CTAO | CONSORTIUM

Enabling intensity interferometry (II) with the Cherenkov Telescope Array Observatory

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A2C Day 2026
Orsay

CTAO

1 What is it?

2 Why adapt it for II?

3 How to?

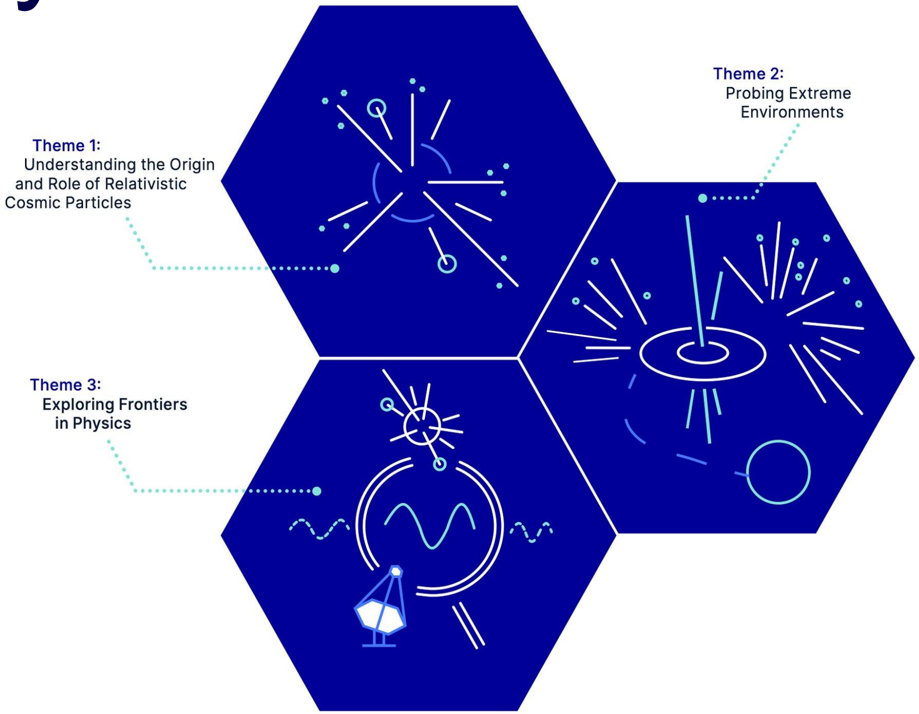
1
What is the CTAO?

An observatory for γ-ray astronomy

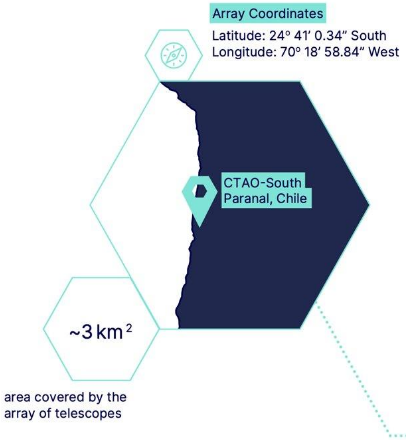
Targets: astrophysical plasmas and fundamental physics

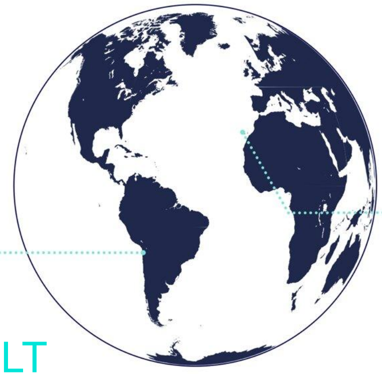
- To be operated for 20+ years
- Open observatory, with about half of the time spent on non-consortium proposals
- Enhancements with respect to its precursors (HESS, MAGIC, VERITAS)
  - sensitivity × 5-10
  - energy resolution × 1.5-2
  - angular resolution × 1.3-1.4

→ see CTAO performance here

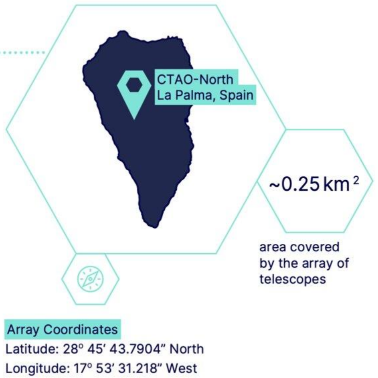


An observatory at two exceptional astronomical sites





- CTAO-North at La Palma (Spain, Canary Islands)
  → half a km away from GTC, WHT, NOT, TNG
- Low energy threshold (20 GeV) to catch transient sources

