Cherenkov Telescope Array Observatory

CTAO: The Upcoming VHE γ-ray Observatory

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What is CTAO?

Beyond Telescopes

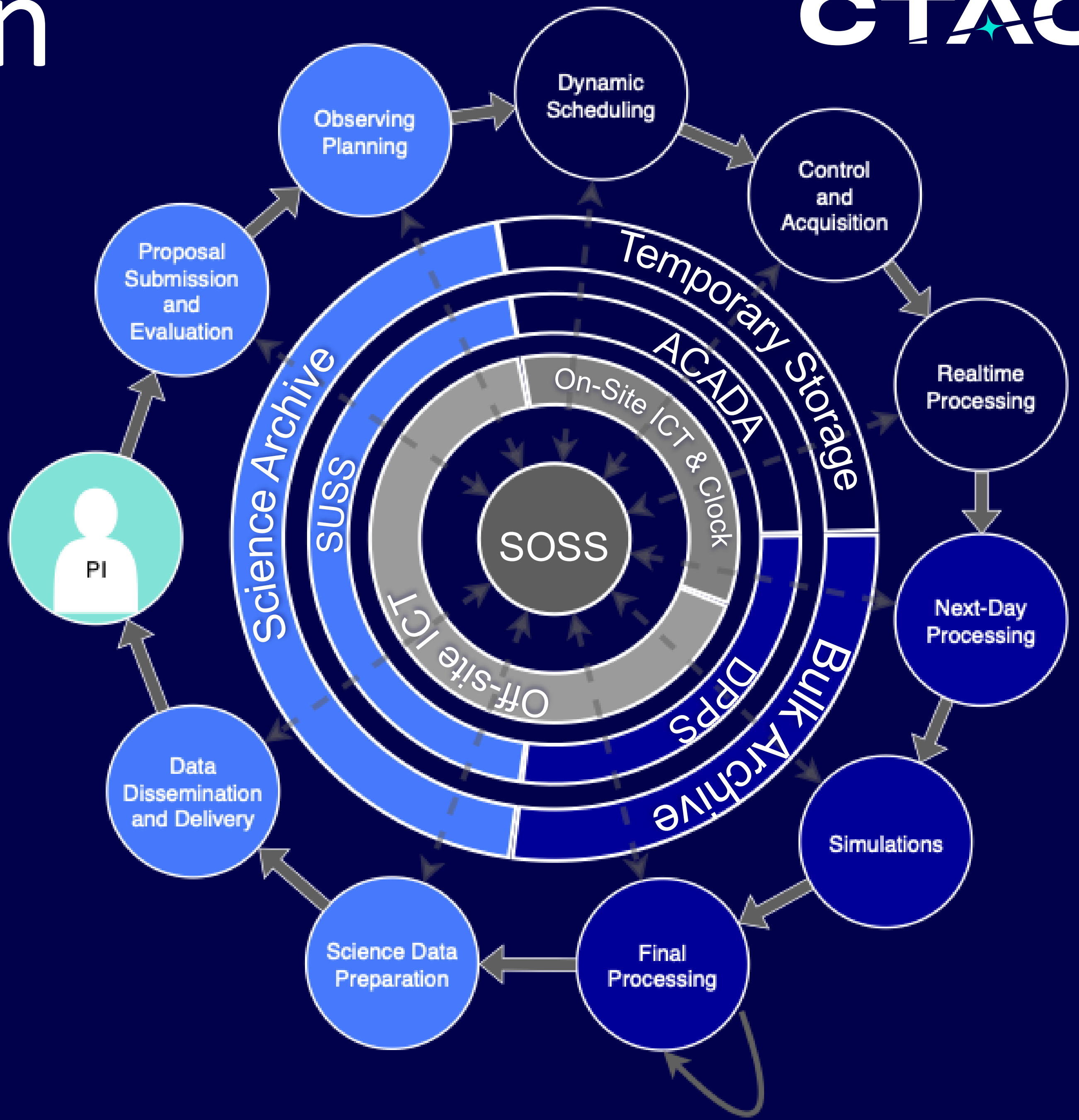
- A facility with 4 sites
  - Headquarters in Bologna (IT)
  - Science data Management Centre in Zeuthen (DE)
  - 2 Observation Stations

- CTAO is an ERIC (European Research and Innovation Consortium)

- Funded by 9 EU member states, Switzerland, ESO, and Japan
  - Australia, Brazil and USA are in talks
    - Acting as contributing parties

A Proposal Driven Observatory

- **All science proposals will be evaluated by the CTAO Time Allocation Committee (TAC) purely on scientific merit**
- Science Ready data is processed and delivered to PI within one month after observations
- Data will have a proprietary period of 1 year after the last observation in an Observing Period
  - After which the data will be public
- Observatory lifetime is is 30 years

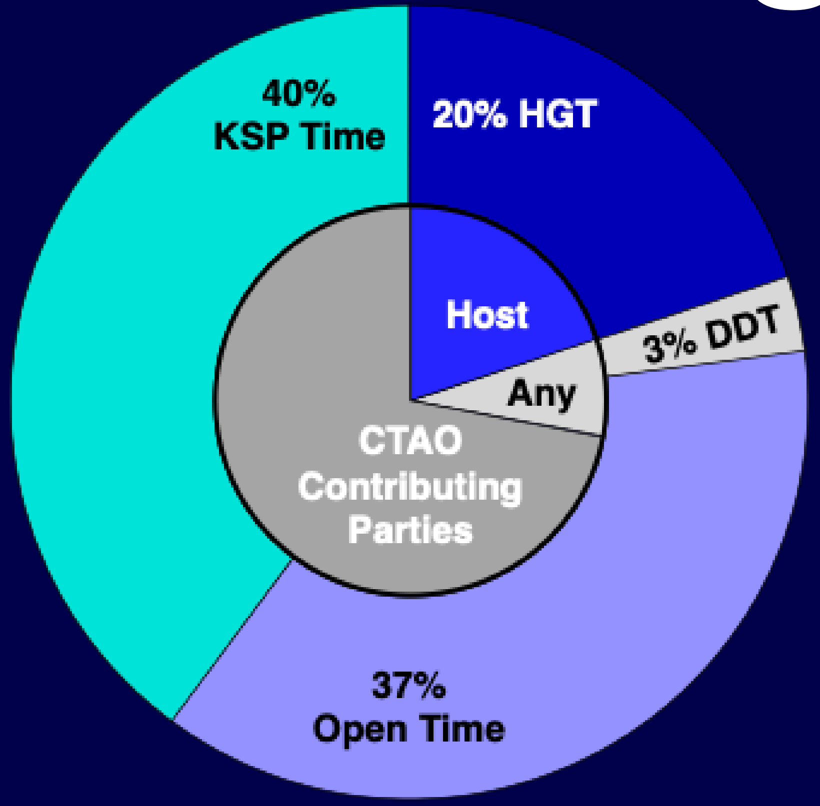


A Proposal Driven Observatory

- AO (Announcement of Opportunity) Calls regularly issued
  - Occurs once every observing period (13 lunar cycles ~1 year)
  - To request Open Time and most of the Host Guaranteed time
  - Issued by CTAO several months before the observing period begins on the CTAO Science Portal
- 8% of time is for any scientist either through DDT or ICOT

- HGT = Host Guarantee Time (CCI, Spain, Chile, ESO)
- DDT = Director's Discretionary Time
- KSP = Key Science Projects Time
- ICOT = International Community Open Time

Integrated over 10 Years



For Illustration Purposes Only

Key Science Projects

Large and Long Proposals

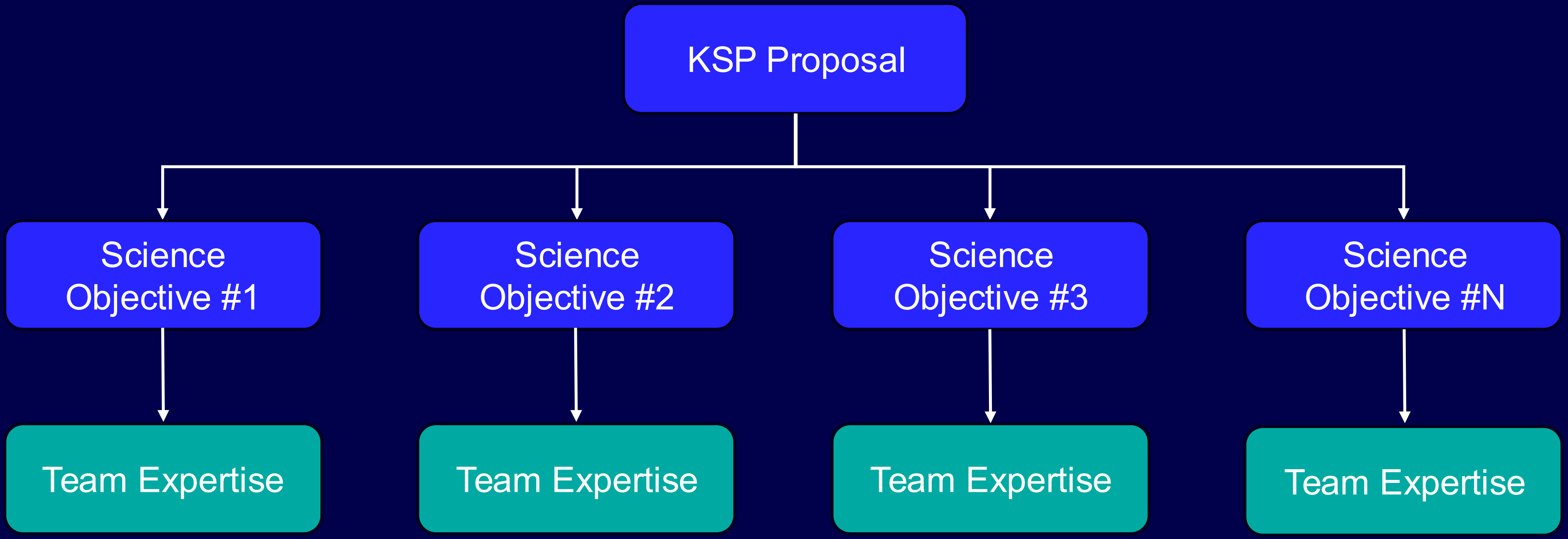
Systematic Analysis

Key Science Projects (KSPs) are observing projects requiring **more than 300 hours** of CTAO observing time allocated over more than one observing period with the aim of delivering legacy datasets, science data products and gamma-ray catalogues, which are produced **in a coherent fashion**, on **key science cases** promising major breakthroughs

Well defined research case

- Dedicated KSP call to submit KSP proposals
- Must be submitted through the CTAO Science Collaboration
  - Up to 10% of external scientists for each KSP proposal

