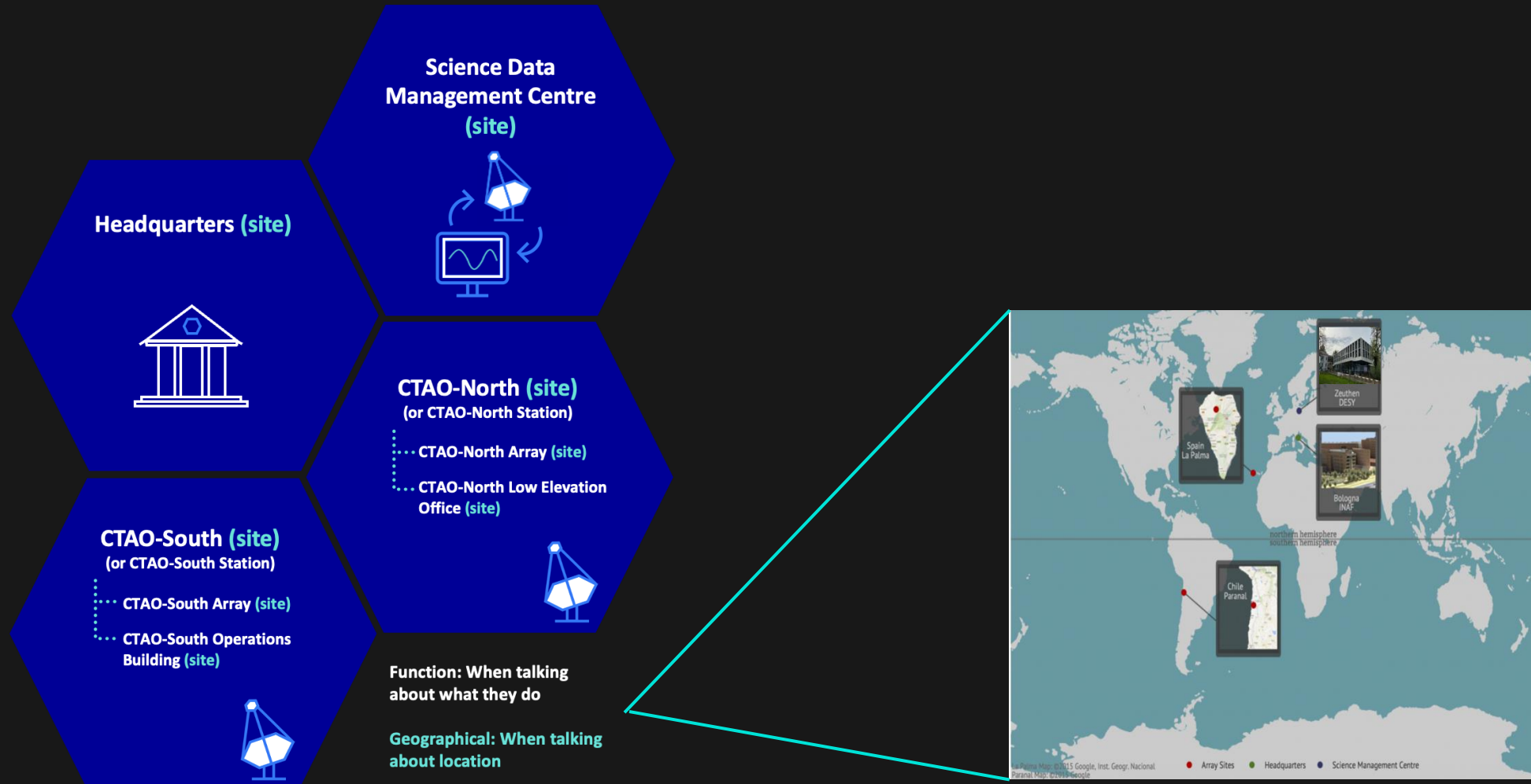


# CTAO: the upcoming VHE $\gamma$ -ray observatory

Roberta Zanin (CTAO Project Scientist)

Gamma 2024– 6 September 2024

# CTAO: a distributed facility

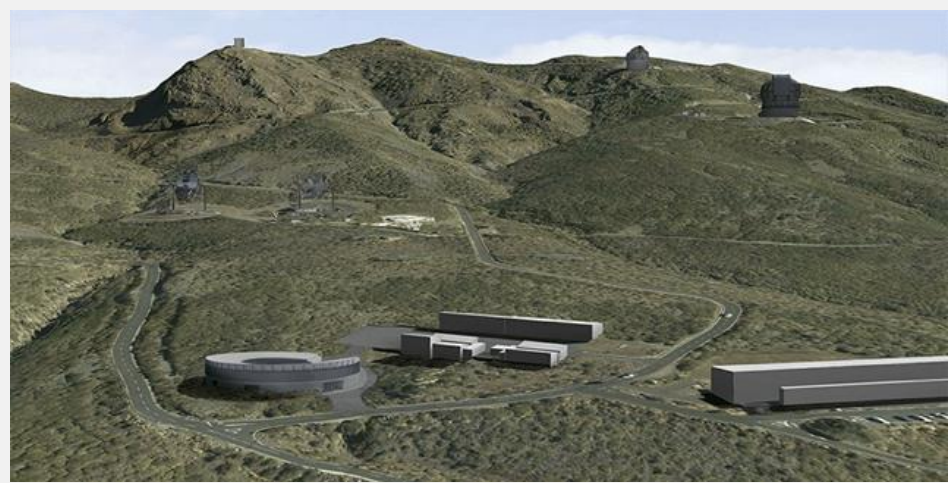
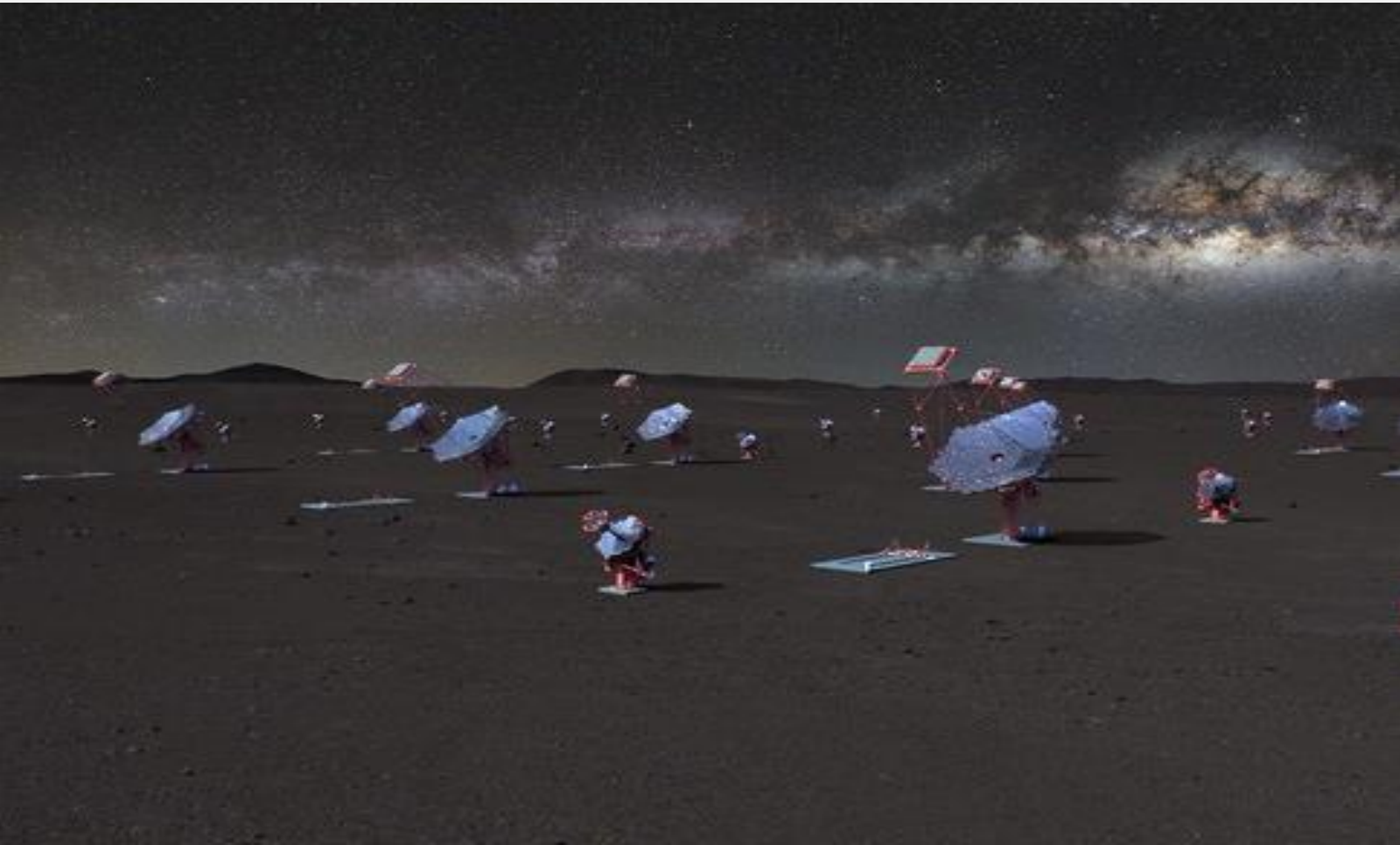
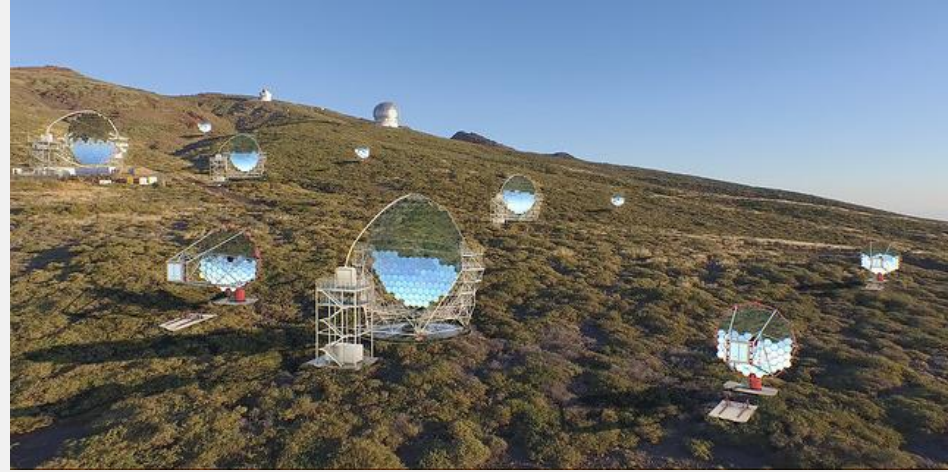




*Credits to G. Tagliaferri*



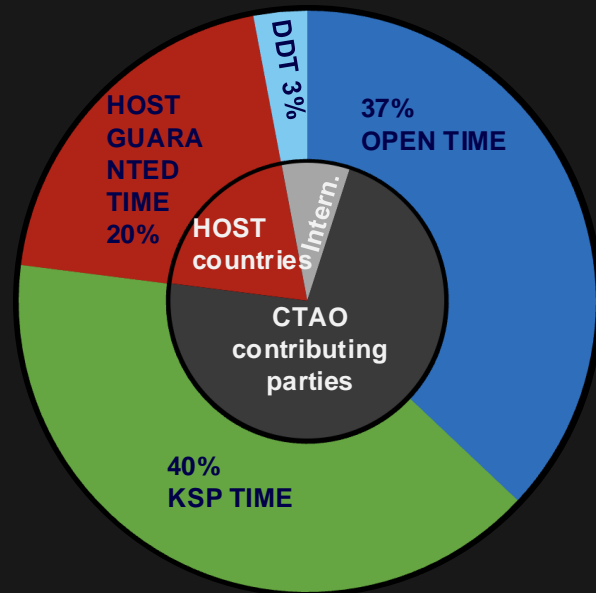
*Credits to DESY*



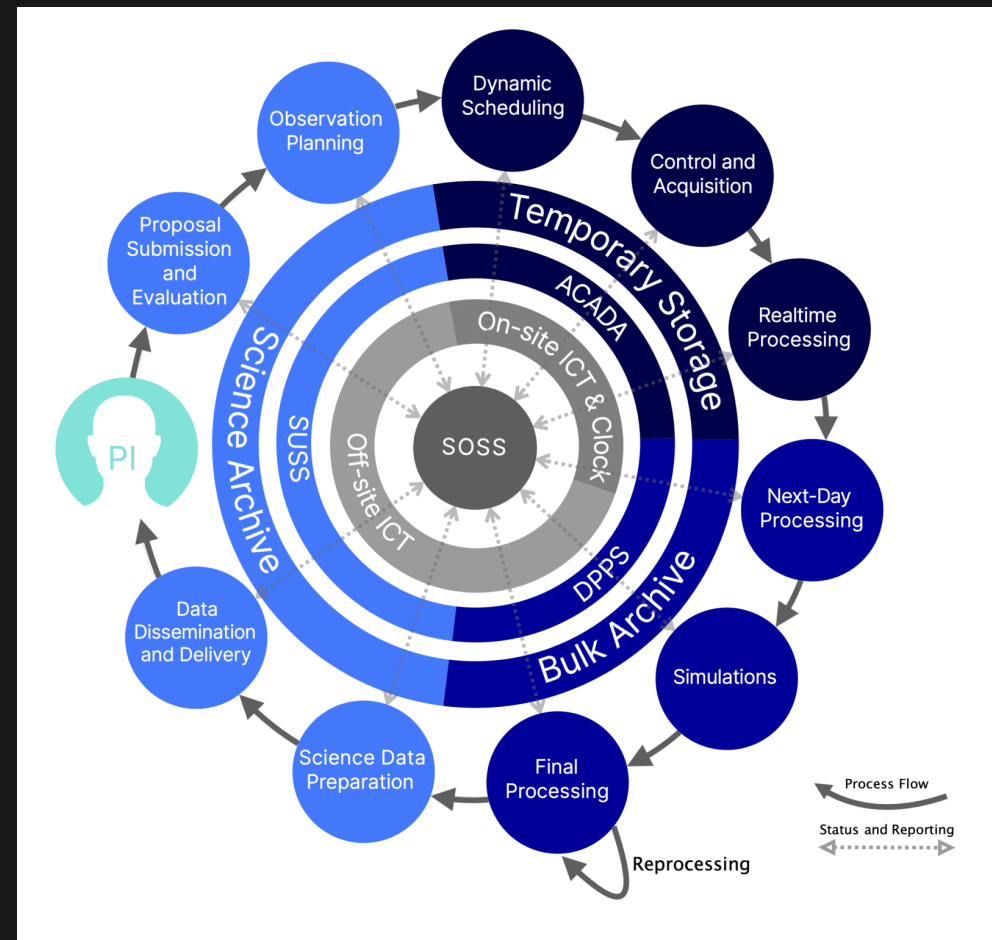
# An astronomical observatory

## An open proposal-driven observatory

- Proposals will be evaluated only on their scientific merit
- Data with a proprietary period of 1 yr after that fully open