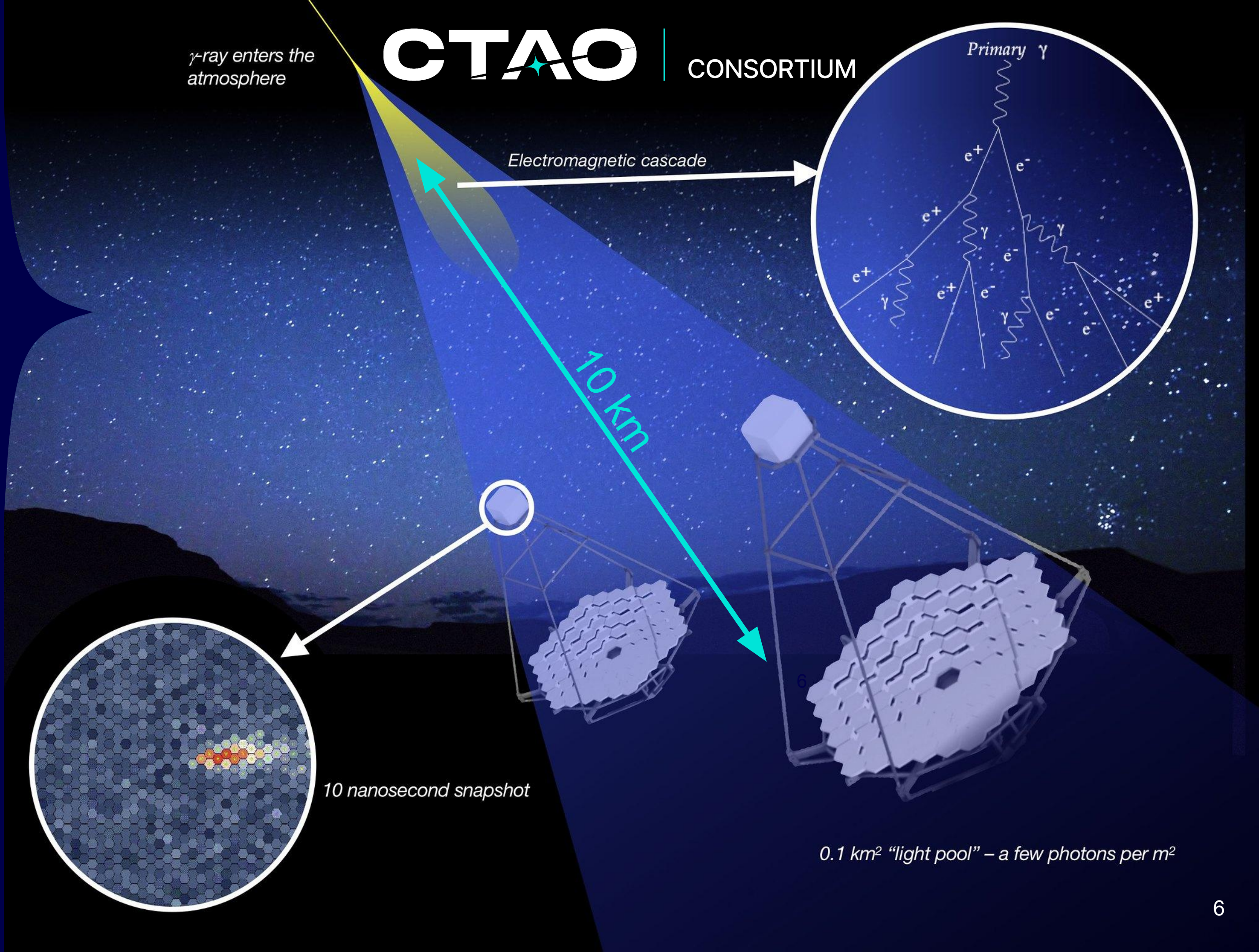


- CTAO-South at Paranal (Chile)
  → 10-20 km away from VLT and ELT
- Large area of ~ 3 km² to catch the rare 100+ TeV ɣ-rays from Galactic astrophysical sources

