The Cherenkov Telescope Array Observatory: Its scientific capabilities will open new windows of exploration at very-high energies

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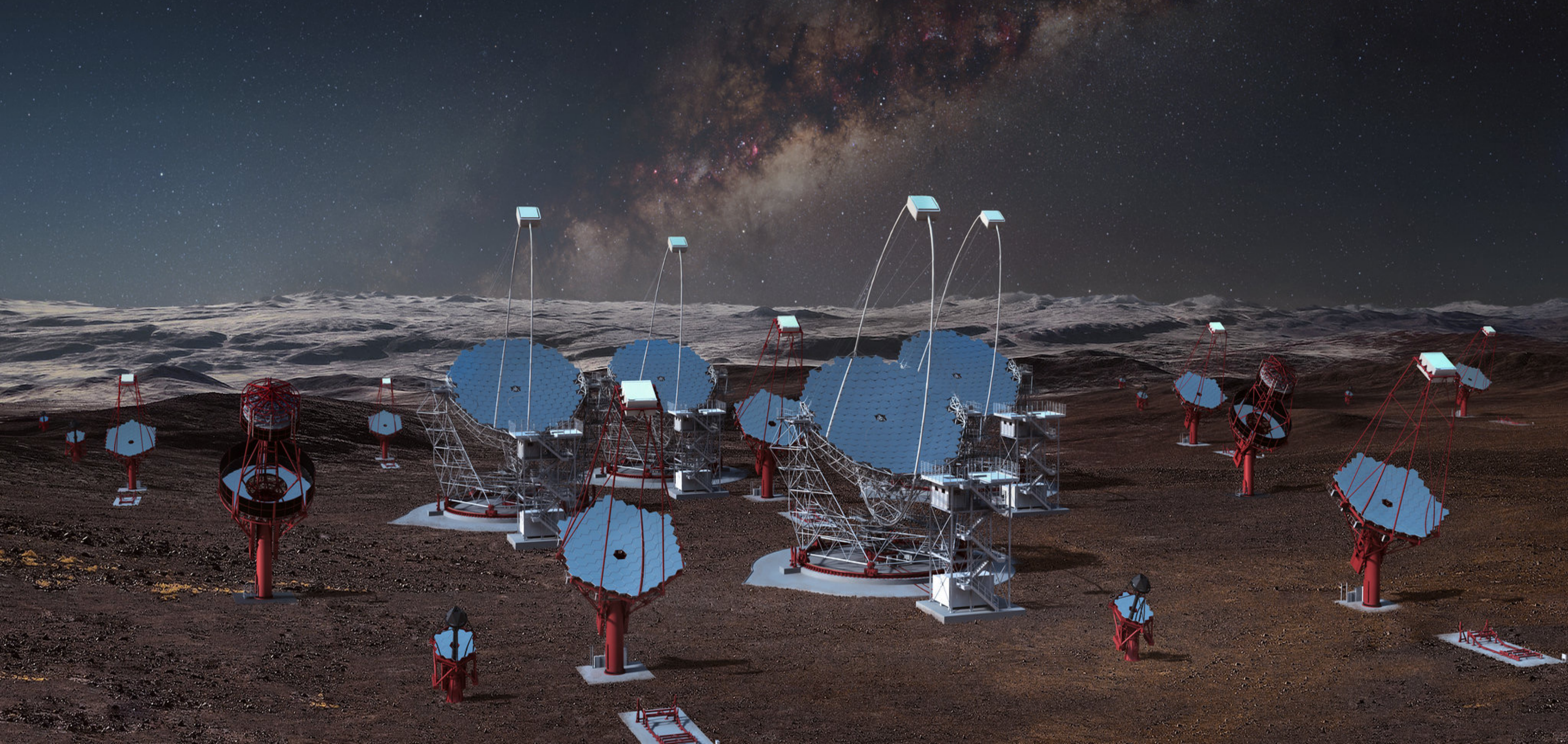
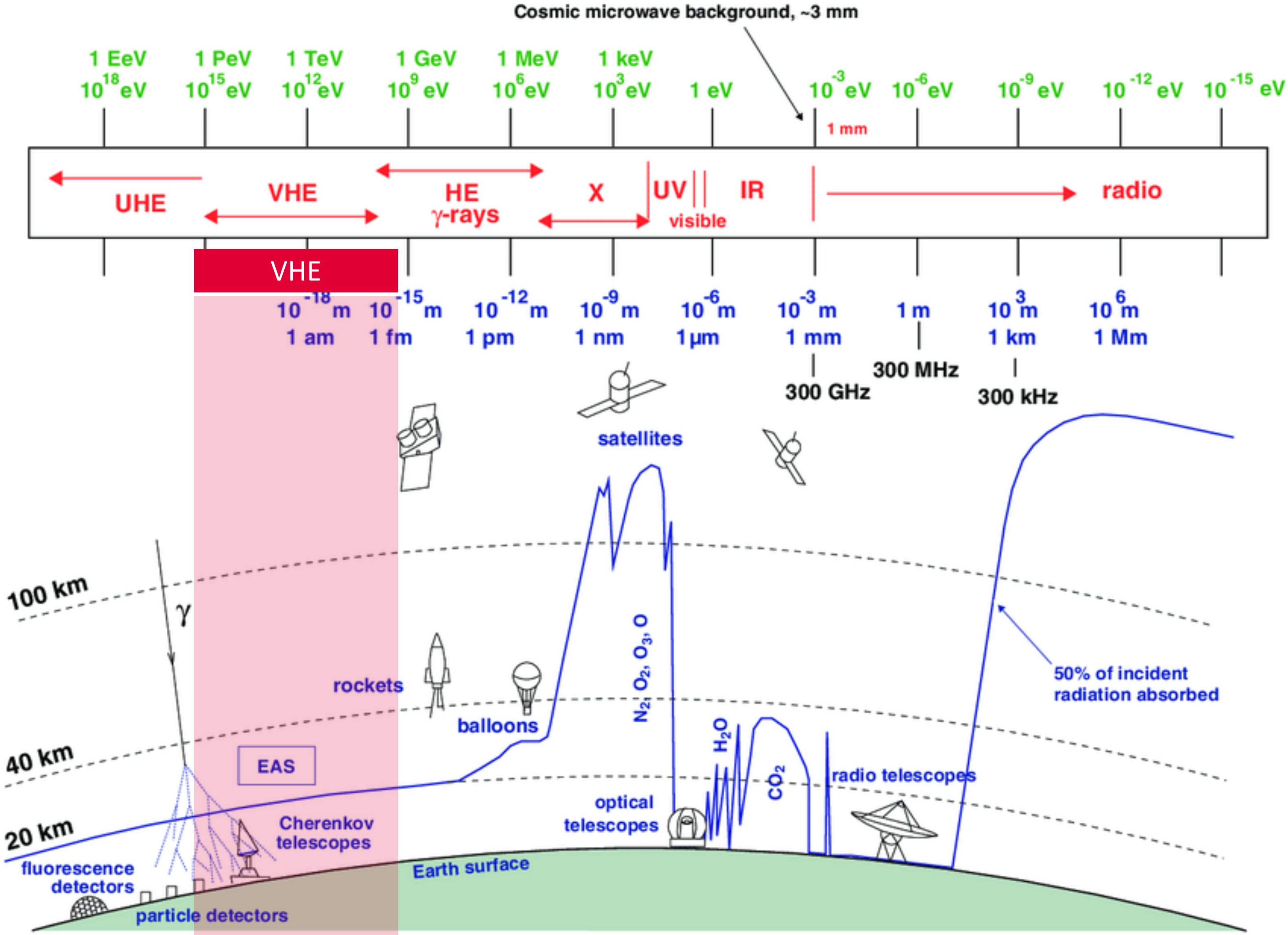


