



CONSORTIUM

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

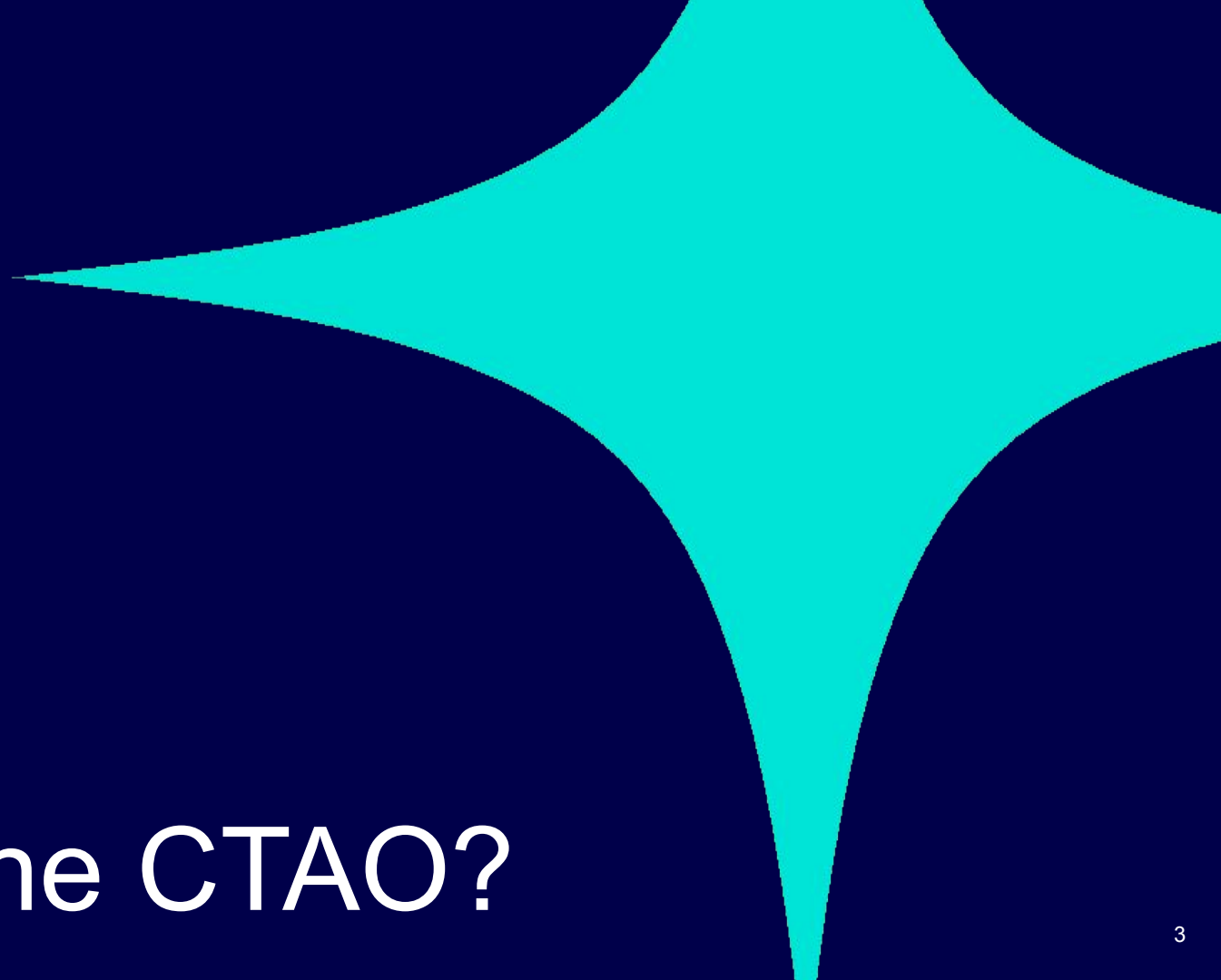
October, 14 2025

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Institut universitaire de France (IUF)
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SII workshop 2025
Waischenfeld

CTAO

- 1 What is it?
- 2 Why adapt it for II?
- 3 How to?

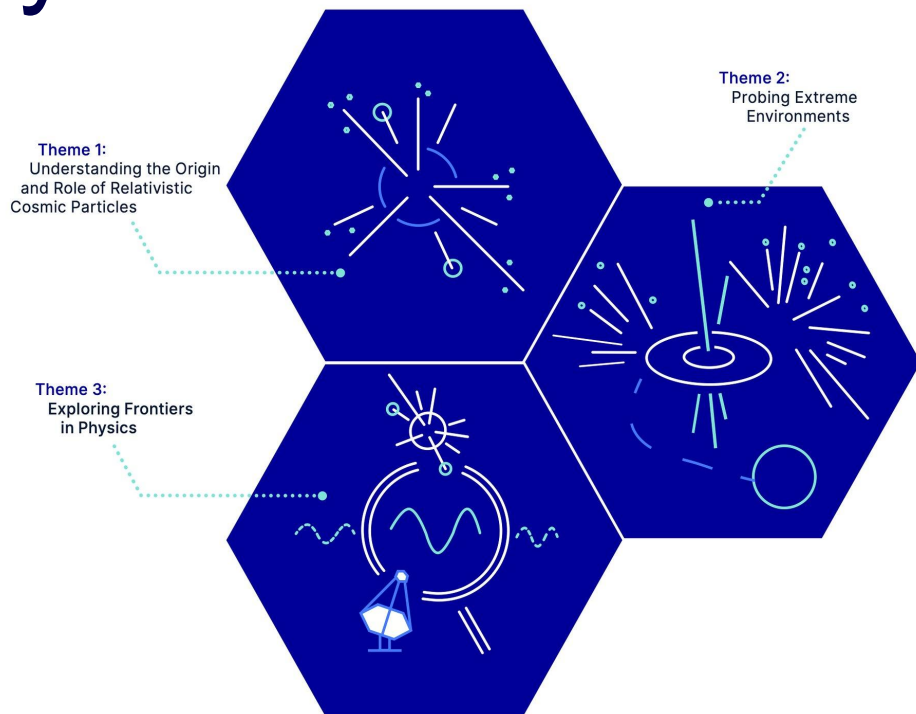


1 What is the CTAO?

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 $\times 5-10$
 - energy resolution $\times 1.5-2$
 - angular resolution $\times 1.3-1.4$
- see CTAO performance [here](#)