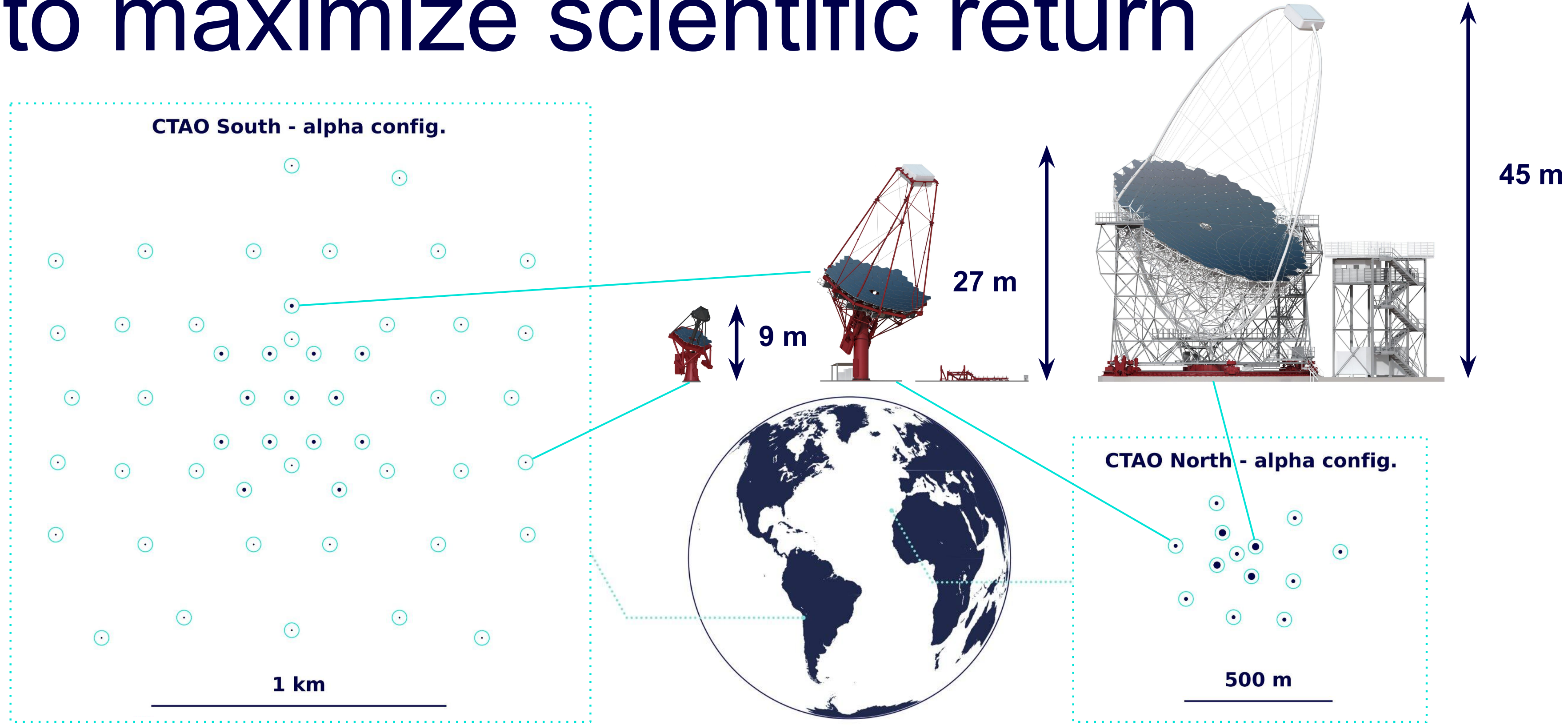
Optical detectors to catch γ-rays

Cherenkov light (400-600 nm) from particle showers.

Imaged with 1 ns sampling by each camera.



A set of different-size telescopes to maximize scientific return



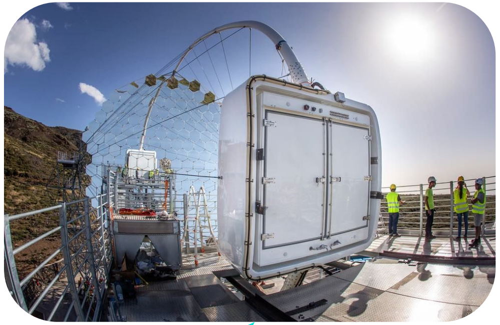
2

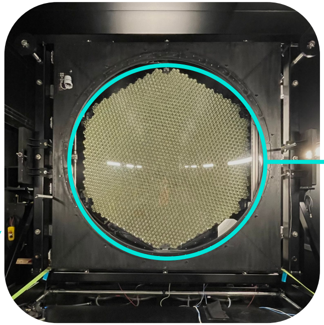
Why CTAO-II?

Photodetectors of the cameras

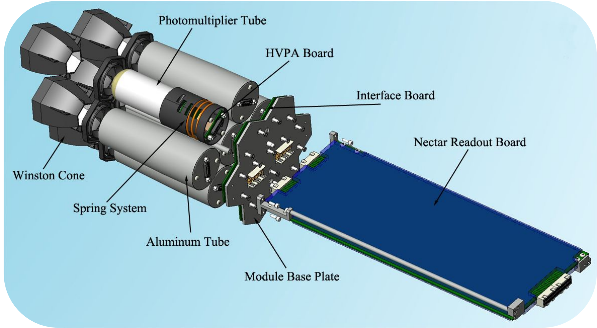
Bradascio et al. (2023)

Glicenstein et al. (2015)



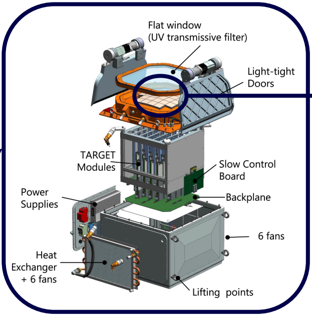


265 hexagons

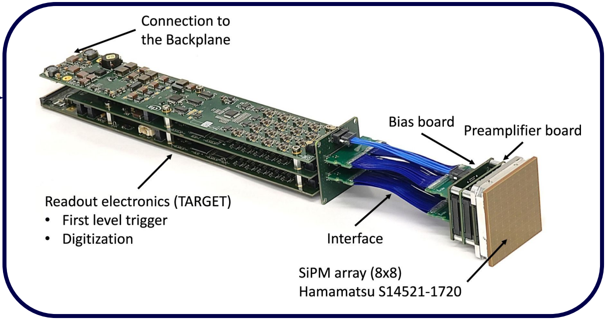


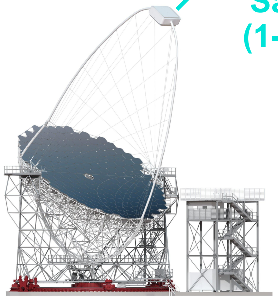
Same PMTs (1-2 ns jitter)

SiPMs

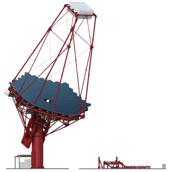


32 tiles





Large-sized telescopes



Medium-sized telescopes

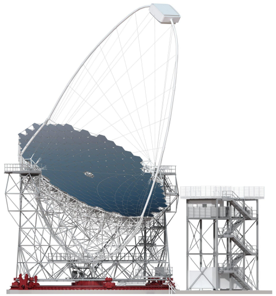
Small-sized telescopes

Depaoli et al. (2024)

Photodetectors of the cameras

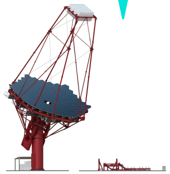
Main limitation for II: pixel field of view

- Large-sized telescopes ~ 0.1 deg per pixel
- Medium- & small-sized tel. ~ 0.17 deg per pixel
- Star above night sky background up to
  ~ 9th magnitude during dark time (2×10^5 stars)
  ~ 6th magnitude during Moon time (9×10^3 stars)



Large-sized telescopes

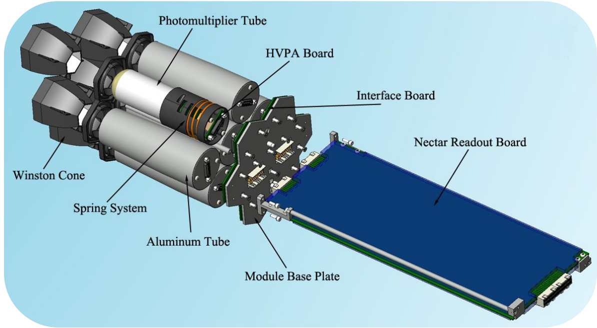
Opportunity to use Moon time when γ-ray observations are difficult.