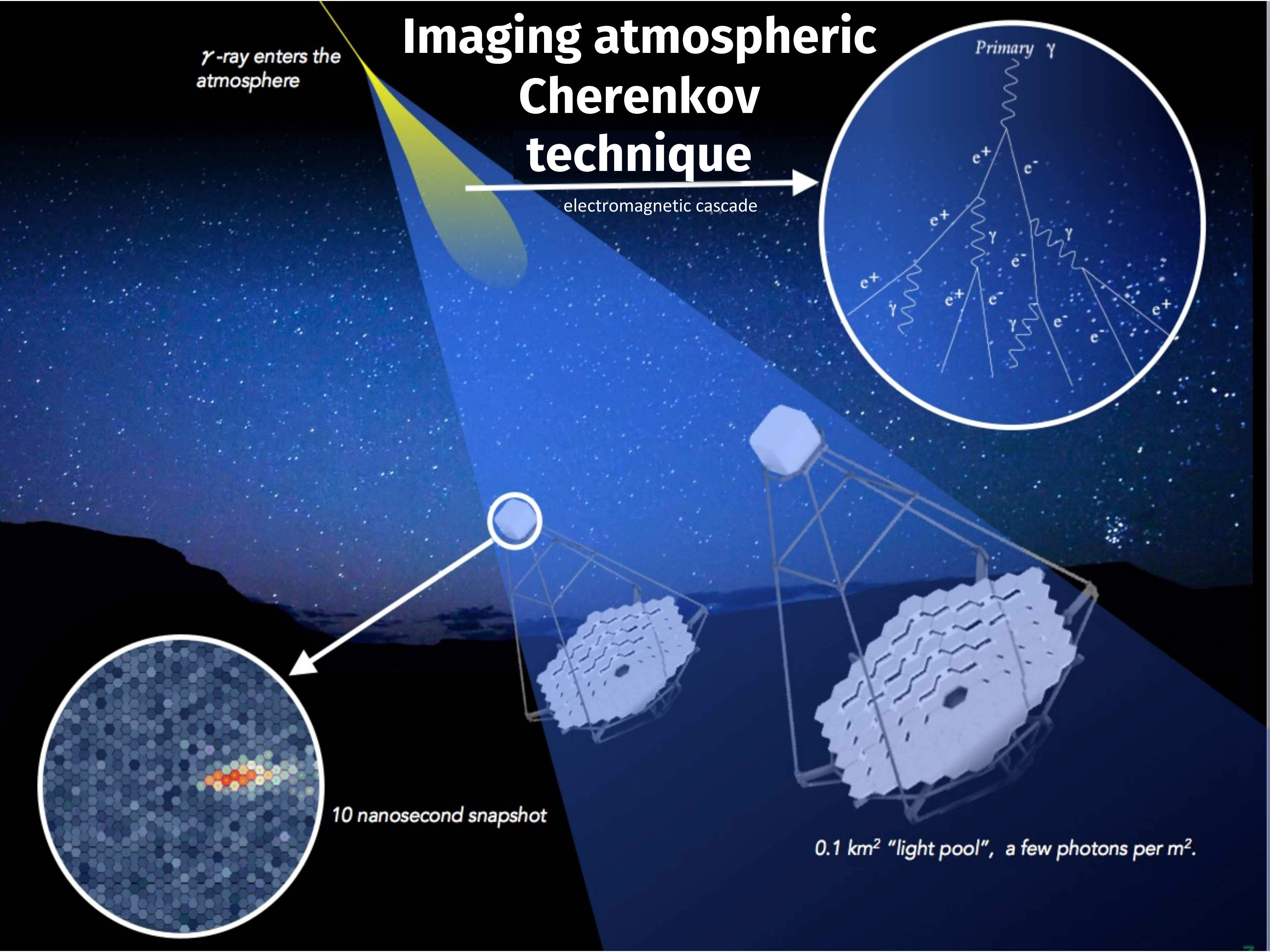
Outline

- **PART I**
  Introduction to the VHE astronomy & to the imaging atmospheric Cherenkov technique
- **PART II**
  Cherenkov Telescope Array Observatory
- **PART III**
  CTAO science case
- **Part IV:**
  Project Status

PART I
Introduction to the VHE astronomy & to the imaging atmospheric Cherenkov technique