An observatory at two exceptional astronomical sites



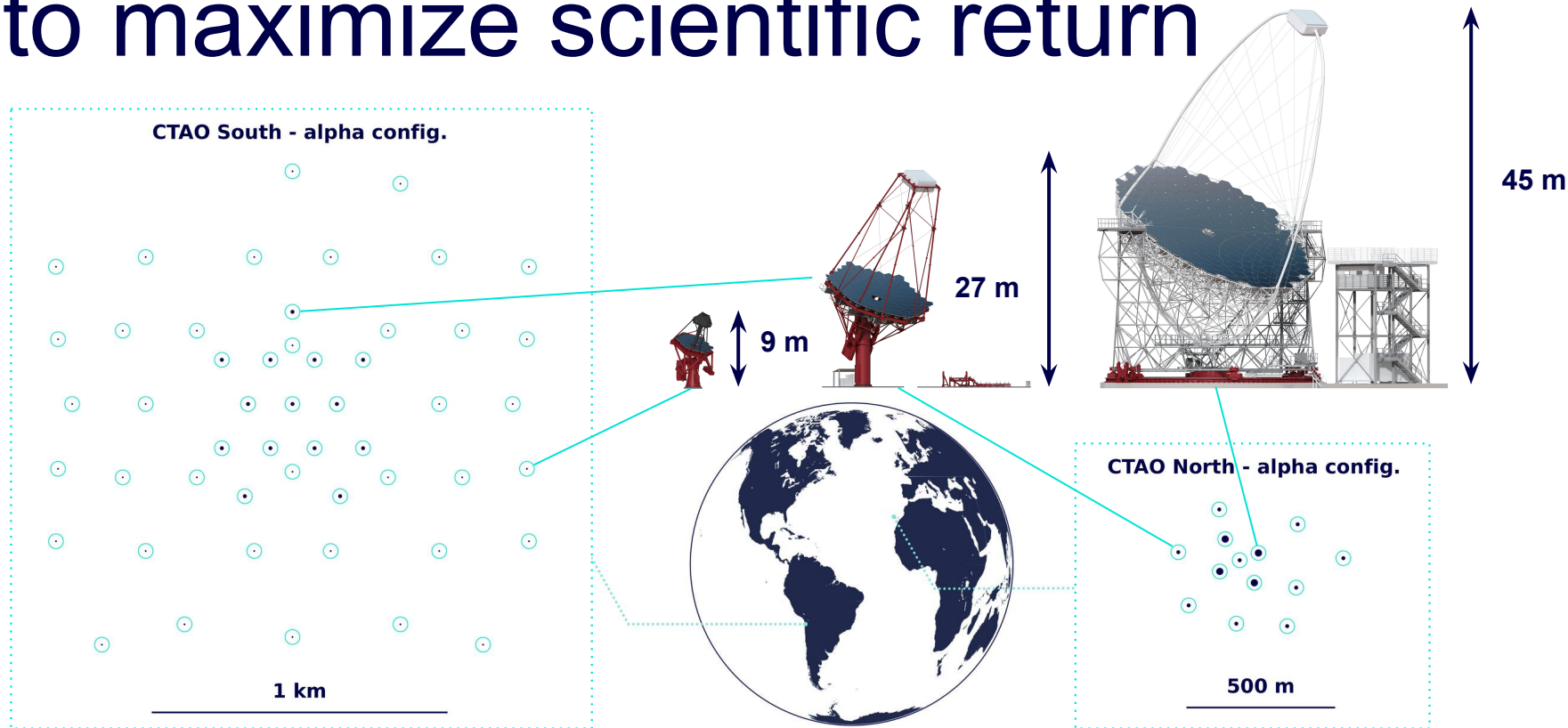
- CTAO-South at Paranal (Chile)
→ 10-20 km away from VLT and ELT
- Large area of ~ 3 km² to catch the rare 100+ TeV γ -rays from Galactic astrophysical sources



- 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



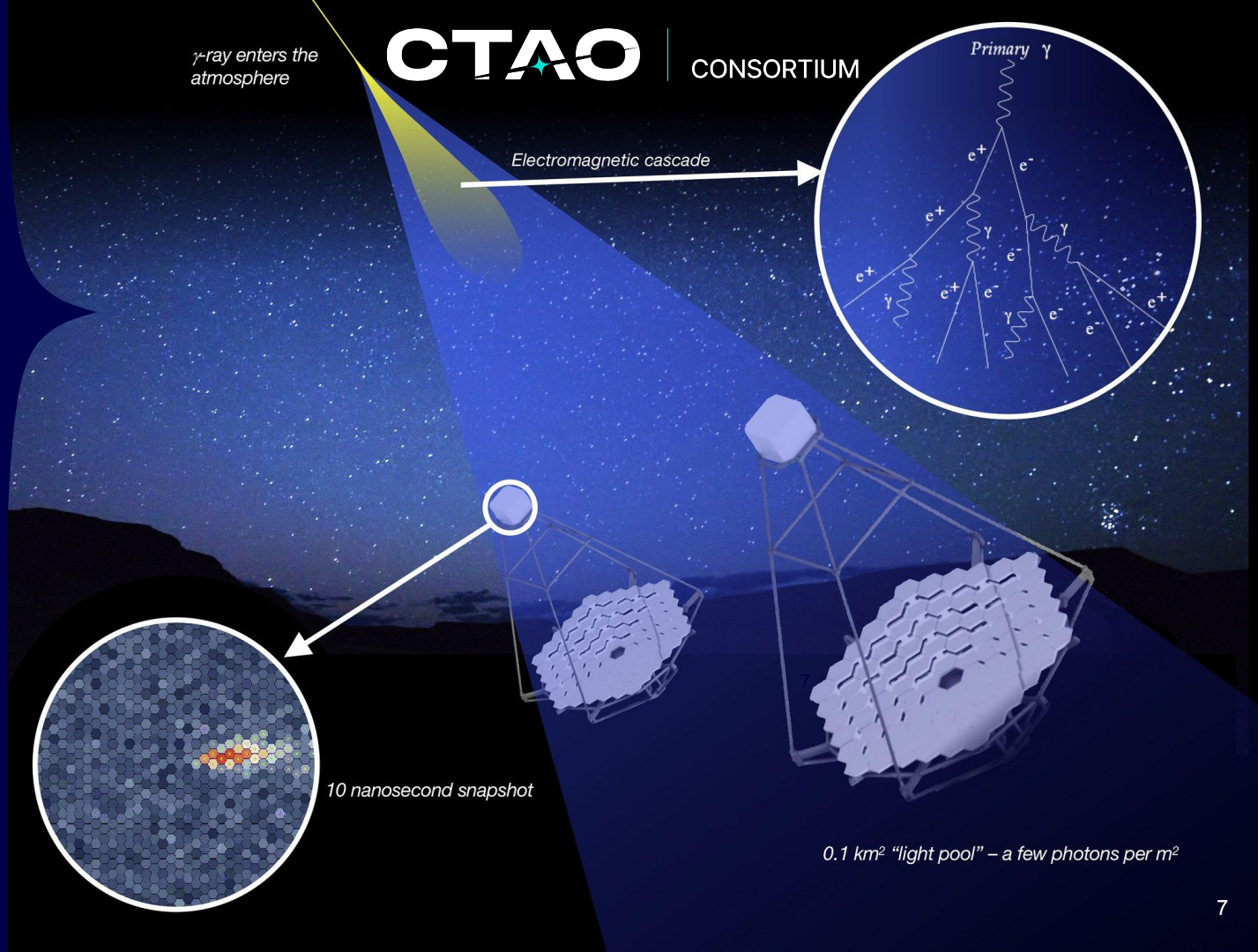
A set of different-size telescopes to maximize scientific return