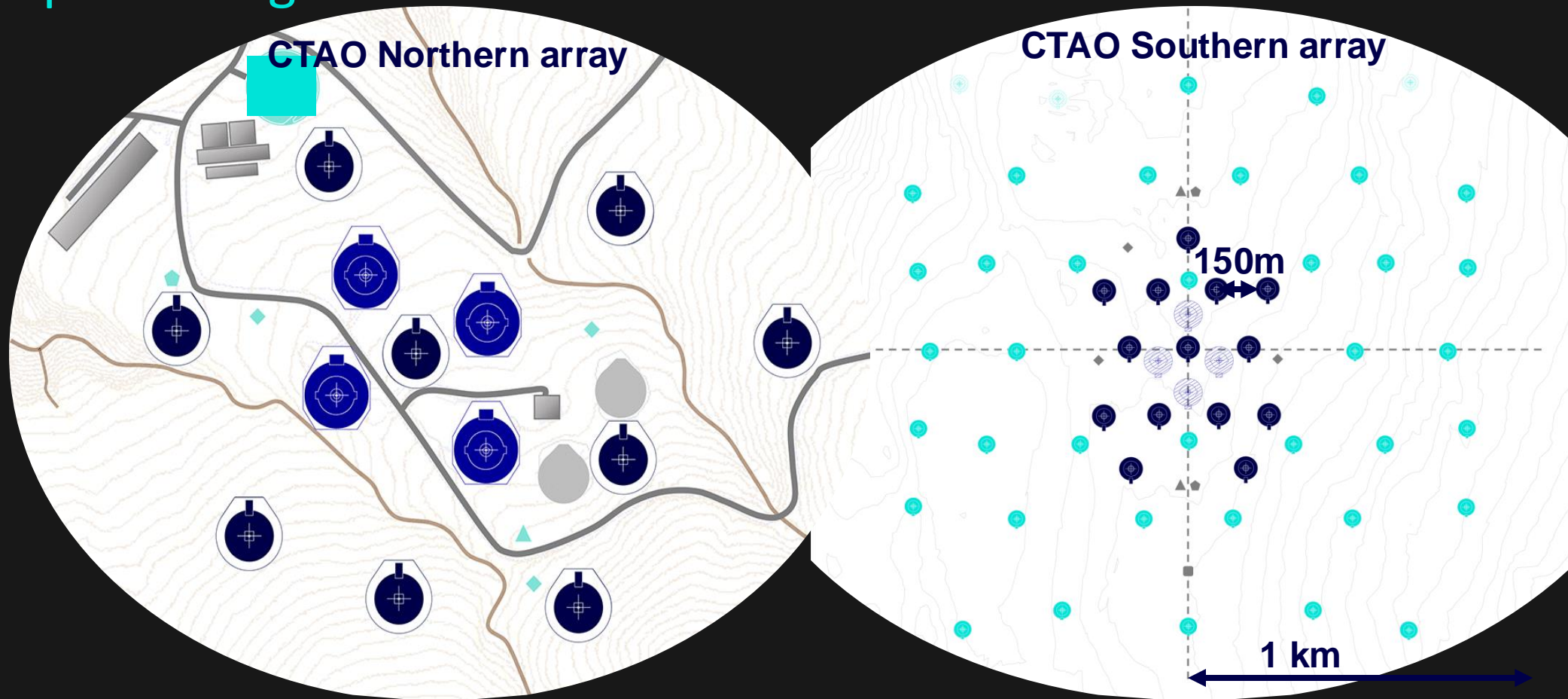


integrated over 10 yr



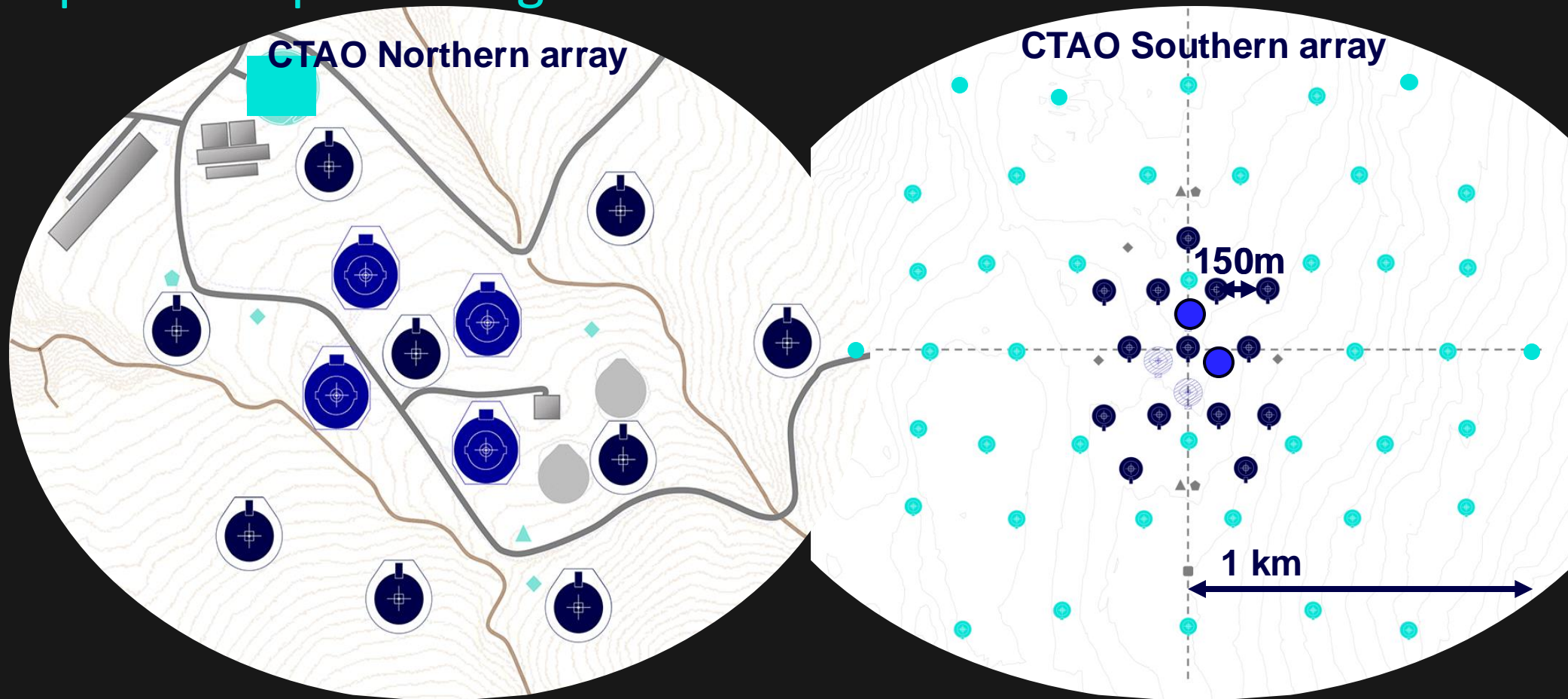
# Two observation stations, one unique observatory

Alpha configuration

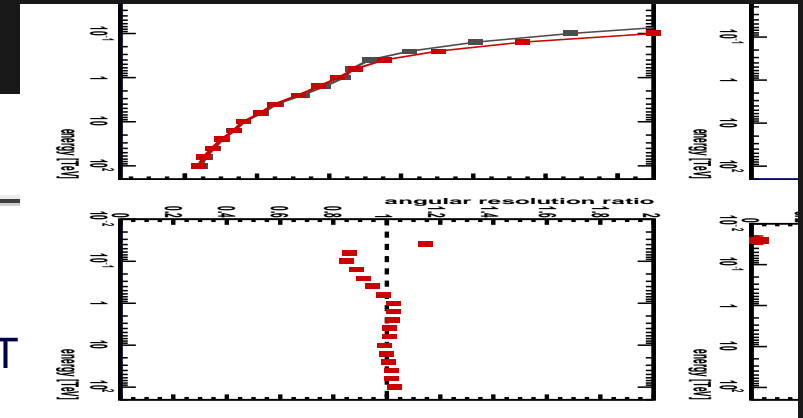
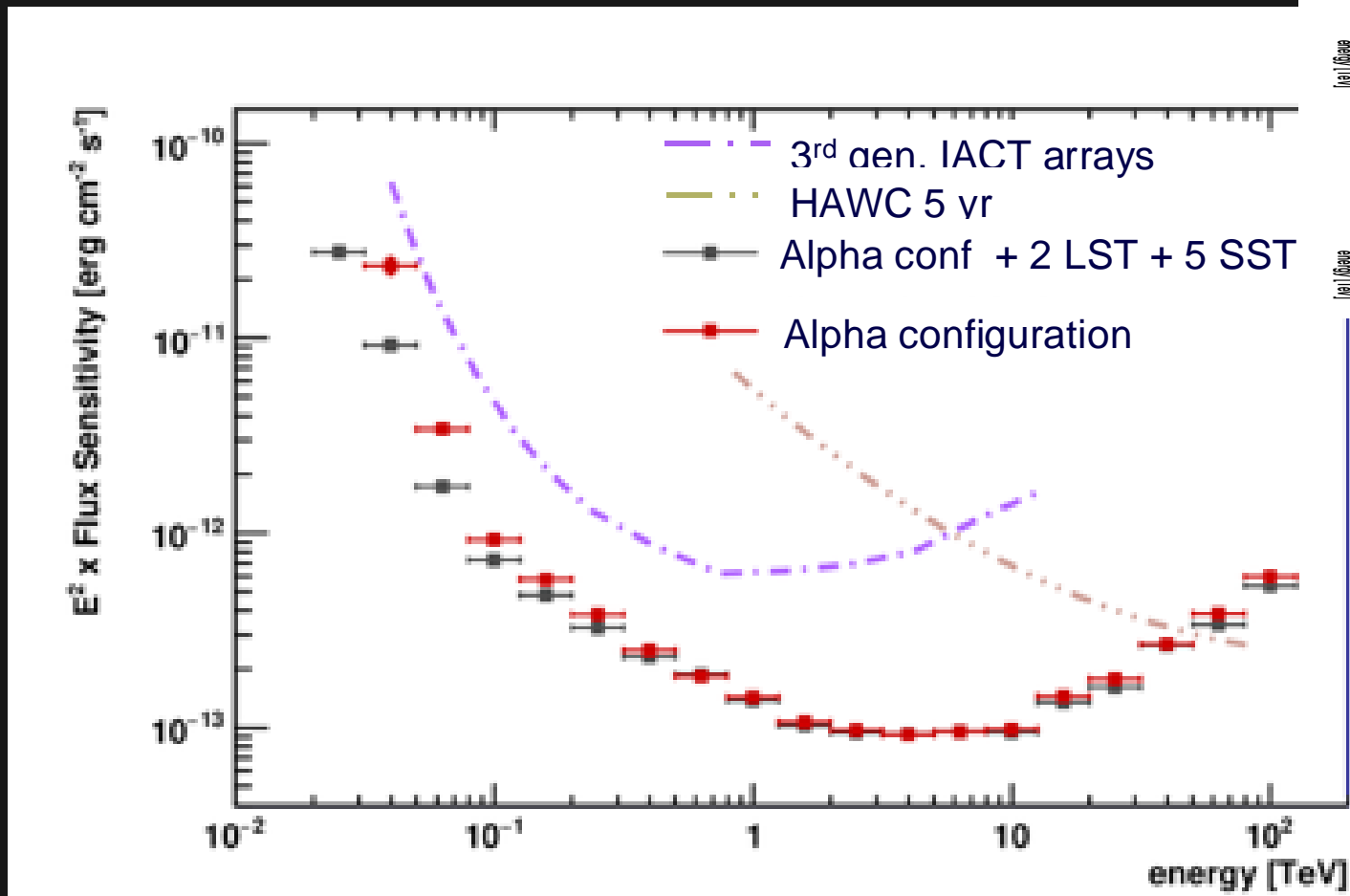


# Two observation stations, one unique observatory

Improved Alpha configuration



# Improved Alpha configuration





# Improved Alpha configuration

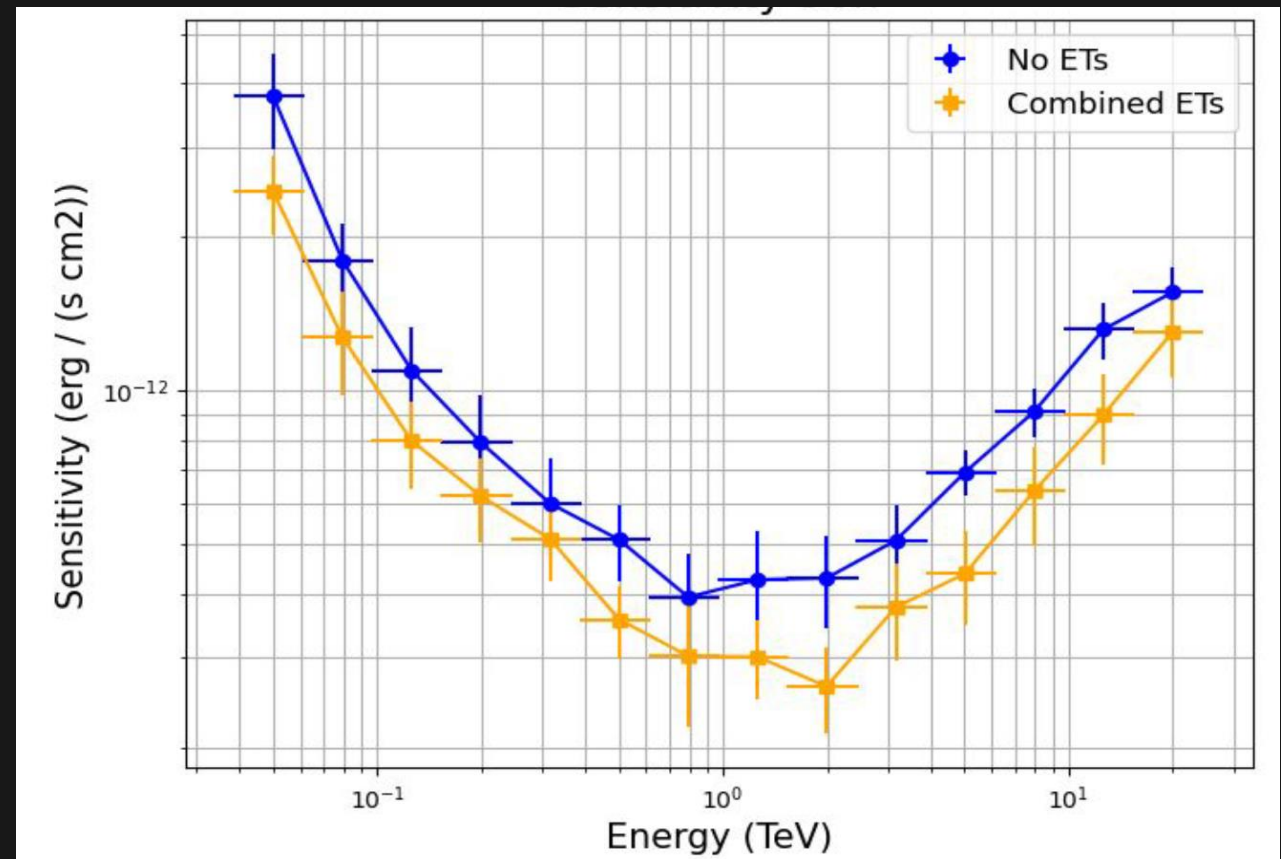
Introducing the concept of the event types