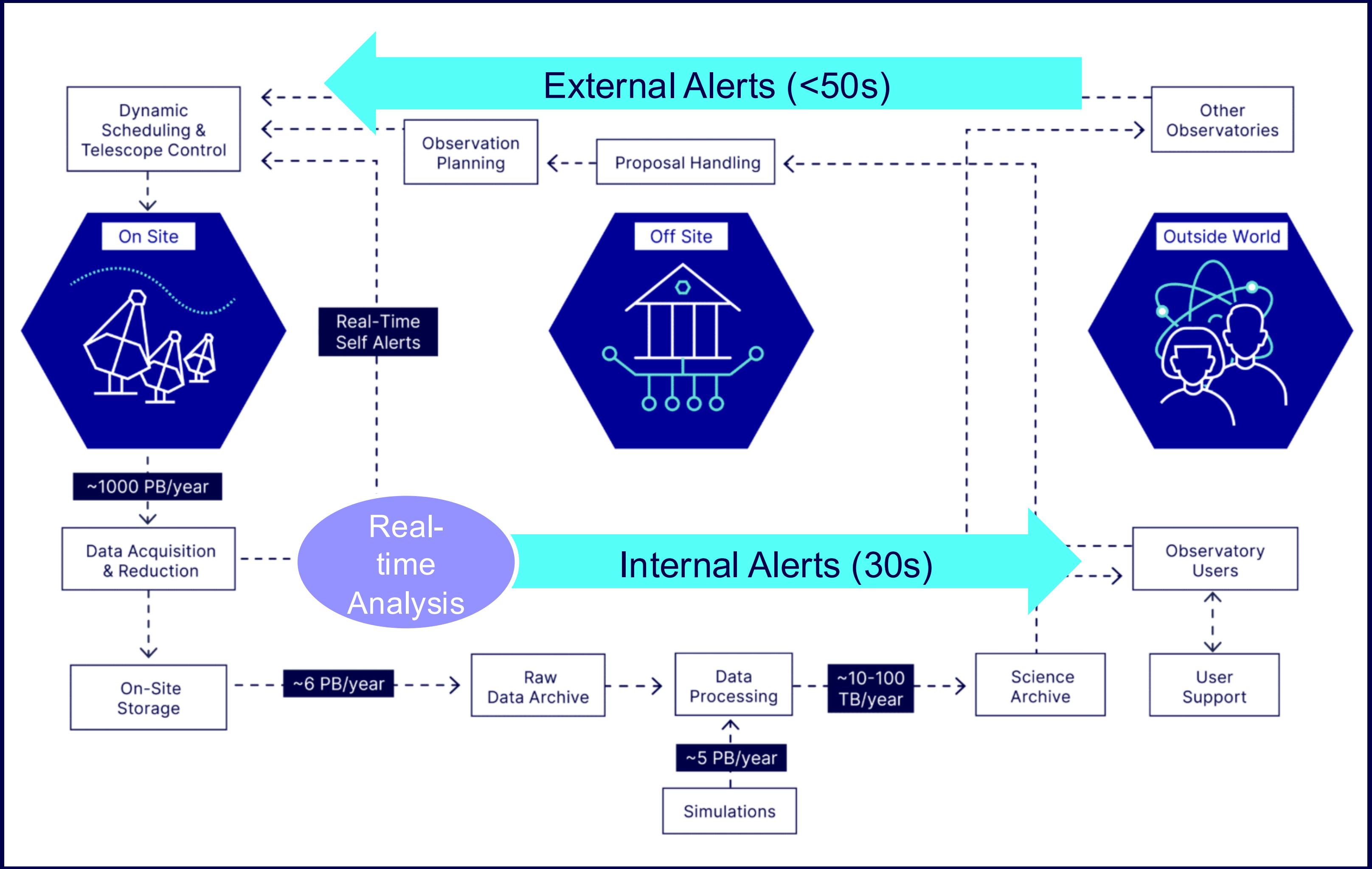
Key Science Projects



- KSP Proposals are made up of several Science Objectives
- Each having their own team PIs and experts

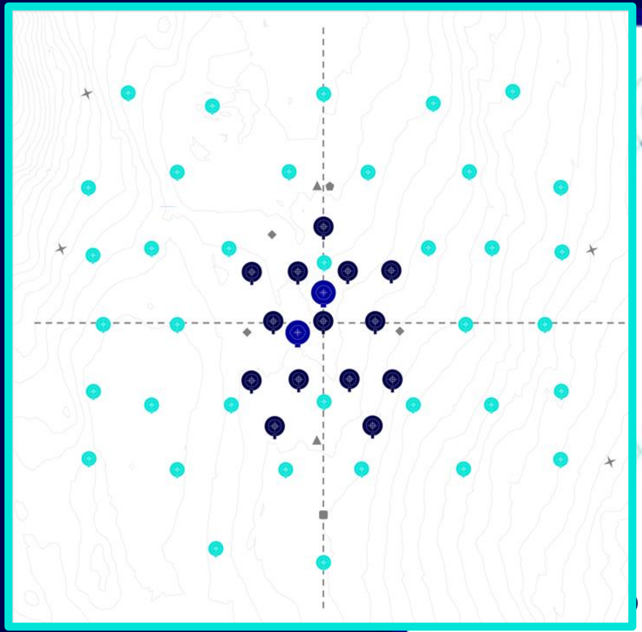
A Cornerstone of MM/MWL Astronomy

- CTAO will have dynamic scheduling and fast repointing (30 seconds) via the LSTs
- Automatic and manual alert generation configurable via proposals
- Building Transient Handlers to use all types of external alerts:
  - Neutrinos, optical, x-rays, radio, other gamma-ray instruments
- Internal Alerts
  - Self triggers from monitoring of sources
  - Serendipitous discoveries

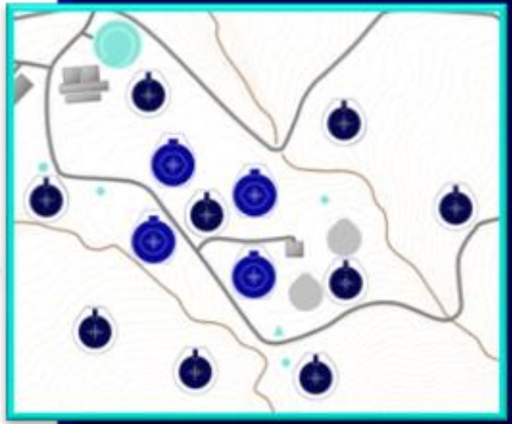


One Observatory, Two Stations

Beta Configuration



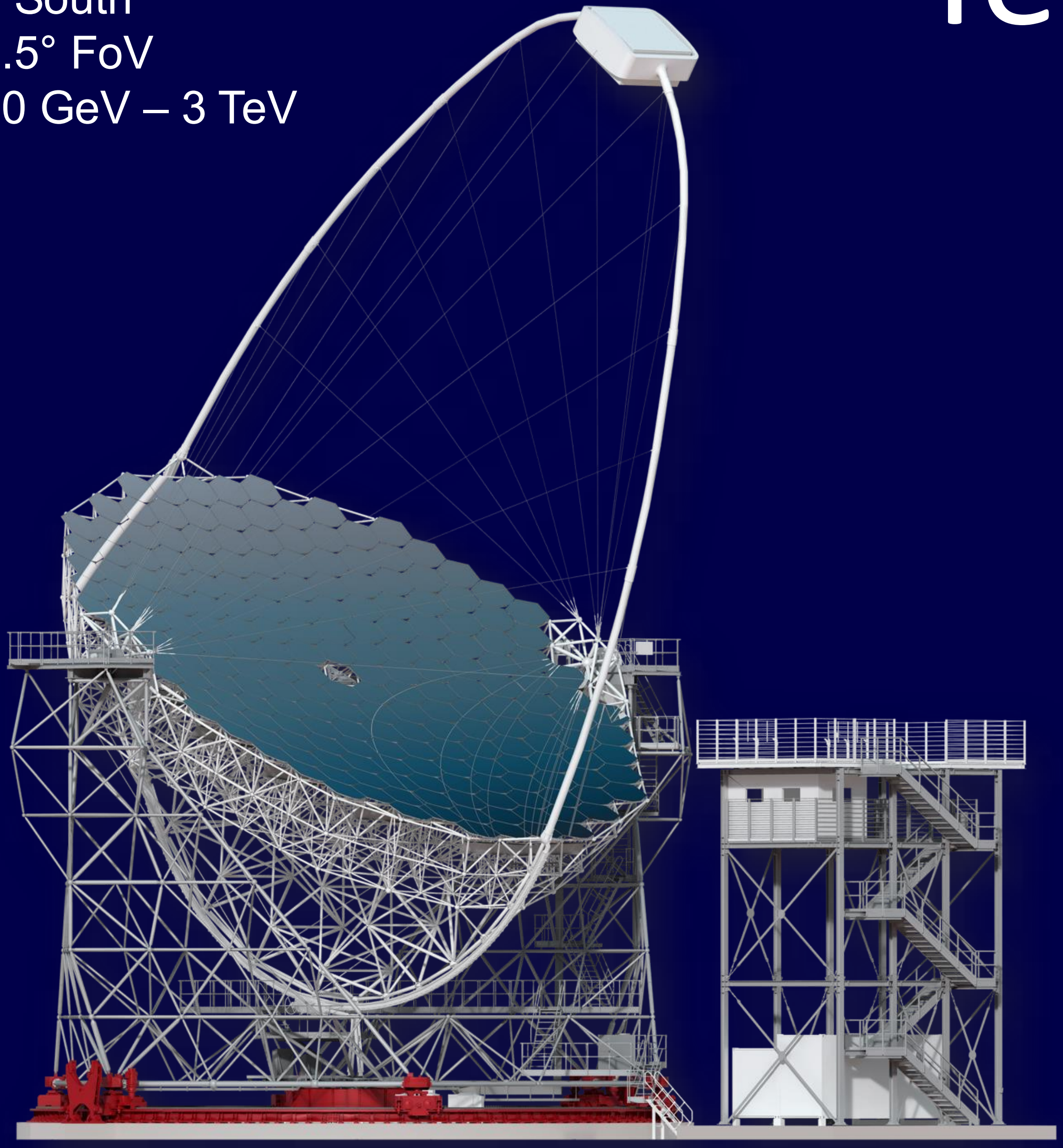
CTAO Northern Array
4 LSTs
9 MSTs



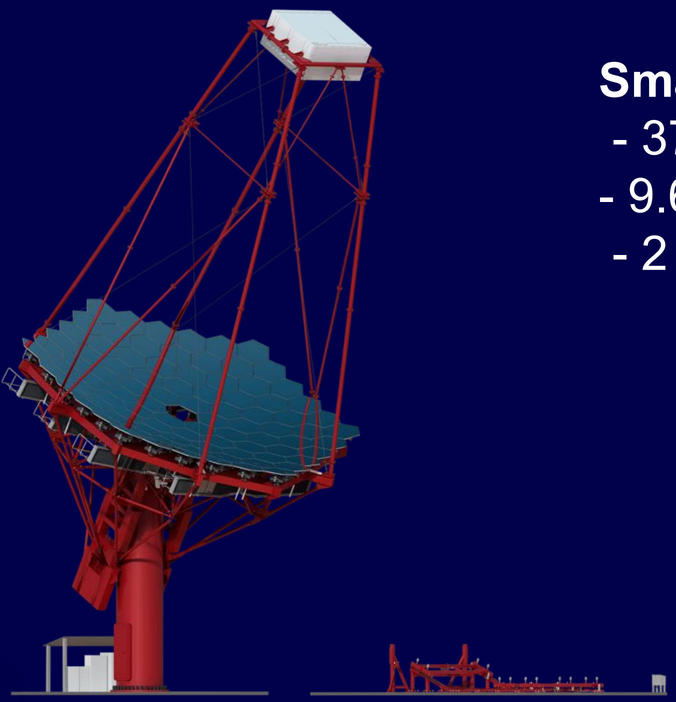
uthern Array
14 MSTs
37 SSTs

Telescopes

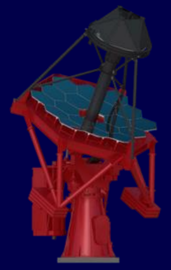
Large-Sized Telescopes:
- 4 North
- 2 South
- 4.5° FoV
- 20 GeV – 3 TeV