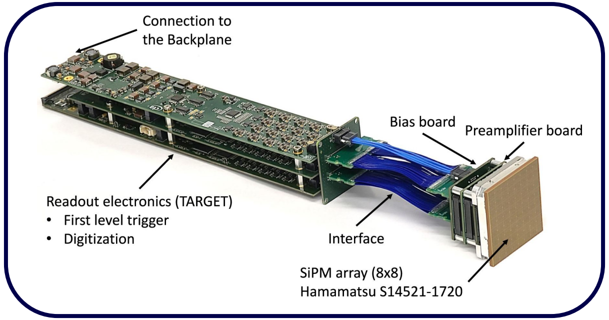


Medium-sized telescopes

Small-sized telescopes

Glicenstein et al. (2015)



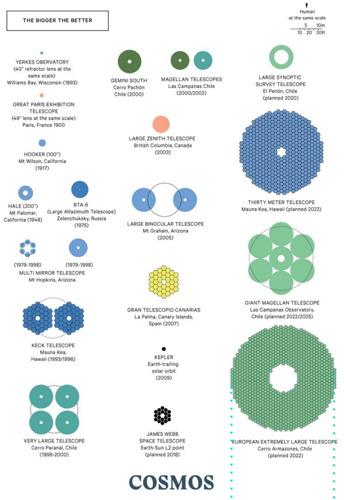


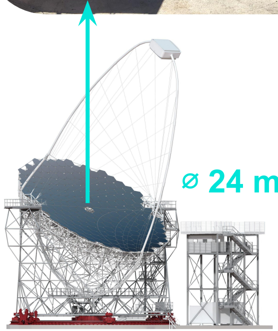
Depaoli et al. (2024)

Mirrors of the telescopes

Tessellated mirrors

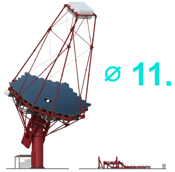
- Parabolic single dish for large-sized tel.
  → ideal timing, off-axis aberration
- Spherical-to-parabolic for medium-sized tel.
  → small aberration, Δt(edge-center) ~ 1 ns
- Dual dish for small-sized tel.
  → best trade off between timing & aberration





⌀ 24 m

Large-sized telescopes



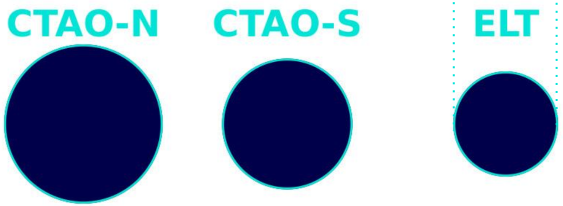
⌀ 11.5 m

Medium-sized telescopes

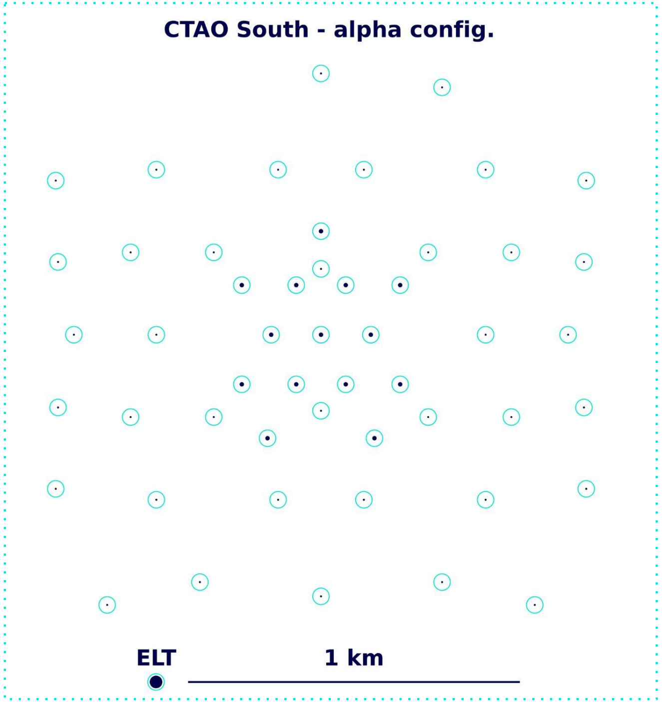
$⌀_1$ 4.3 m
$⌀_2$ 1.8 m

Small-sized telescopes

$\sum_{tel}$ mirror area =



Baselines of the two arrays



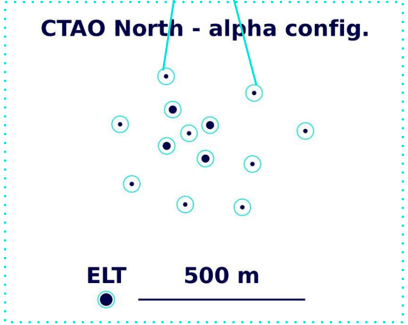
Rayleigh criterion

$$1.22\frac{\lambda}{D} = 0.2\,\mathrm{mas} \times \left(\frac{\lambda}{400\,\mathrm{nm}}\right)\left(\frac{D}{500\,\mathrm{m}}\right)^{-1}$$