... learning from Fermi LAT

PASS 8: SOURCE SENSITIVITY

• Combination of larger acceptance and better PSF at high energy  
 • 20-50% increase in sensitivity for a given observing time

credits to L. Baldini 2014



credits to J. Bernete-Medrano et al

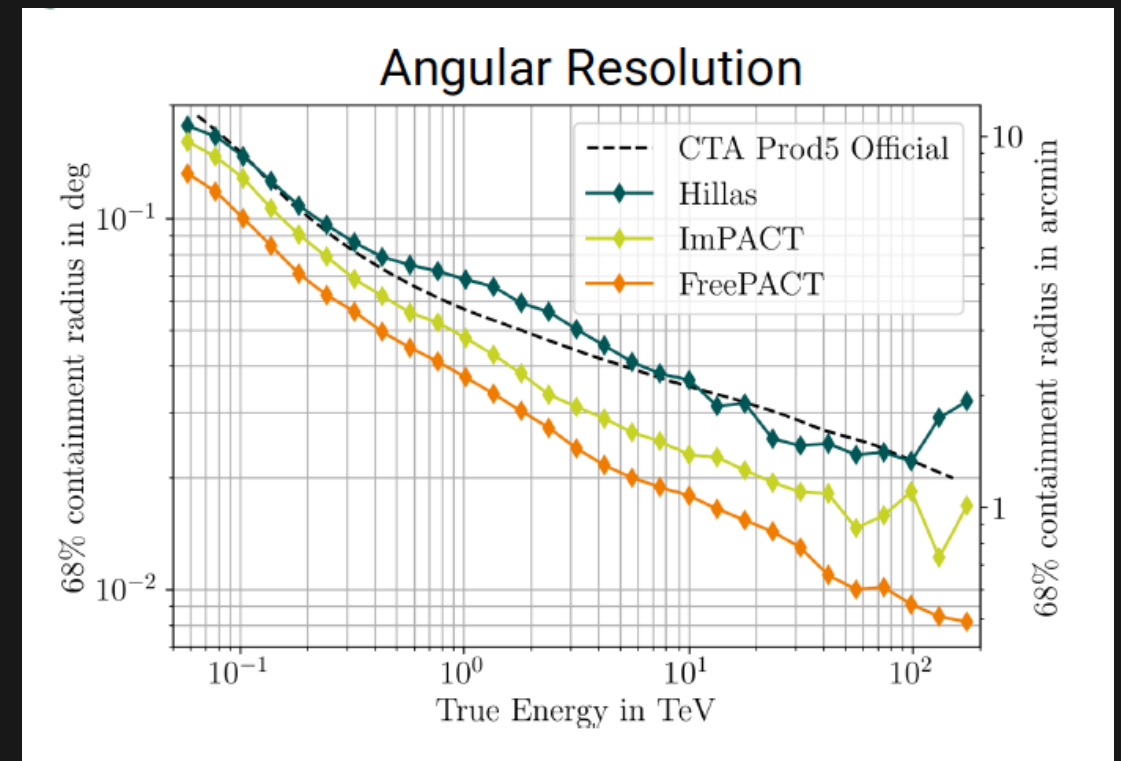
# Improved Alpha configuration

exploiting the machine-learning

There is more room

... using a hybrid likelihood,  
machine-learning  
algorithm

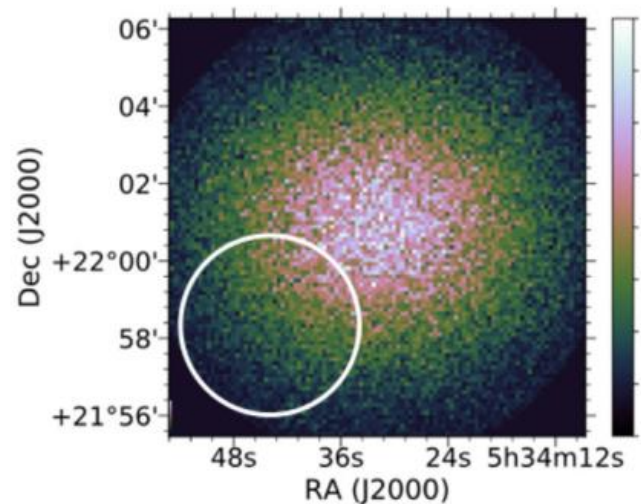
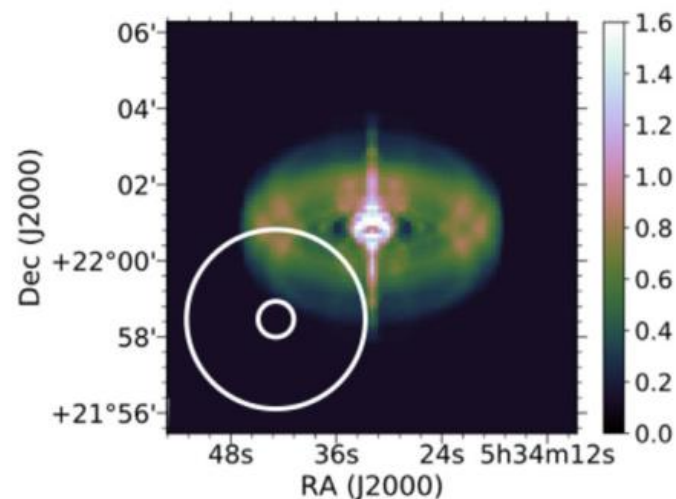
What does this imply  
for science?



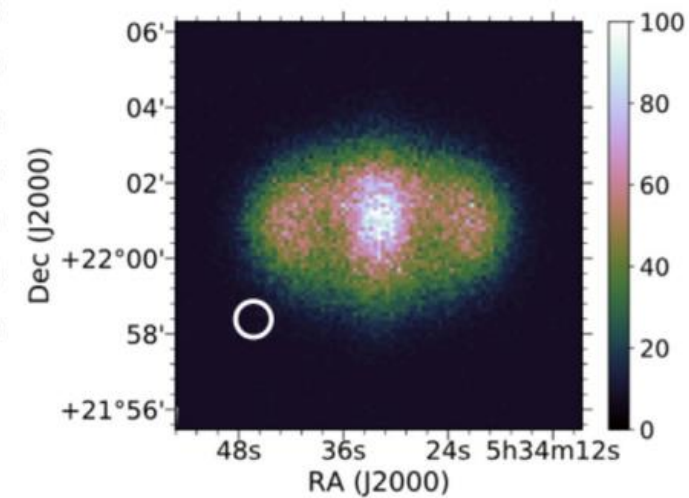
Credits to G. Schwefer et al.

# Improved Alpha configuration

*Mestre et al 2019*



0.04° as in the requirement

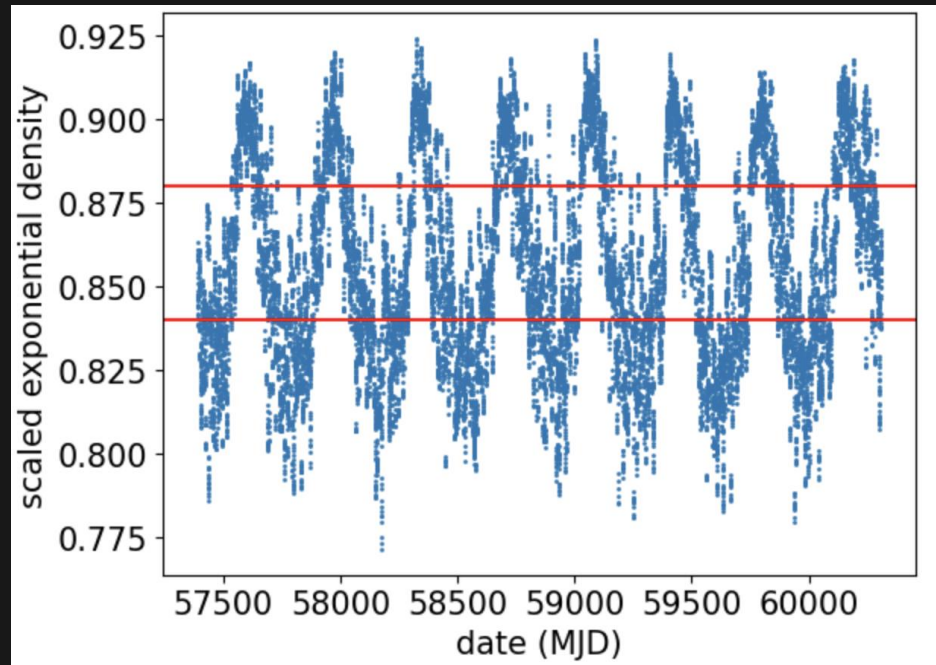


factor 4 better angular resolution

# Controlling systematic uncertainties

Detailed characterization of the atmosphere at the sites

## AN EXAMPLE

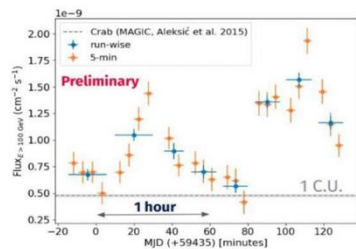


- Discrepancy between the real molecular density profile and the simulated can be maintained within  $<2\%$  systematic uncertainty if we simulate three reference molecular density profiles to account for its seasonal variations
- To compute the accuracy and precision of the ECMWF info we are organizing radio sonde campaigns --> participating in the ESO atmospheric characterization campaign

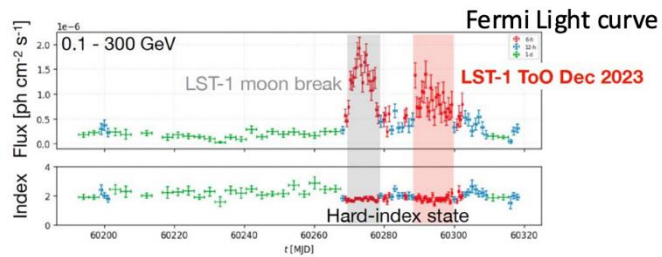
# The prototype LST-1 is already producing science

2024 - LST1 performance paper

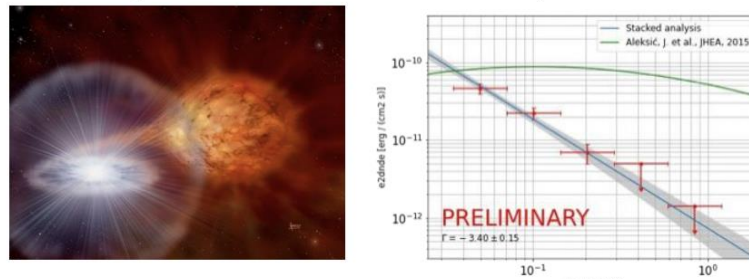
### BL Lac intranight fast variability (a few min)



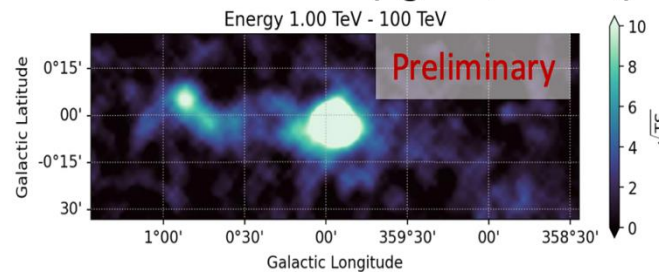
### OP313: discovery of the most distant VHE AGN



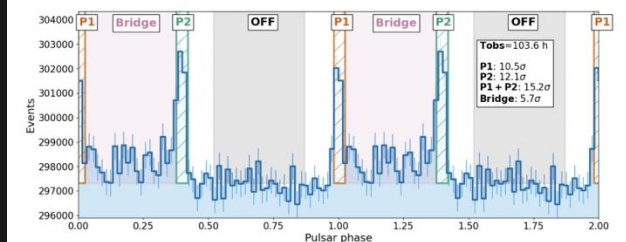
### Symbiotic Nova RS Ophiuchi



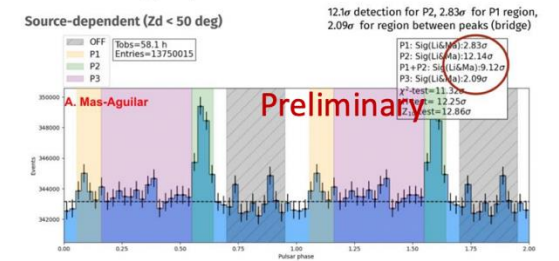
### Galactic Center 39hrs (Sgr A\*, diffuse)