Medium-Sized Telescopes:
- 9 North
- 14 South
- 8° FoV
- 80 GeV – 50 TeV



Small-Sized Telescopes:
- 37 South
- 9.6° FoV
- 2 TeV – 300 TeV

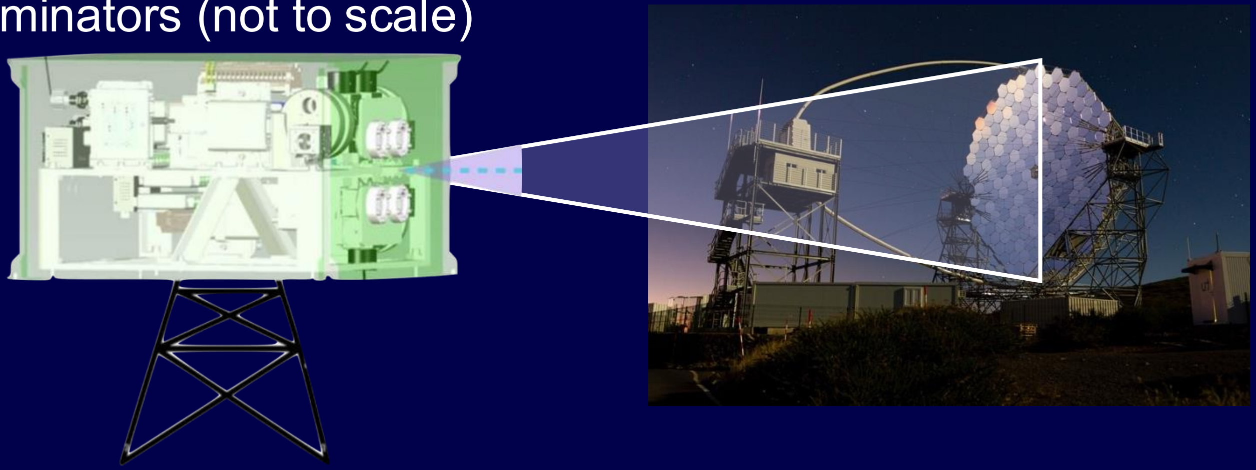


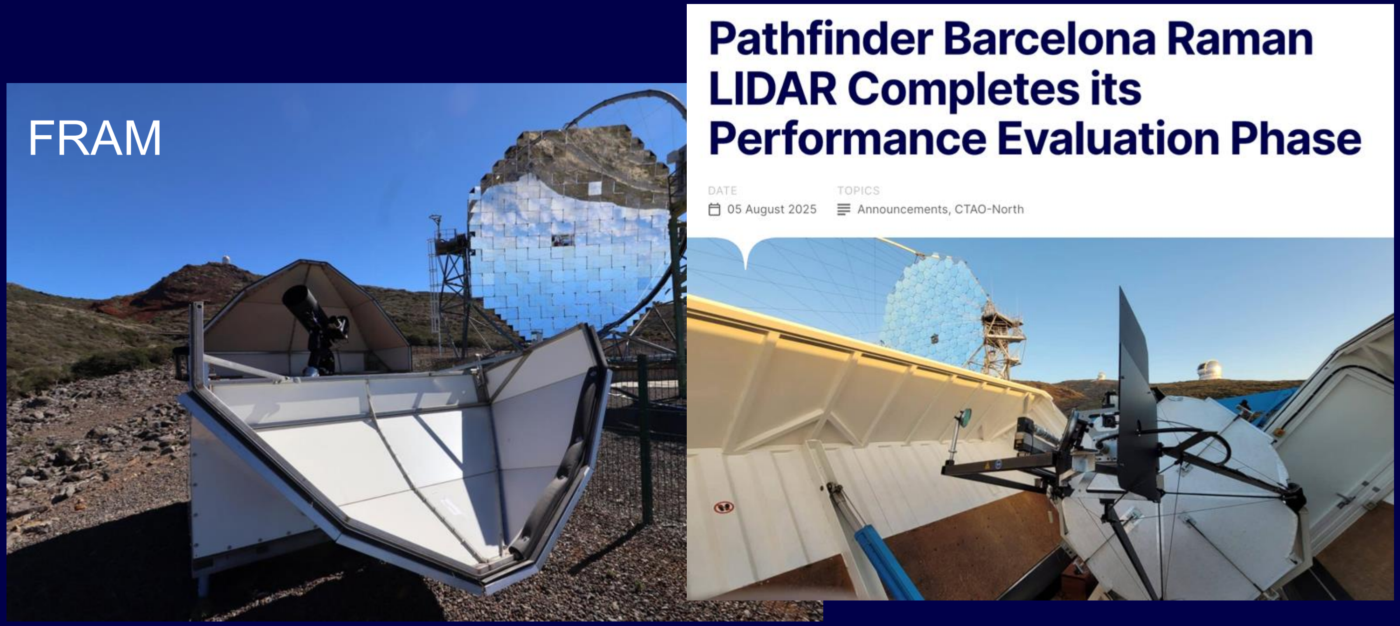
Array Common Elements

CTAO

- Ensure that CTAO meets all science performance requirements
  - Under telescope aging
  - Under all atmospheric conditions
- Ensure that CTAO site environment is sufficiently characterized to
  - Allow efficient protection of humans and instruments
  - Maximize the science output duty cycle
- This is done through LIDARs, FRAMs, Weather stations, and illuminators
- Needed to characterize the systematic uncertainties of the array

Illuminators (not to scale)





Construction

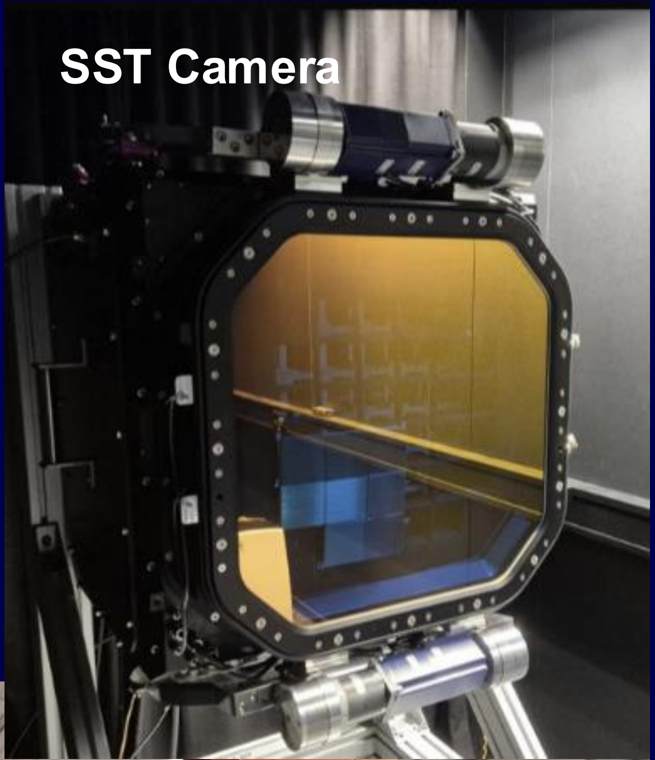
CTAO Construction has already begun!

CTAO South Groundbreaking
December 2025

CTAO North Progress
September 2025

CTAO


SST Foundation (Paranal)


SST Camera


MST Structure
Under Construction


MST Mirror

SST Structure

CTAO Timeline

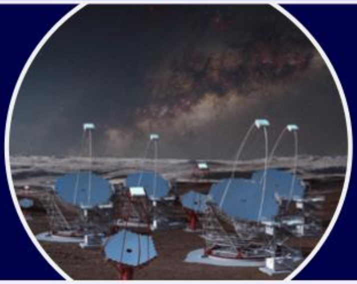
CTAO

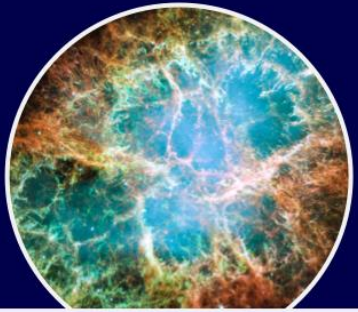
IKC Construction

- Telescopes
- Array Common Elements
- Commission of array elements
- CTAO software

System Commissioning

- Integration, verification, and validation of array elements and software
- Science verification of system releases





CTAO Construction

- Infrastructure
- Roads, on-site data centers

Guaranteed Early Science

- Guaranteed observing time for Contributors to construction of beta configuration
- Collection of targets for Science Validation

Public Early Science

- Call for proposals
- Start of Host Guaranteed Time
- Use of verified intermediate configuration