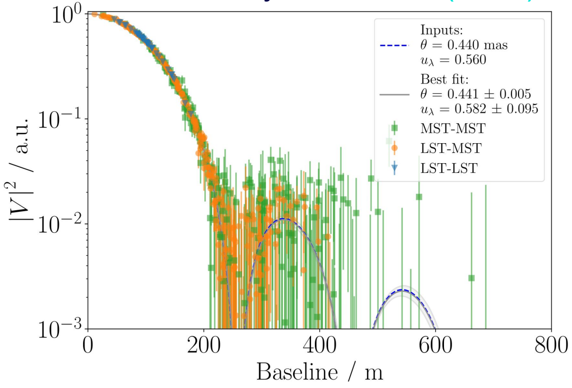
$$= 50\,\mu\mathrm{as} \times \left(\frac{\lambda}{400\,\mathrm{nm}}\right)\left(\frac{D}{2\,\mathrm{km}}\right)^{-1}$$

→ half as good as EHT @ 1 mm!

$$g^2(\theta) = \langle I_0 I_1 \rangle / \langle I_0 \rangle \langle I_1 \rangle$$

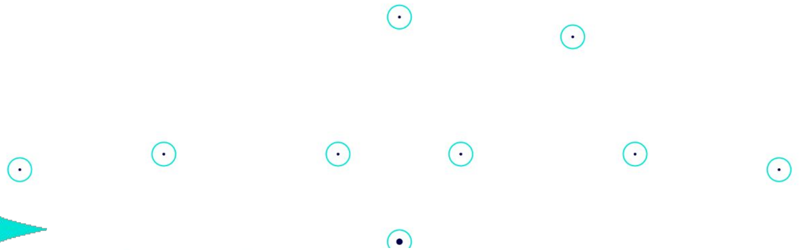


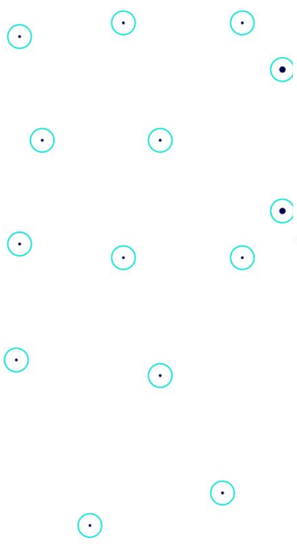
2nd mag. star from CTAO-N,
simulation by Luce et al. (2025)



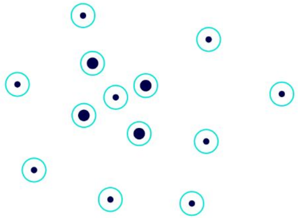
CTAO and its precursors

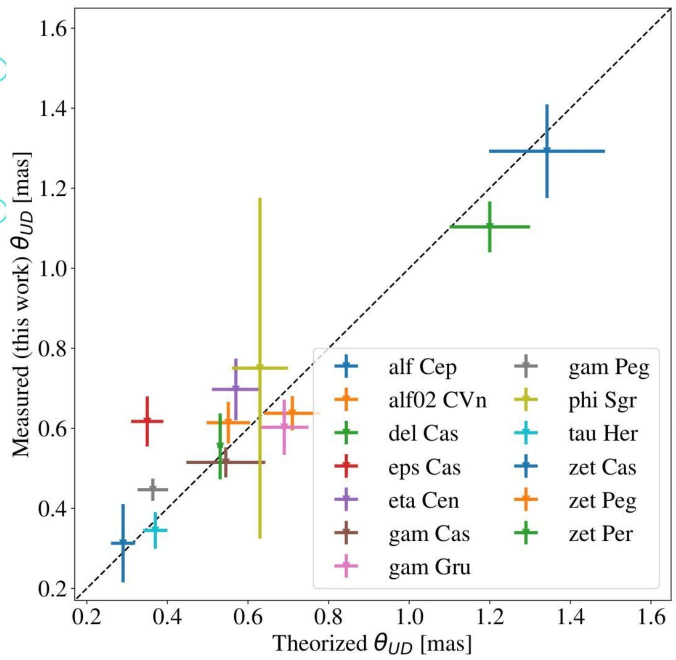
CTAO South - alpha config.

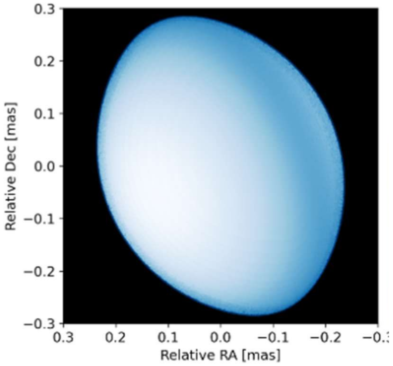




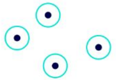
CTAO North - alpha config.