### Crab pulsar above 20GeV



### Geminga pulsar above 15GeV



# Towards the first CTAO data

## Intermediate array configurations

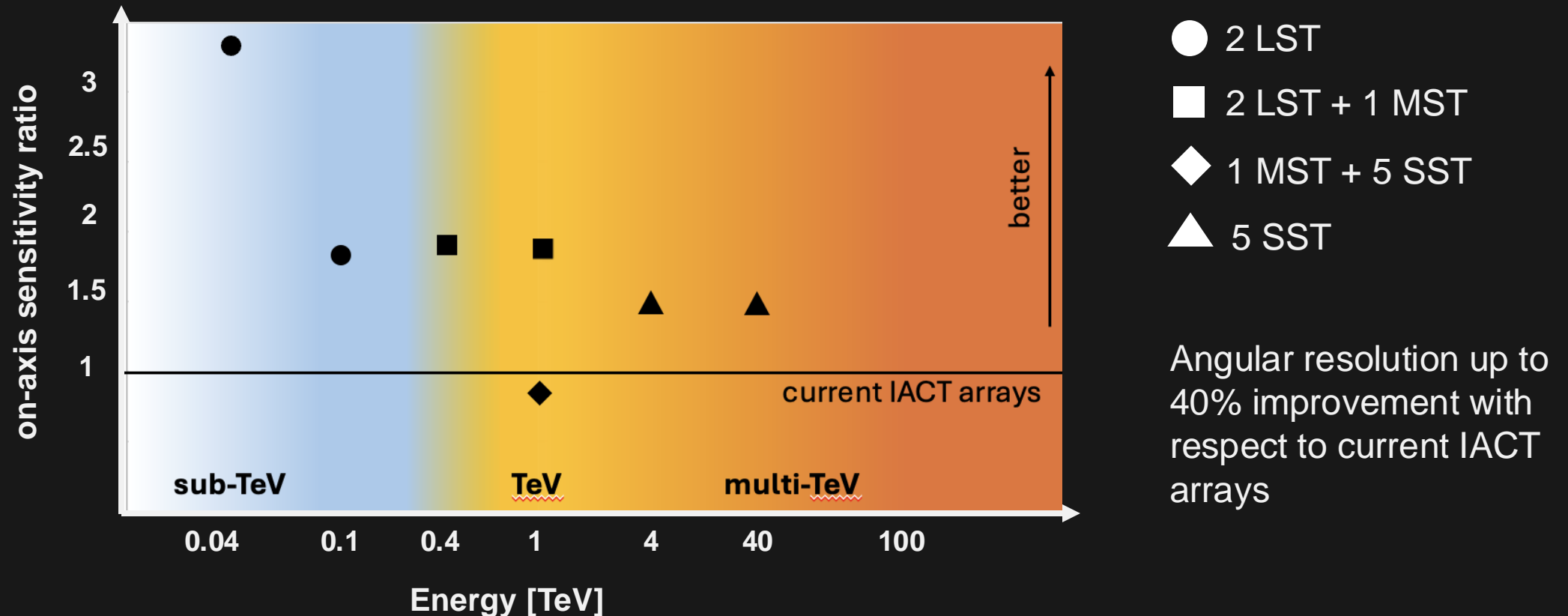
### CONCEPT

**Intermediate array configurations:** incremental array configurations that become progressively operative

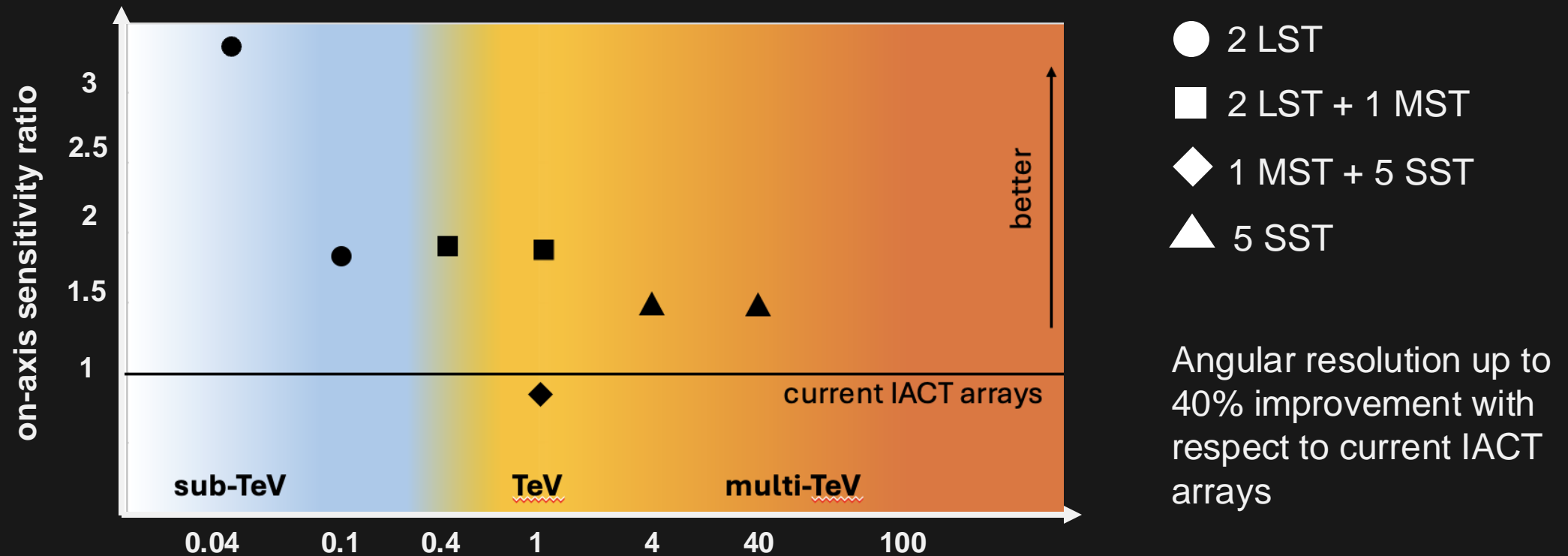
- array elements fully integrated with the intermediate releases of the software packages
- array elements include telescopes but also calibration devices and atmospheric characterization instruments

MID-PERIOD PLAN (3 yr long) BASED ON THE CONSTRUCTION SCHEDULE  
built accounting for the inputs of the in-kind contribution teams

# When will the scientific impact begin?



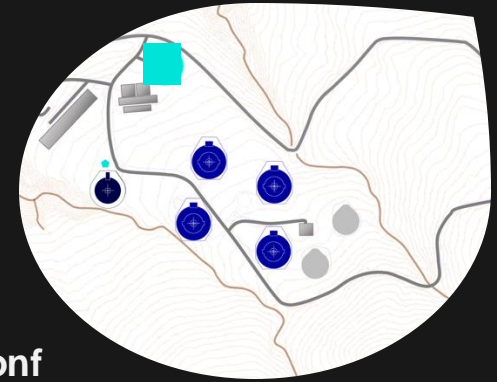
# When will the scientific impact begin?



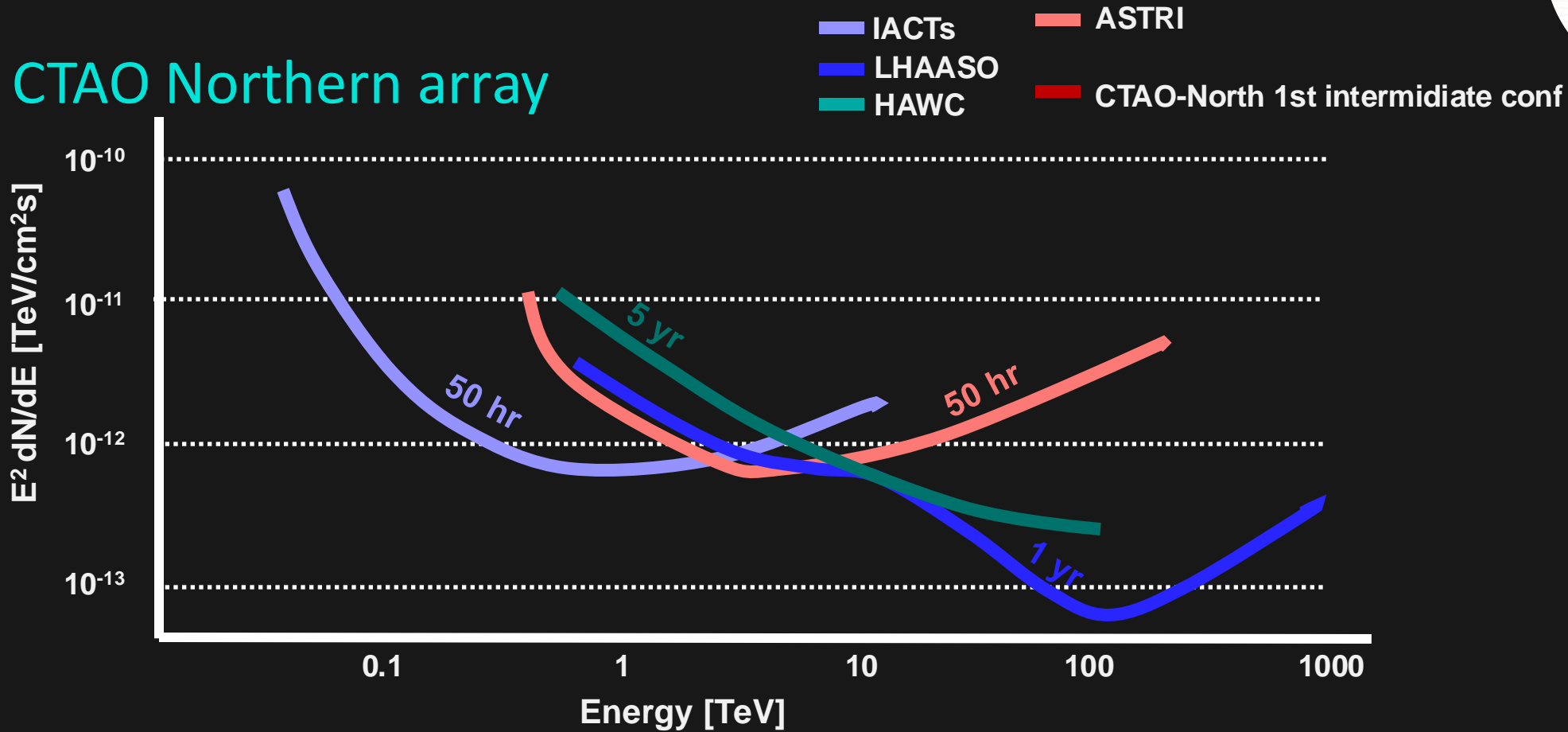
To get first high impact results we shall focus on science cases needing sensitivity more than angular resolution



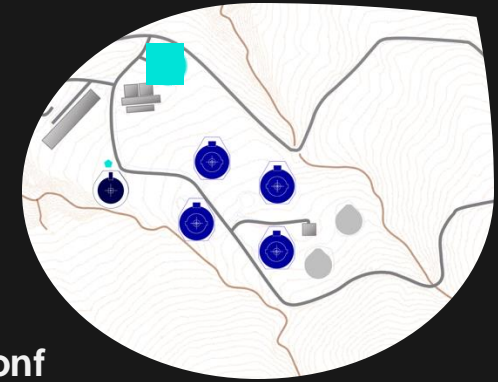
# In 3 years from now



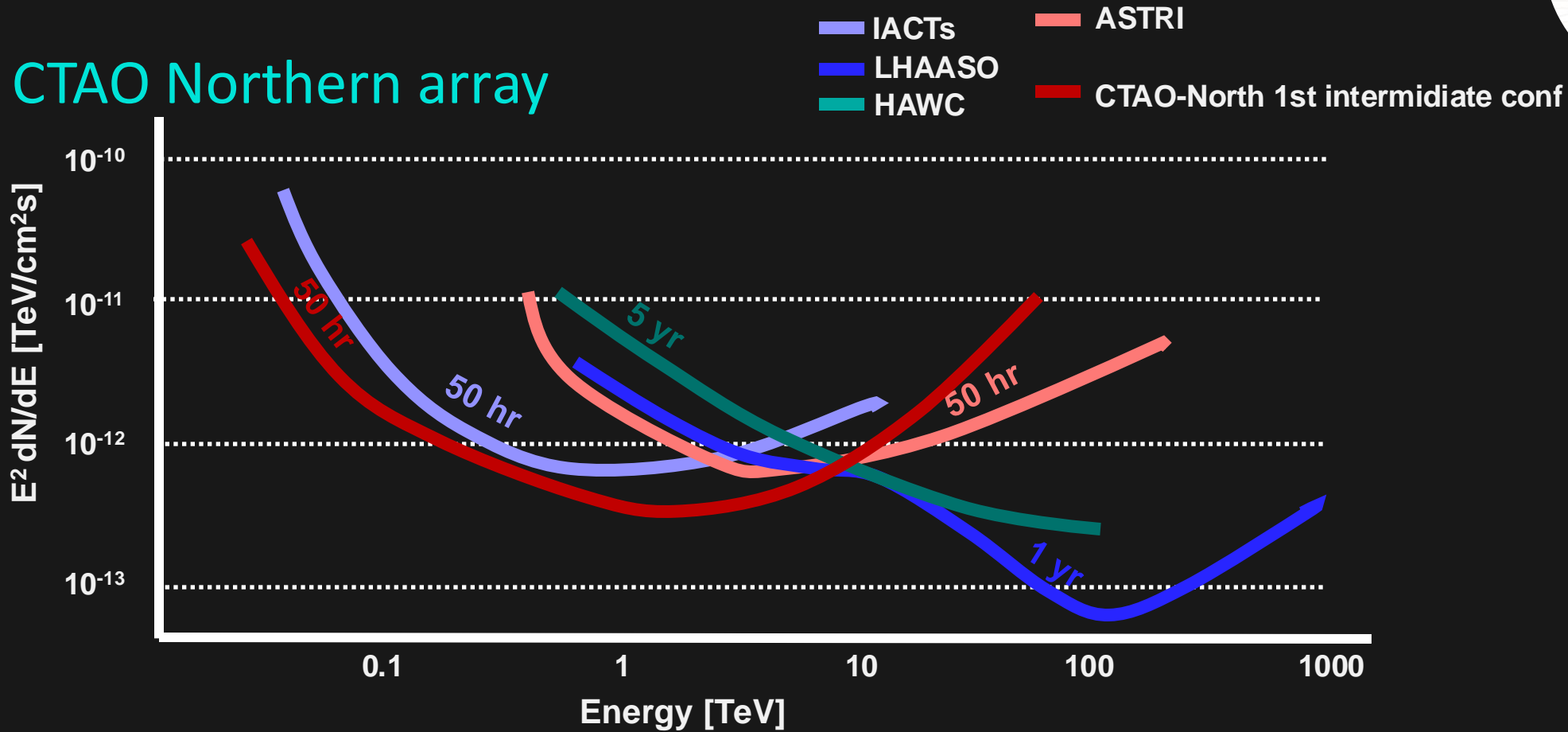
## CTAO Northern array



# In 3 years from now

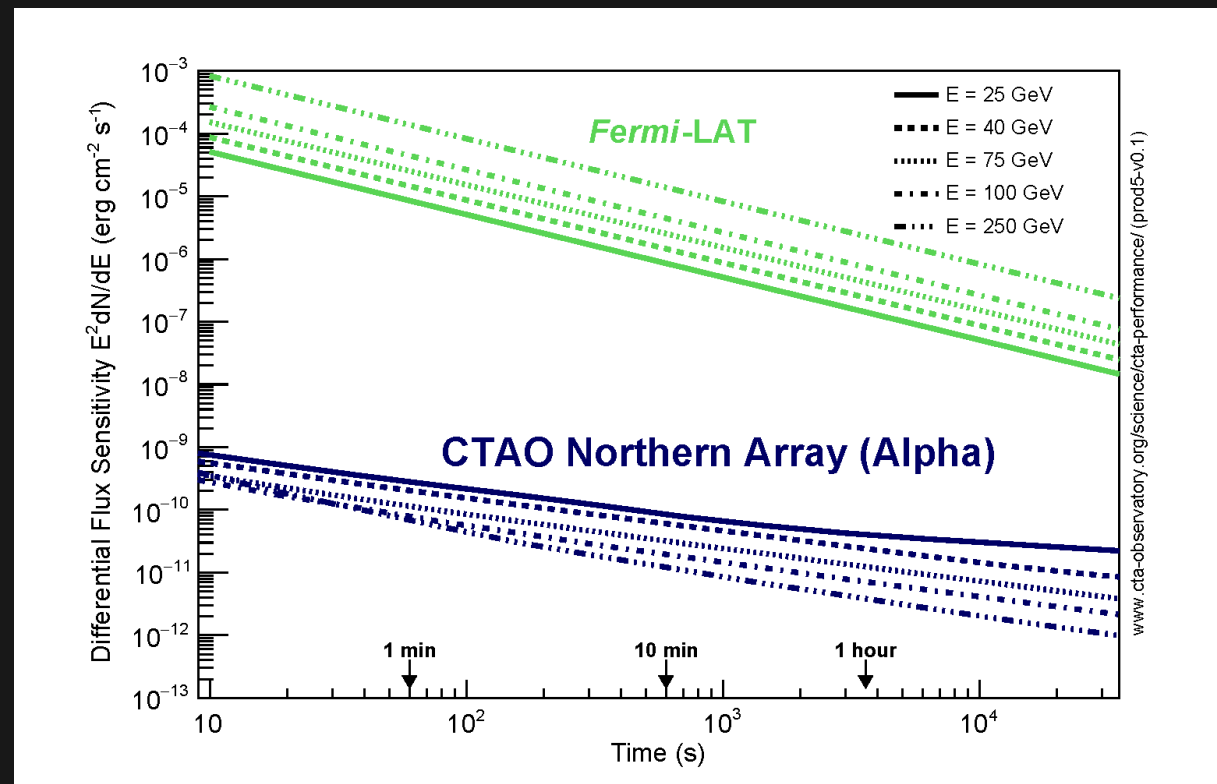
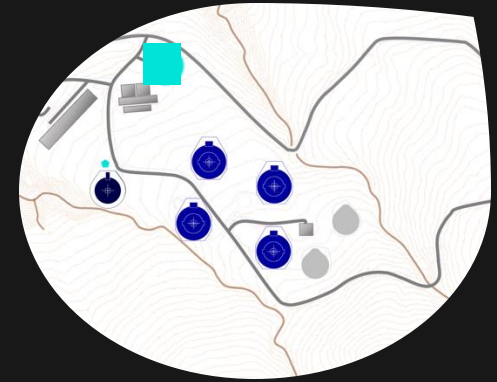