Very-high-energy gamma rays

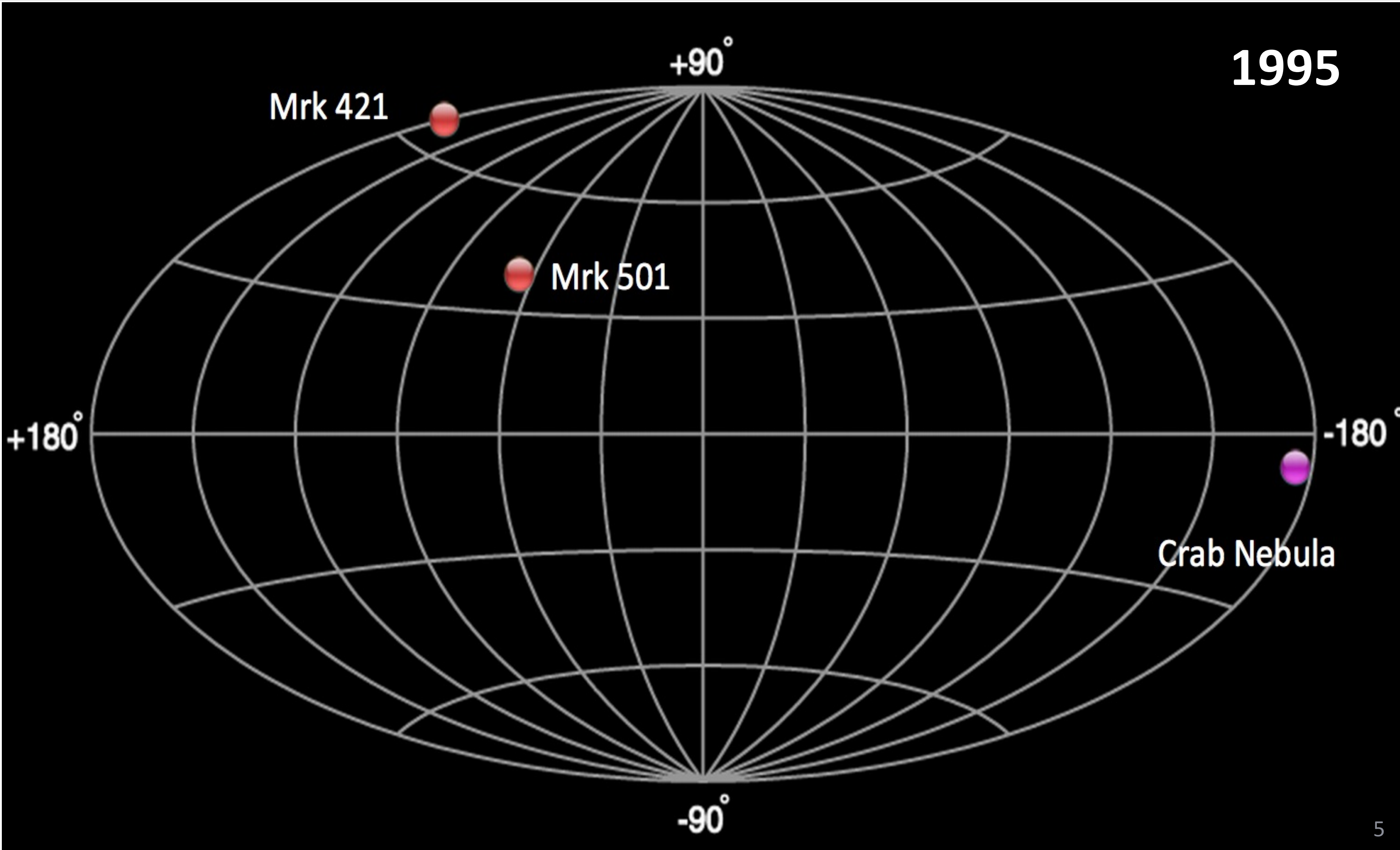




Imaging atmospheric Cherenkov technique
γ-ray enters the atmosphere
electromagnetic cascade
Primary γ
e+
e-
γ
10 nanosecond snapshot
0.1 km² "light pool", a few photons per m².

