THE “FUTURE” OF GAMMA-RAY ASTRONOMY

Patrizia Caraveo
INAF

INAF IS VERY ACTIVE IN GAMMA-RAY SPACE ASTRONOMY

– –

Integral Swift Agile Fermi (MAGIC)

Cos-b
Exosat
1975
BEPPO-SAX
XMM-Newton
Integral
Geminga
G.F.Bignami & J.Halpern
Swift
1998
1993
Agile
2007
2012
Rossi prizes
Fermi
2011
tomorrow: CTA

GAMMA-RAYS AS THE MISSING LINK

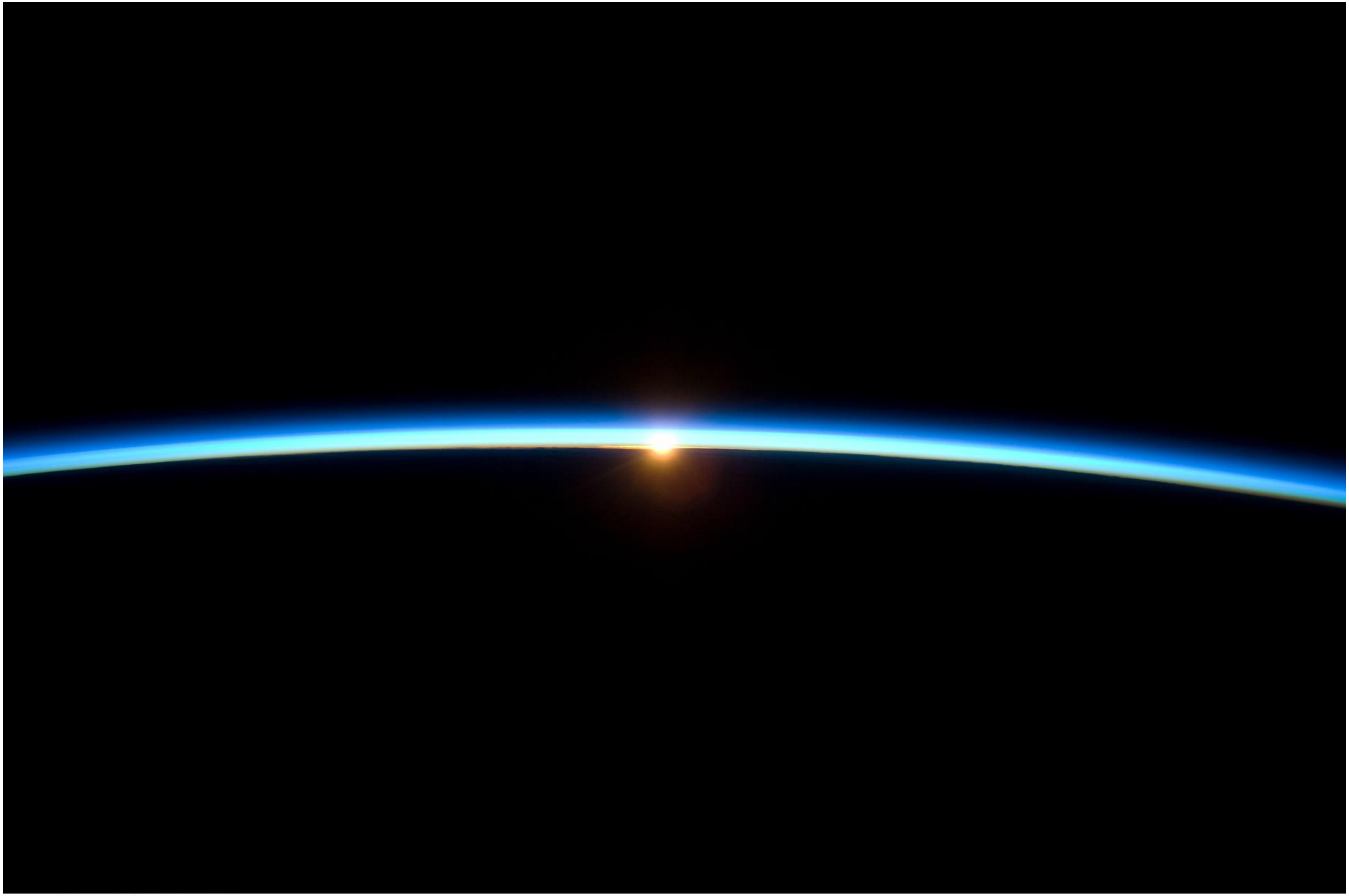
- photons- ground and space telescopes
- Cosmic rays
- neutrinos
- Gravitationl waves

E' la somma che fa il totale

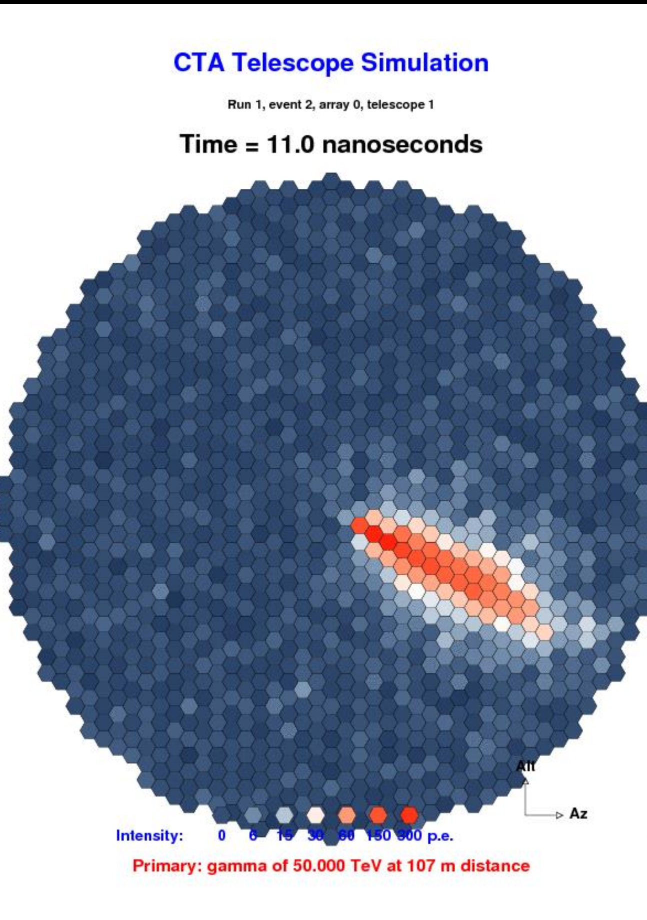
WHAT ABOUT THE FUTURE?

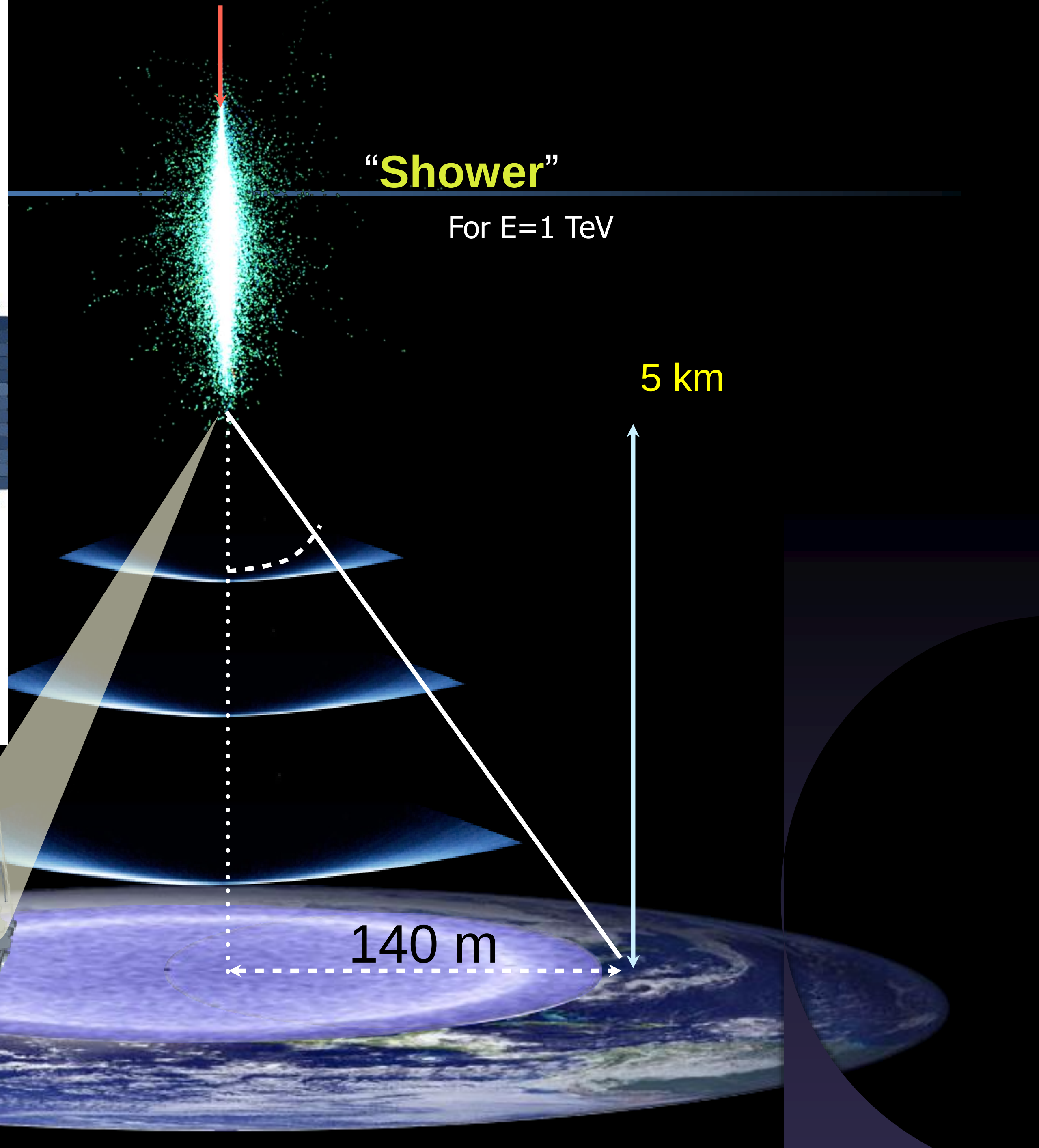
WHY IS INAF INVESTING IN CHERENKOV TELESCOPES ?

The challenge of ground based γ-ray astronomy



ISS021E031766



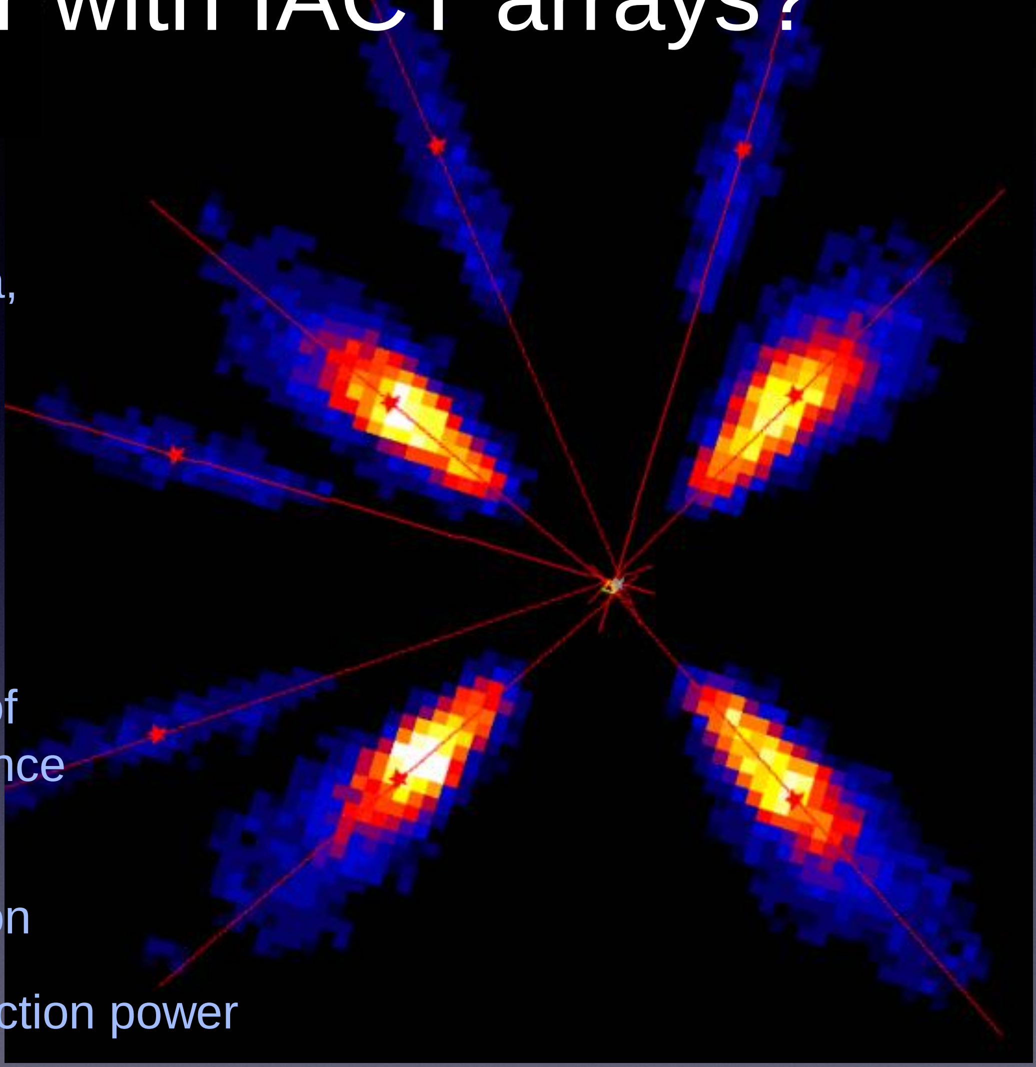


of Cherenkov light produced by air-showers into ns-sensitive cameras.

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!