## CTAO Northern array



# In 3 years from now

## CTAO Northern array



# In 3 years from now

@10 TeV

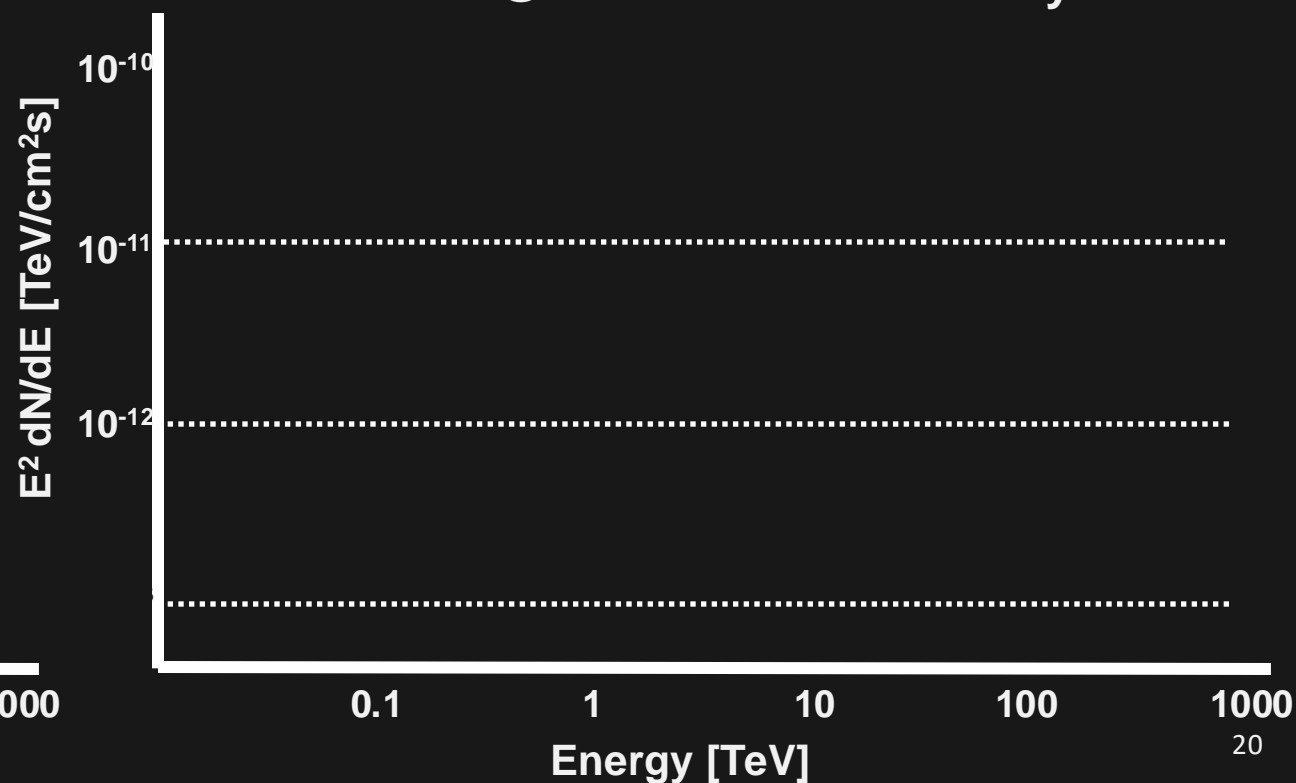
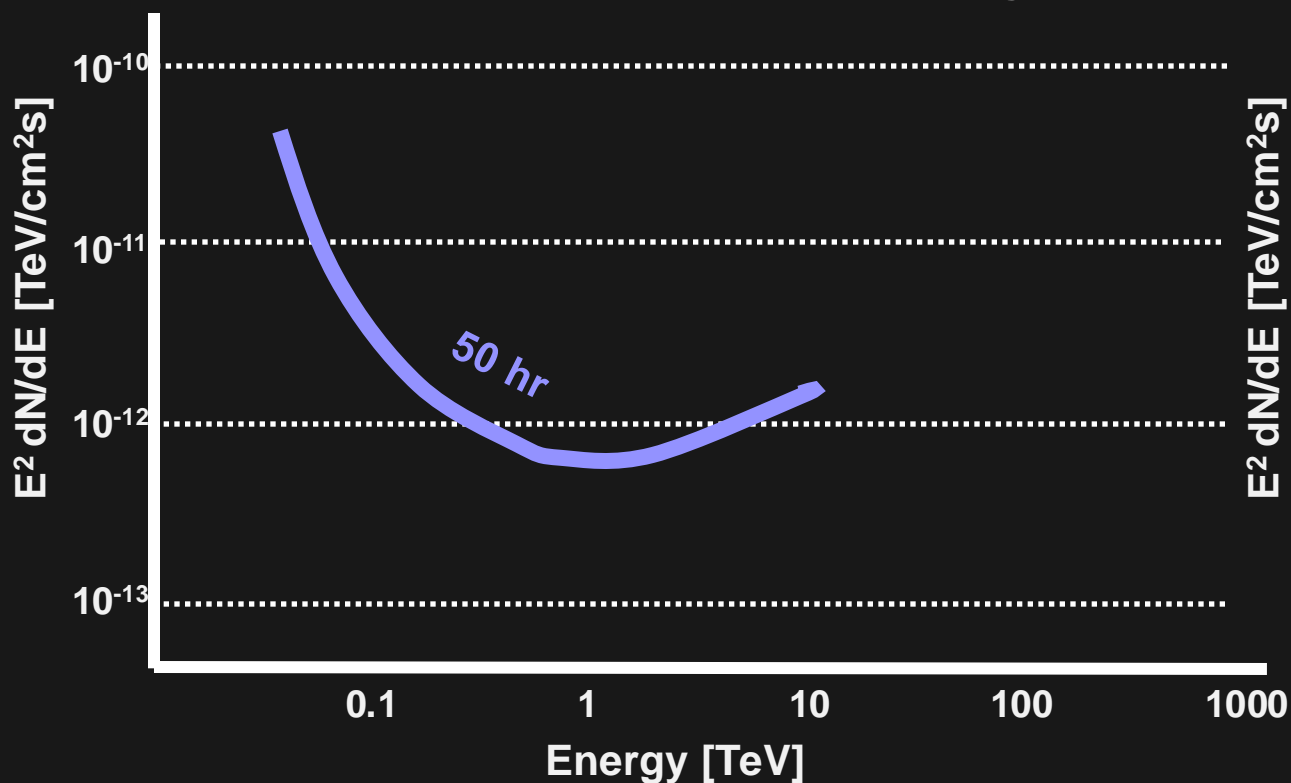
- as good as LHAASO
- 80% better than ASTRI

## CTAO Southern array

■ IACTs    ■ Alpha+2LSTs+5SSTs  
■ 1st intermediate configuration

on-axis

off-axis @ 3° → critical for surveys



# In 3 years from now

@10 TeV

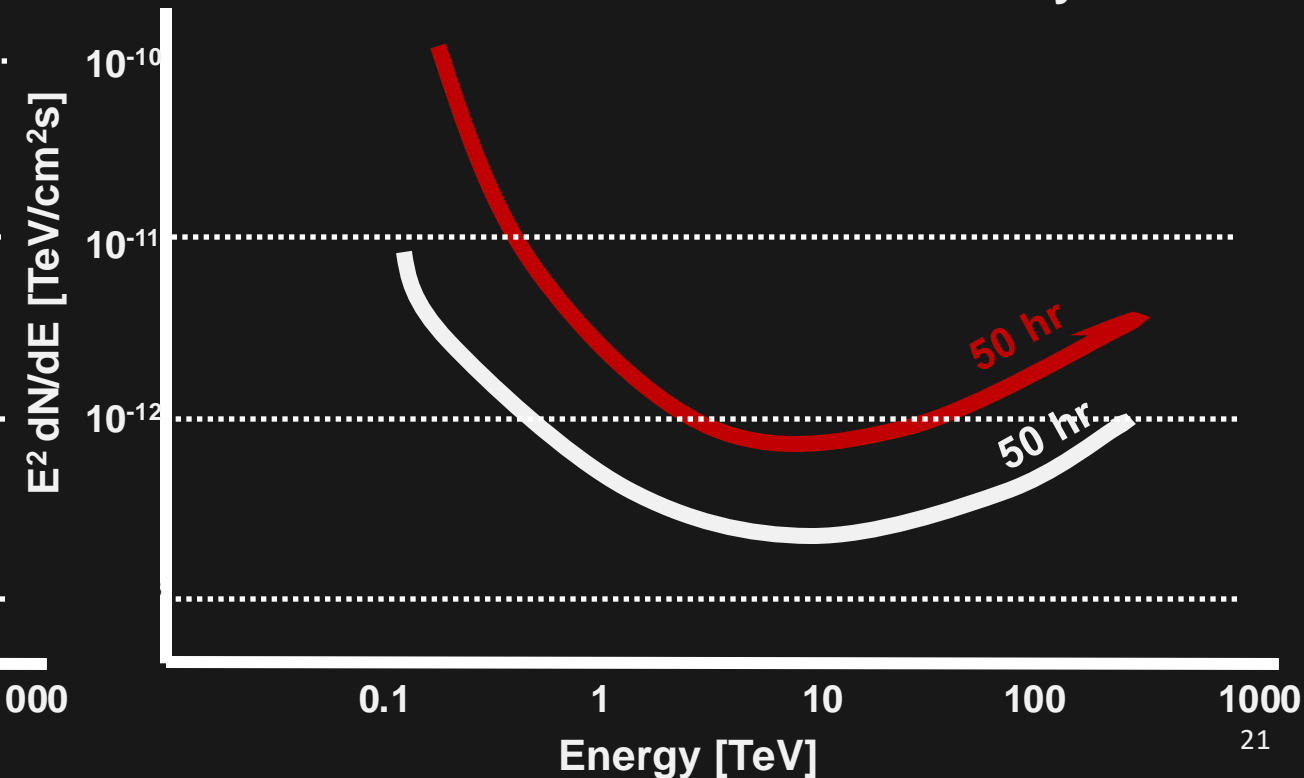
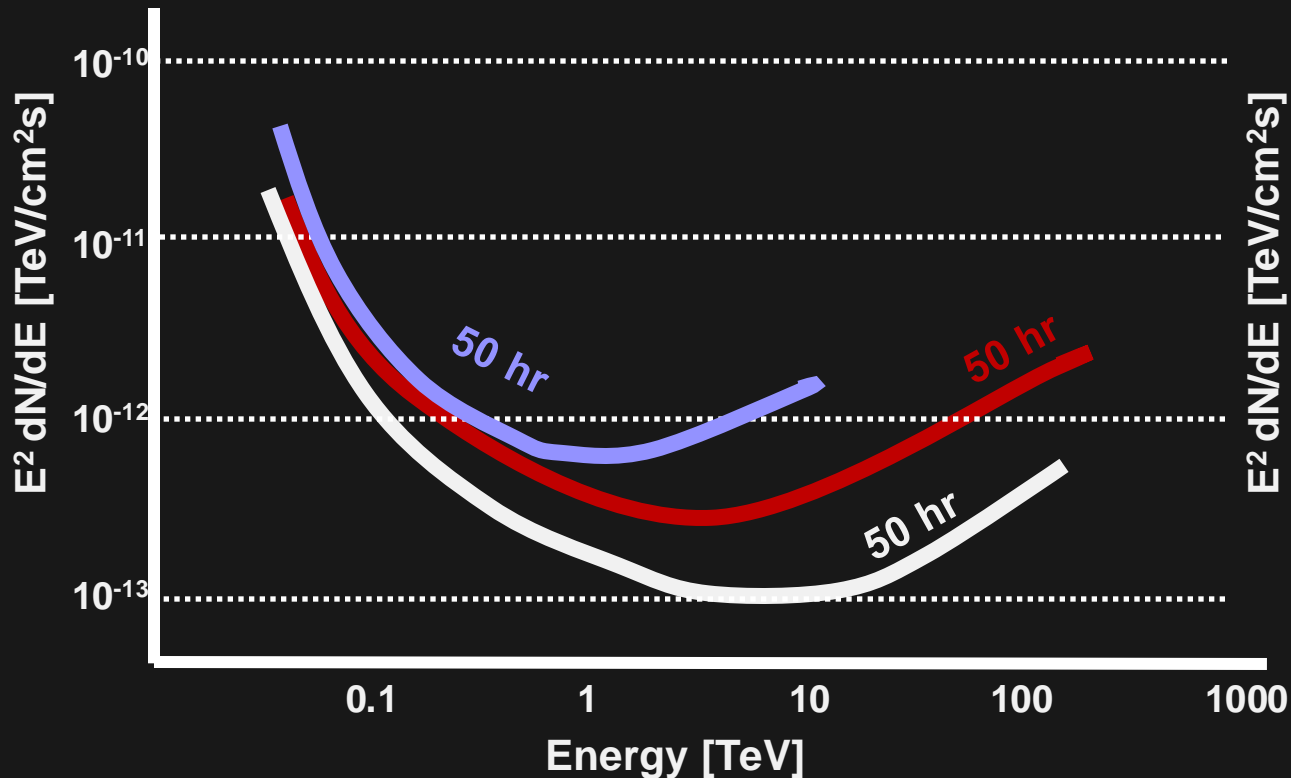
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## CTAO Southern array