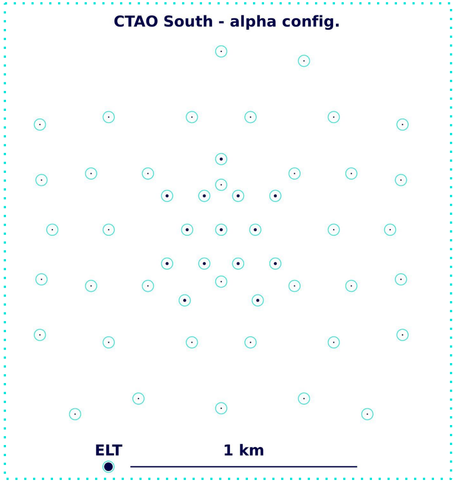


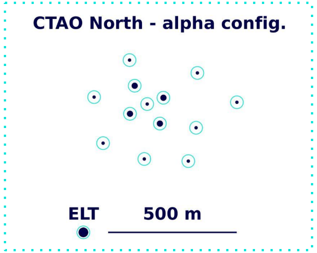


MAGIC **VERITAS**



Coverage in the (u,v) plane



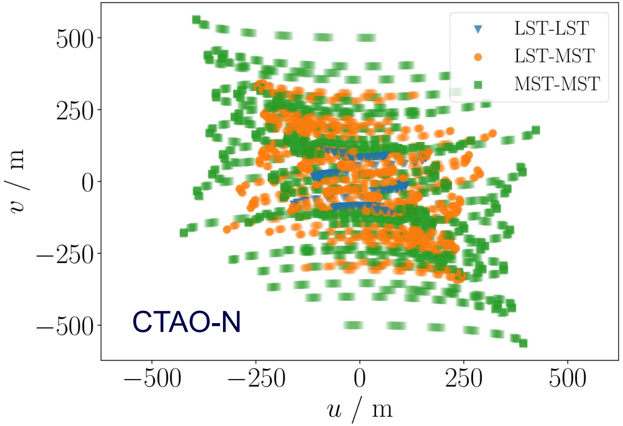


Intensity interferometry:

squared modulus of visibility

$$V(u,v) \propto \int S(\theta_x,\theta_y)\; e^{\frac{2\pi i}{\lambda}(u\theta_x+v\theta_y)}\; d\theta_x\, d\theta_y$$

Simulation by Luce et al. (2025)



CTAO-II at its acme!

for an infinitely good phase retrieval algorithm and multi-band observations

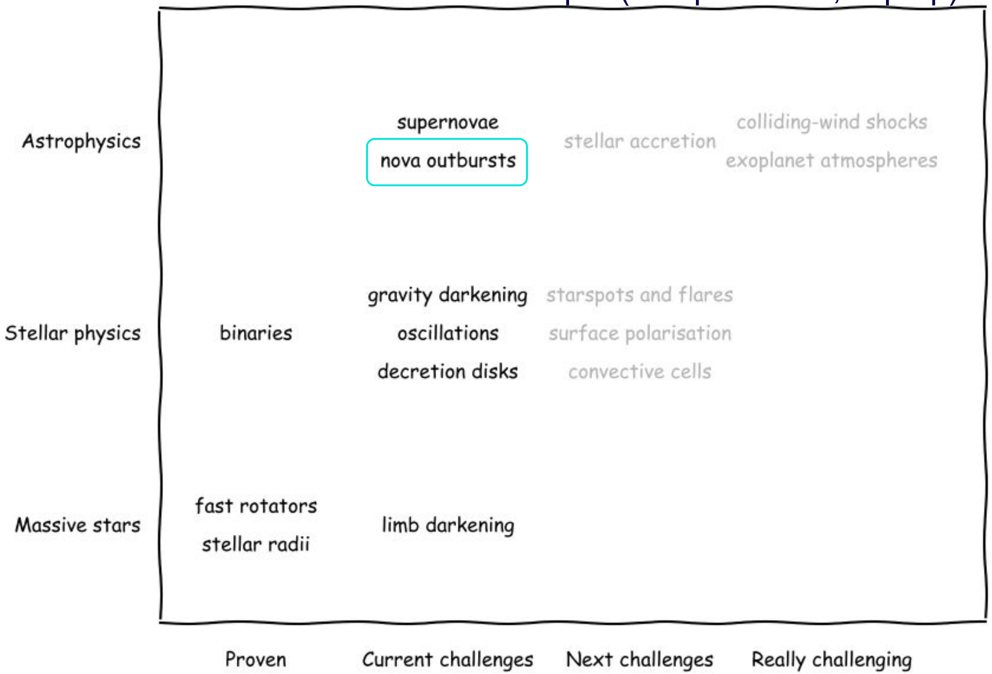
Visu by Dravins (2016)
40 μas ~ CTAO-S

120 μas ~ CTAO-N

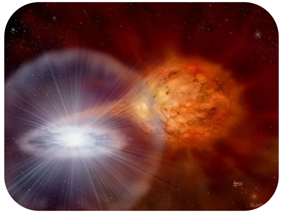
Science reach of CTAO-II

With minor adaptations of the arrays (see "How to")

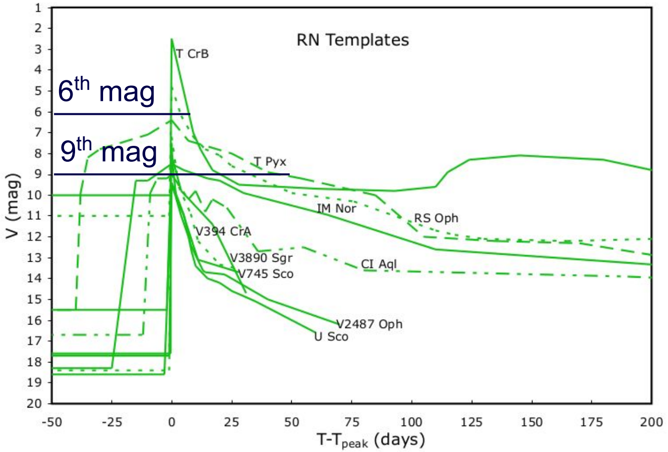
P. Saha in CTAO-II White Paper (Zampieri et al., in prep)