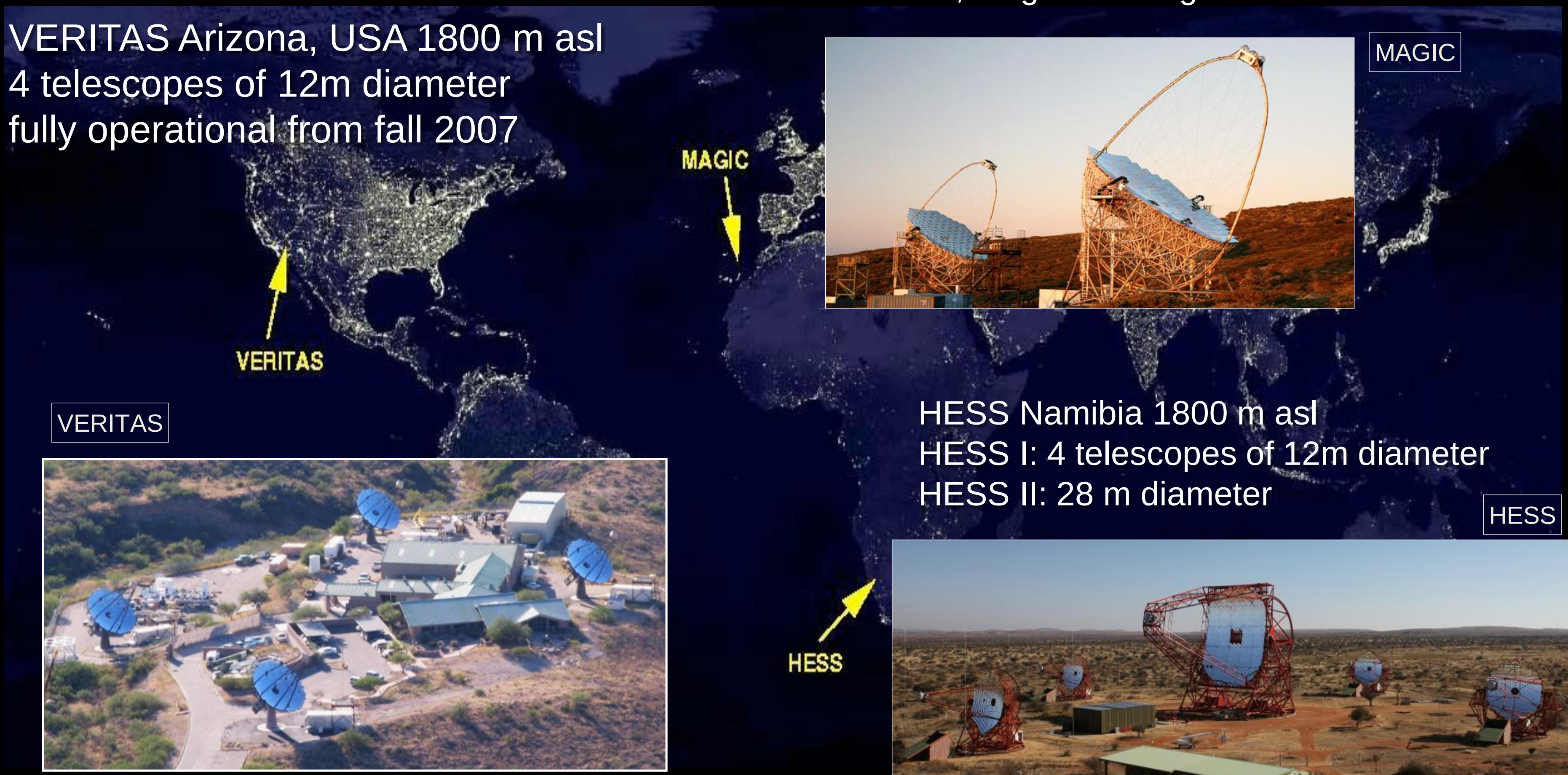


Simulation:
Superimposed images from 8 cameras

Major IACT Instruments

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

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

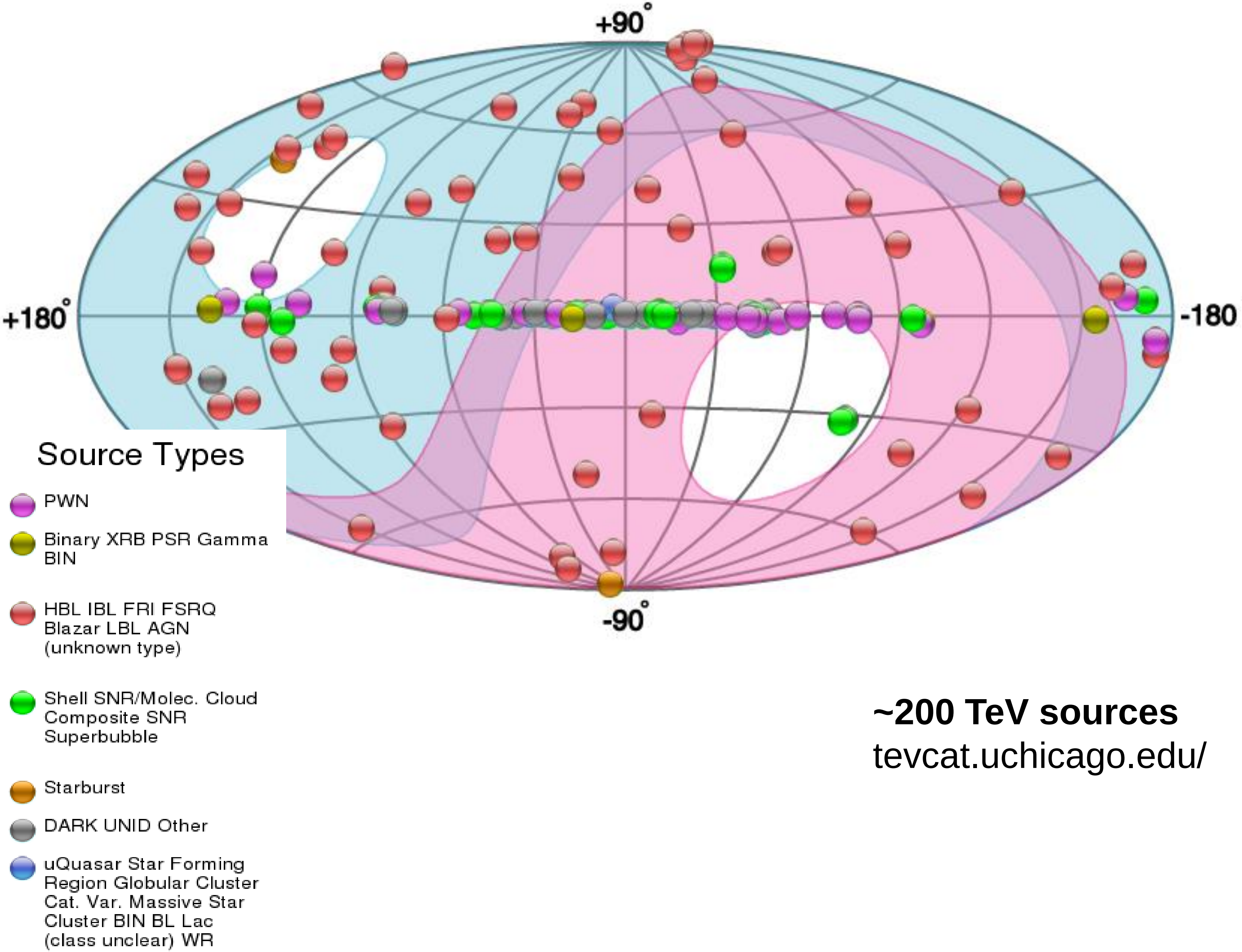


MAGIC

HESS Namibia 1800 m asl
HESS I: 4 telescopes of 12m diameter
HESS II: 28 m diameter

VERITAS

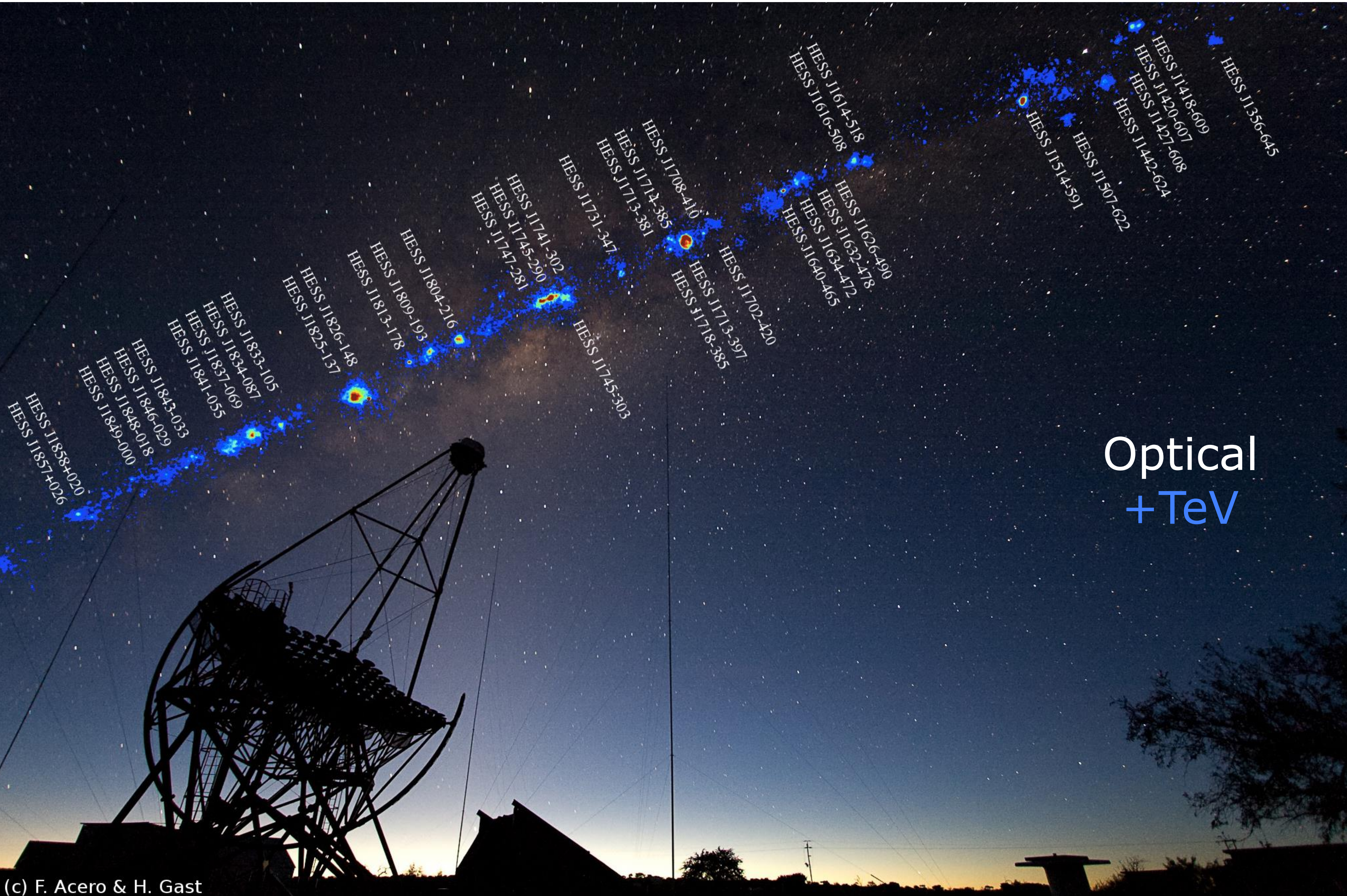
HESS



~200 TeV sources

tevcat.uchicago.edu/

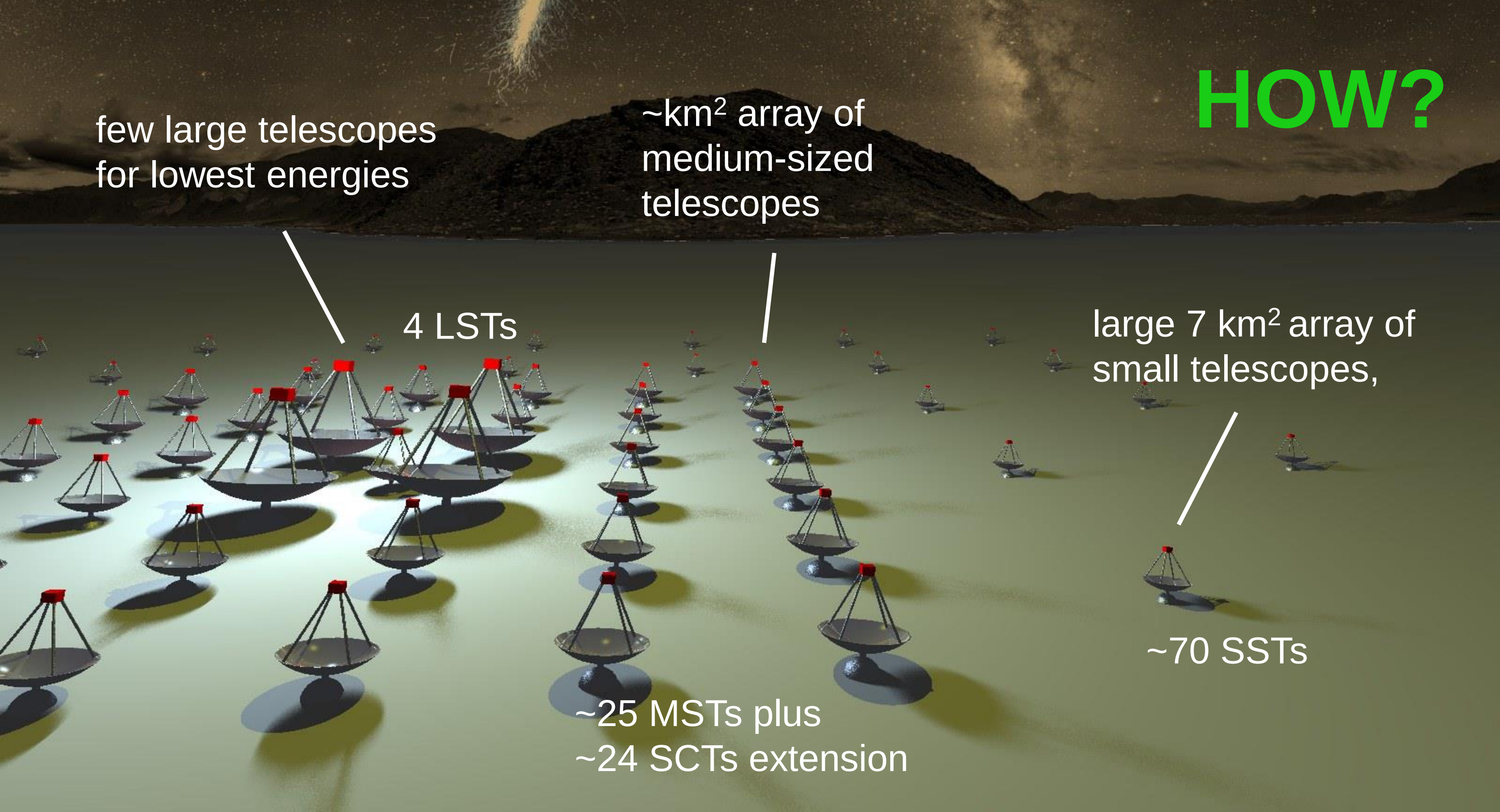
Each object is a cosmic particle accelerator…




cta
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



WHY?