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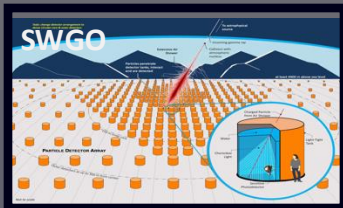
on-axis

off-axis @ 3° → critical for surveys



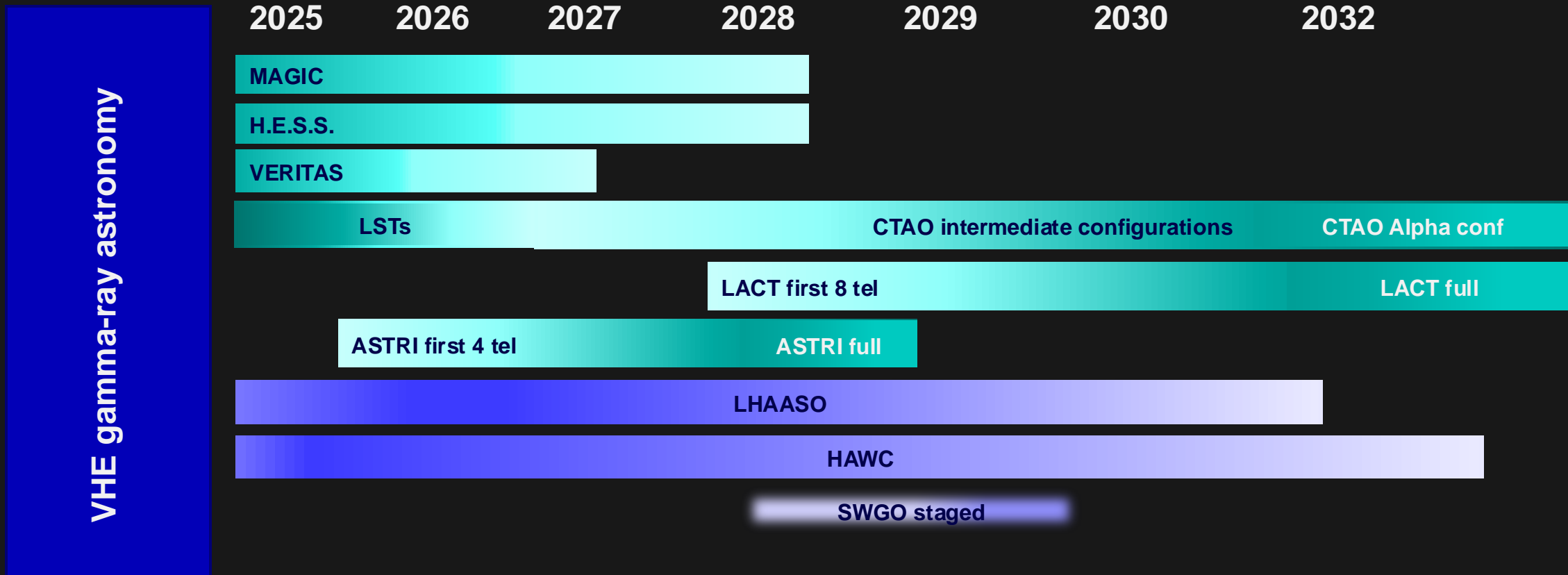
# A bright upcoming future

ASTRI - CTAO - SWGO - ALPACA



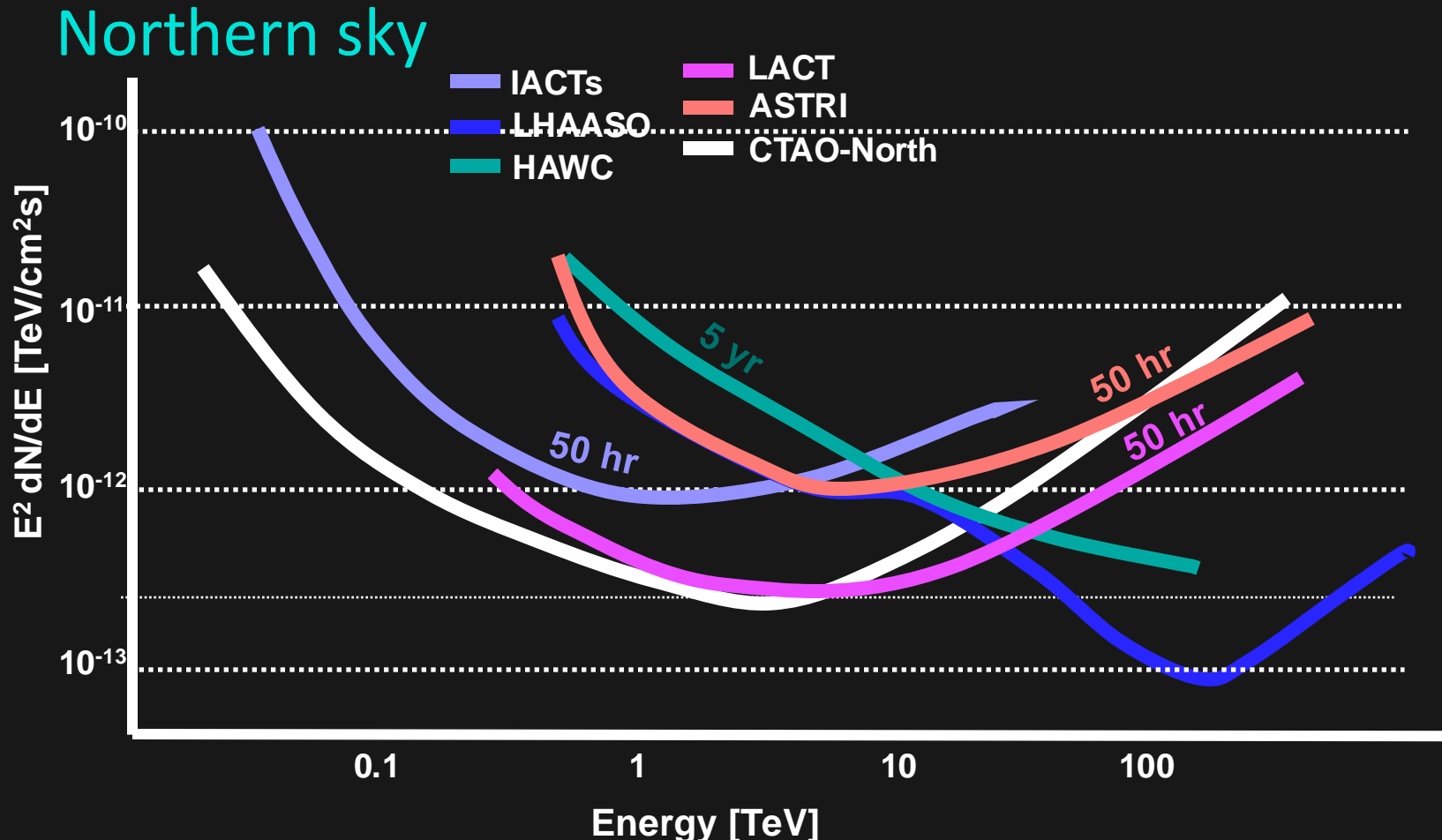
Galactic equator

# Status of the VHE astronomy



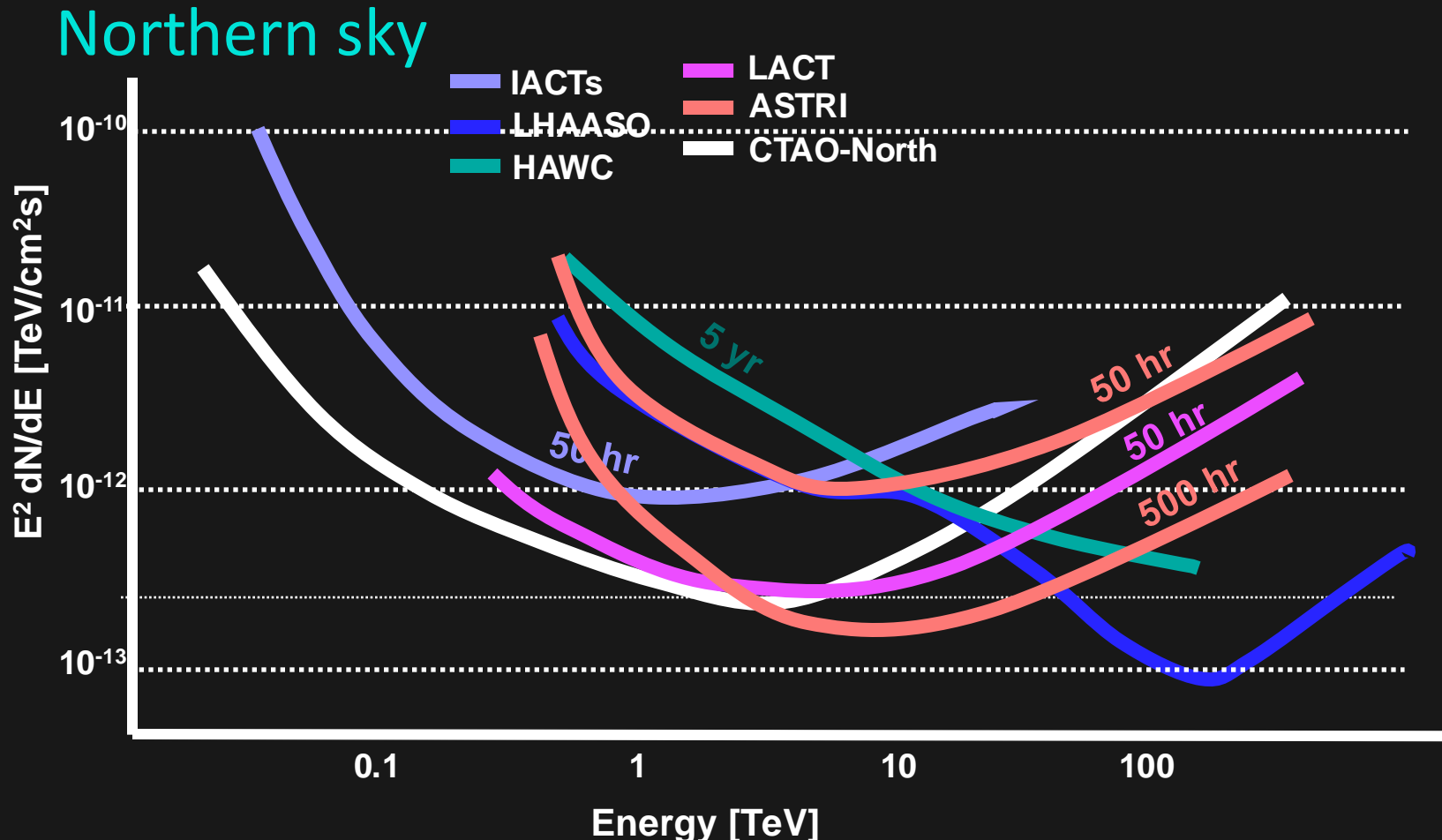
*The end dates of the facilities are just indicative: the fate of these instrument is currently under discussion*