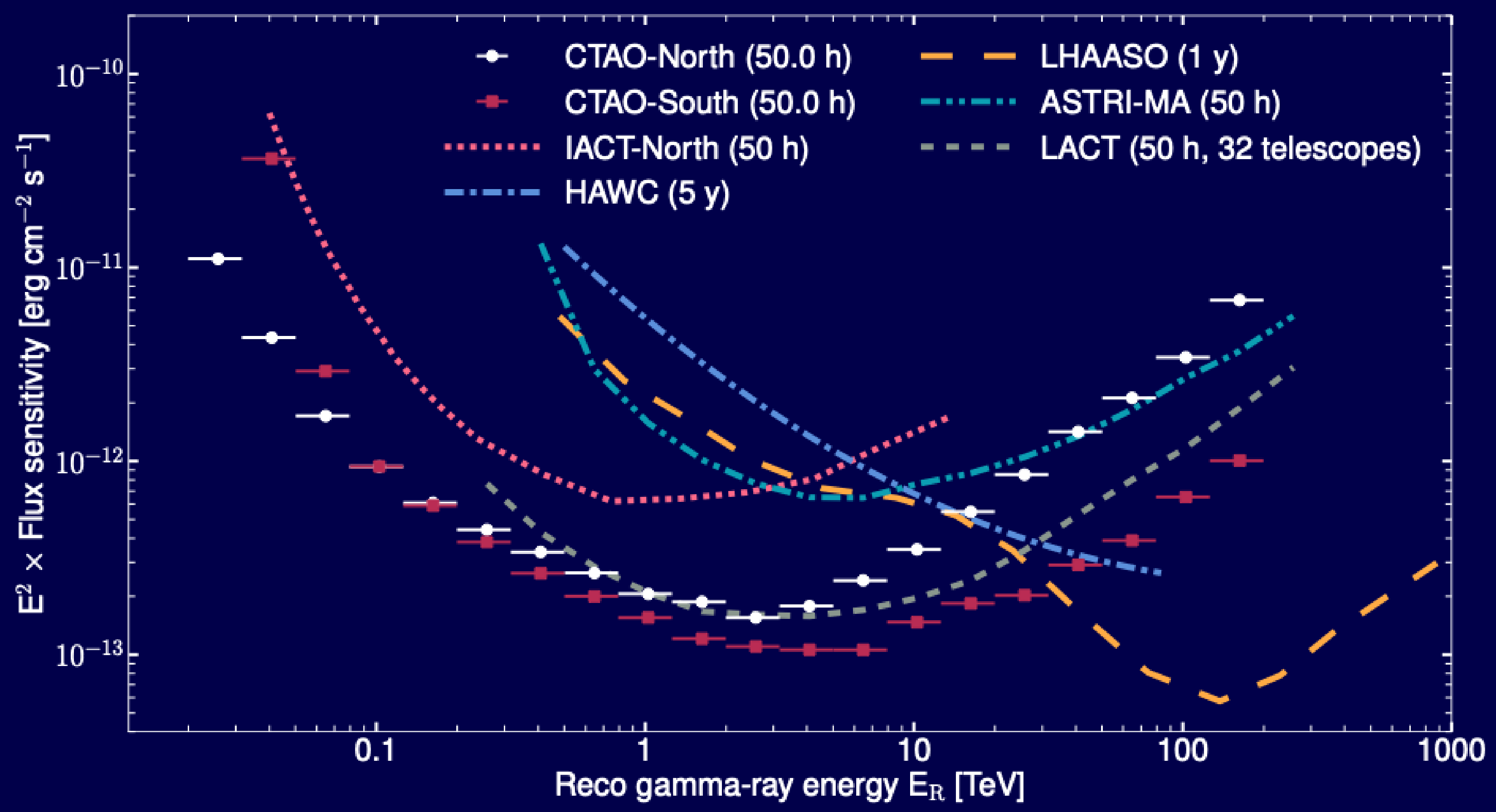
Steady State Operations

- Full Beta configuration
- Steady State Operations begin
- KSP begins

Now — 2028 — 2030 — 2032+

CTAO Sensitivity

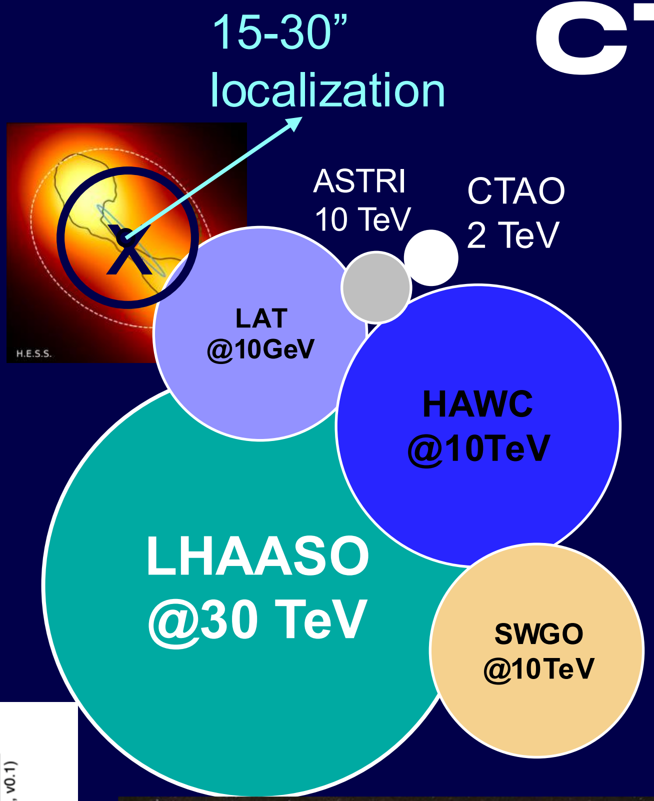
Beta Configuration Coming Soon!

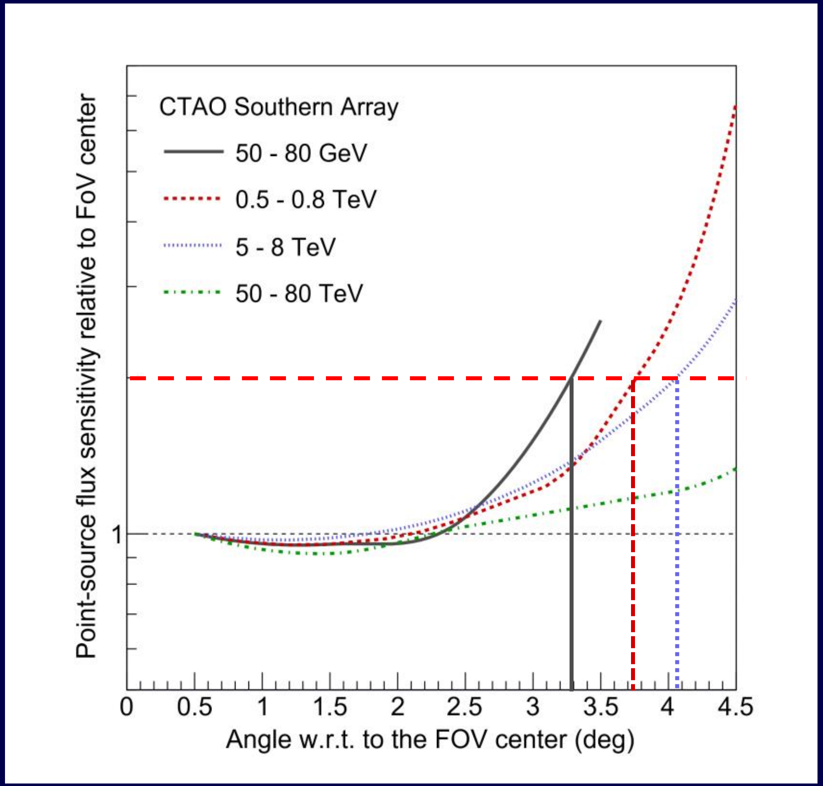


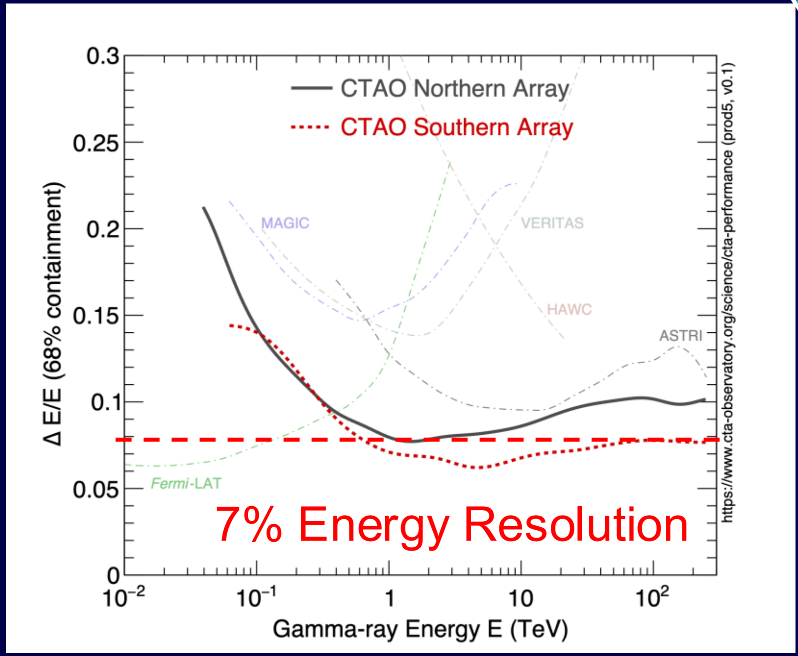
- Based on Prod5 Simulations
- Full array sensitivity
- Prod6 expected in the upcoming months

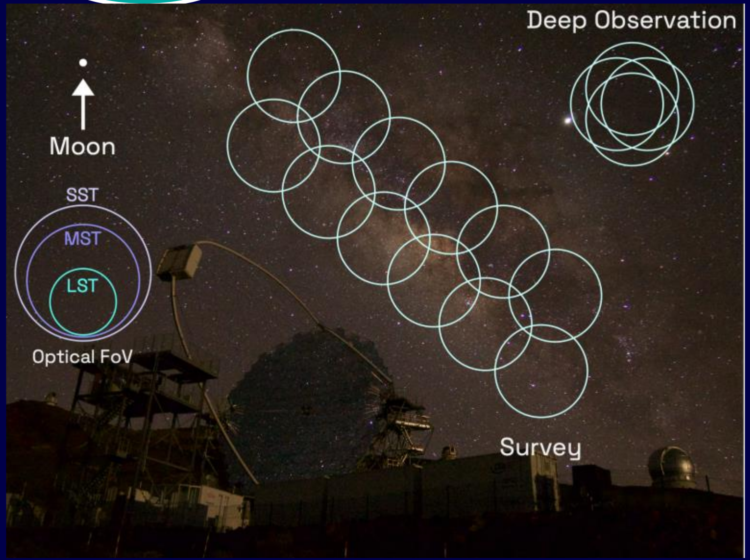
Beyond Sensitivity

Observational Functionalities
- Surveys and Deep Observations
- Fixed ICRS and fixed Horizon (i.e. drift scan)
- Sub-array configurations
- Parallel and Divergent (under investigation)









CTAO Science

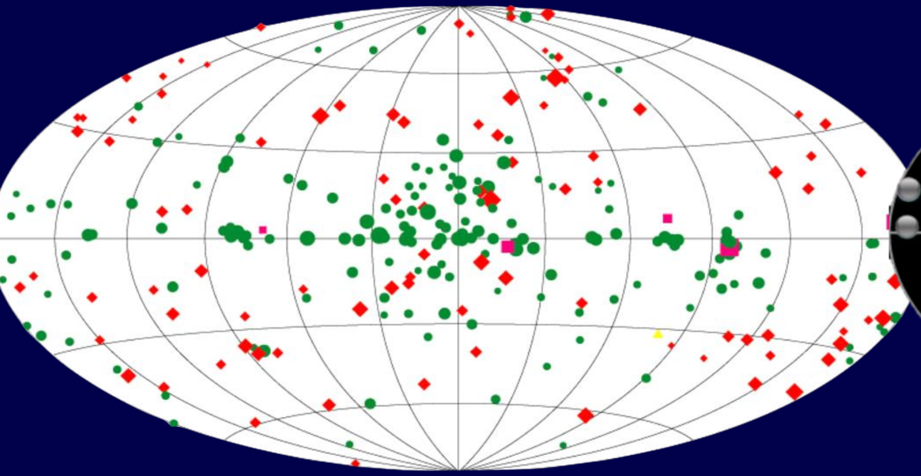
High Energy (>100 MeV)

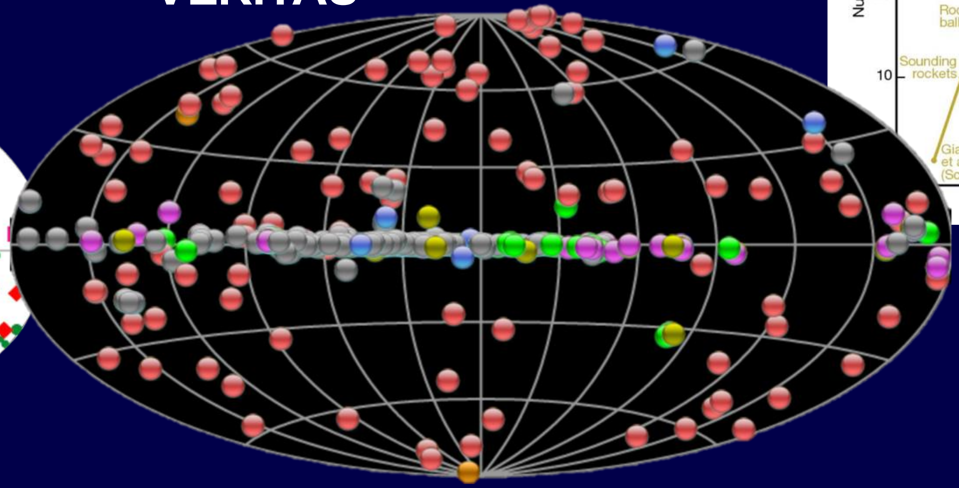
EGRET → **Fermi-LAT**

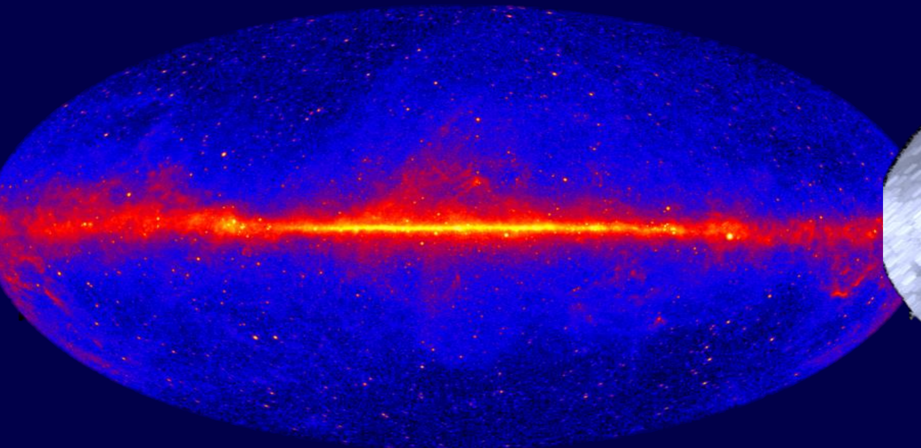
188 → 7194

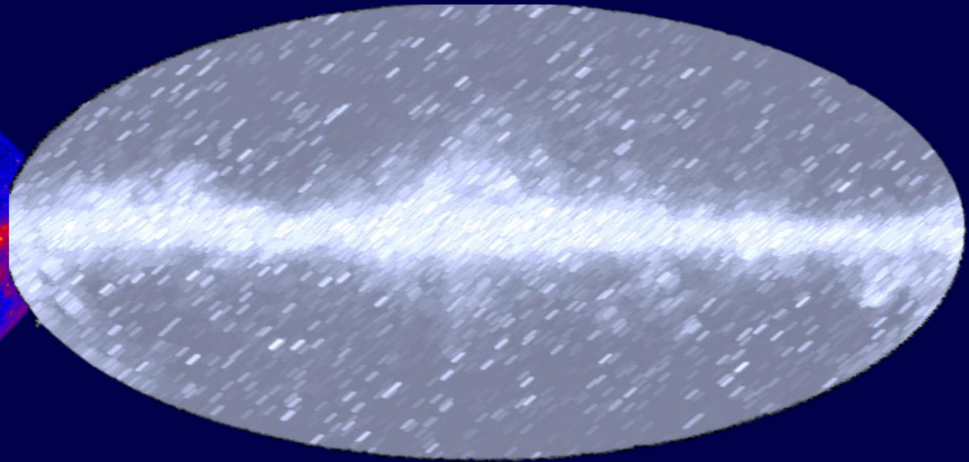
Very High Energy (>100 GeV)