Theme 1: Cosmic Particle Acceleration

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

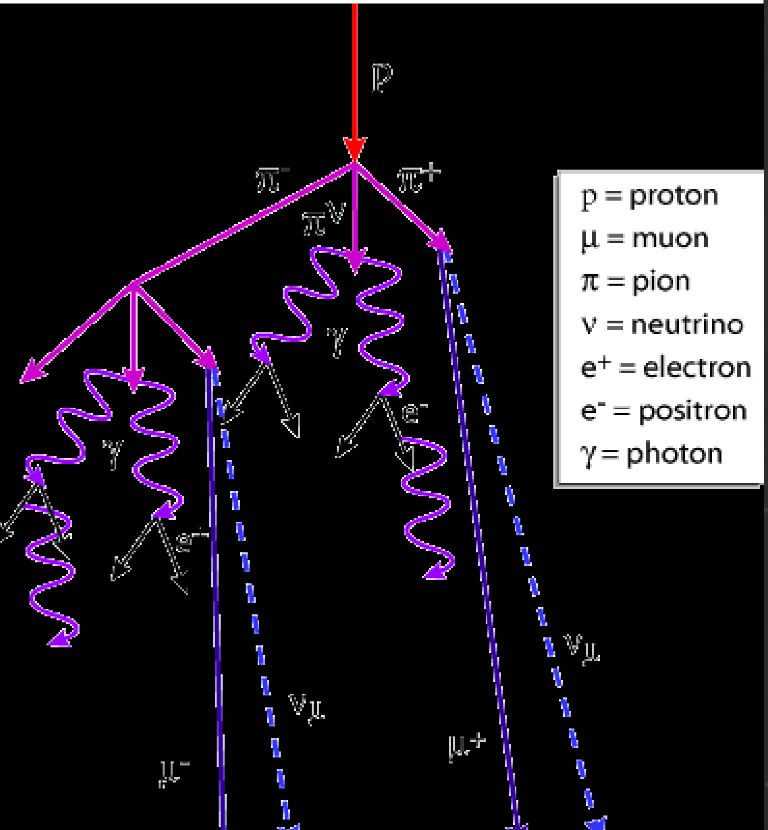
Theme 2: Probing Extreme Environments

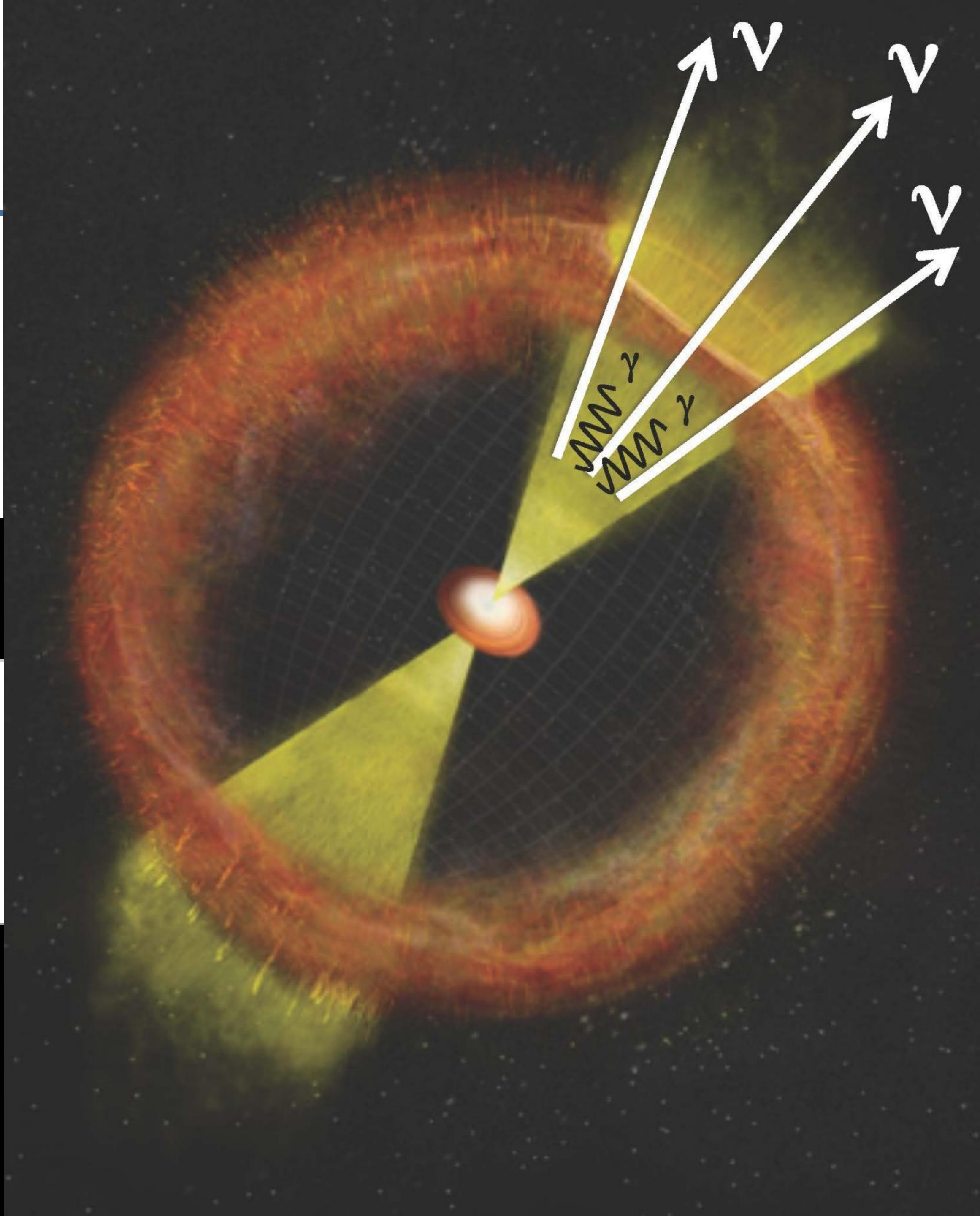
- Processes close to neutron stars and black holes?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

Theme 3: Physics Frontiers – beyond the SM

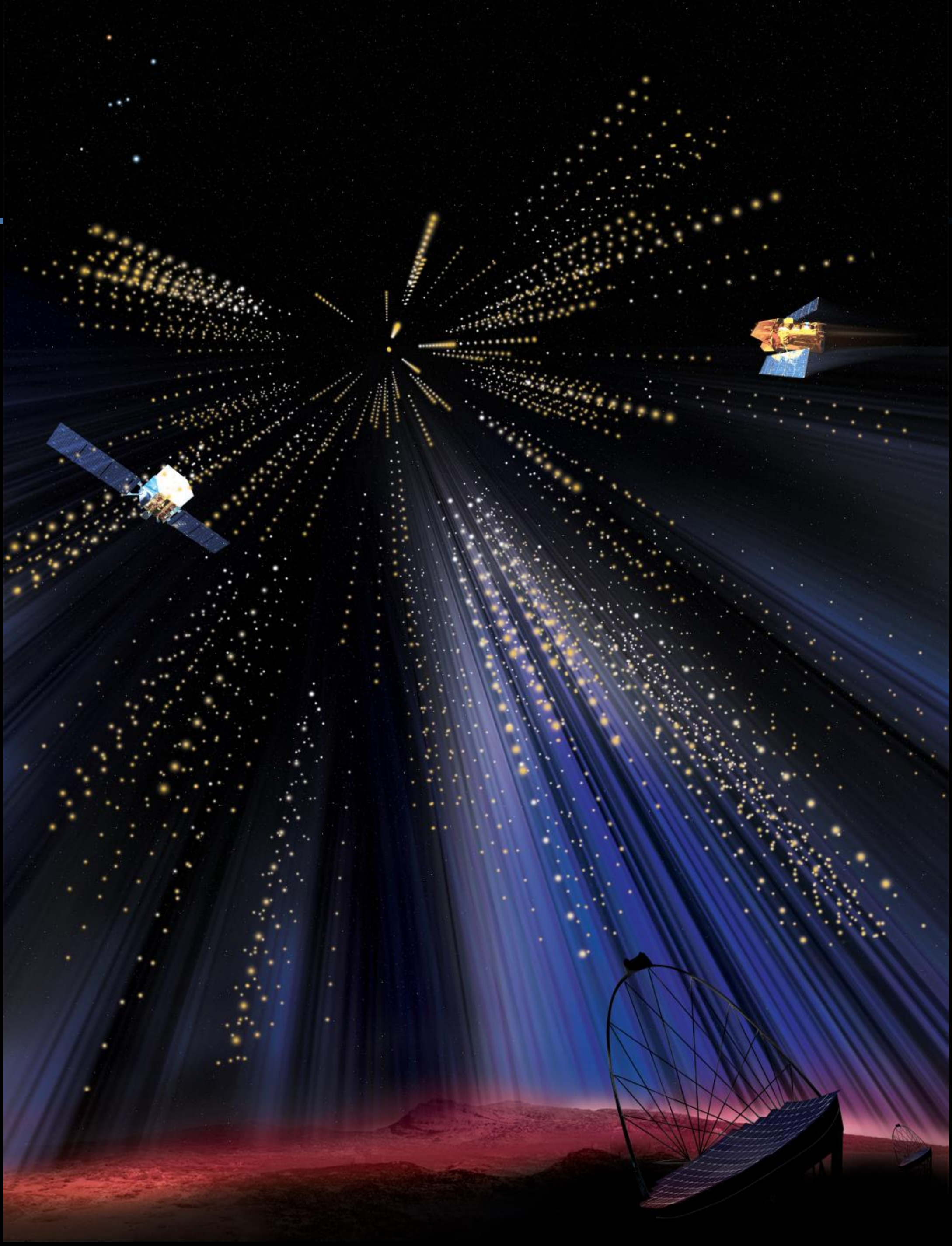
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