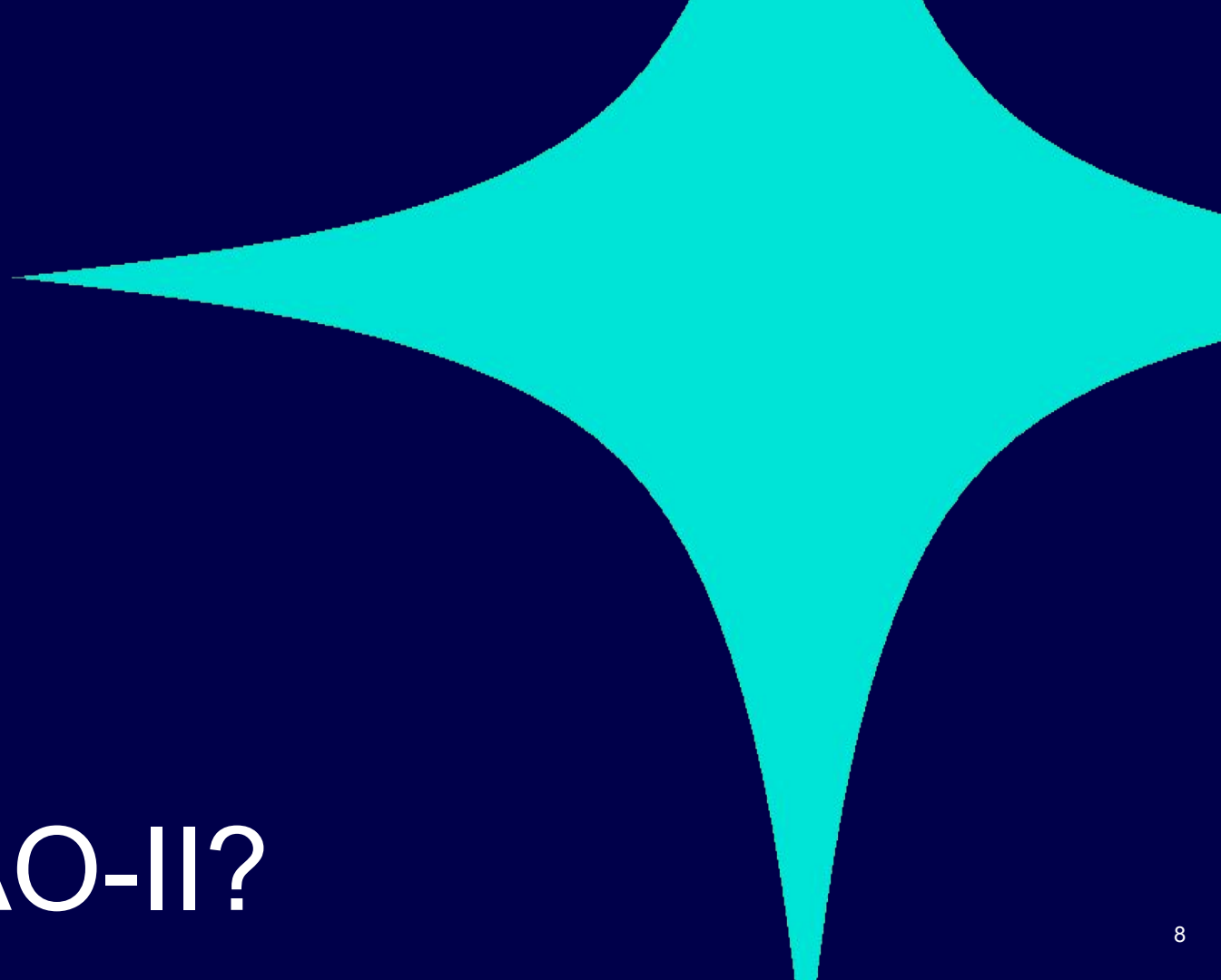


Optical detectors to catch γ -rays

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

Imaged with 1 ns sampling by each camera.



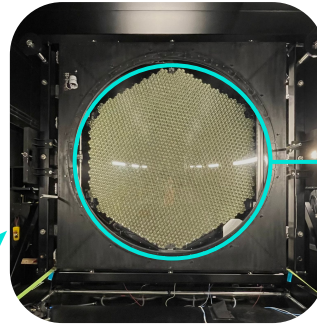
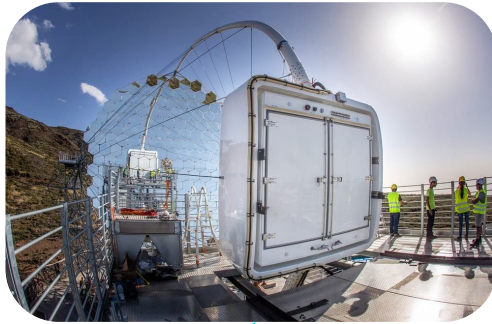


2 Why CTAO-II?

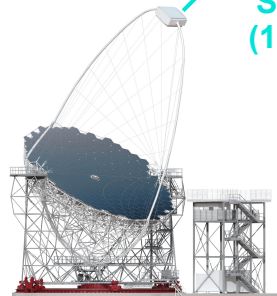
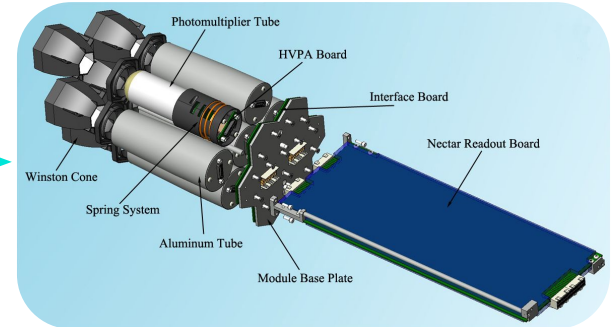
Photodetectors of the cameras

Bradascio et al. (2023)

Glicenstein et al. (2015)



265
hexagons



Large-sized
telescopes

Same PMTs
(1-2 ns jitter)

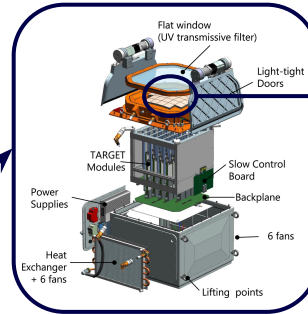


Medium-sized
telescopes

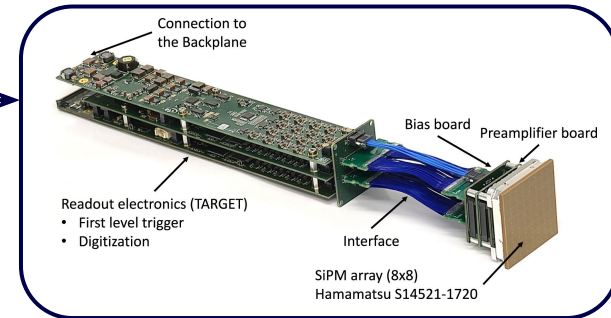
SiPMs



Small-sized
telescopes



32
tiles

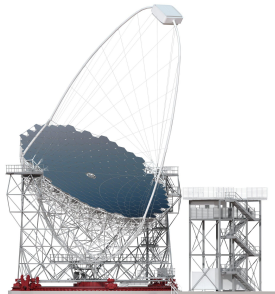


Depaoli et al. (2024)

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
 $\sim 9^{\text{th}}$ magnitude during dark time (2×10^5 stars)
 $\sim 6^{\text{th}}$ magnitude during Moon time (9×10^3 stars)



Large-sized
telescopes



Medium-sized
telescopes

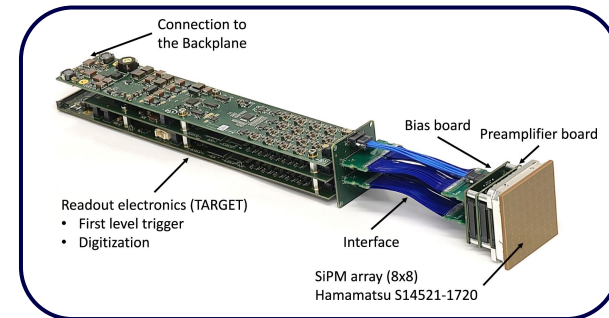
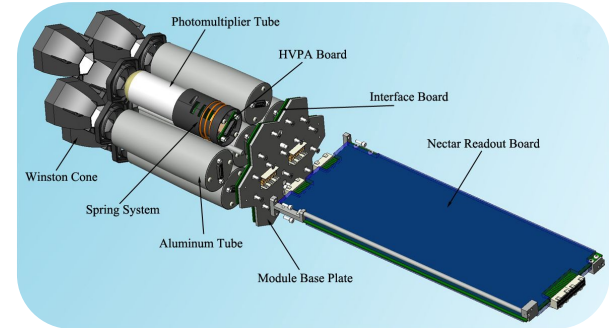