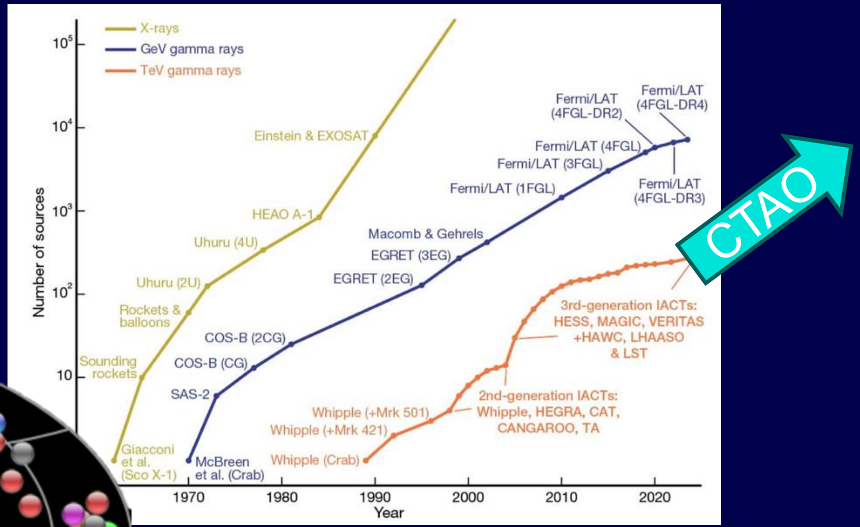
MAGIC
H.E.S.S.
VERITAS → **CTAO**











Kifune Plot

CTAO Science

Theme 1: Origin and role of Cosmic-rays in the Universe

Galactic PeVatrons

Identify sources capable of *accelerating cosmic rays to PeV* energies.

Key targets: Galactic Center, SNRs, PWNe, mircoquasars.

SNRs and the Origin of Cosmic Rays

Study *acceleration, diffusion, and escape* of particles.

Combine CTAO data with Fermi-LAT, radio, and X-ray observations.

Cosmic-Ray Diffusion and Propagation

Probe *cosmic-ray transport* through molecular clouds and diffuse emission.

Binary Systems

Investigate *particle acceleration* in compact binaries, microquasars.

Pulsar Wind Nebulae (PWNe)

Examine leptonic acceleration, cooling, and nebular structure.

Star-forming Systems

Explore *collective acceleration* in starburst regions and OB associations.

CTAO Science

Theme 2: Probing Extreme Environments

Clusters of Galaxies

Probe cosmic-ray confinement, cluster energetics and intracluster medium heating.

The Galactic Center Environment as a whole

Study diffuse gamma-ray emission, potential PeVatron, and dark matter.

Radio Galaxies and Misaligned AGN

Test jet models and large-scale VHE emission.

Gamma-Ray Bursts (GRBs)

Explore prompt and afterglow VHE emission; Lorentz factor limits; new physics.

Pulsars and Magnetospheres

Search for VHE pulsed emission; constrain emission zones.

Active Galactic Nuclei (AGN)

Study particle acceleration, jet formation, B-field and variability.

Transient and multi-wavelength/multi-messenger program

CTAO Science

Theme 3: Exploring Frontiers in Physics

Cosmology and Intergalactic Magnetic Fields (IGMF)

Hubble Constant via EBL

Study pair cascades and delayed emission to probe IGMF strength

Extragalactic Background Light (EBL)

Constrain EBL density through *attenuation of AGN and GRB spectra.*

Dark Matter Searches

WIMP *annihilation/decay* from Galactic Center, dwarf spheroidals, galaxy clusters.

Lorentz Invariance Violation (LIV)

Use GRBs and AGN flares to test quantum-gravity effects through *time-delay and threshold effects*

Axion-like Particles (ALPs)

Search for photon–ALP mixing through *irregularities in spectra and photon-recovery*.

Cosmic-Ray Electron Spectrum and Anisotropy

Measure *local spectrum* up to tens of TeV to test nearby sources.

Expected performance in *heavier CRs*

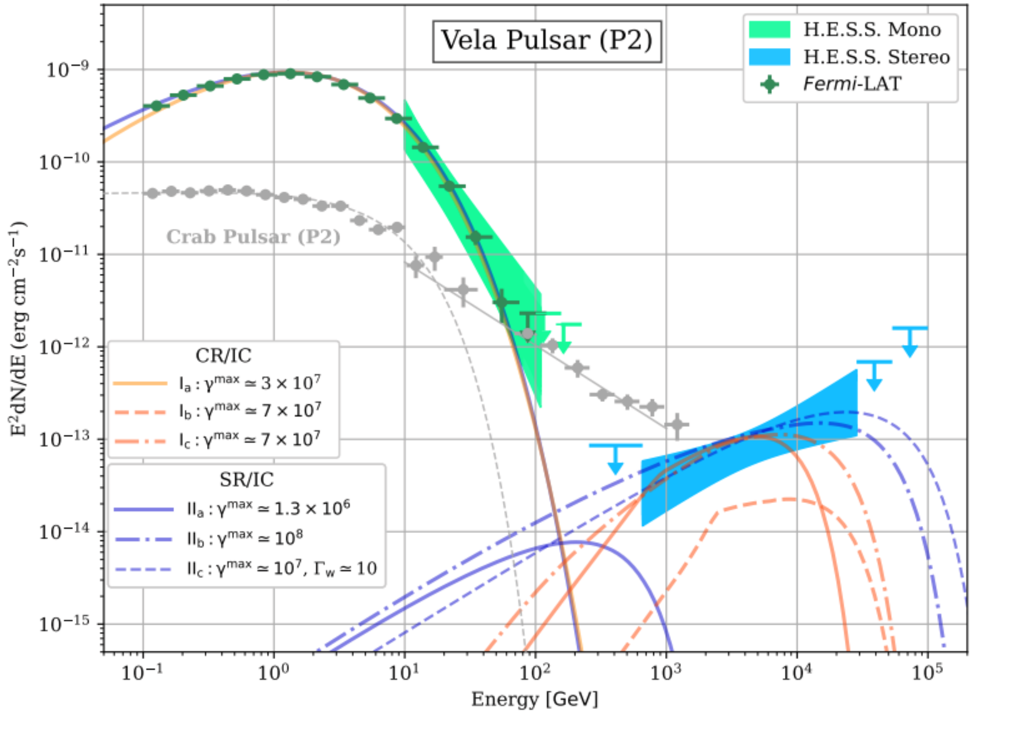
Some Personal Highlights

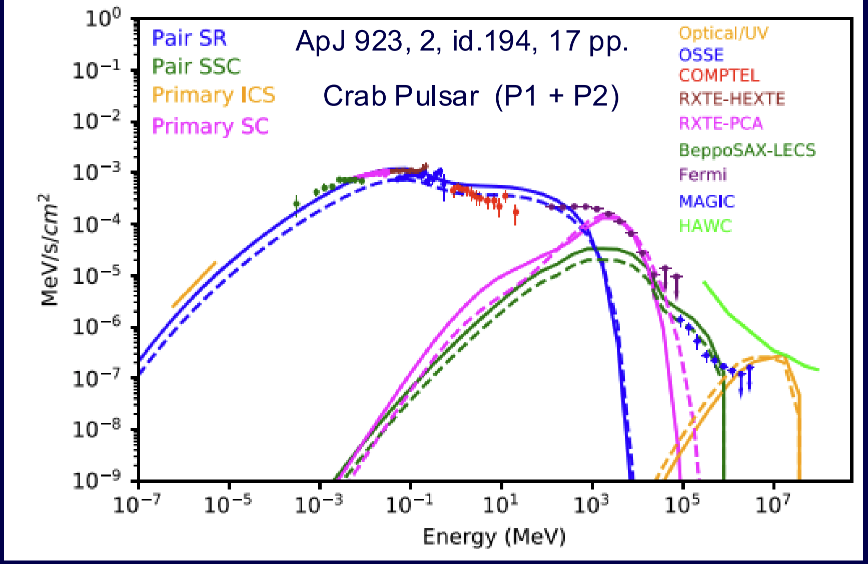
1. Pulsars
2. Microquasars
3. YMSC
4. Novae

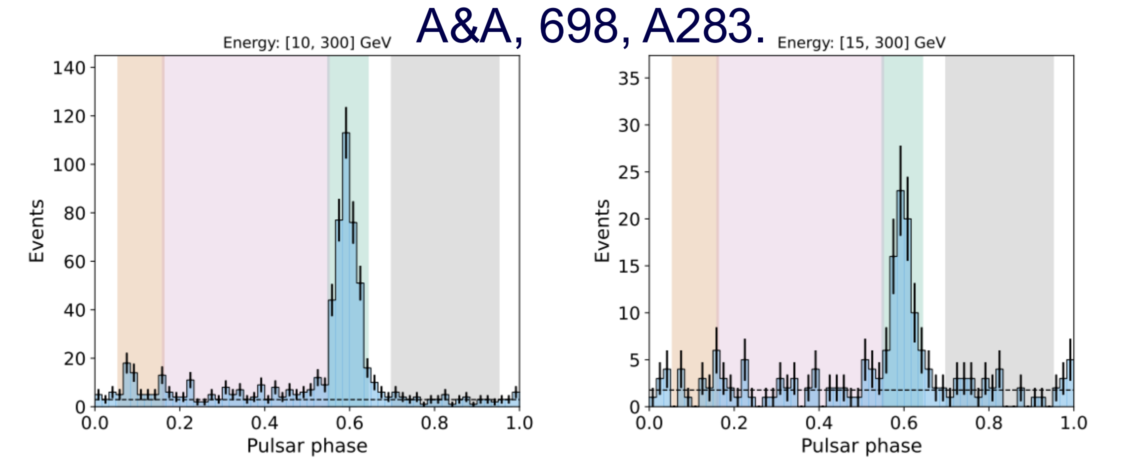
Pulsars

- What does the primary spectrum look like: Simple cutoffs vs extra components
- How many other pulsars have an IC peak?
- How many more VHE pulsars
- More targets mean more constraints on theory
- Extreme e+- accelerators -> Understand positron fraction