# Steady-source performance

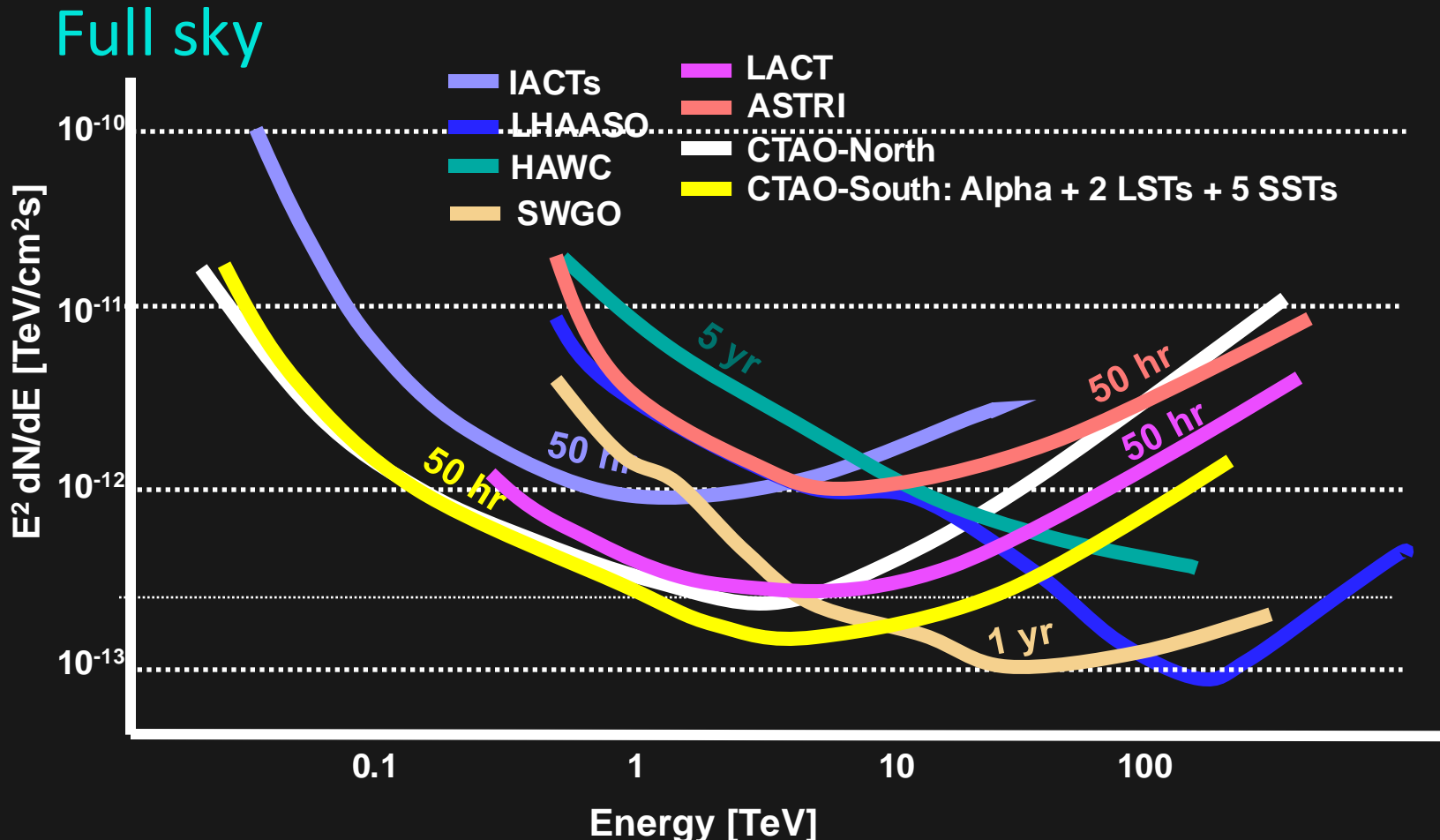




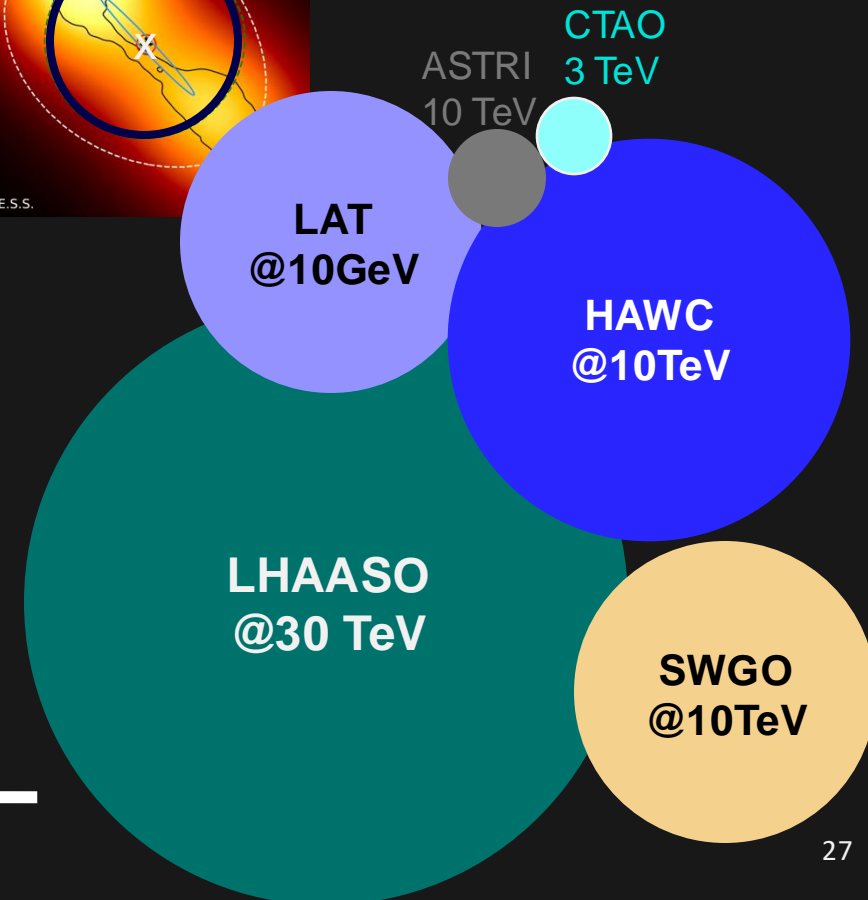
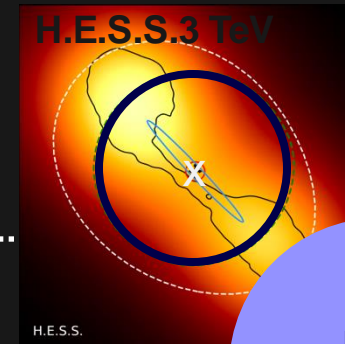
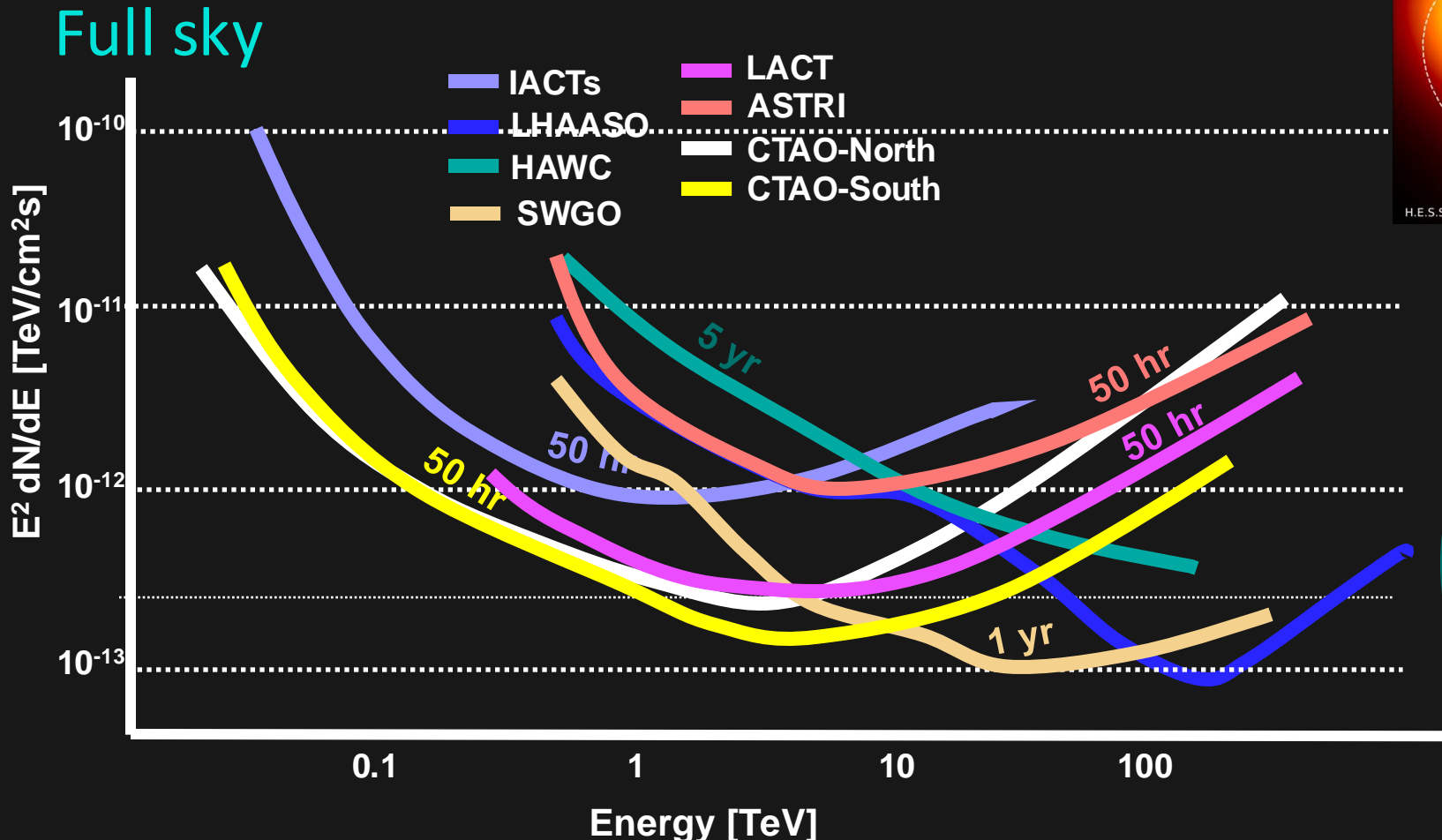
# Steady-source performance



# Steady-source performance

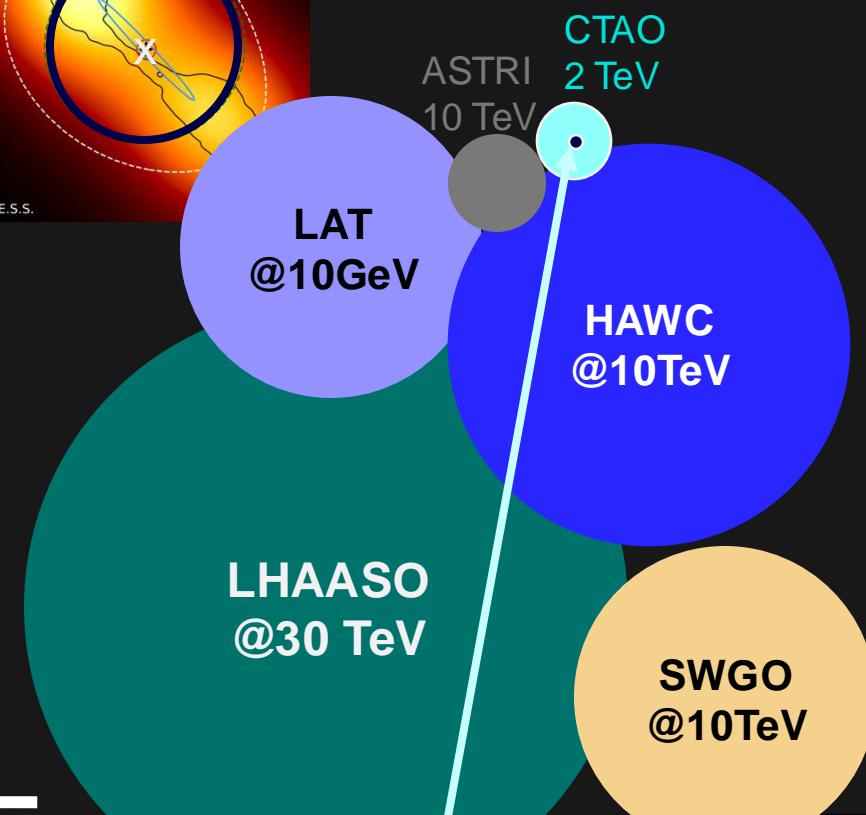
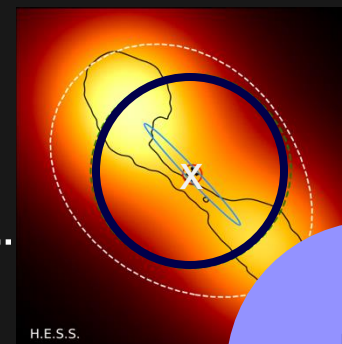
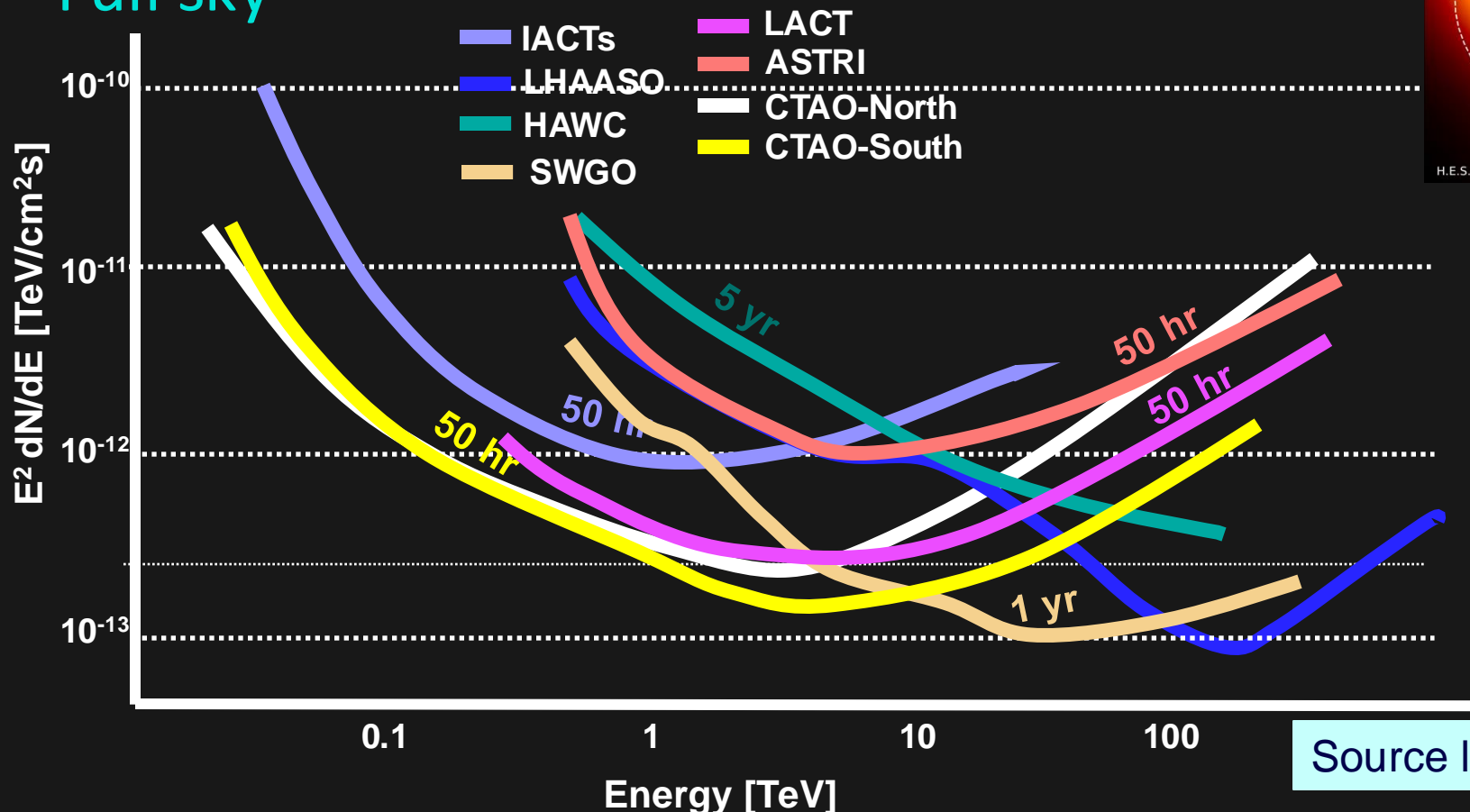