Small-sized
telescopes



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

[Glicenstein et al. \(2015\)](#)

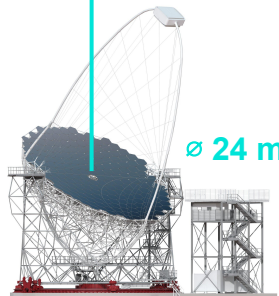


[Depaoli et al. \(2024\)](#)

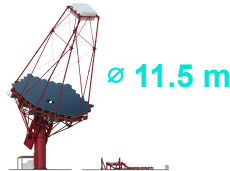
Mirrors of the telescopes

Tessellated mirrors

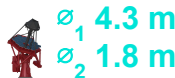
- Parabolic single dish for large-sized tel.
→ ideal timing, off-axis aberration
- Spherical-to-parabolic for medium-sized tel.
→ small aberration, $\Delta t(\text{edge-center}) \sim 1 \text{ ns}$
- Dual dish for small-sized tel.
→ best trade off between timing & aberration



Large-sized telescopes



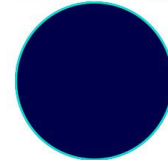
Medium-sized telescopes



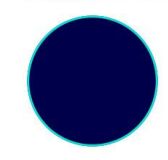
Small-sized telescopes

$$\sum_{\text{tel}} \text{mirror area} =$$

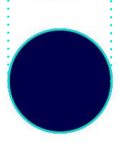
CTAO-N



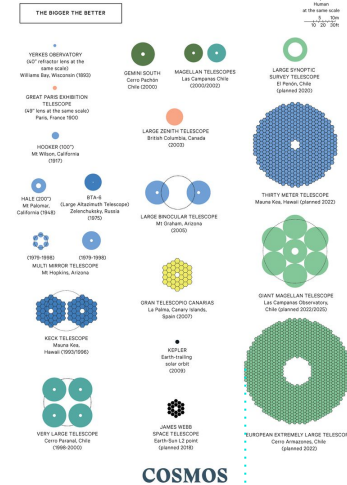
CTAO-S



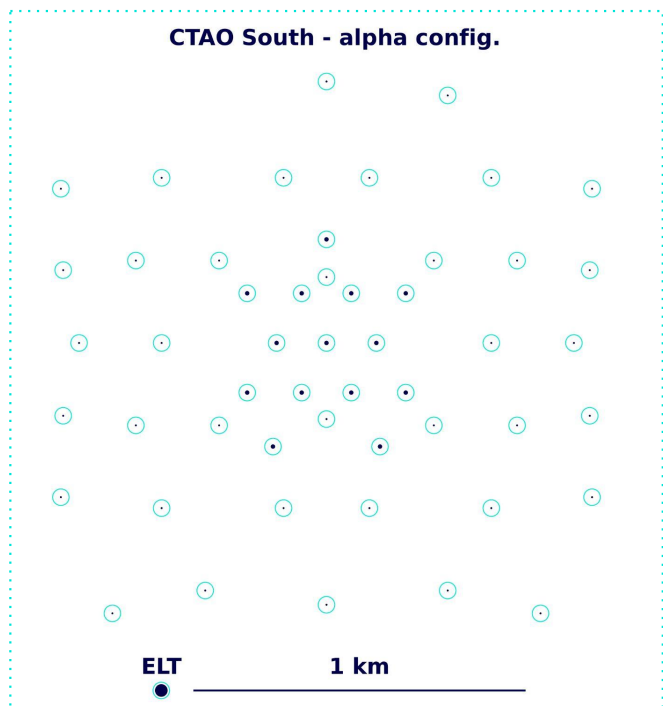
ELT



$\propto$ config.



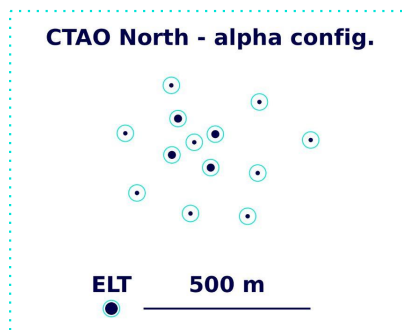
Baselines of the two arrays



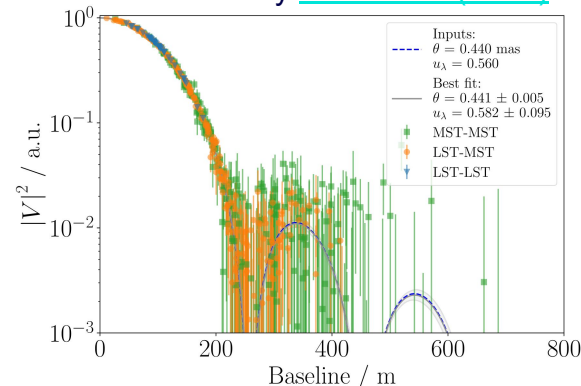
Rayleigh criterion

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

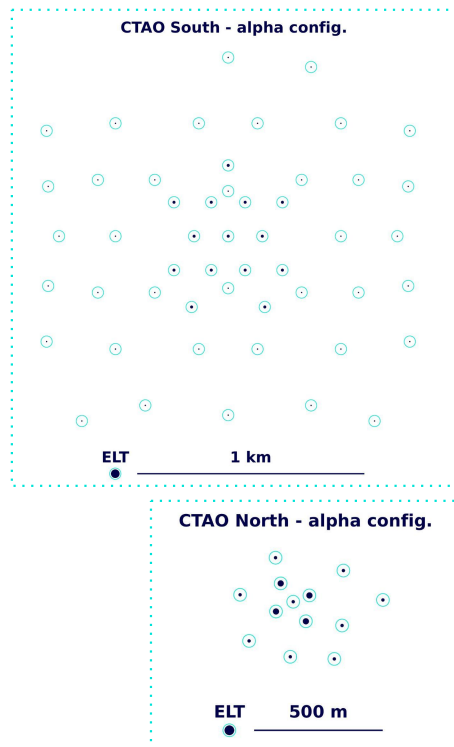
$$= 50 \mu\text{as} \times \left(\frac{\lambda}{400 \text{ nm}} \right) \left(\frac{D}{2 \text{ km}} \right)^{-1} \rightarrow \text{half as good as EHT @ 1 mm!}$$