Nature Astronomy, Vol 7, p. 1341-1350



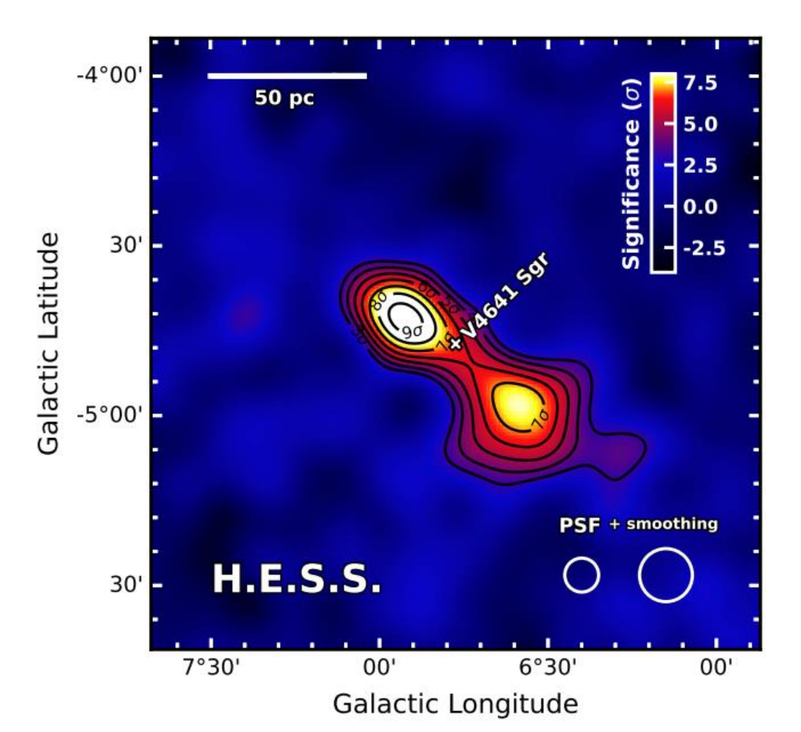




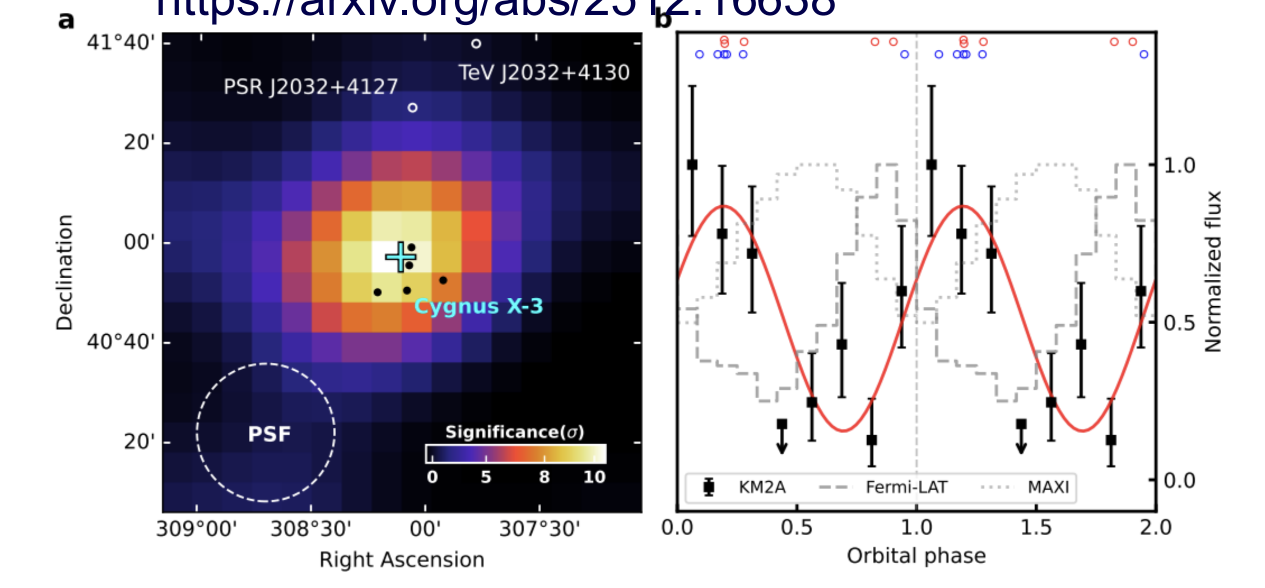
Microquasars

A&A, Vol 706, id.A8, 23 pp.

- What is the maximum energy from these sources:
  - LHAASO says 100s TeV Requires high power (~Ledd) and high magnetic fields
- V4641 Sgr has been radio quiet but gamma-ray bright
- What determines whether a microquasar is gamma-ray bright?
  - No clear correlation between average power
  - Only small sample size!
- CTAO sensitivity, FoV, and PSF can determine:
  - Emission mechanisms,
  - Maximum Energy
  - New microquasars

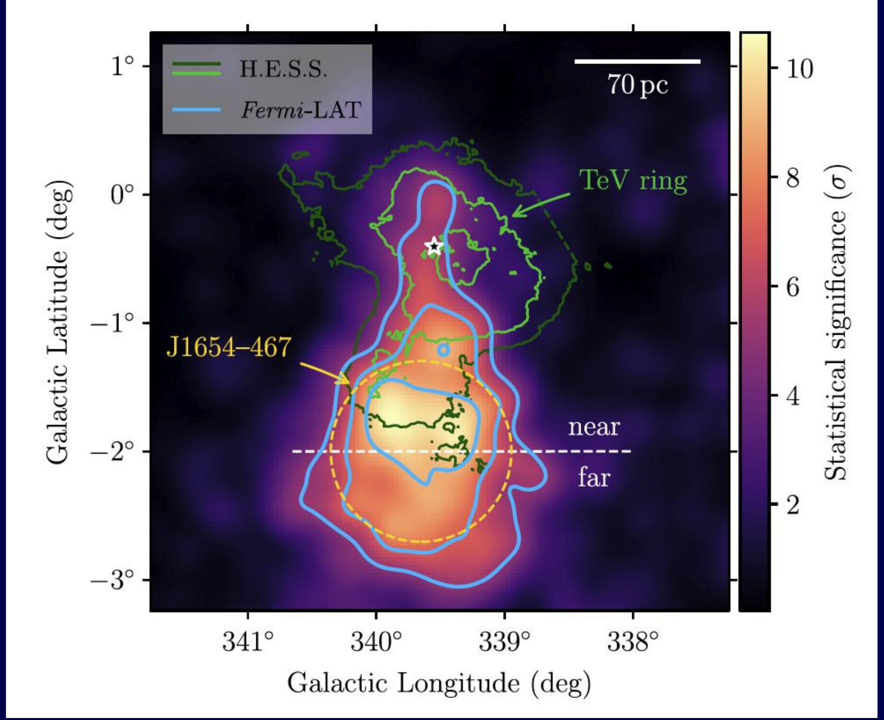


https://arxiv.org/abs/2512.16638

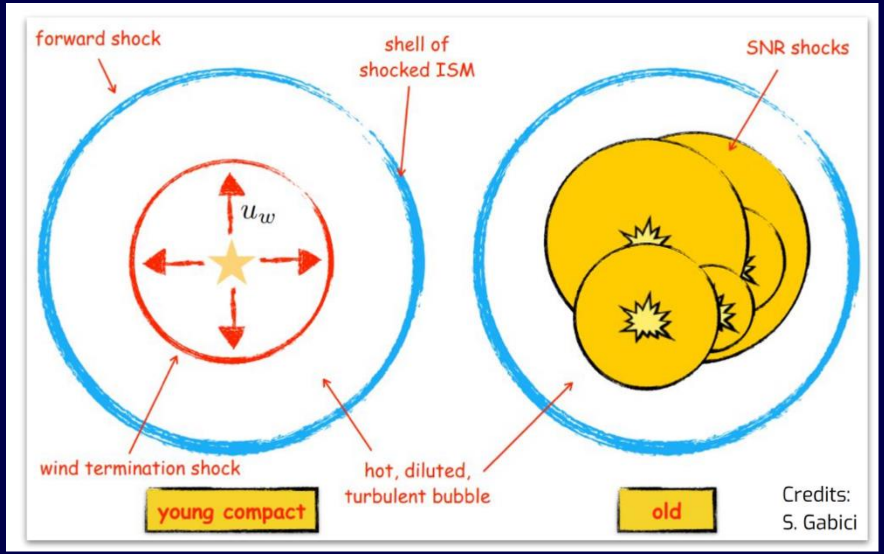


YMSC

- Increasingly promising sources for CRs
- Show clear 100s TeV to PeV emission
- Multiple components and energy dependent morphologies
    - What is the maximum energy and where in the YMSC is it emitted?
    - What is the role of escaping CRs?
- How much to YMSC contribute to overall CR population?
- Only a few detected currently, CTAO will increase by 10x



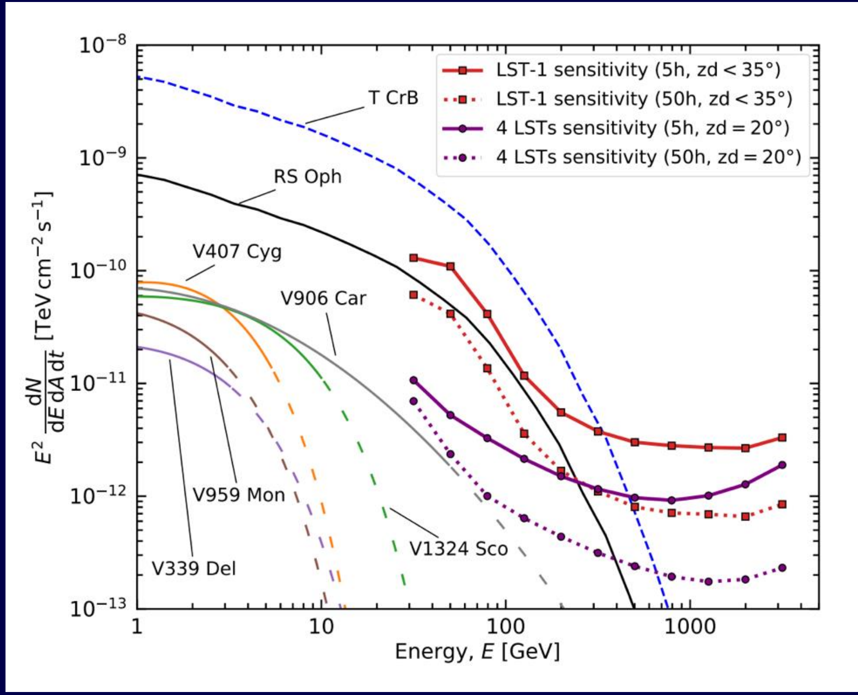
Nature Communications 16: 10820 (2025)

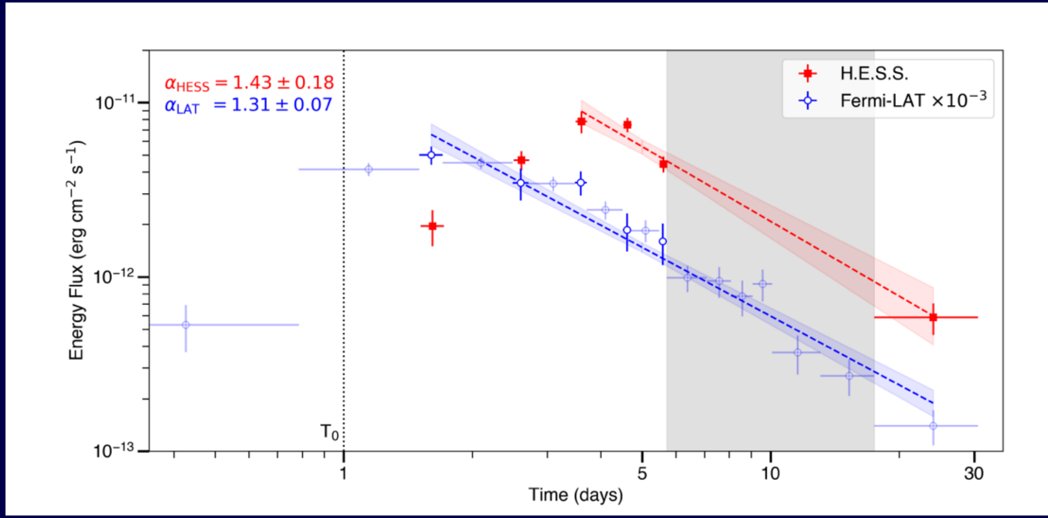


Novae

- Only one nova has been detected in VHE
    - RS Oph – Symbiotic Novae
    - Dozens in HE
- What does the role of the donor environment play?
    - What about classical novae?
- Deeper temporal observations are needed
    - Both long term and immediate follow up (< 1 day after optical outburst)
- Next RS Oph outburst is ~2035