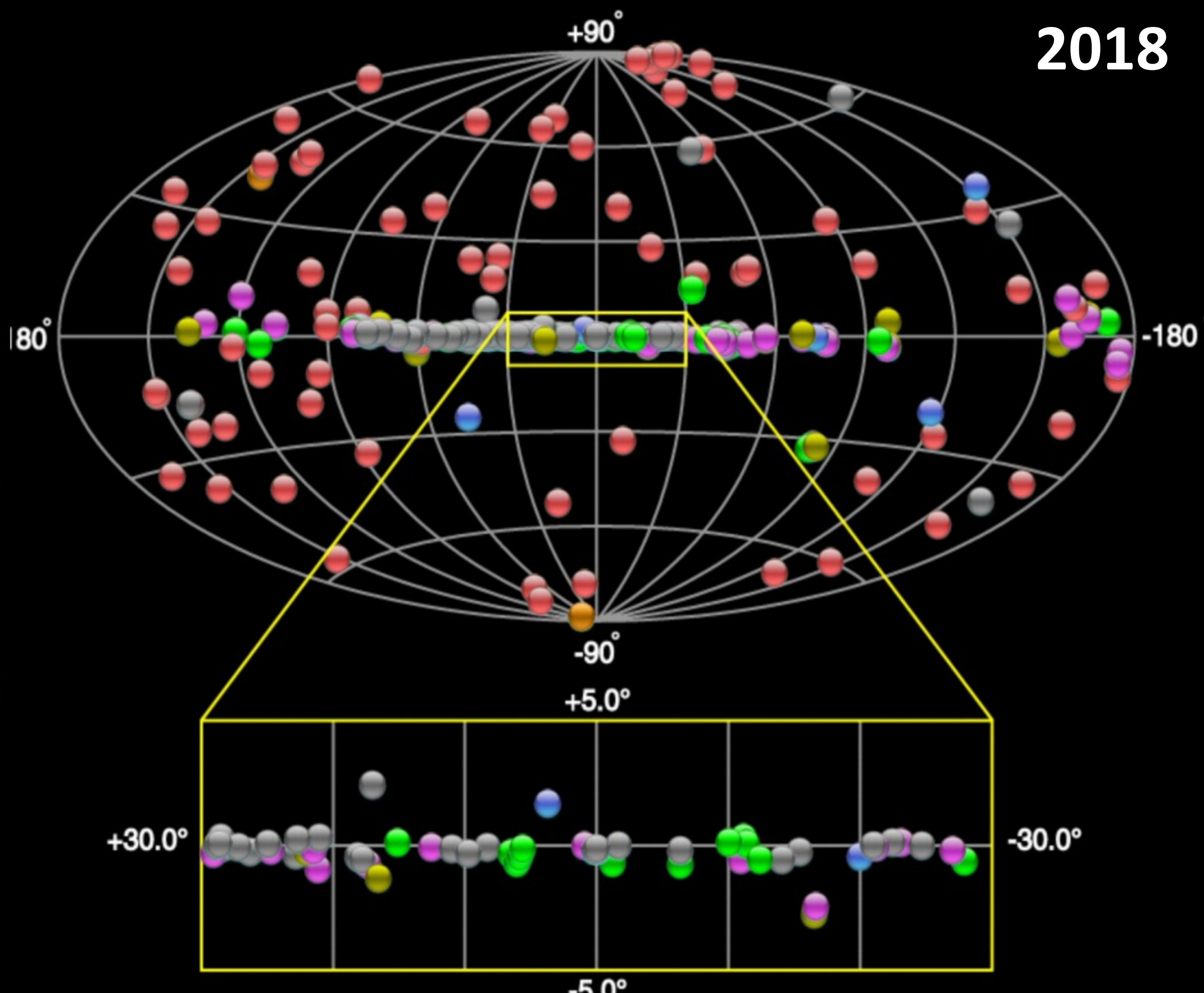
Imaging Atmospheric Cherenkov Telescopes