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



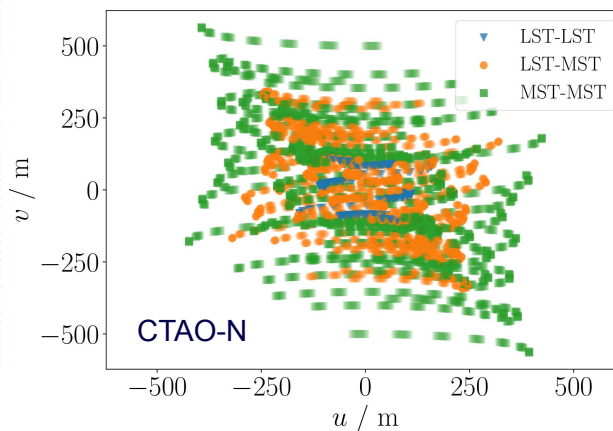
Coverage in the (u,v) plane



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 μs ~ CTAO-S



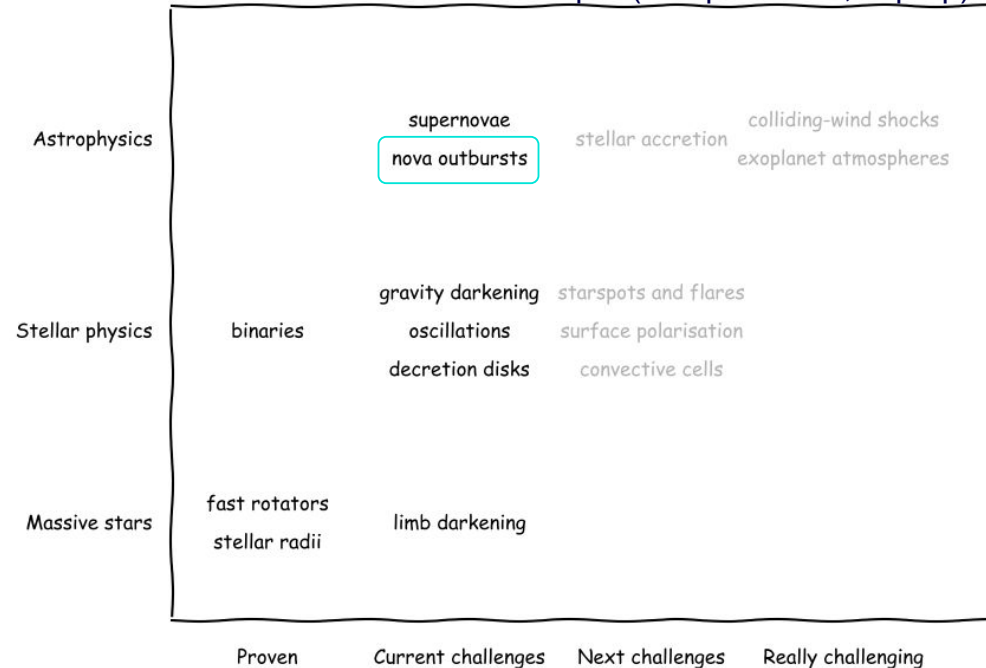
120 μs ~ CTAO-N



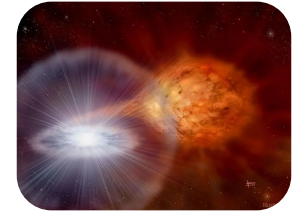
Science reach of CTAO-II

With minor adaptations of the arrays (see “How to”)

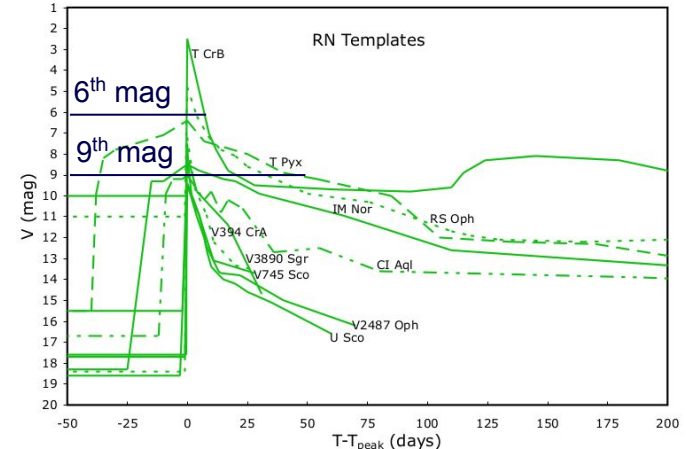
P. Saha in CTAO-II White Paper (Zampieri et al., in prep)



Credit: Hardy & PPARC



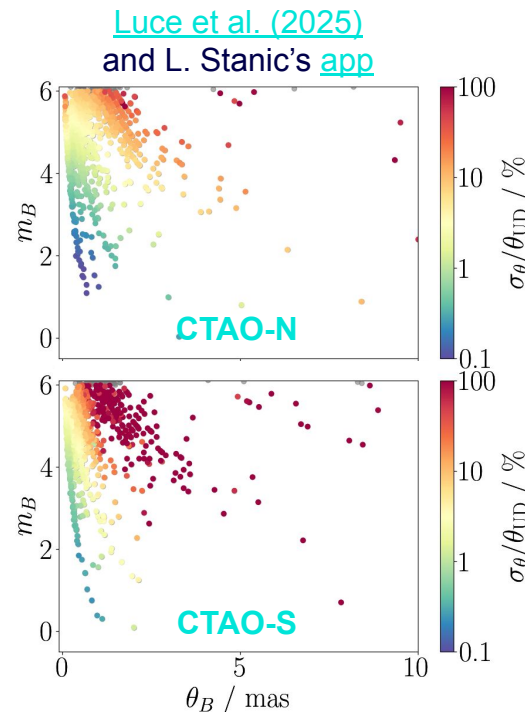
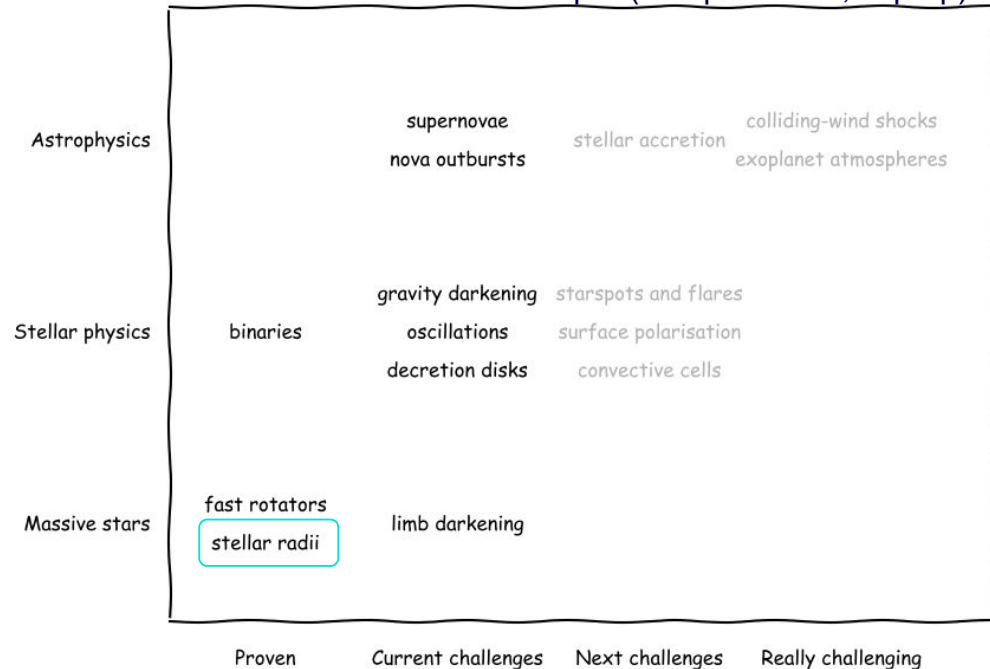
Shaefer (2010)