Credit: Hardy & PPARC



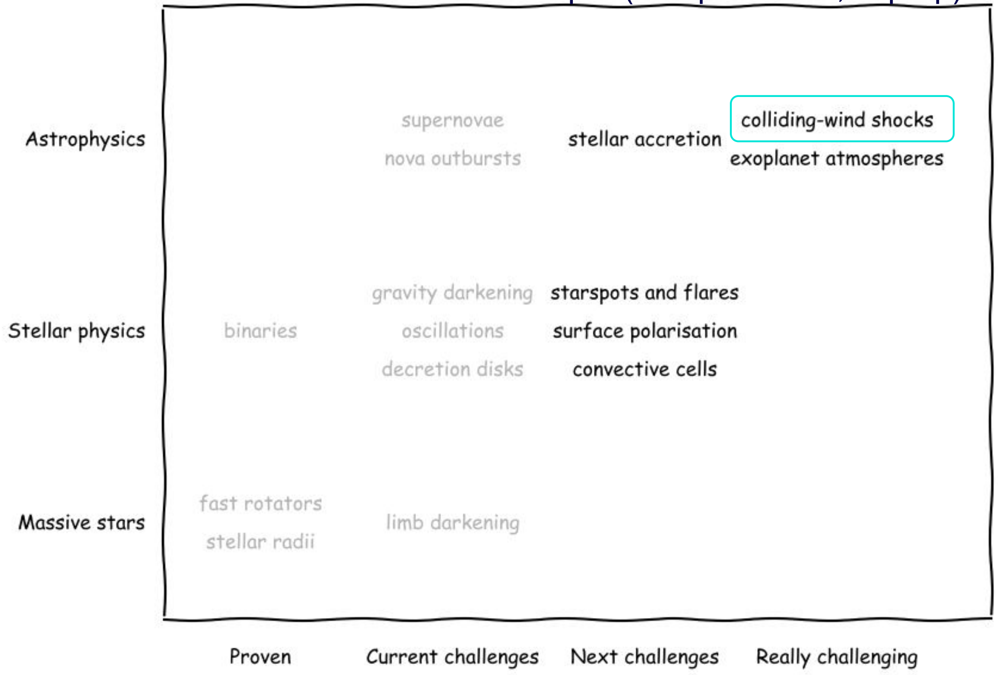
Shaefer (2010)



Science reach of CTAO-II

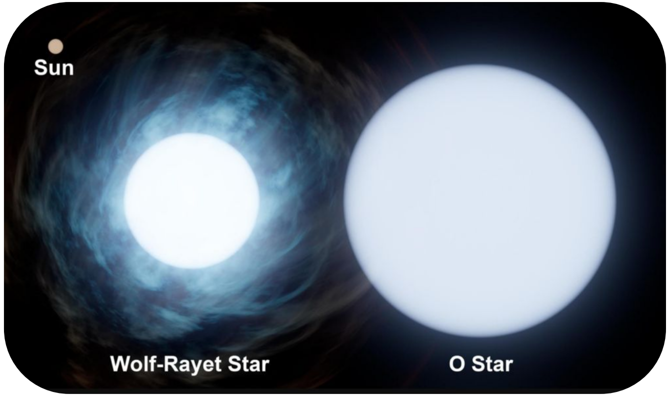
With upgraded arrays (see “How to”)

P. Saha in CTAO-II White Paper (Zampieri et al., in prep)



Science cases

- Stellar astrophysics
- Exoplanet characterization
- Geometry of particle accelerators



e.g. γ^2 Velorum (2nd mag)

3
CTAO-II: How to?

Array level

Data

- Waveform streams with b_v = 1 GHz
  → 150 TB/night per telescope if stored
  → 0.2 TB/night for CTAO-N if GPU processed
- GPU-based correlator procured with ERC grant
  → next: tests with MAGIC & CTAO large-sized tel.

Clocks

- White Rabbit already distributed to telescopes
- Relative timing accuracy already < 1 ns
  - Additional nodes needed for II

Fiber deployment

Telescopes

No change needed

- Requirement on positioning
  → better than 10 cm (0.3 ns)
- Pointing accuracy requirement
  → better than 60”, i.e. sub-cm precision at focal length of 24 m

Cameras

1st stage - CTAO-II Pathfinder

- Add robotic narrow-band (Δλ = 26 nm) optical filters in front of relevant photodetectors

  → opportunity: use star imaging system of CTAO-N large- and medium-sized telescopes

  → procured (ERC & Paris-Saclay)

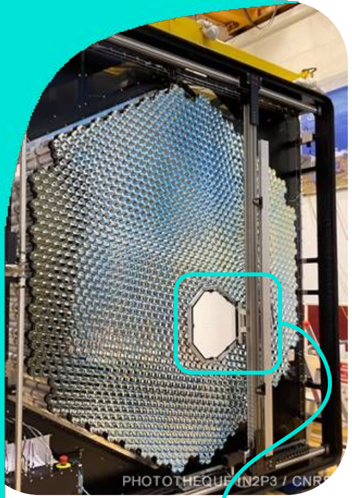
- Modified readout (waveform sampler / TDC)

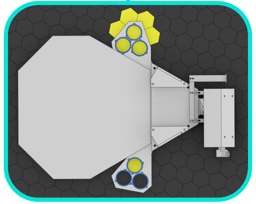
  → analog/digital solutions tested, incl. IDROGEN

2nd stage - CTAO-II

- Add very-narrow band filters (Δλ = 1 nm) and high time resolution (100 ps) detectors
- Opportunity: benefit from ongoing tests by the community (incl. ASTRII, QUASAR, I2C teams)

NectarCAM





CTAO-II: conclusion


Credit: F. Acero

The CTAO intensity interferometer

The CTAO is currently under construction.