STRONG LINK BETWEEN NEUTRINOS AND GAMMA-RAYS

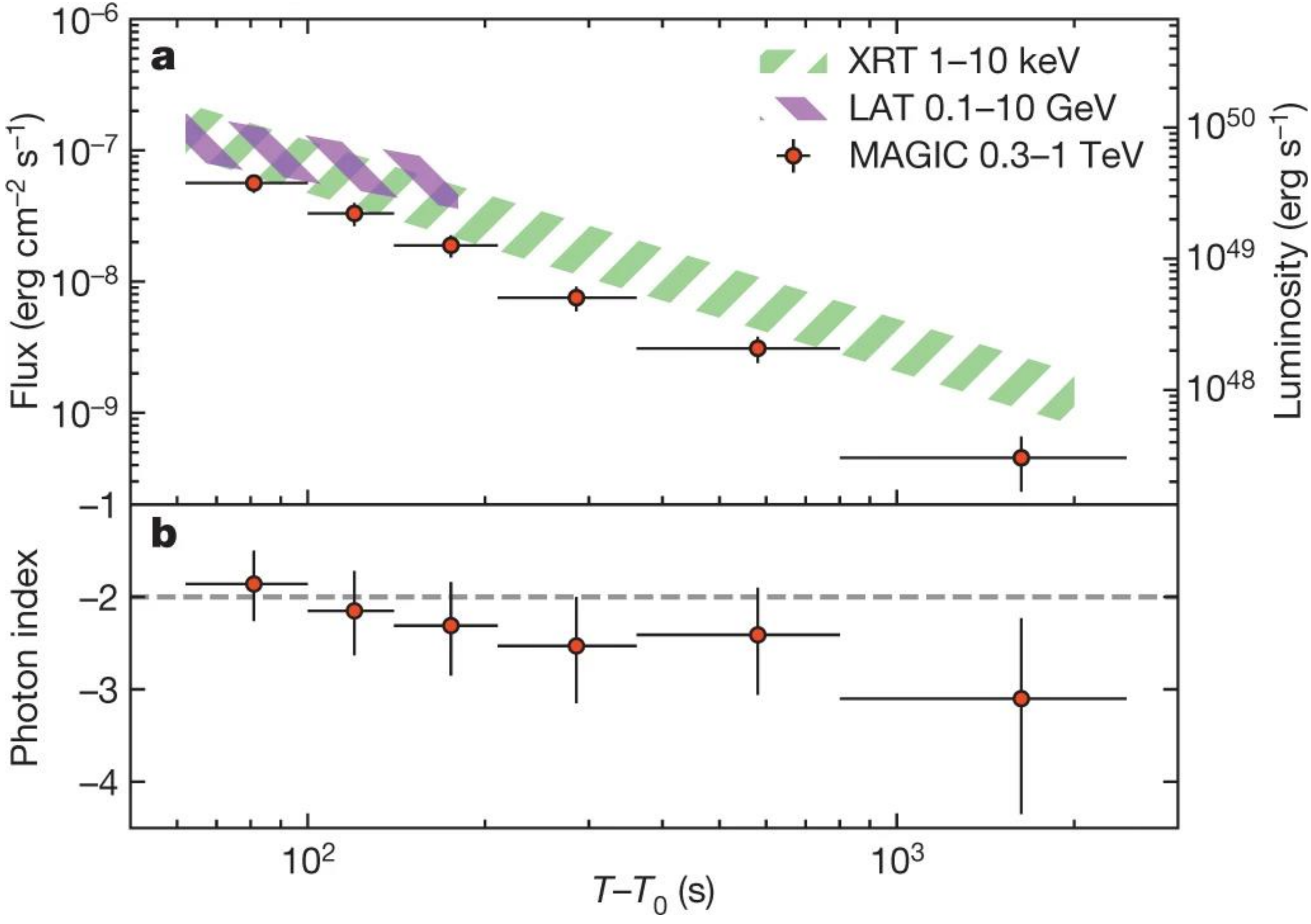




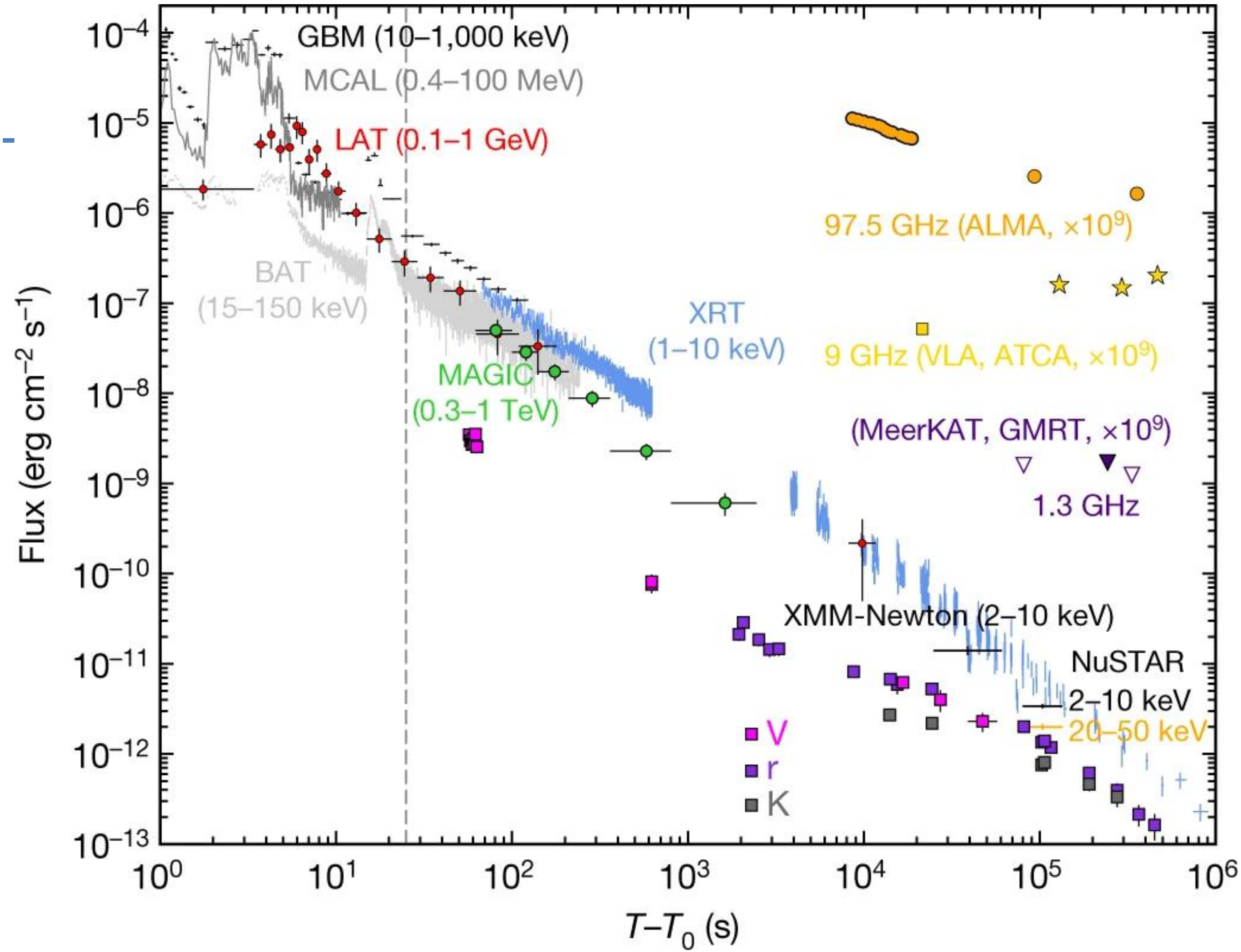
NEWS



GRB 190114C

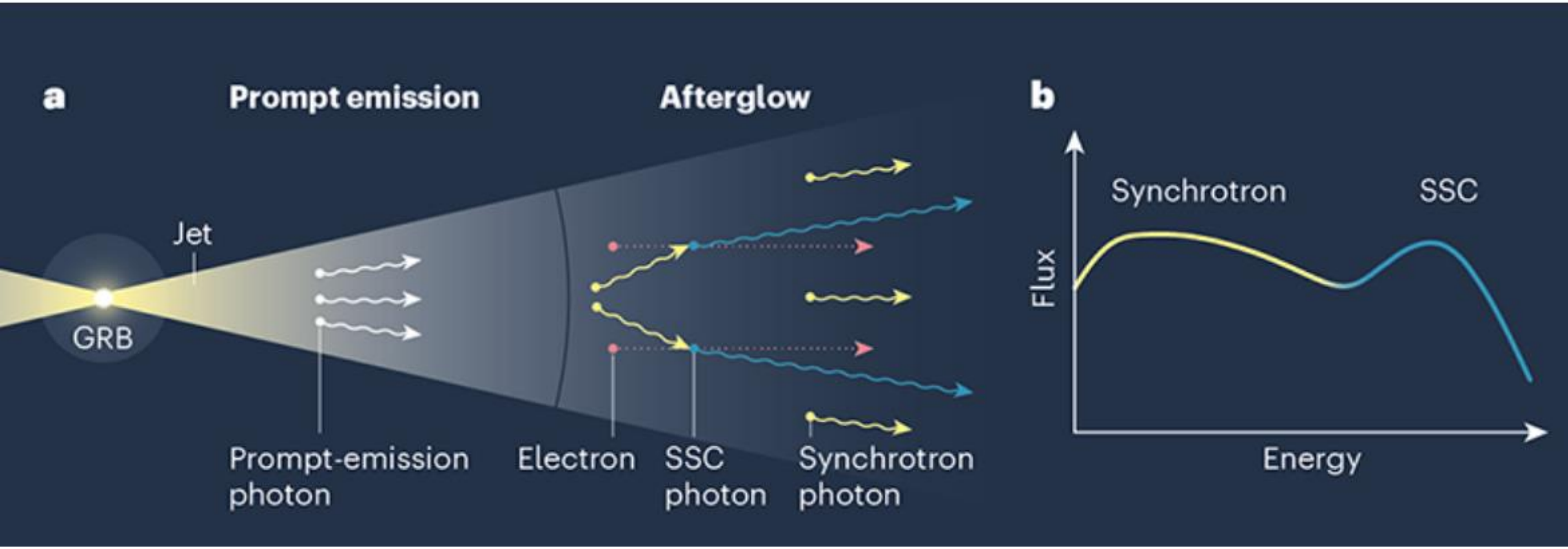


a
XRT 1–10 keV
LAT 0.1–10 GeV
MAGIC 0.3–1 TeV
Flux (erg cm^{-2} s^{-1})
Luminosity (erg s^{-1})
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{50}
10^{49}
10^{48}
b
Photon index
–1
–2
–3
–4
10^2
10^3
$T–T_0$ (s)

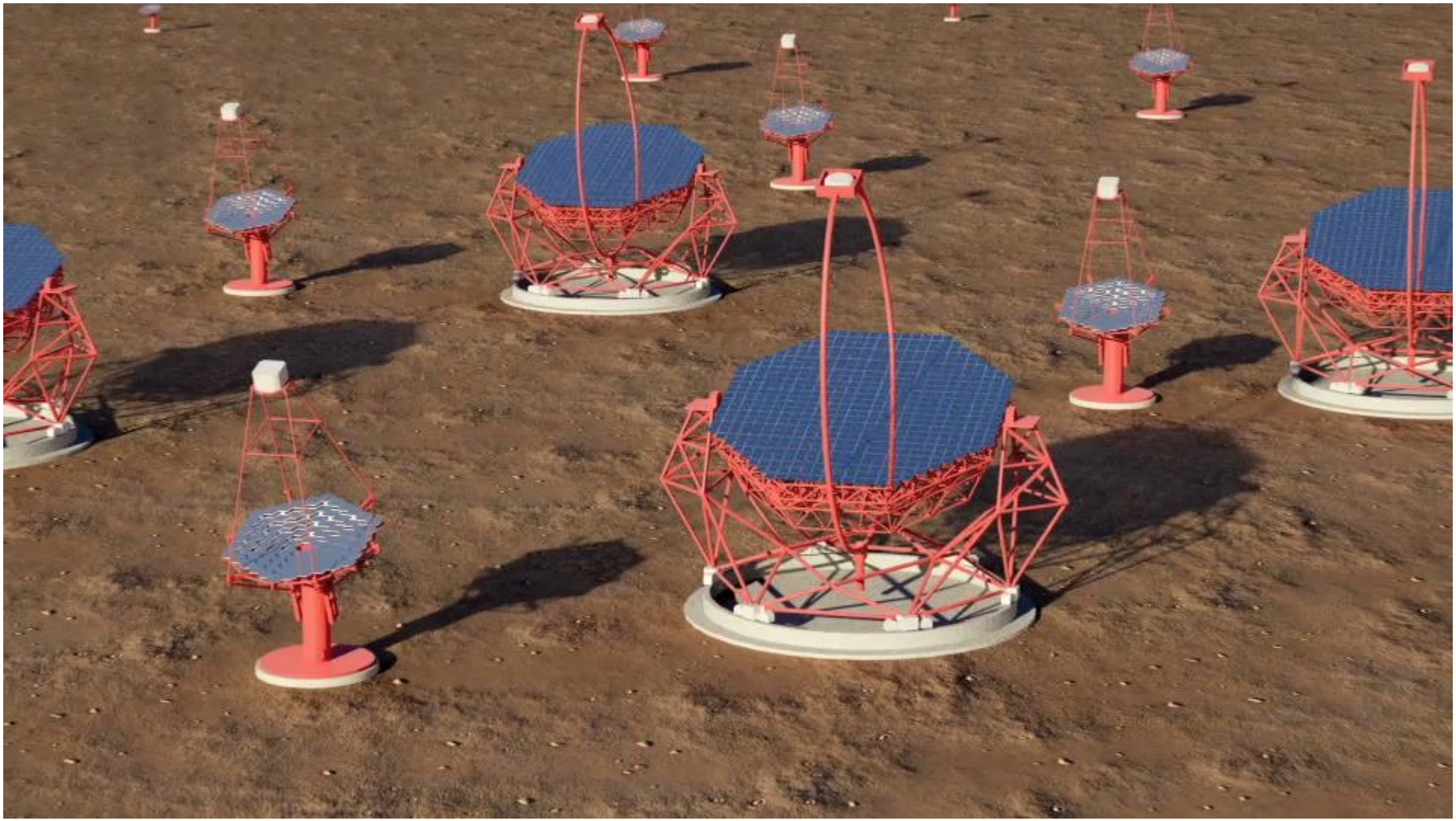


GBM (10–1,000 keV)
MCAL (0.4–100 MeV)
LAT (0.1–1 GeV)
BAT
(15–150 keV)
XRT
(1–10 keV)
MAGIC
(0.3–1 TeV)
97.5 GHz (ALMA, ×10^9)
9 GHz (VLA, ATCA, ×10^9)
(MeerKAT, GMRT, ×10^9)
1.3 GHz
XMM-Newton (2–10 keV)
NuSTAR
2–10 keV
20–50 keV
V
r
K
Flux (erg cm^−2 s^−1)
T–T0 (s)

New emission model

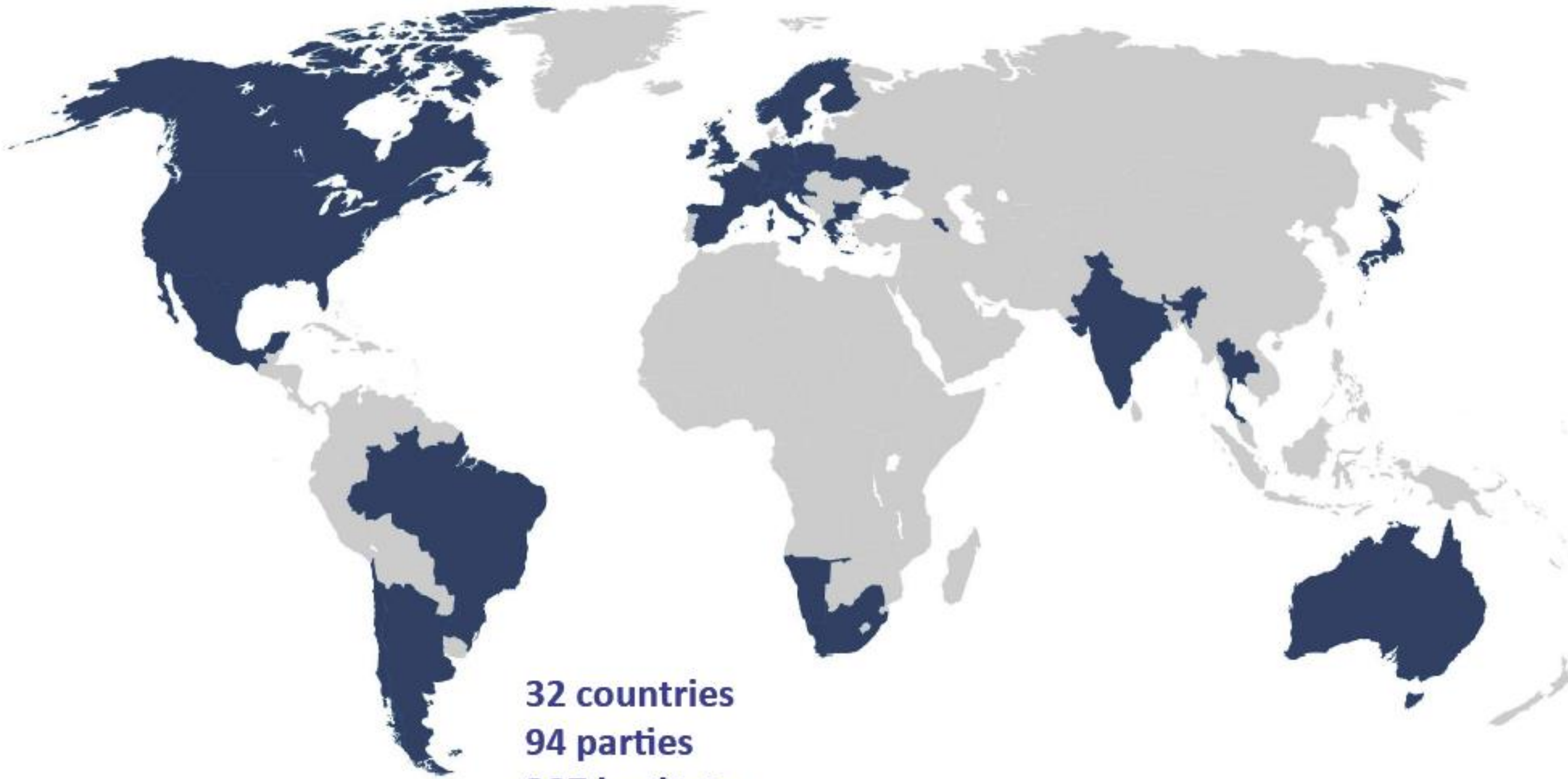


Rendering of the southern Array



WHO? CTA CONSORTIUM

SPOKESPERSON WERNER HOFMANN (HEIDELBERG)
CO-SPOKESPERSON RENÉ ONG (UCLA)



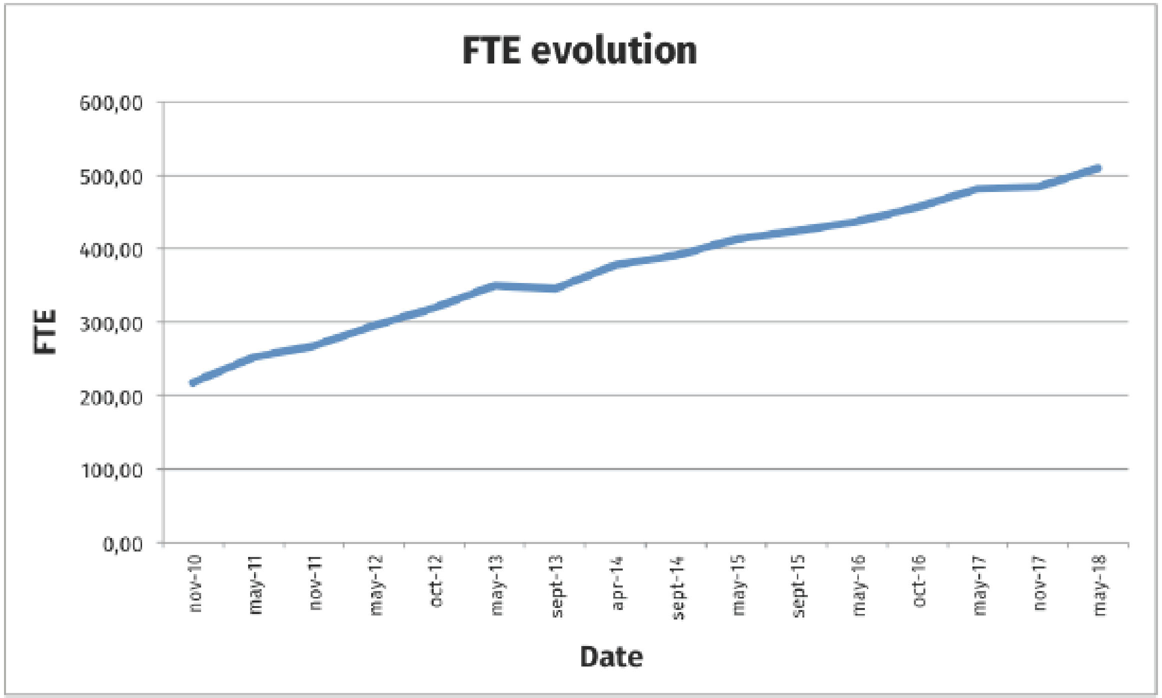
32 countries
94 parties
207 institutes
1473 members (508 FTE)