Science reach of CTAO-II

With minor adaptations of the arrays (see “How to”)

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



Radius measured in 2.5h with a precision of:

< 5% for 1 star out of 2

→ 1200+ targets

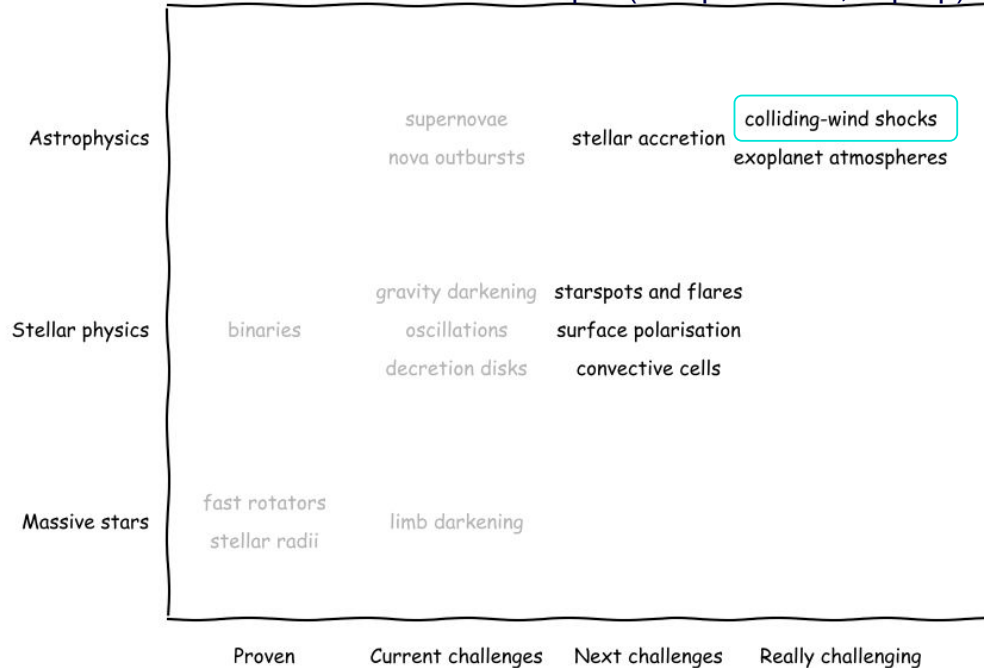
< 1% for 1 star out of 10

→ 200+ targets

Science reach of CTAO-II

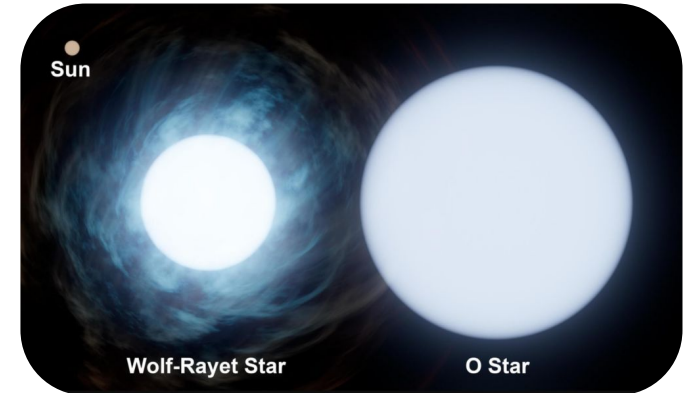
With upgraded arrays (see “How to”)

