S. Lombardi¹,², L. A. Antonelli¹, O. Catalano³, S. Scuderi⁴, G. Pareschi⁵, E. M. de Gouveia Dal Pino⁶, and M. Böttcher⁷ on behalf of the ASTRI Collaboration⁸

(Affiliations can be found after the references)

Received: XXX / Accepted: XXX

ABSTRACT

We report on the first detection of very-high-energy (VHE) gamma-ray emission from the Crab Nebula by a Cherenkov telescope in dual-mirror Schwarzschild-Couder (SC) configuration. The result has been achieved by means of the end-to-end 4 m diameter ASTRI-Horn telescope, operated on Mt. Etna (Italy) and developed in the context of the Cherenkov Telescope Array Observatory preparatory phase. The dual-mirror SC design is aplanatic and characterized by a small plate scale, allowing us to implement large field of view cameras with small pixel sensors and a high compactness. The curved focal plane of the ASTRI Camera is covered by silicon photo-multipliers (SiPMs), managed by an unconventional front-end electronics based on a customized peak-detector mode. The system embraces an end-to-end approach, which includes internal and external calibration systems, hardware and software for control and acquisition, and the complete data archiving and processing chain. The observations of the Crab Nebula were carried out in December 2018, during the telescope verification phase, for a total observation time (after data selection) of 24.4 h, equally divided into on- and off-axis source exposure. The camera system was still under assessment and its functionality not completely exploited. Furthermore, due to recent eruptions of the Etna Volcano, the mirror reflection efficiency was partially reduced. Nevertheless, the observations led to the detection of the source with a statistical significance of 5.4σ above an energy threshold of ∼3.5 TeV. This result provides a significant step towards the use of dual-mirror systems in Cherenkov gamma-ray astronomy. A pathfinder mini-array based on nine large field-of-view ASTRI-like end-to-end telescopes is under implementation.

Key words. Very high energy gamma rays — Ground-based gamma-ray astronomy — Imaging atmospheric Cherenkov telescopes — Dual-mirror Schwarzschild-Couder optical design — Cherenkov Telescope Array Observatory — ASTRI-Horn — Data reduction and analysis methods.
Updated Mechanical Structure

2 Telescopes

2.1 Documentation

2.2 Foundations

2.3 Mechanical Structure

2.3.1 Mount Structure
2.3.2 Optical Support Structure
2.3.3 Control Hardware
2.3.4 M2 Control Hardware
2.3.5 Mount Control SW
2.3.6 Active Mirror Control SW

2.4 Mirrors

2.4.1 Primary Mirror (M1)
2.4.2 Secondary Mirror (M2)

2.5 Cherenkov Camera

2.5.1 Thermo-mechanical Assembly
2.5.2 SIPM Assembly
2.5.3 Electronics Assembly
2.5.4 Calibration System
2.5.5 Camera Server
2.5.6 Camera Control Software

2.6 Auxillaries

2.7 Telescope Protection System

2.8 Telescope Shelter
Second leg of the journey: ASTRI mini-array

End-to-end implementation of a mini-array of 9 Telescopes
FIRST TELESCOPE AT SITE EXPECTED IN FALL 2020!
and be ready for the next
• neutrinos
• GRBs
• whatever