May 2018

cta

Consortium status

Country	Members	FTE	FTE (%)
Italy	268	101,6	20,0%
Germany	204	87,2	17,1%
France	221	86,4	17,0%
Spain	112	50,4	9,9%
Japan	124	37,4	7,4%
USA	74	22,0	4,3%
Poland	60	18,1	3,6%
United Kingdom	57	17,0	3,3%
Switzerland	27	16,7	3,3%
Brazil	46	14,6	2,9%
Chile	49	7,6	1,5%
Czech Republic	29	6,8	1,3%
Netherlands	13	4,8	0,9%
South Africa	19	4,2	0,8%
Australia	25	3,4	0,7%
Croatia	12	2,9	0,6%
Ukraine	9	2,8	0,5%
Norway	7	2,5	0,5%
Slovenia	10	2,5	0,5%
Greece	23	2,3	0,5%
Mexico	10	2,3	0,5%
Austria	9	2,2	0,4%
India	10	2,2	0,4%
Canada	6	2,0	0,4%
Thailand	5	1,9	0,4%
Argentina	10	1,7	0,3%
Ireland	10	1,4	0,3%
Sweden	6	1,2	0,2%
Finland	5	1,1	0,2%
Armenia	4	0,9	0,2%
Bulgaria	7	0,6	0,1%
Namibia	2	0,3	0,1%



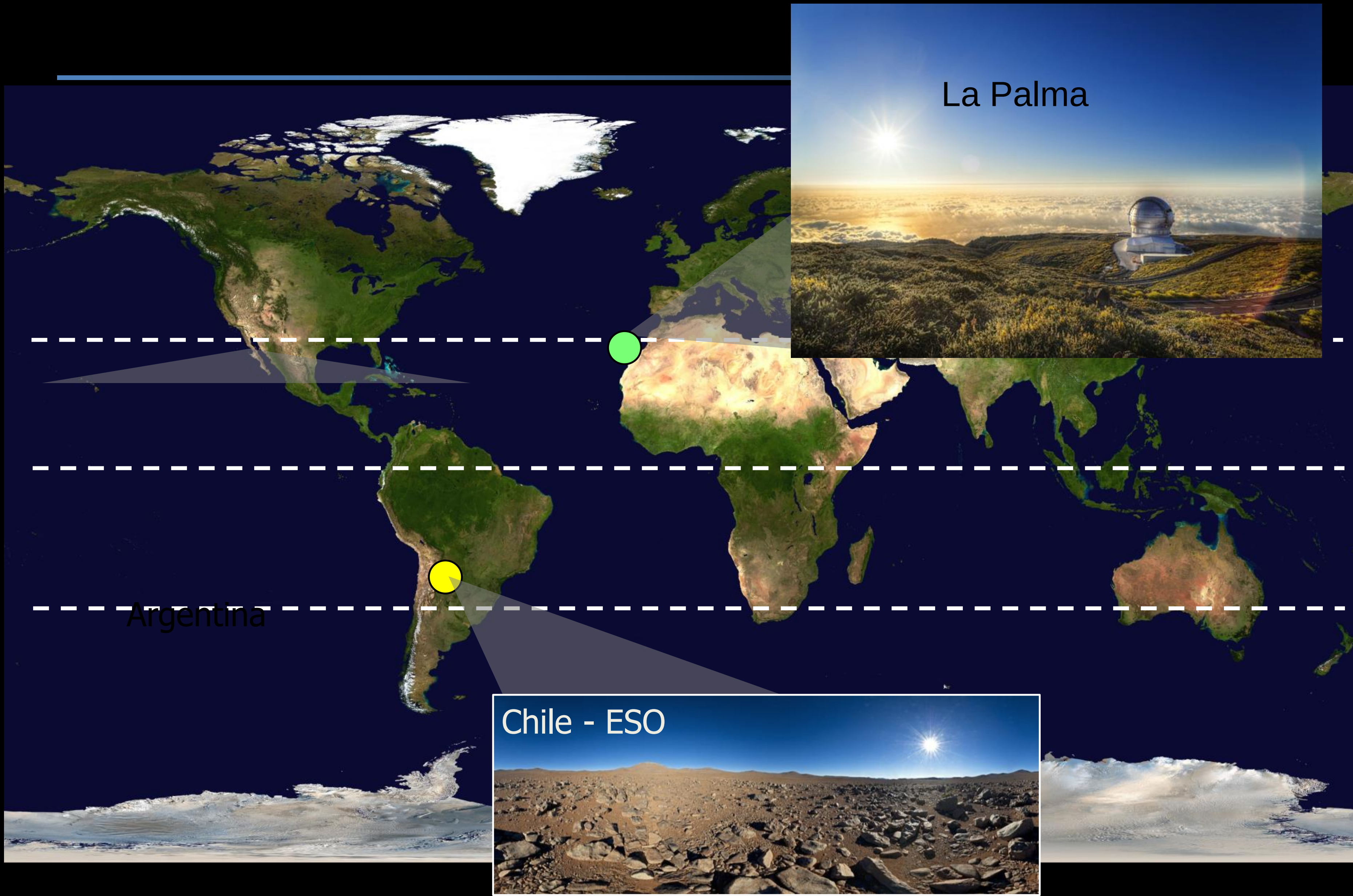
Breakdown:

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

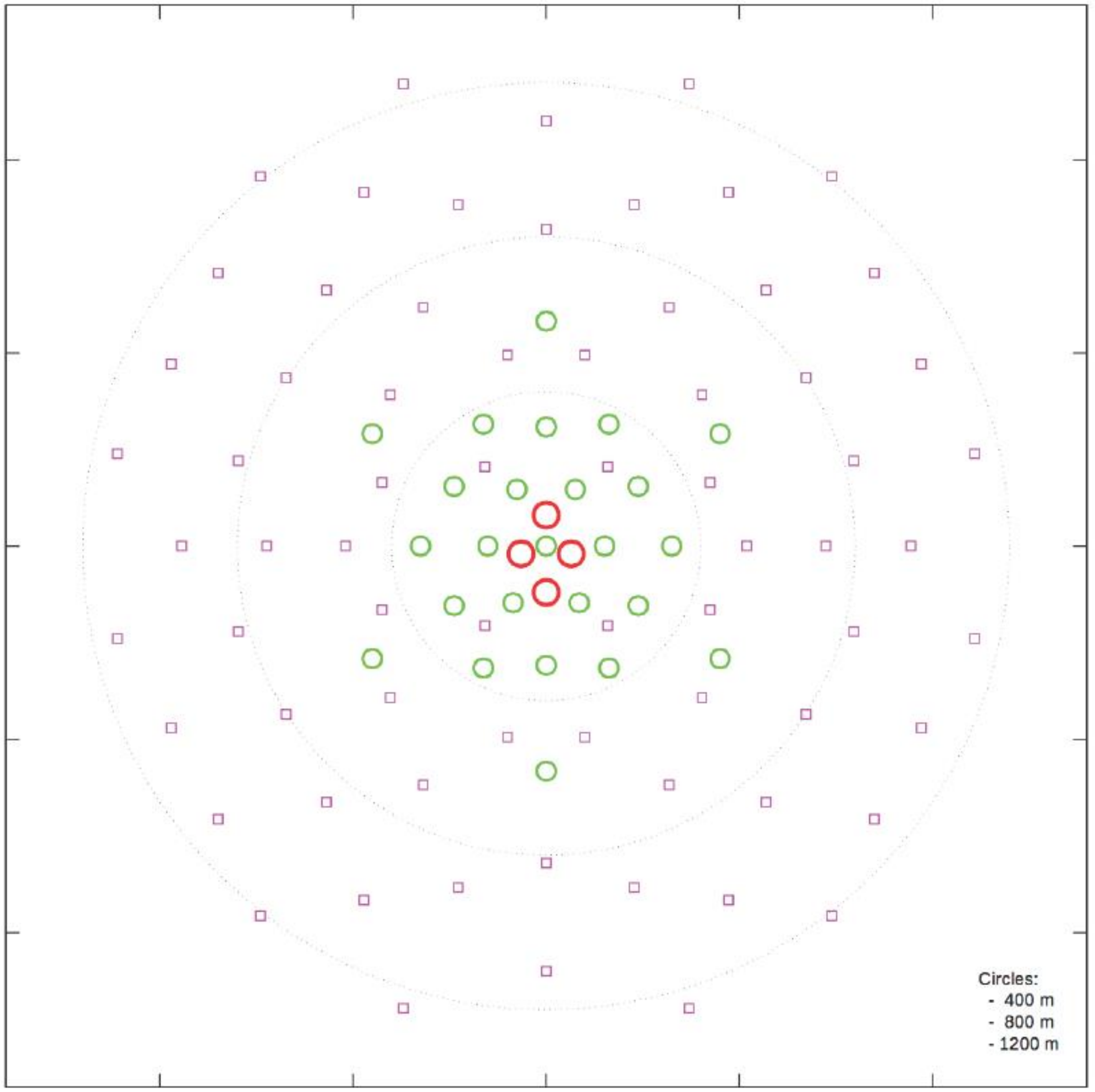
Chair Consortium Board

Jürgen Knödlseder

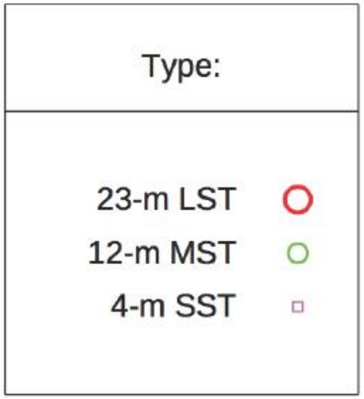
WHERE? CTA SITES

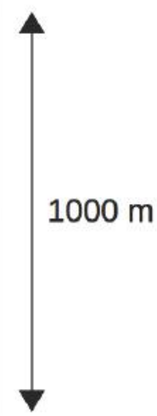


FINAL LAYOUT – SOUTHERN AND NORTHERN SIDE



4 LSTs, 25 MSTs, 70 SSTs

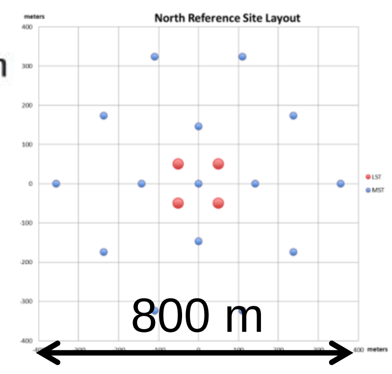


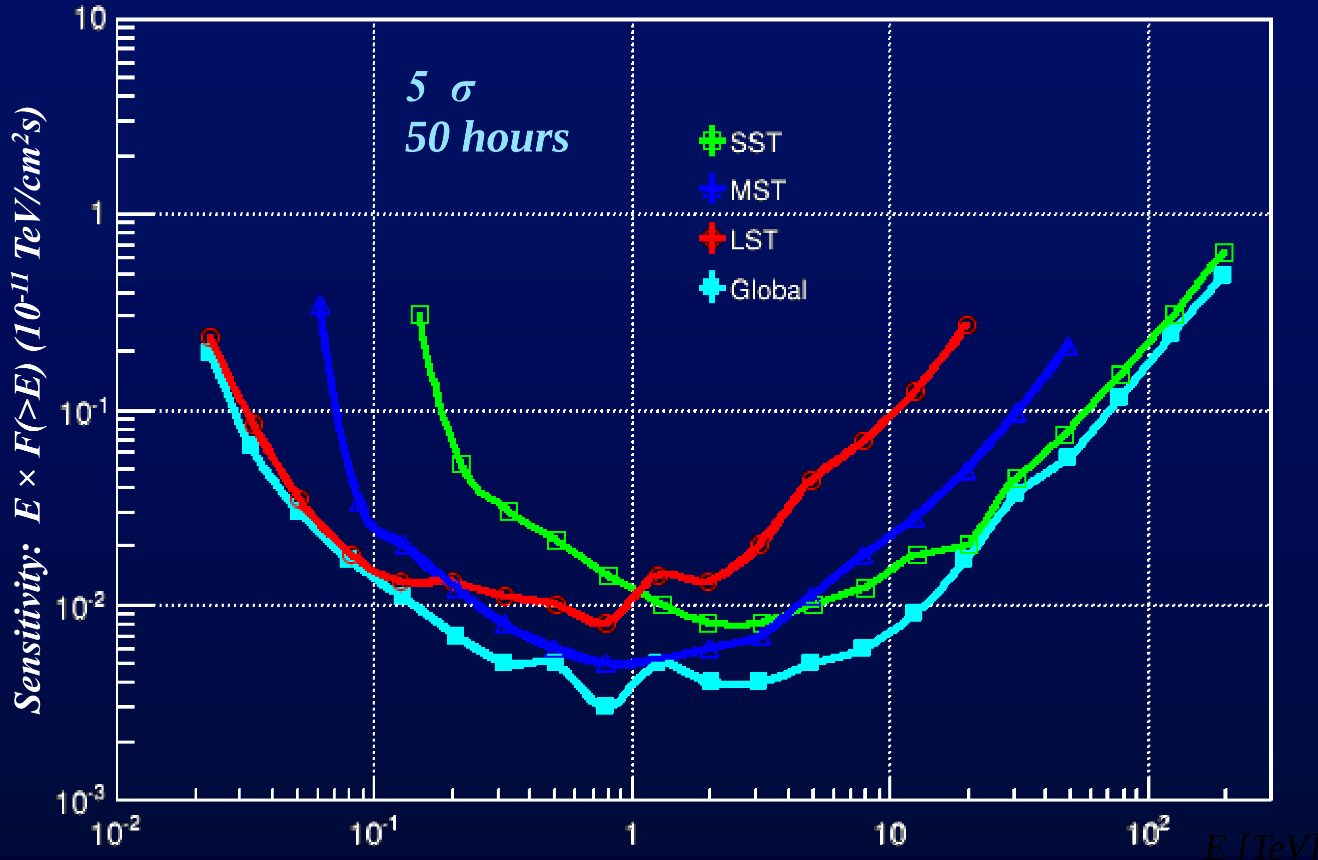


North site

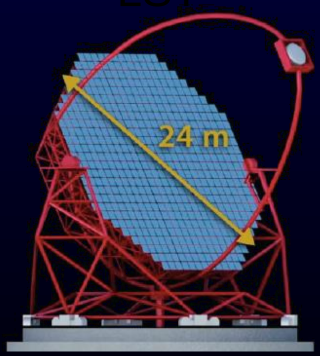
4 large LST

15 medium MST

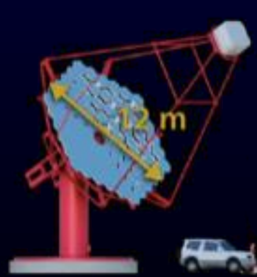



5 σ
50 hours
SST
MST
LST
Global
Sensitivity: E × F(>E) (10^-11 TeV/cm^2 s)
E [TeV]
10
1
10^-1
10^-2
10^-3
10^-2
10^-1
1
10
10^2