Abe, K., et al.: A&A, 695, A152 (2025)



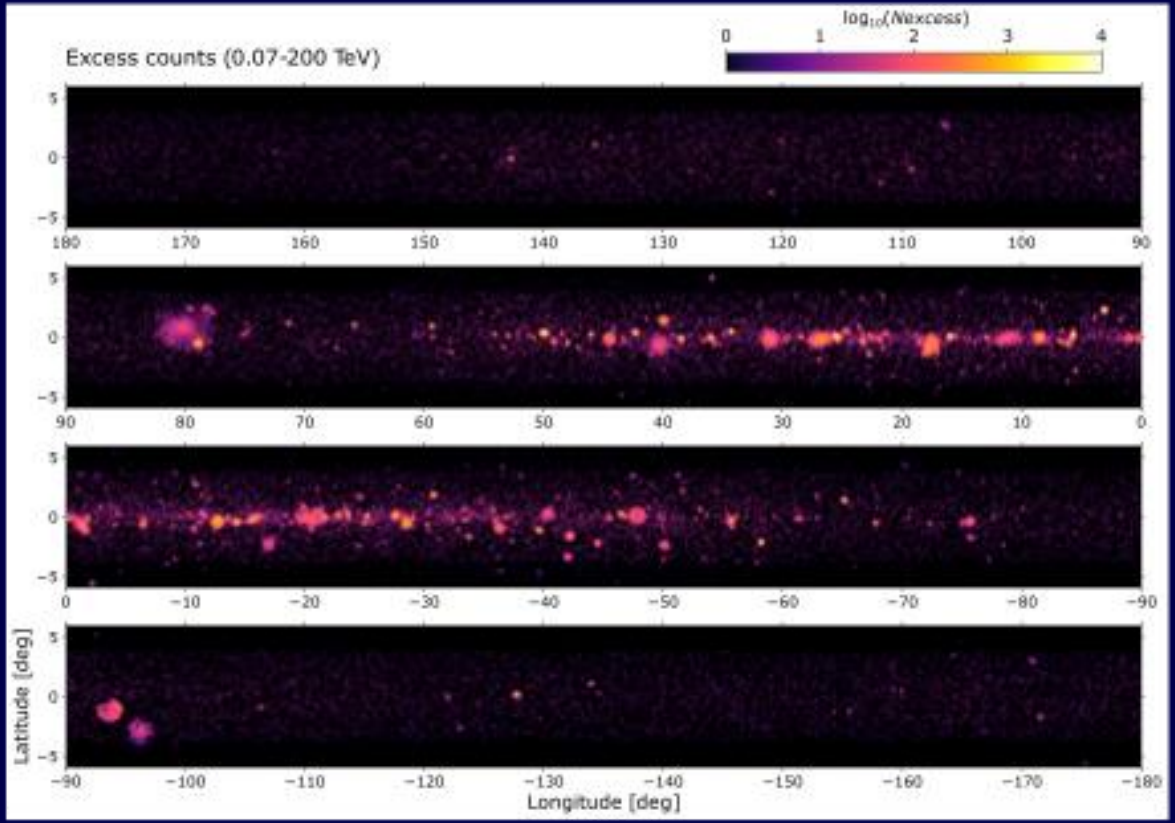


Science, 376,6588, pp. 77-80 (2022).

Science Data Challenge

Fully open and blind!

Seven years of simulated CTAO observations provided as science-ready datasets



Goals:

- Allow the scientific community to explore CTAO Scientific capabilities
- Allow users to become familiar with the technicalities of the analysis as well with the CTAO SAT/Gammapy
- Good opportunity to learn Gammapy

Release of Science Data Challenge Q4 2026

Conclusions

- **VHE gamma-ray astronomy is a key discipline within the broader field of astrophysics**

- **CTAO** will be the first proposal driven open astronomy observatory in the field of VHE astronomy

- The scientific community will have the possibility to request observing time and to access the data (after a one year of proprietary period)

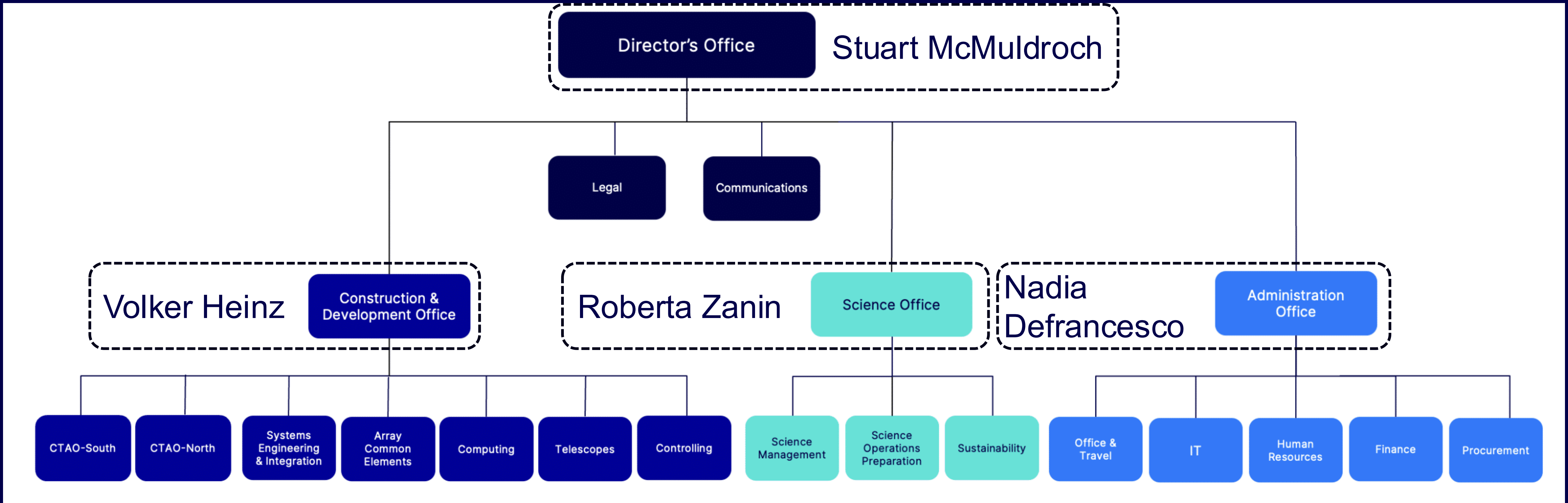
- **CTAO** is set to become a **cornerstone** of mutli-messenger and mutli-wavelength (MM/MWL) astronomy

- The construction of the **CTAO project** has already started! First data is coming soon.

Backup Slides

Who is the CTAO ERIC?

Beyond Telescopes



More information on the CTAO team:
https://www.ctao.org/it/organisation/team/

Data Categories

CTAO

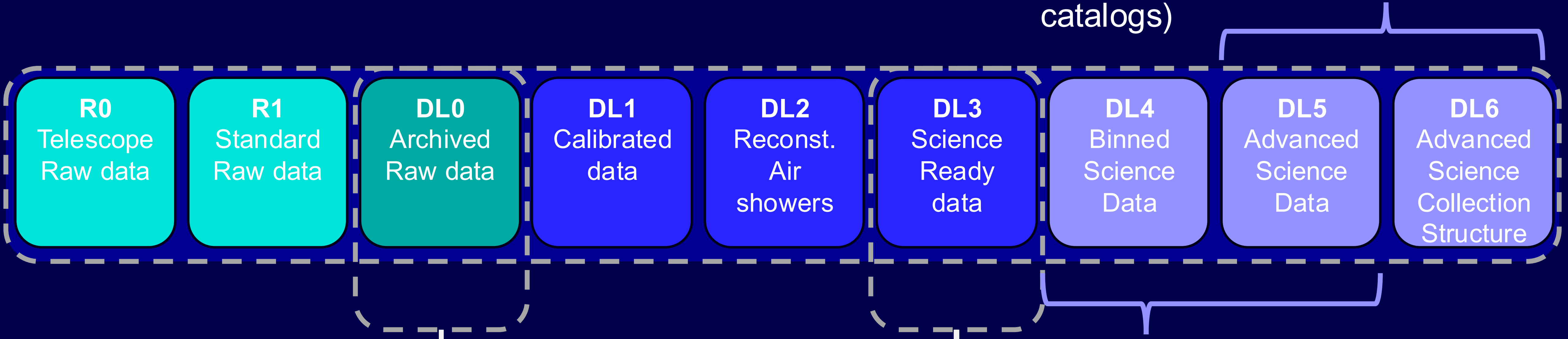
CAT-A data Realtime analysis	CAT-B data On-site analysis	CAT-C data Off-site analysis

Latency	Within the same observing night	Next day (before the start of the next observing night)	Within 1 month of observation
Goal	Issue Scientific alerts and follow-up observations	Data quality and check of CAT-A results	Delivery of best quality data for scientific analysis == used in publications

Performance Requirements in terms of systematic uncertainties

Data Levels

CTAO will offer a storage service on selected DL5/6 data (e.g., skymaps, catalogs)



Preserved Data

Distributed to the Scientific Community

Produced by:

- Users with SAT
    - User-contributed data products
- CTAO with standardized pipeline
    - Observatory data products for quick-look results

Towards first CTAO data

Intermediate array configurations

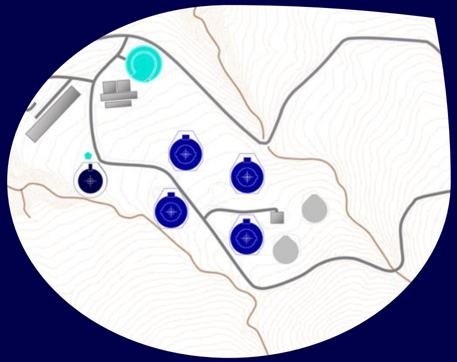
- Incremental array configurations that become progressively available to community

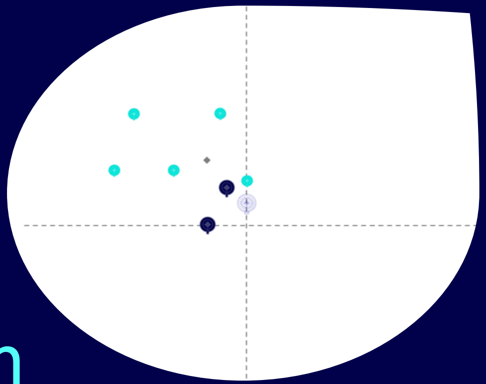
  - Telescopes and array elements fully integrated with the intermediate release of software packages
  - Array elements include telescopes but also calibration devices and atmospheric characterization instruments

- Mid-period plan (~3 years) based on the construction and acceptance schedule
  - **Built accounting for the inputs of the in-kind contribution teams**