The gamma-ray TeV catalogue



The gamma-ray TeV catalogue

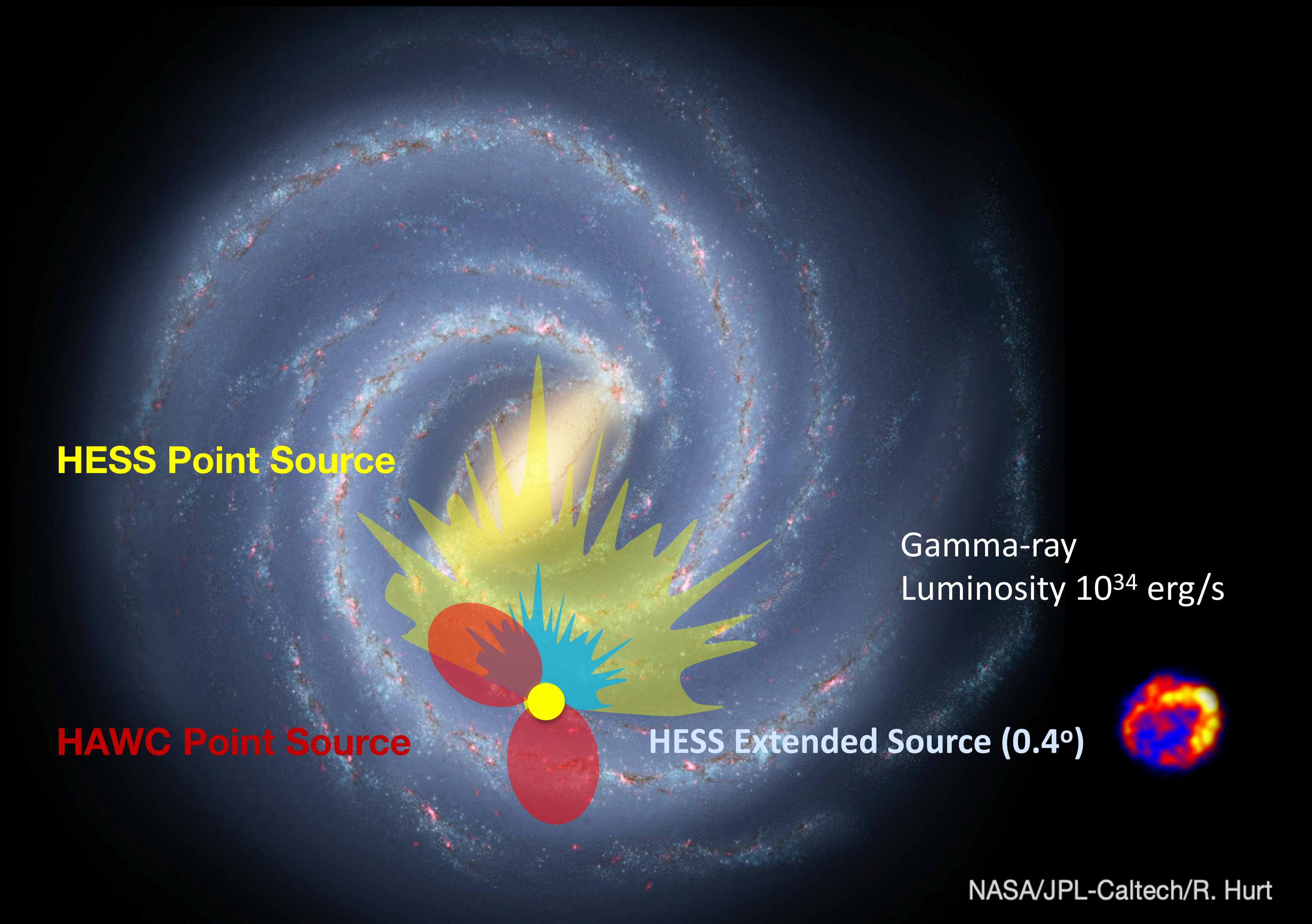
2018



Extended TeV Halo, PWN
Starburst
HBL, IBL, FRI, Blazar, FSRQ, LBL, AGN (unknown type)
Globular Cluster, Star Forming Region, uQuasar, Cat. Var., Massive Star Cluster, BIN, BL Lac (class unclear), WR
Shell, SNR/Molec. Cloud, Composite SNR, Superbubble
DARK, UNID, Other
Binary, XRB, PSR, Gamma BIN