# Steady-source performance



# Steady-source performance

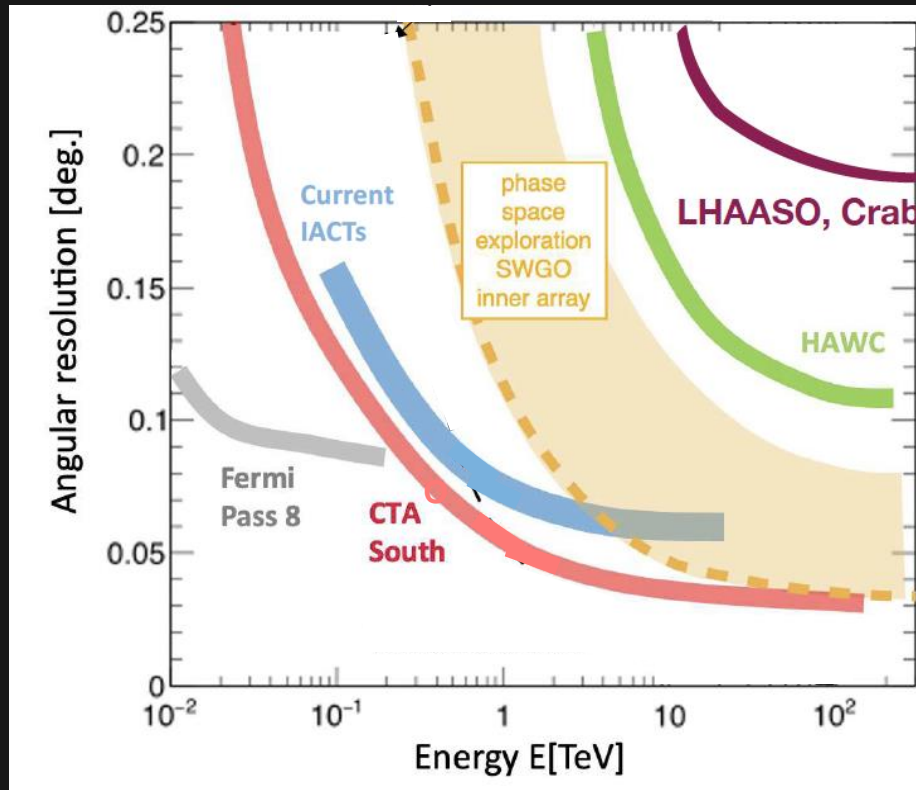
Full sky



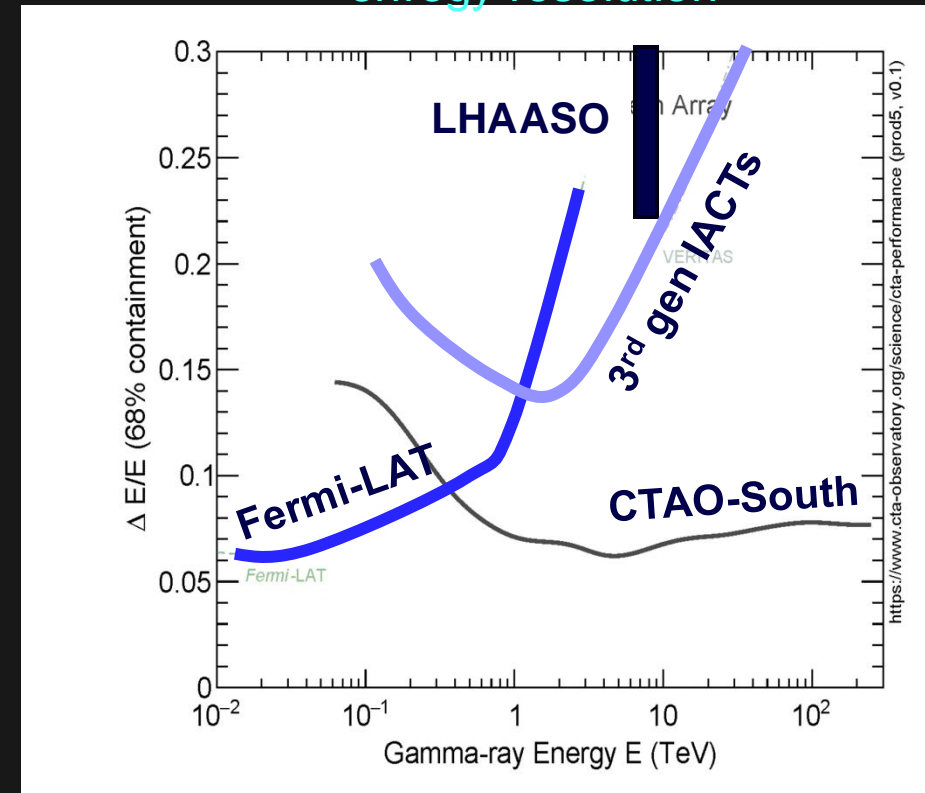
Source localization of the order of 15-30 arcsec!

# Angular & energy resolution

angular resolution



energy resolution

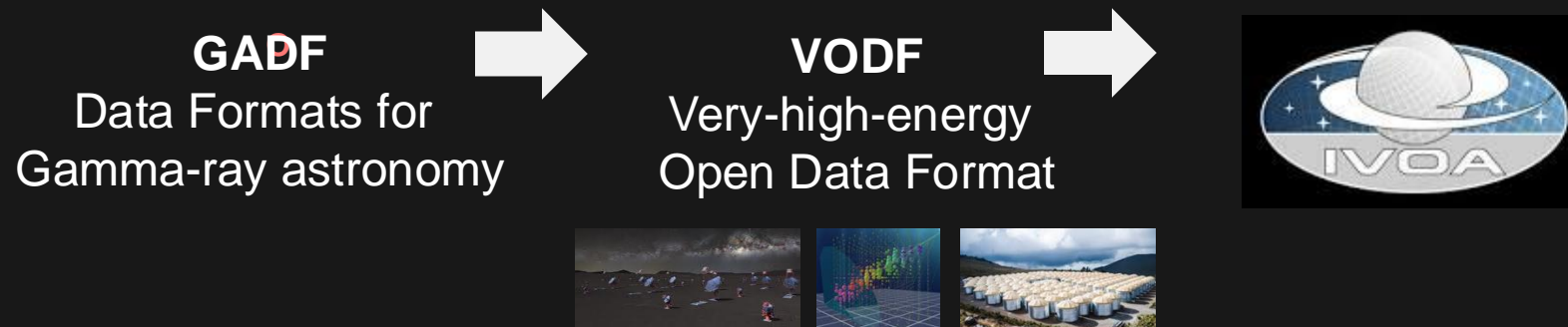


# Photometry vs spectroscopy

## 2 complementary approaches in VHE gamma-ray astronomy

- The maximum scientific exploitation requires coordination at different levels
  - Triggering information exchange → operational procedures
  - Common Data model and format → establishing common format at VO level

See Jim Hinton's talk



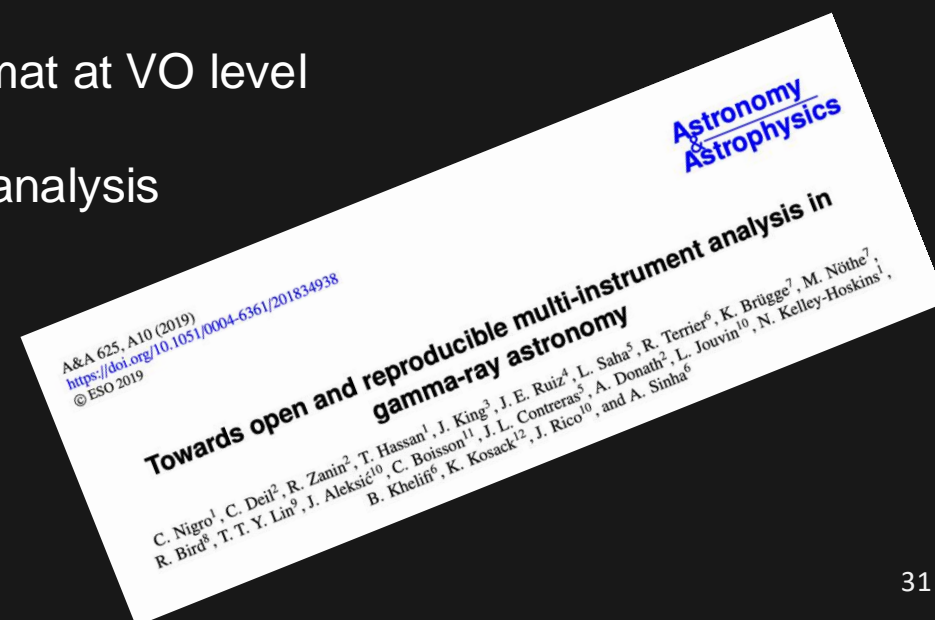
# Photometry vs spectroscopy

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  - Analysis software packages supporting joint multi-instrument analysis



See Regis Terrier's talk



# Photometry vs spectroscopy

## 2 complementary approaches in VHE gamma-ray astronomy

- The maximum scientific exploitation requires coordination at different levels
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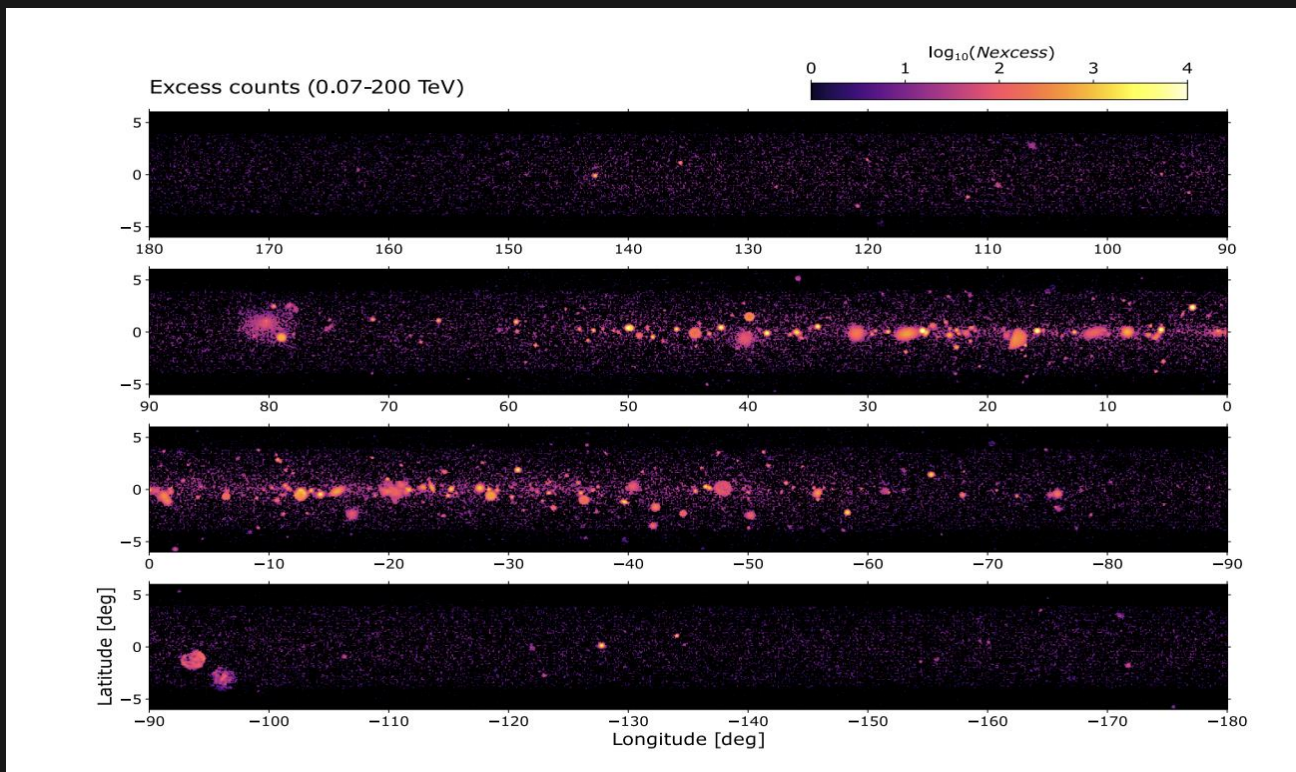
○

Such change in operational paradigm aimed at open science will benefit a lot also the multi-wavelength science



# Science Data Challenge

Blind and open! ... coming soon



- 7 yr of simulated CTAO observations provided as science-ready data sets (DL3)
- Goal #1: allow the gamma-ray community as well as the broad astronomical community to explore the CTAO scientific capabilities
- Goal #2: allow the users to familiarize with the technicalities of the analysis as well as with the CTAO science analysis tools, based on `gammapy`

# Conclusions

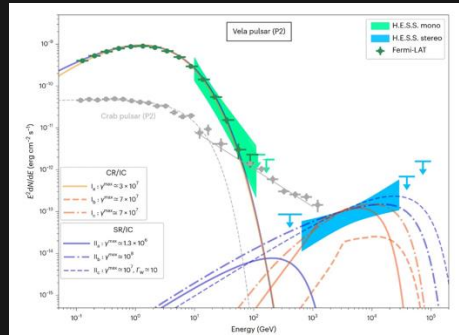
- The future of the VHE gamma-ray astronomy in the next decade is very bright
  - **2 technologies carried on given their complementarity:**  
photometry versus spectroscopy
- CTAO first data is at reach within the next 3 years with performance capabilities that are already a factor 2 better than the existing facilities
- Transient phenomena can be explored at maximum capabilities already in 3 years from now
- We can start exploring the highest energies also in the Southern sky thanks to the first *tenish* of SSTs

Thank you

Thank to the IAC for the infrastructure construction!

# Science cases of the VHE astronomy

H.E.S.S. coll. Nature 2023



**sub-TeV**

- Transients
- Cosmological sources
- Pulsars

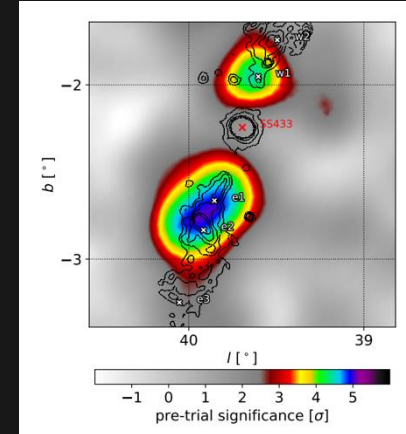
**TeV**

- EBL
- Dark Matter
- diffuse emission
- morphological studies
- surveys

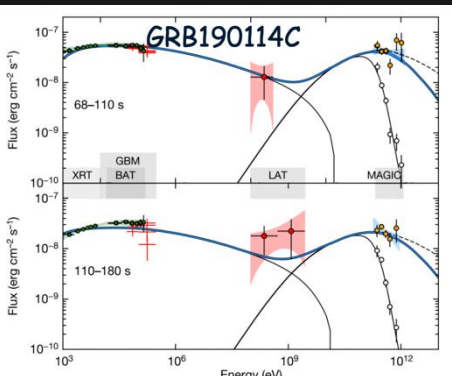
**multi-TeV**

- PeVatrons
- SFRs

HAWC coll. Nature 2018



MAGIC coll. Nature 2020



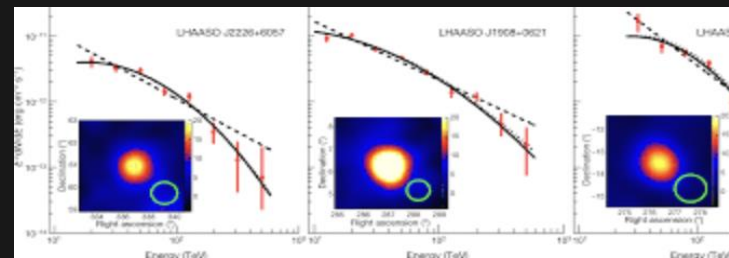
20 GeV

500 GeV 1 TeV

10 TeV

300 TeV

LHAASO coll. Nature 2021



GPS VERITAS + H.E.S.S.