LST


24 m

MST


12 m

SST


4 M

Contents

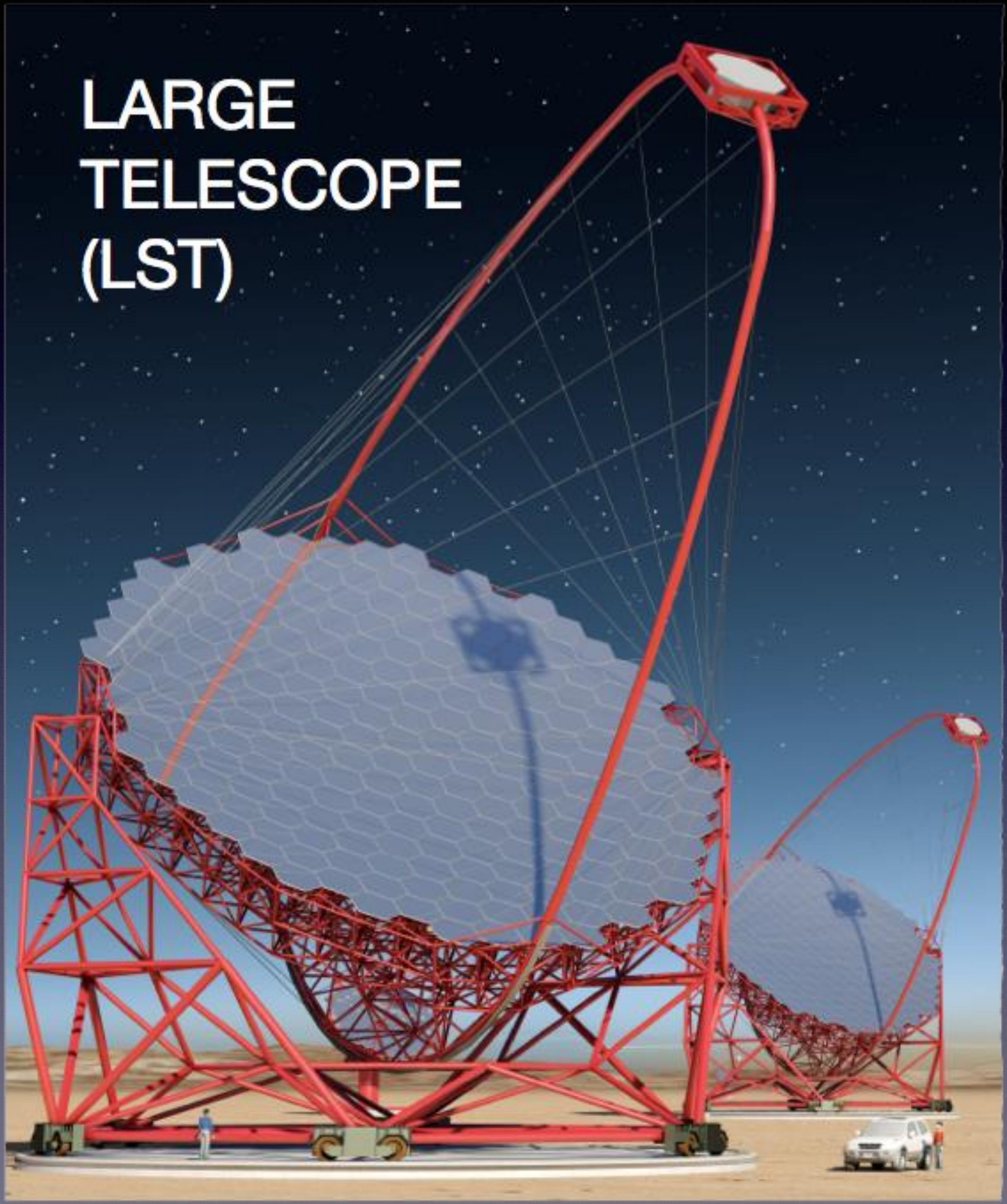
Chapters and corresponding authors:

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



Optimized for Energies < 100 GeV

23 m diameter

389 m^2 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

cta cherenkov telescope array

LST 1

Medium Size Telescope

Optimized for 100 GeV - 10 TeV Range

MST Prototype in Berlin

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

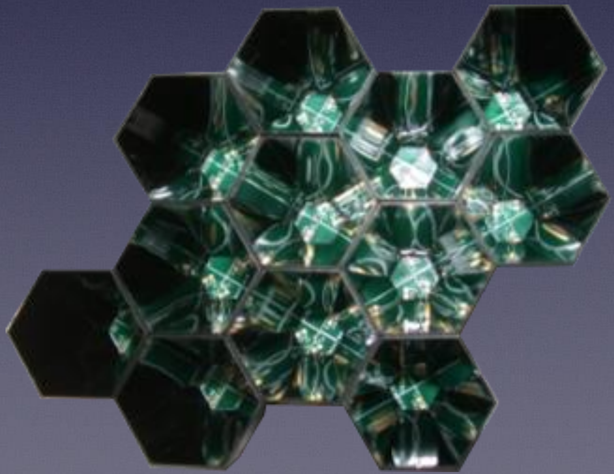
15 MST on North site

cta cherenkov telescope array

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

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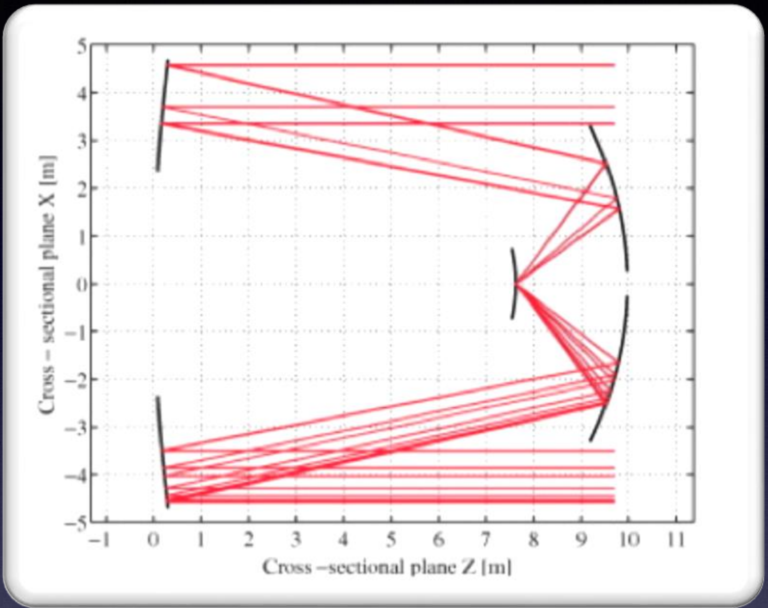
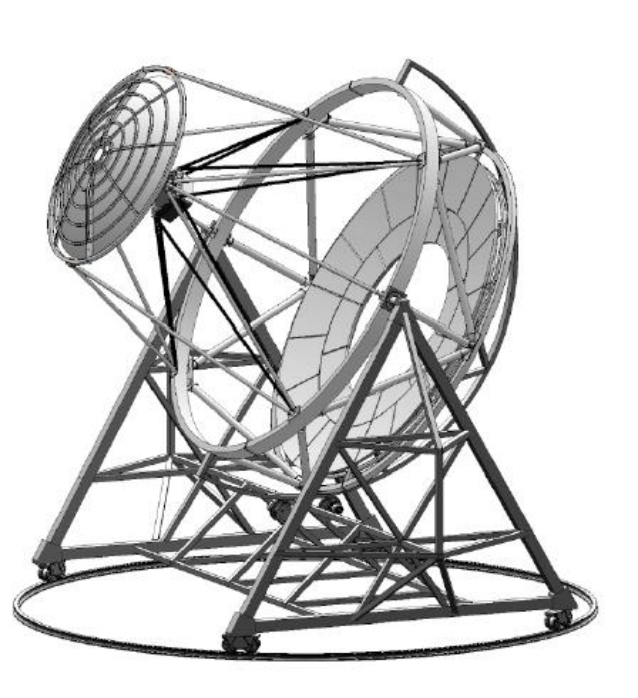
cherenkov telescope array

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**

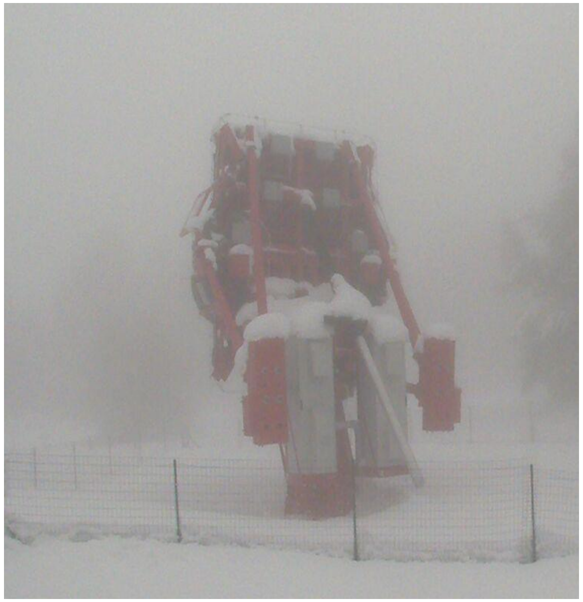
SST-GATE

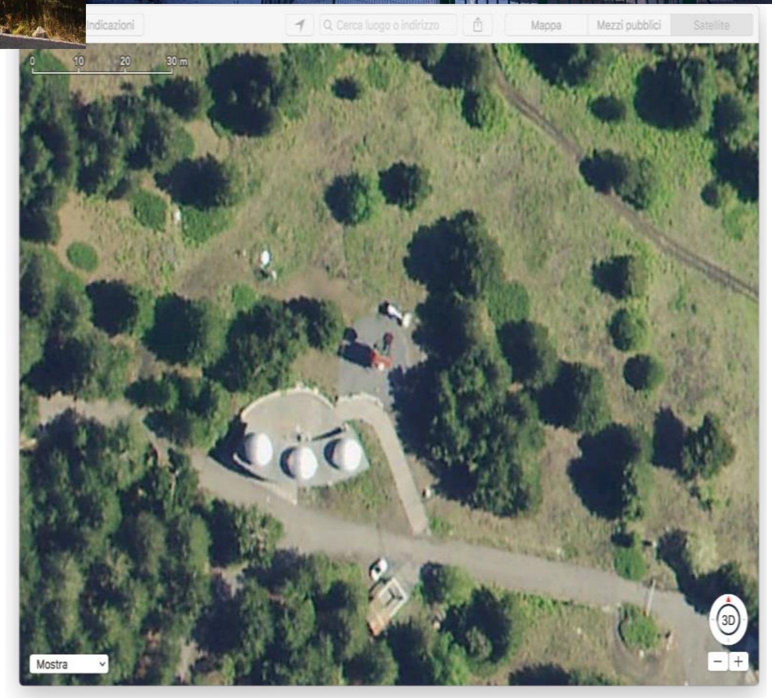
SST-ASTRI
end-to-end prototype

SST harmonization → ASTRI-like

ASTRI : the telescope @ Serra La Nave

The prototype is placed at 1725 m. on the Etna volcano @ INAF-Catania mountain station in Serra La Nave