>200 sources as of April' 18

More to come



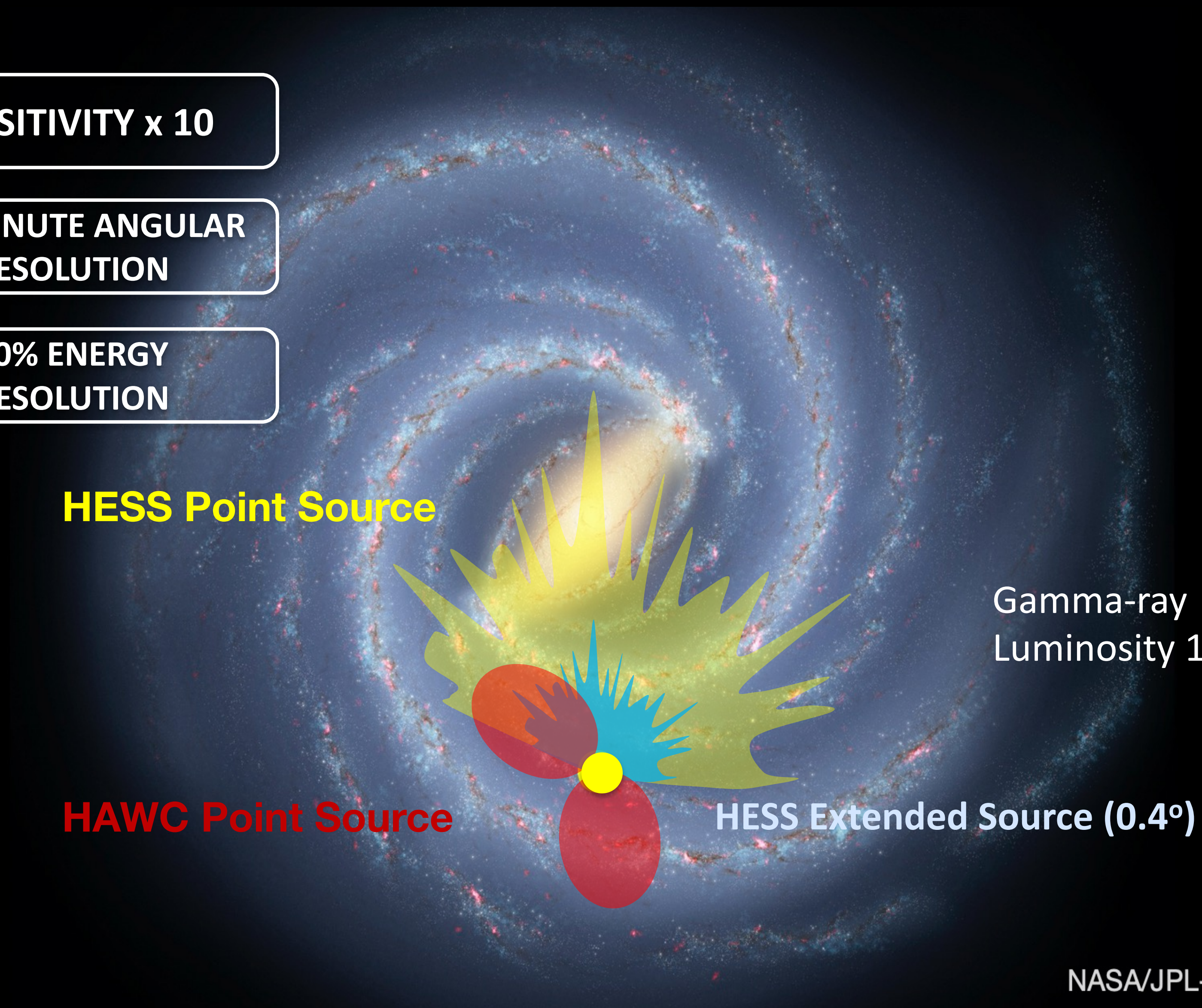
HESS Point Source
Gamma-ray
Luminosity 10³⁴ erg/s
HAWC Point Source
HESS Extended Source (0.4°)
NASA/JPL-Caltech/R. Hurt

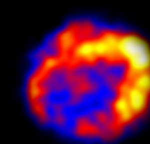
Design drivers for next generation IACT facility