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

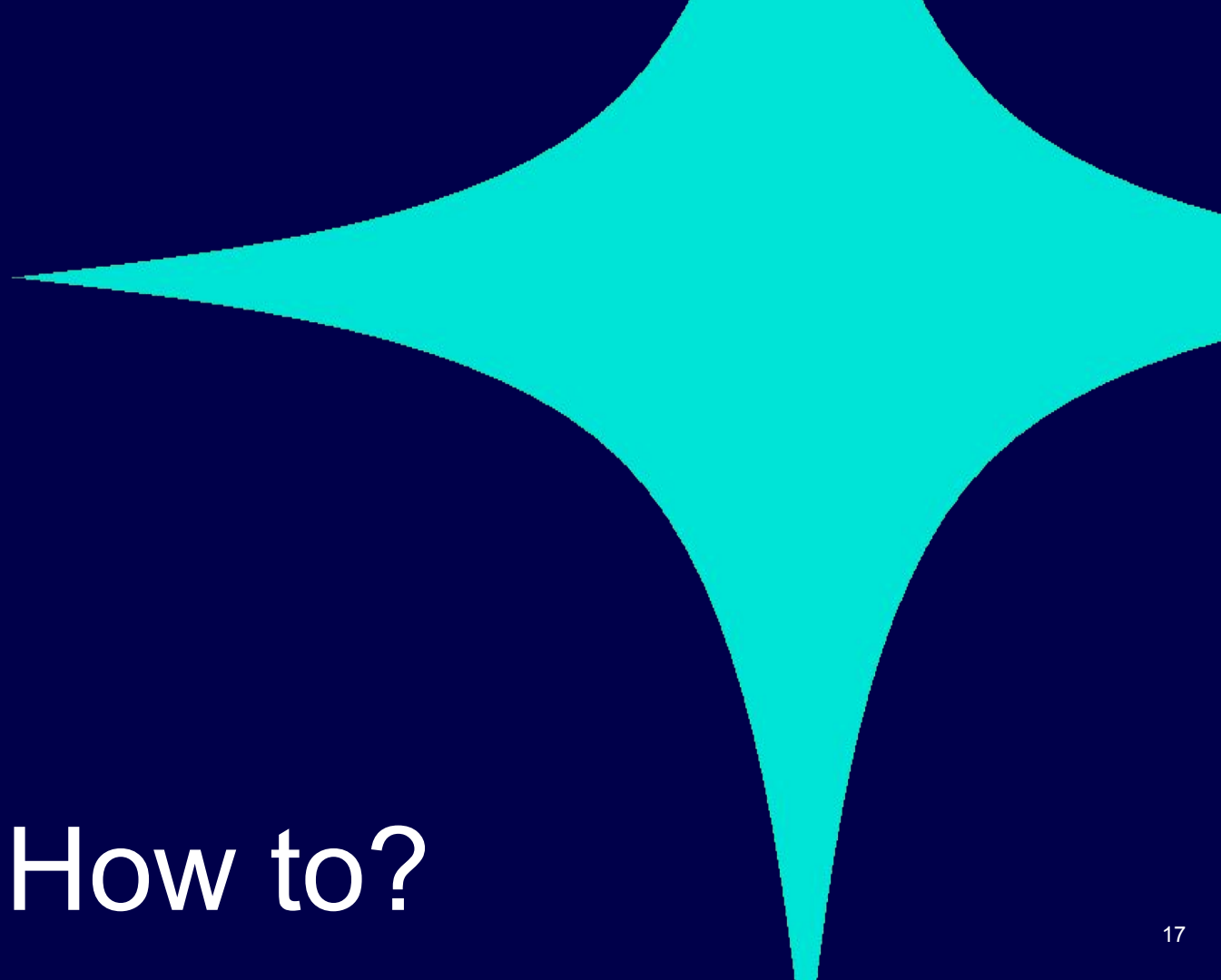


Science cases

- 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



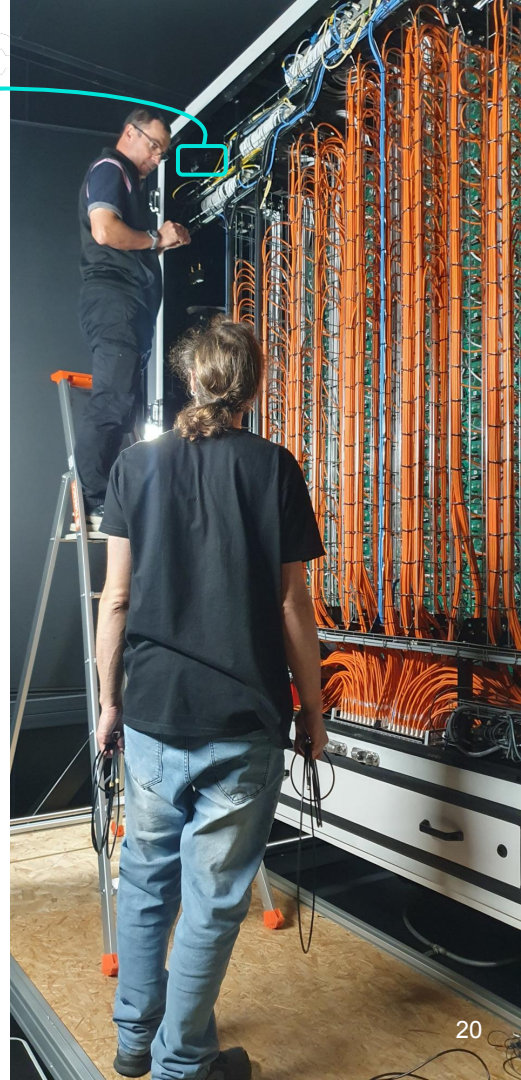
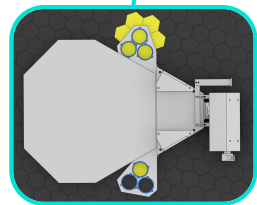
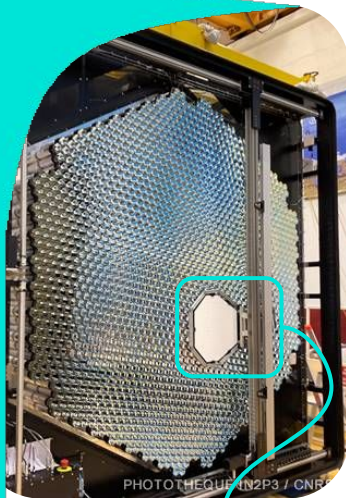
Cameras

1st stage - CTAO-II Pathfinder

- Add robotic narrow-band ($\Delta\lambda = 26$ 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 on cameras