With kilometer-scale baselines and an unprecedented collection area, the CTAO has the potential to become an exceptional interferometer.

Busy and exciting path forward. Scientific and technical reviews on their way.

Backup

Return

Broadening of the science cases

- Stellar astrophysics
- Aim for exoplanets (dreamland for stage 1)
- Geometry of non-thermal emitters

Broadening of the community & techniques

- Interferometry community
- Quantum community

Efficient use of our "beam time"

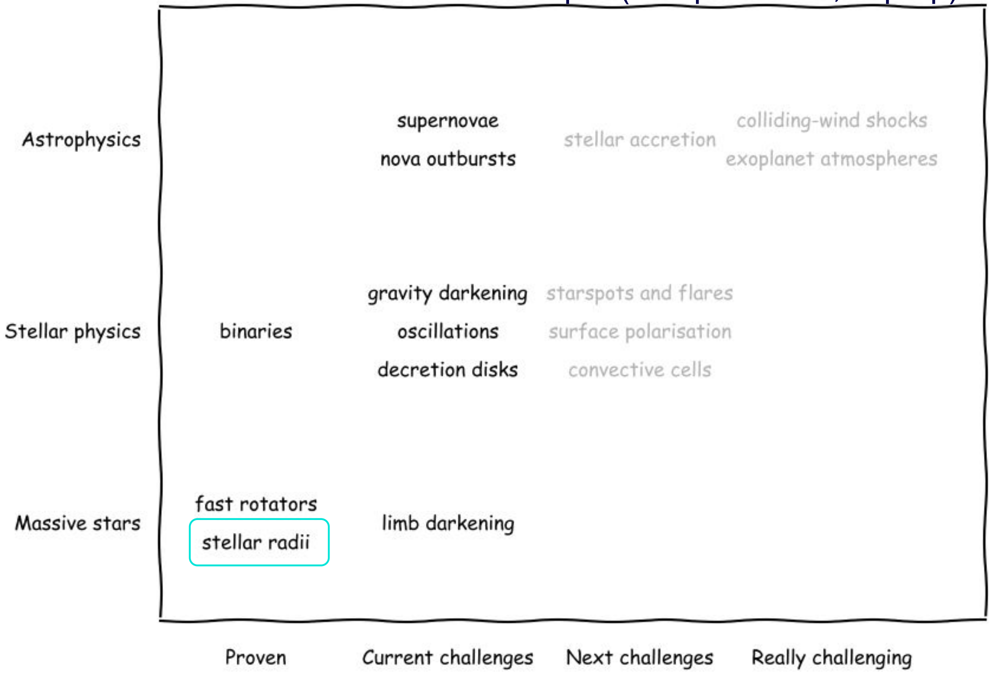
- Low hardware cost from independent funding
- < 1 M€ per site vs. 15% of CTAO obs. time ~ 50 M€

CTAO CONSORTIUM

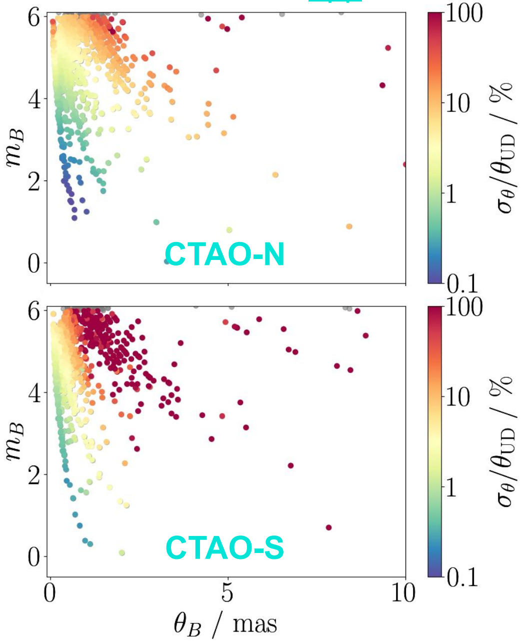
Science reach of CTAO-II

With minor adaptations of the arrays (see "How to")

P. Saha in CTAO-II White Paper (Zampieri et al., in prep)



Luce et al. (2025)
and L. Stanic's app



Radius measured in 2.5h with a precision of:

< 5% for 1 star out of 2
→ 1200+ targets

< 1% for 1 star out of 10
→ 200+ targets

The “box”

ADC + IDROGEN

- Analog inputs: 2 SMA up to 1.7 V
- White Rabbit: monomode fiber
- Data links: 2 simplex fibers 10 Gb/s
- Power supply: 1.8A @ 12V (or 24V)

What for?

- ADC: GHz sampling, 14 bits / ns

→ or timestamps, pulse shape…

- White Rabbit: down to 20 ps jitter

Use cases:

- KEK acc. synchro. & monitoring
- NENUFAR (FR LOFAR station)
- Proposed for CTAO-II Pathfinder