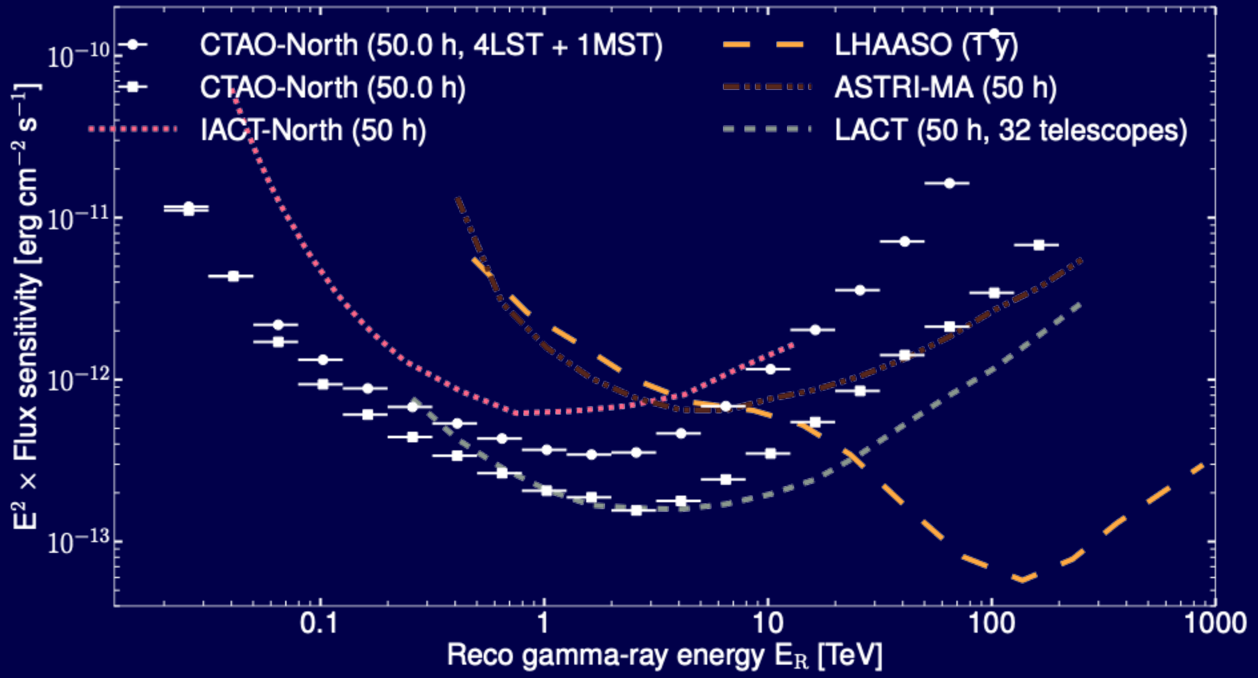
1st Intermediate Arrays

3 years from today

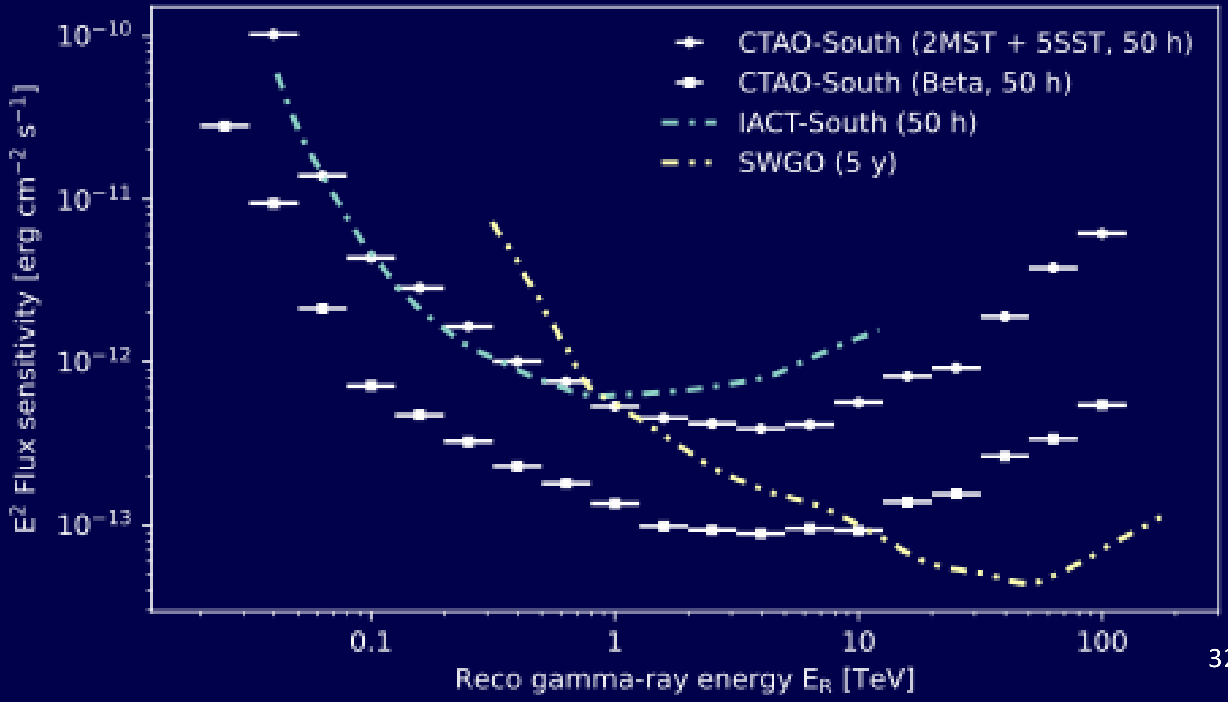




CTAO-North



CTAO-South

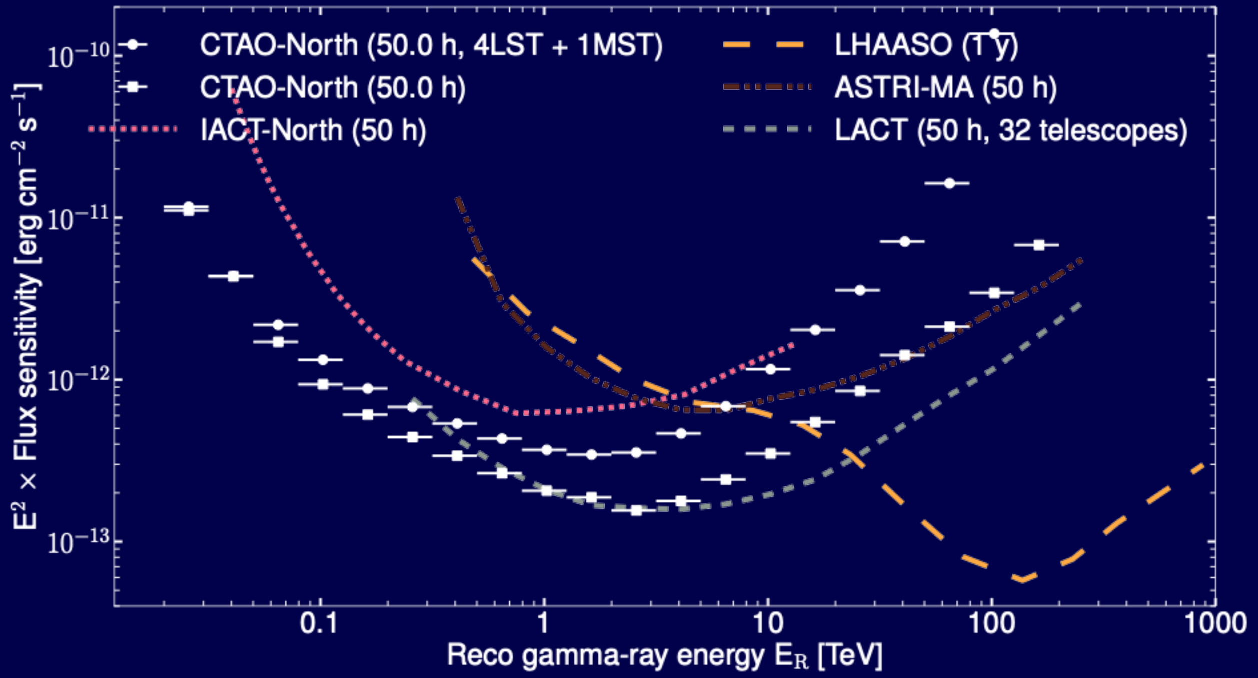


1st Intermediate Arrays

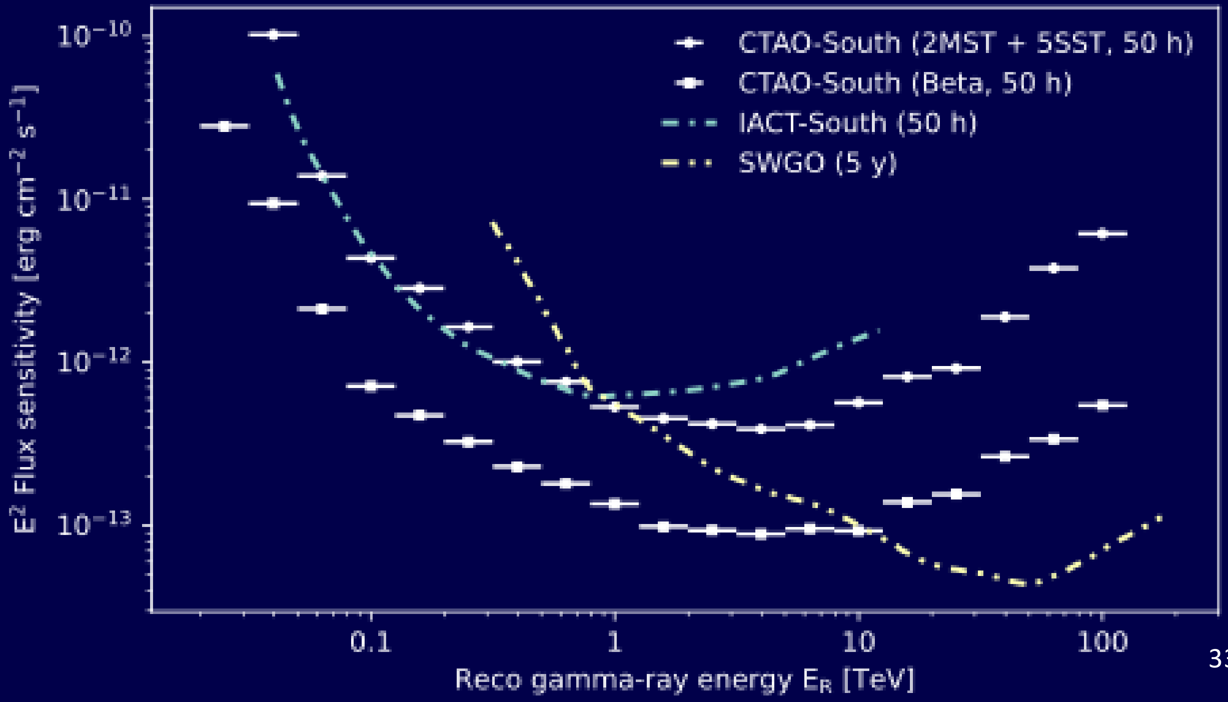
- Intermediate array configurations should be available in 2029
  - CTAO Central Office is working closely with IKC teams

- CTAO-North -> 4 LST + 1 MST
- CTAO-South -> 2 MST + 5 SST

CTAO-North



CTAO-South



Public Early Science Timeline

CTAO

2029	2030	2031	2032
4x LST 1x MST	4x LST 5x MST	4x LST 9x MST	4x LST 9x MST
Observatory Release 2	Observatory Release 3	Observatory Release 4	Official Start of Operations
Verified in 2028 AO Call in 2029	Verified in 2029 AO Call in 2030	Verified in 2030 AO Call in 2031	AO Call in 2032
2x MST 5x SST	TBD	14x MST 37x SST	14x MST 37x SST
Early Science OP 1	Early Science OP 2	Early Science OP 3	OP1

2028 — 2029 — 2030 — 2031 — 2032

Public Early Science

- **Goals: Get data to community, get community ready for CTAO**
- Best effort Announcement of Opportunity
- CTAO guarantees the performance of the intermediate configuration prior to the start of the Public Early Science Observing Period
  - Done after science validation and verification
- **Stay tuned for more information!**