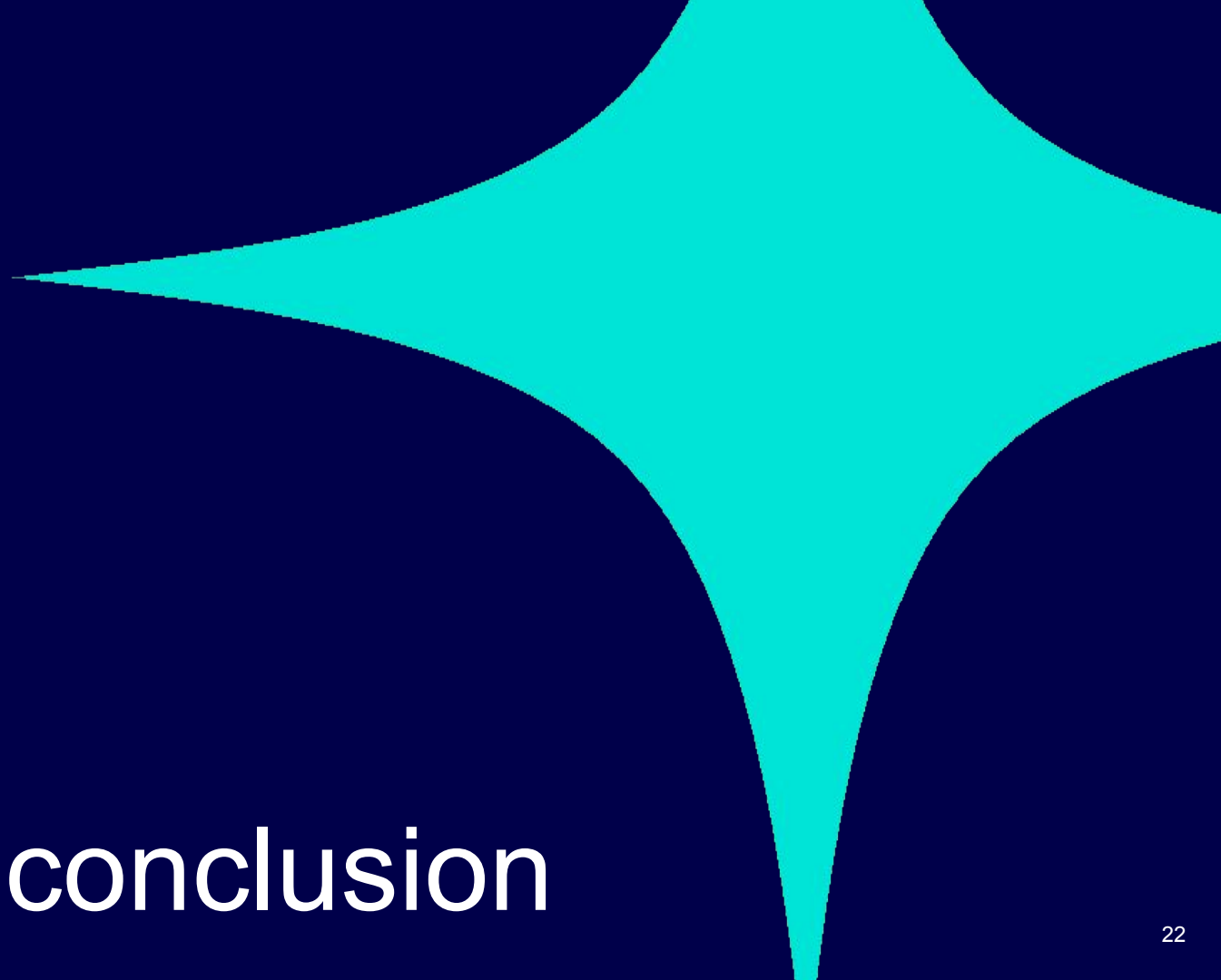
2nd stage - CTAO-II

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



A community driven effort





CTAO-II: conclusion



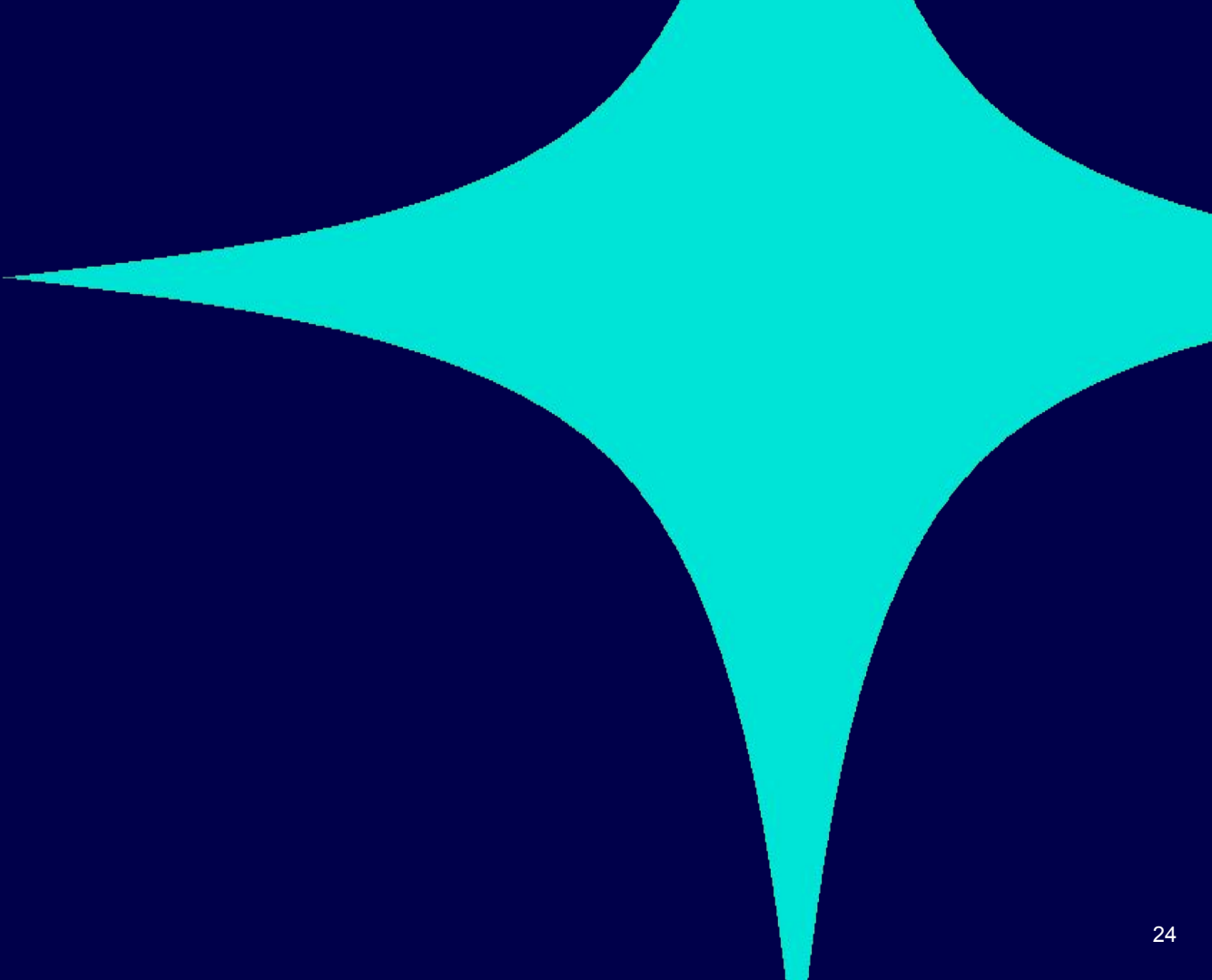
Credit: F. Acero

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.

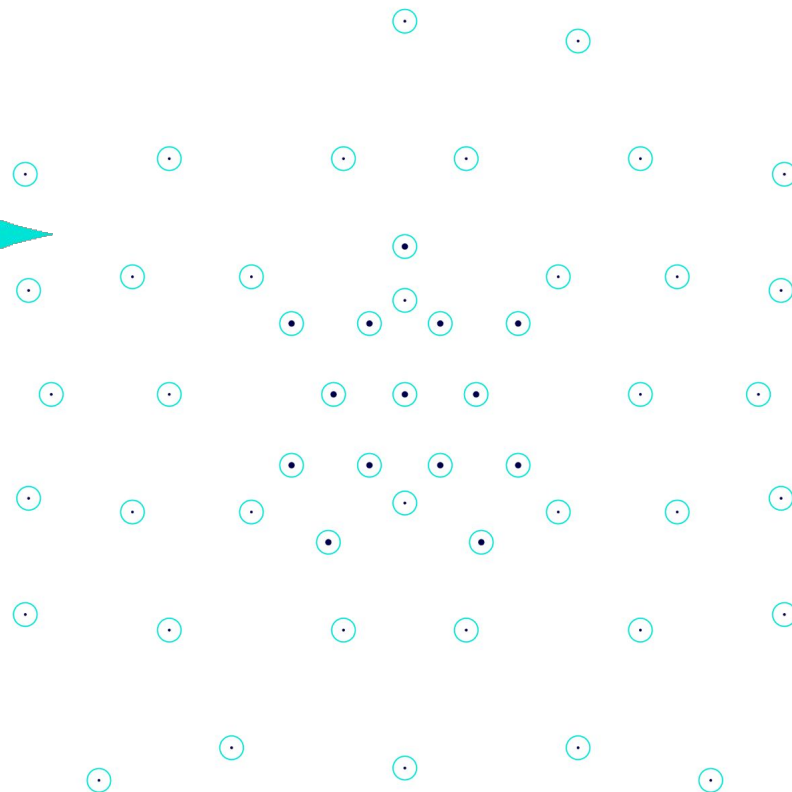
The **support of a broad community** is essential to the success of the CTAO-II!



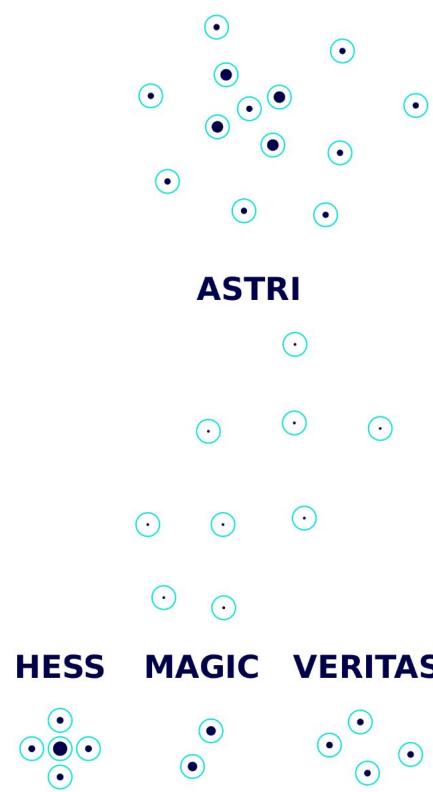
Backup

CTAO and its precursors

CTAO South - alpha config.



CTAO North - alpha config.



ASTRI

HESS

MAGIC

VERITAS

ELT

500 m



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?

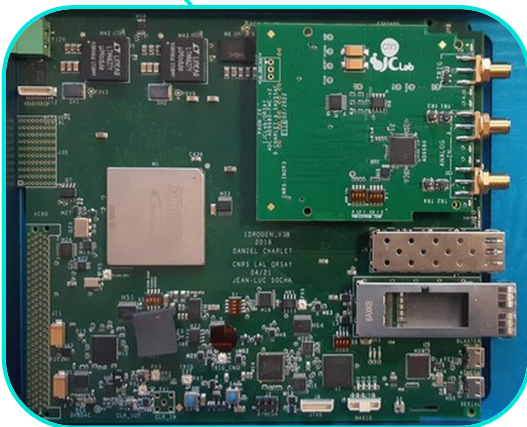
- ADC: GHz sampling, 14 bits / ns
→ or timestamps, pulse shape...
- White Rabbit: down to 20 ps jitter

Use cases:

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



Analog input 1 →
Analog input 2 →



White Rabbit →
Data link ←