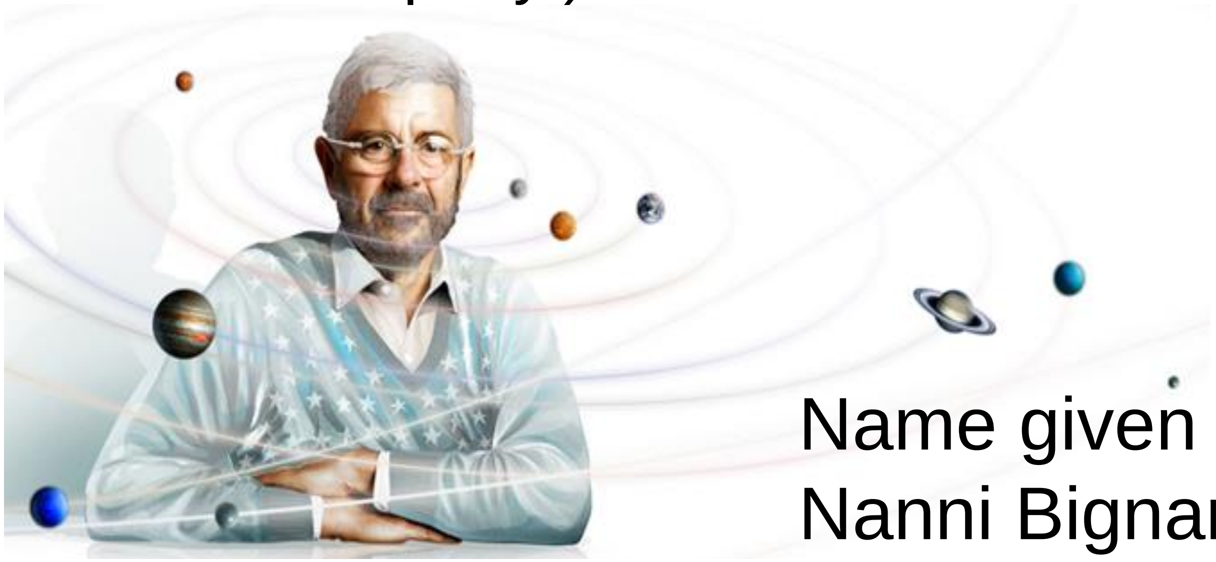


ASTRI

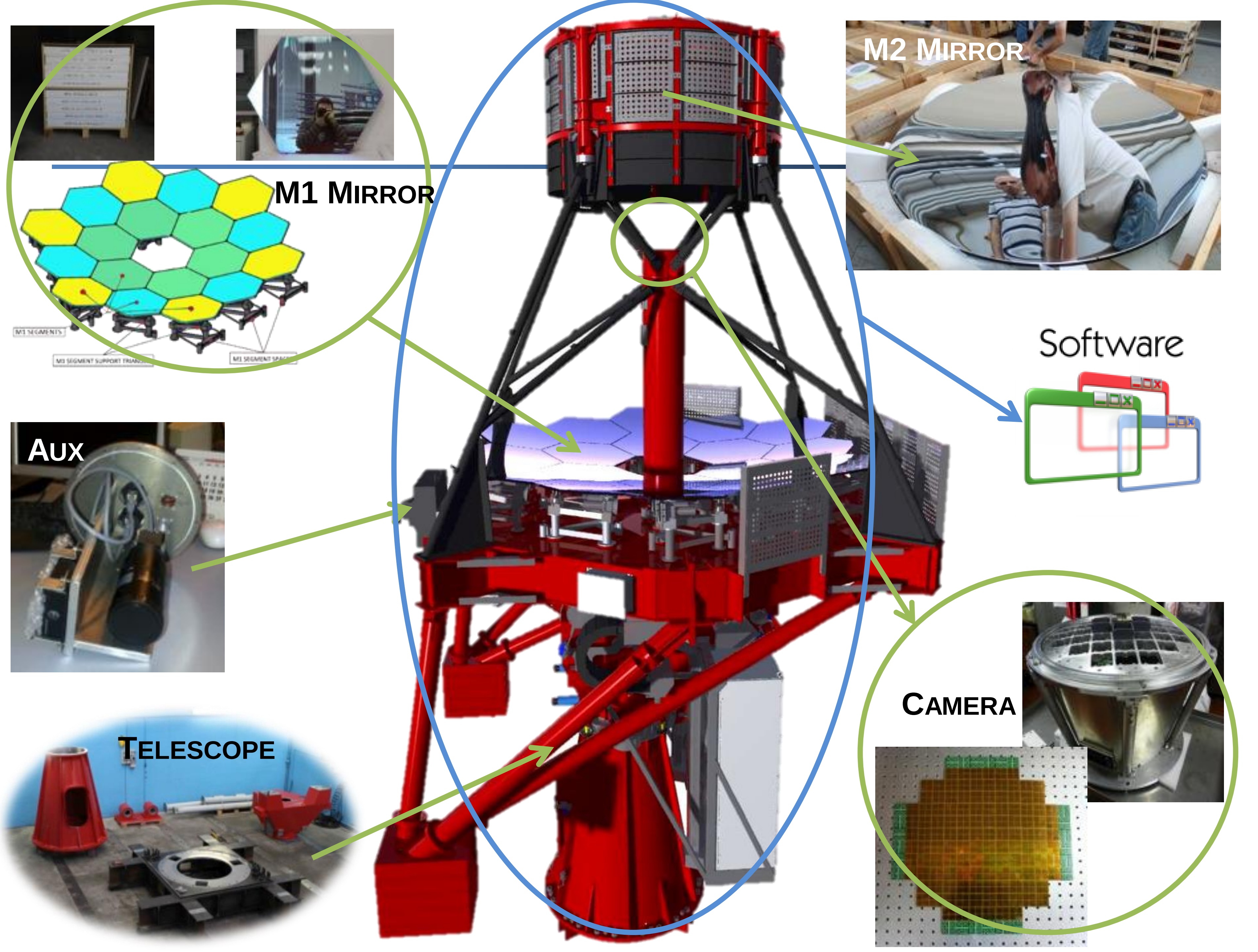
Astrofisica con Specchi a Tecnologia Replicante Italiana

Astrophysics with Mirrors via Italian Replication Technology

(No mirrors, no party!)

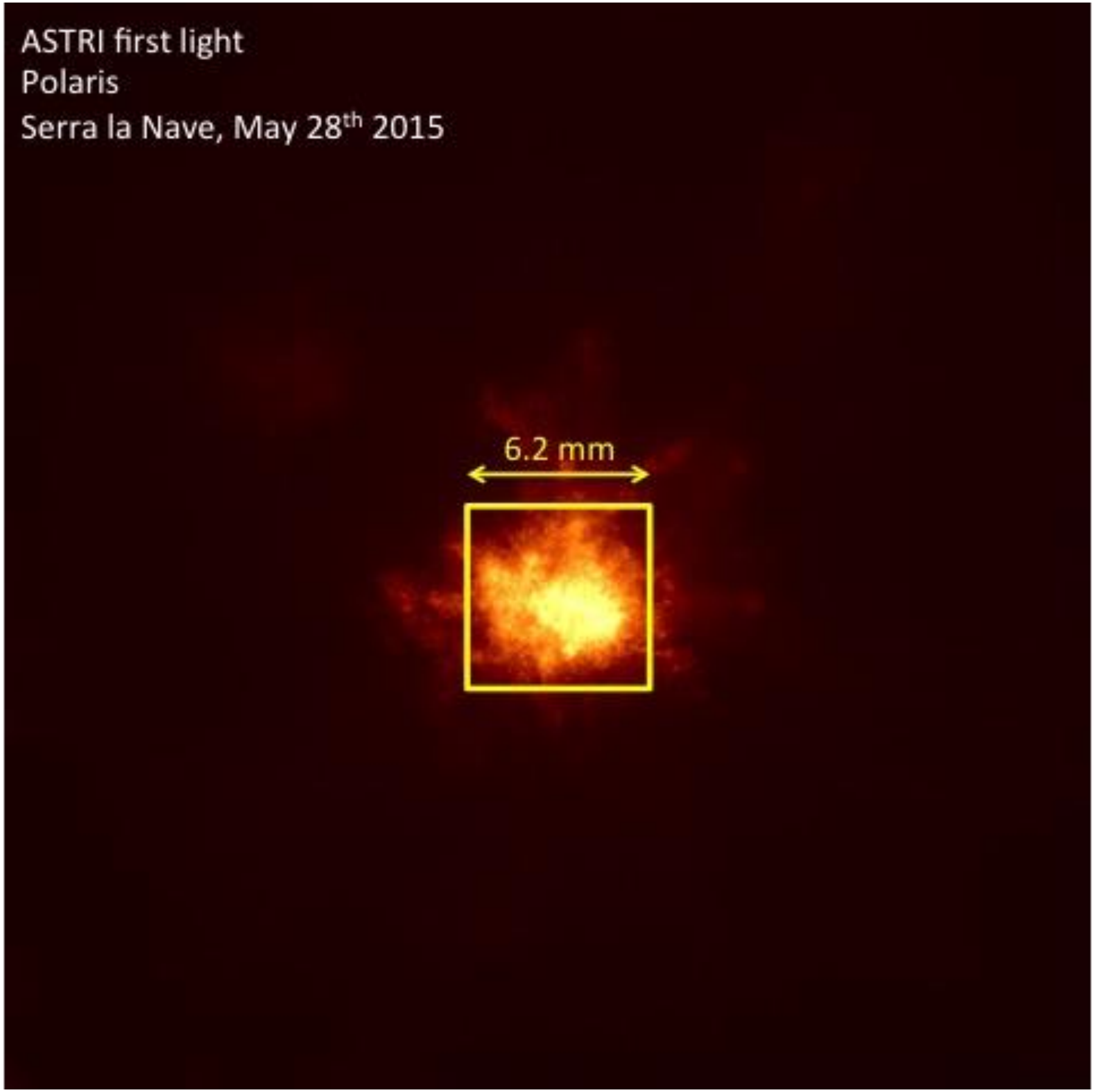


Name given by
Nanni Bignami:


M1 Mirror
M1 SEGMENTS
M2 Mirror
Software
Aux
Telescope
Camera


INAF


NAF

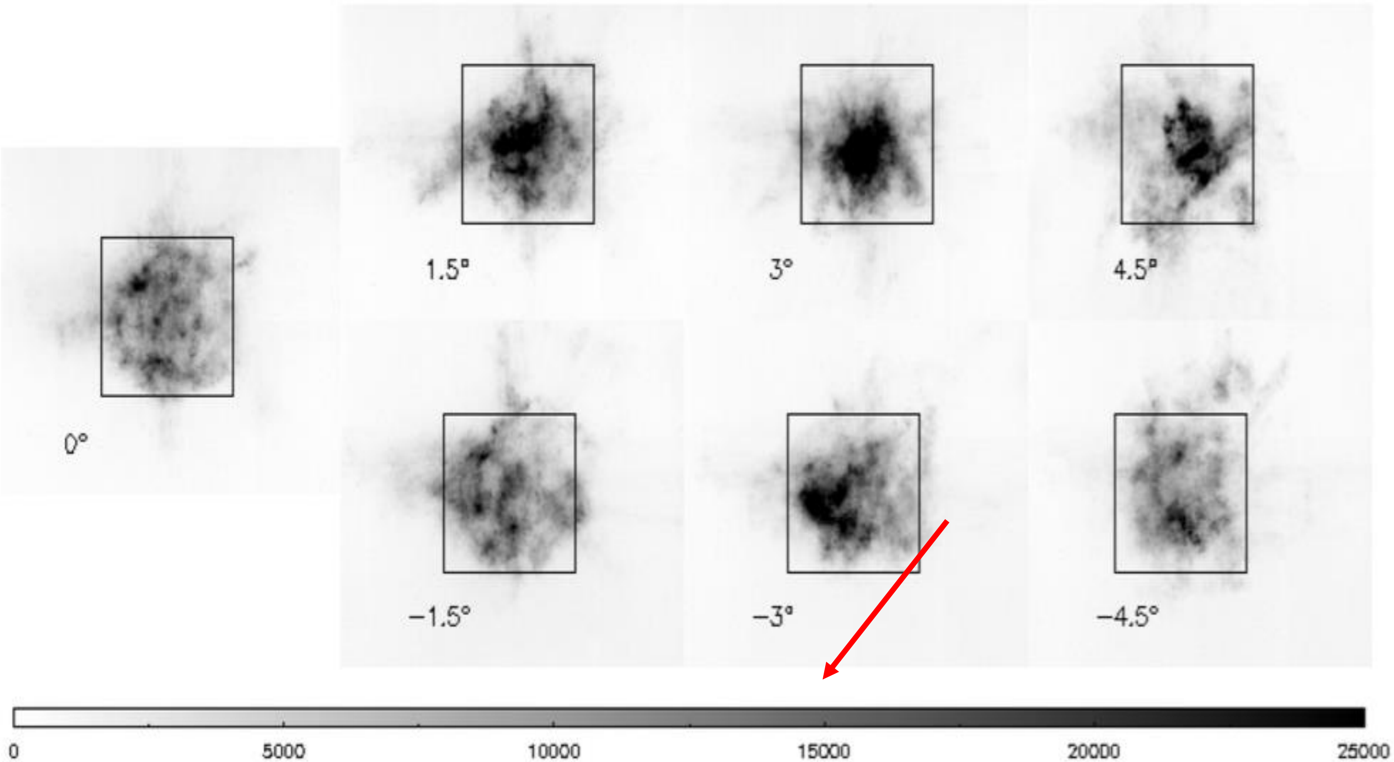

ASTRI first light
Polaris
Serra la Nave, May 28th 2015
6.2 mm

ASTRI Prototype: PSF across the field of view

Astronomy & Astrophysics manuscript no. a˙a˙paper˙optical˙quality˙ver3˙arXiv
September 28, 2017

First optical validation of a Schwarzschild Couder telescope: the ASTRI SST-2M Cherenkov telescope

E. Giro[1,2], R. Canestrari[2], G. Sironi[2], E. Antolini[3], P. Conconi[2], C.E. Fermino[4], C. Gargano[5], G. Rodeghiero[1,6], F. Russo[7], S. Scuderi[8], G. Tosti[3], V. Vassiliev[9], and G. Pareschi[2]



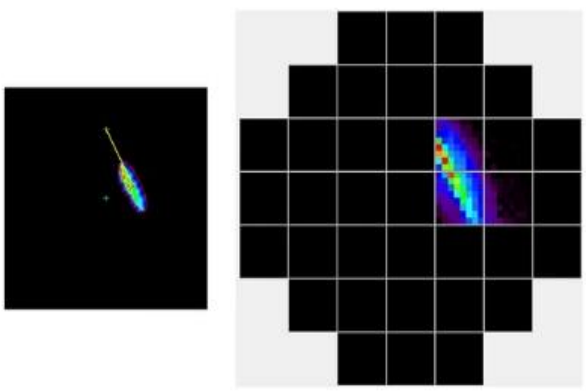
FoV position (deg)	D80 (mm)
4.5	6.72
3.0	6.32
1.5	7.28
0.0	6.86
-1.5	6.32
-3.0	5.50
-4.5	6.90

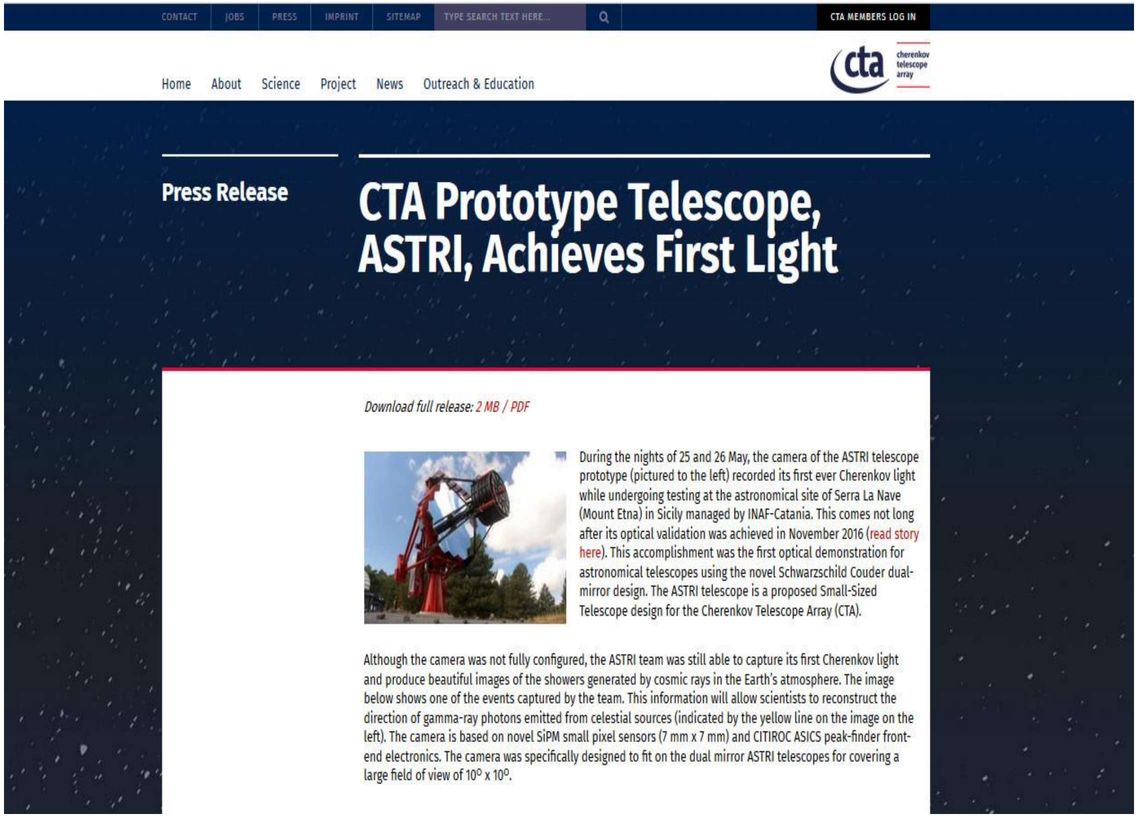
SiPM pixel linear dimension: 7 mm→ 11.2 arcmin

ASTRI Prototype: First Cherenkov Light

25th of May 2017

First Cherenkov light with the ASTRI camera





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cta cherenkov telescope array

Press Release

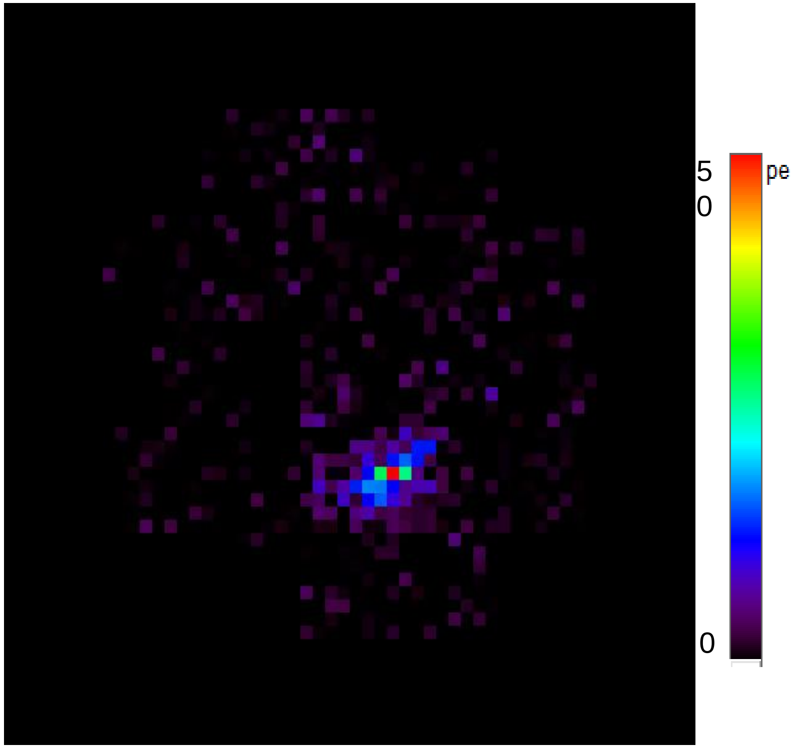
CTA Prototype Telescope, ASTRI, Achieves First Light

Download full release: 2 MB / PDF

During the nights of 25 and 26 May, the camera of the ASTRI telescope prototype (pictured to the left) recorded its first ever Cherenkov light while undergoing testing at the astronomical site of Serra La Nave (Mount Etna) in Sicily managed by INAF-Catania. This comes not long after its optical validation was achieved in November 2016 (read story here). This accomplishment was the first optical demonstration for astronomical telescopes using the novel Schwarzschild Couder dual-mirror design. The ASTRI telescope is a proposed Small-Sized 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 SiPM small pixel sensors (7 mm x 7 mm) and CITIROC ASICS peak-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

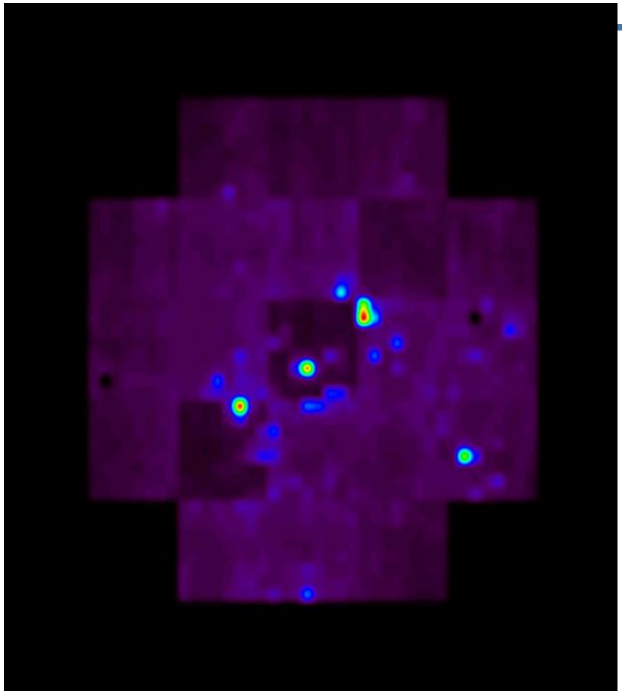


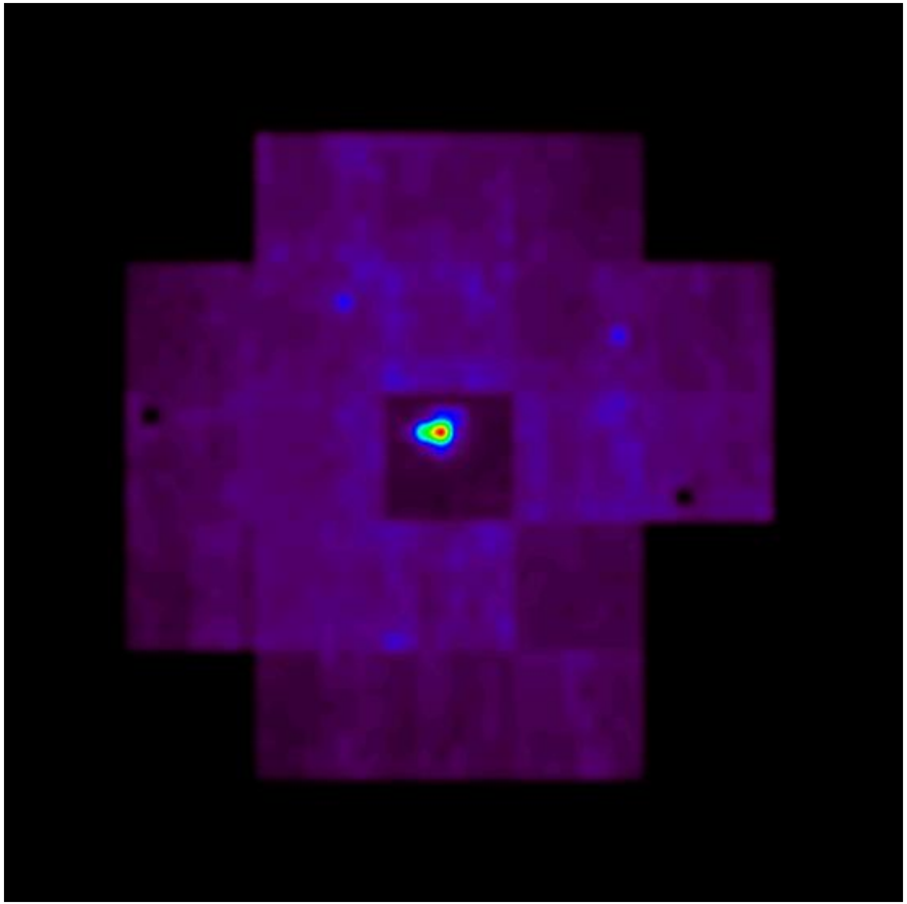
- Runs in December, January, May
  February & March bad weather

- Technical calibrations (lots) and scientific observations (very few up to now) on going

ASTRI Prototype: Variance data

Run January 2018





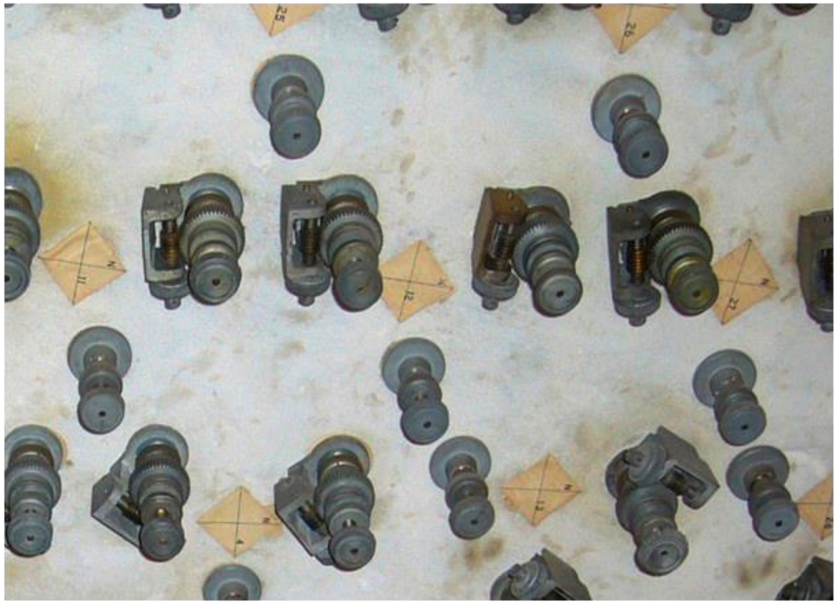
- Implemented at level of front end electronics
- Data taken in parallel to science data

ASTRI Prototype: Dedication to Horn D’Arturo

10th of November 2018

Dedication of ASTRI prototype telescope to Guido Horn D’Arturo → ASTRI – HORN telescope

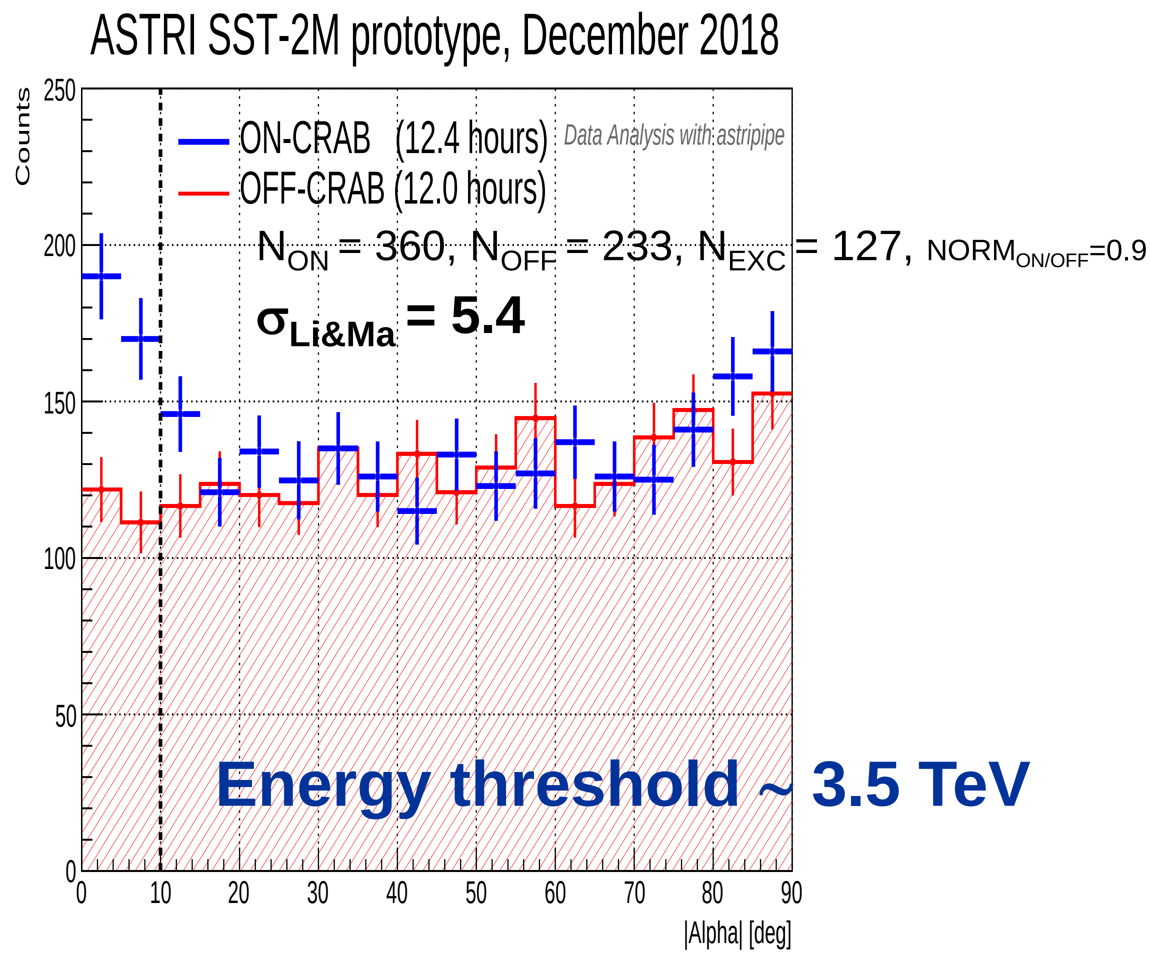
Horn d'Arturo: Italian- Jewish astronomer, inventor of the "segmented" astronomical mirrors



ASTRI – Horn: Crab Nebula Detection

Observations between 5th and 11th december 2018

First detection of a Gamma Ray Source with a IACT dual-mirror telescope!!!



Energy threshold ~ 3.5 TeV

ASTRI – HORN: Crab Nebula Detection

Submitted to A&A Letter

(with full author list)

Astronomy & Astrophysics manuscript no. letter
June 6, 2019

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. Lombardi[1,2], L. A. Antonelli[1], O. Catalano[3], S. Scuderi[4], G. Pareschi[5], E. M. de Gouveia Dal Pino[6], and M. Böttcher[7] on behalf of the ASTRI Collaboration[8]

(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 5.4 σ 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.

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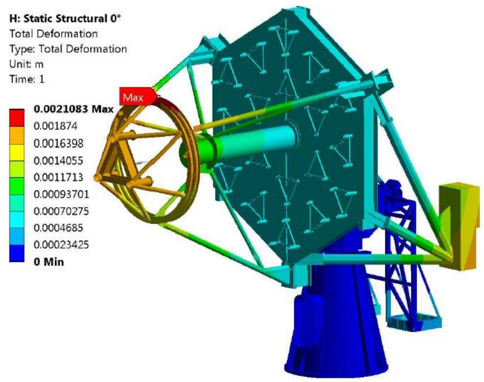

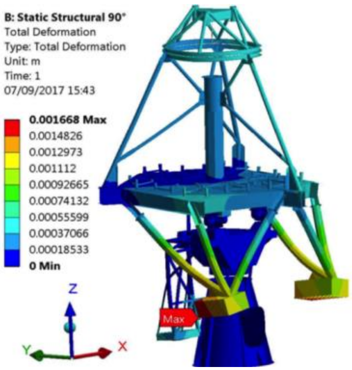

Second leg of the journey: ASTRI mini-array

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**