SENSITIVITY x 10

ARCMINUTE ANGULAR RESOLUTION

10% ENERGY RESOLUTION





NASA/JPL-Caltech/R. Hurt

Design drivers for next generation IACT facility

SENSITIVITY x 10

ARCMINUTE ANGULAR RESOLUTION

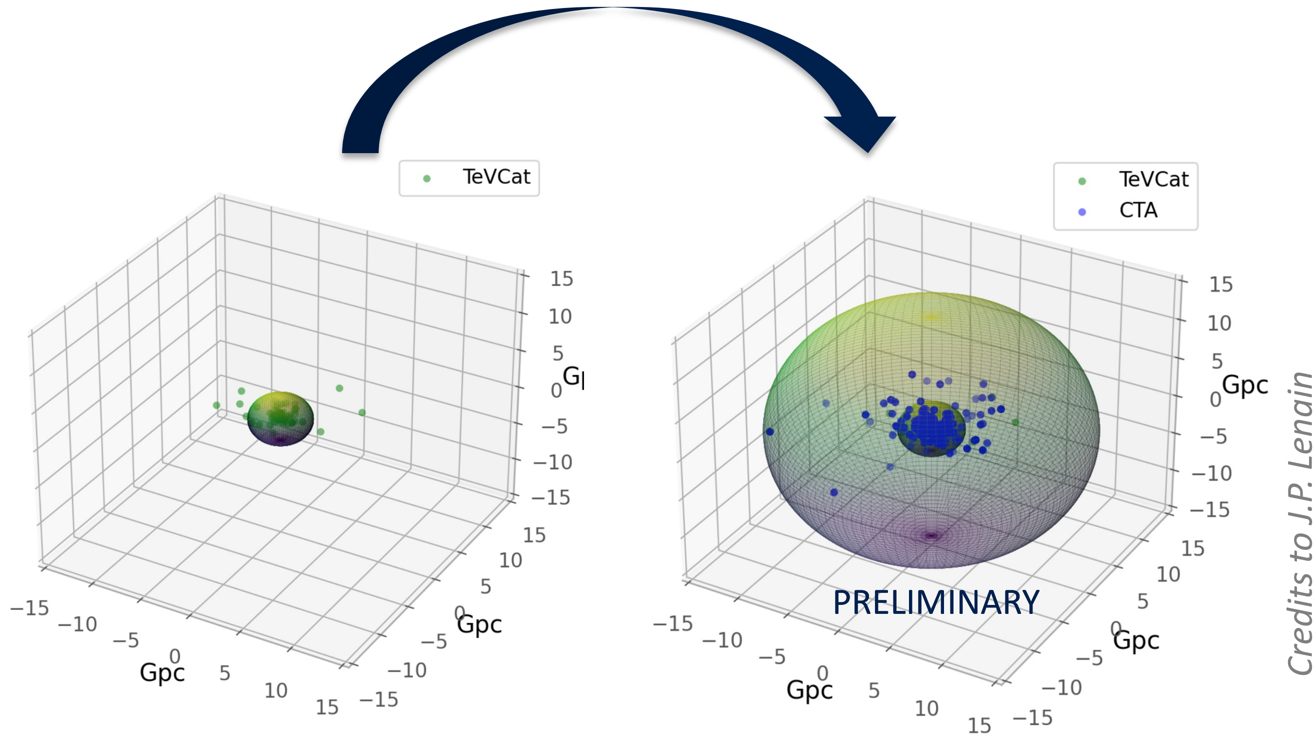
10% ENERGY RESOLUTION

WIDE ENERGY RANGE 20 GeV – 300 TeV

FoV x 2

FULL SKY COVERAGE

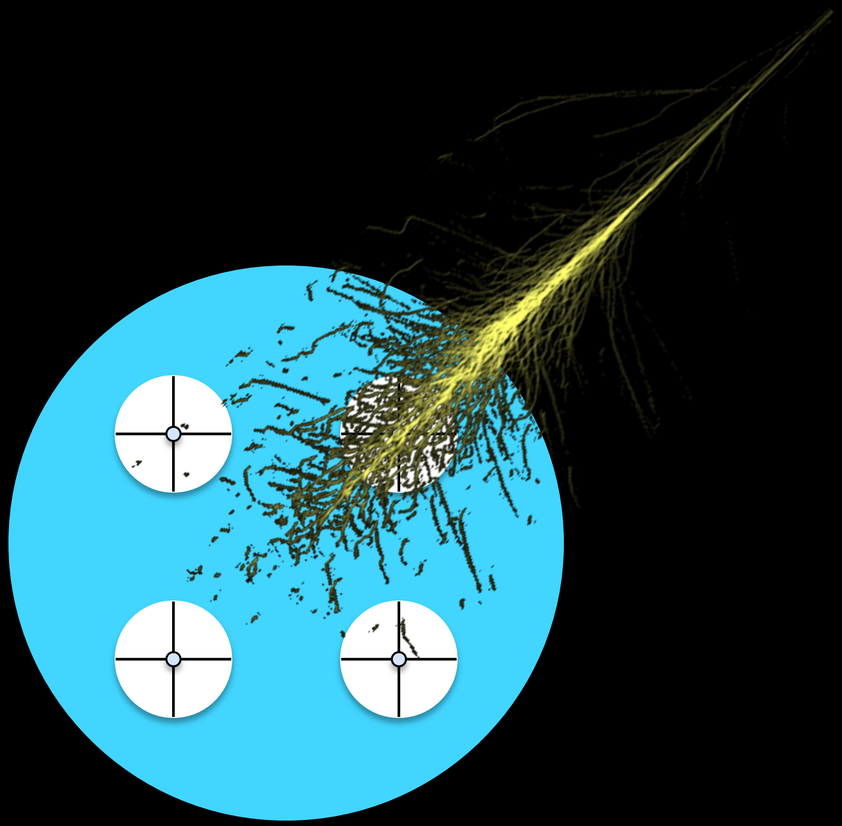
30 s RESPONSE TO EXTERNAL ALERTS



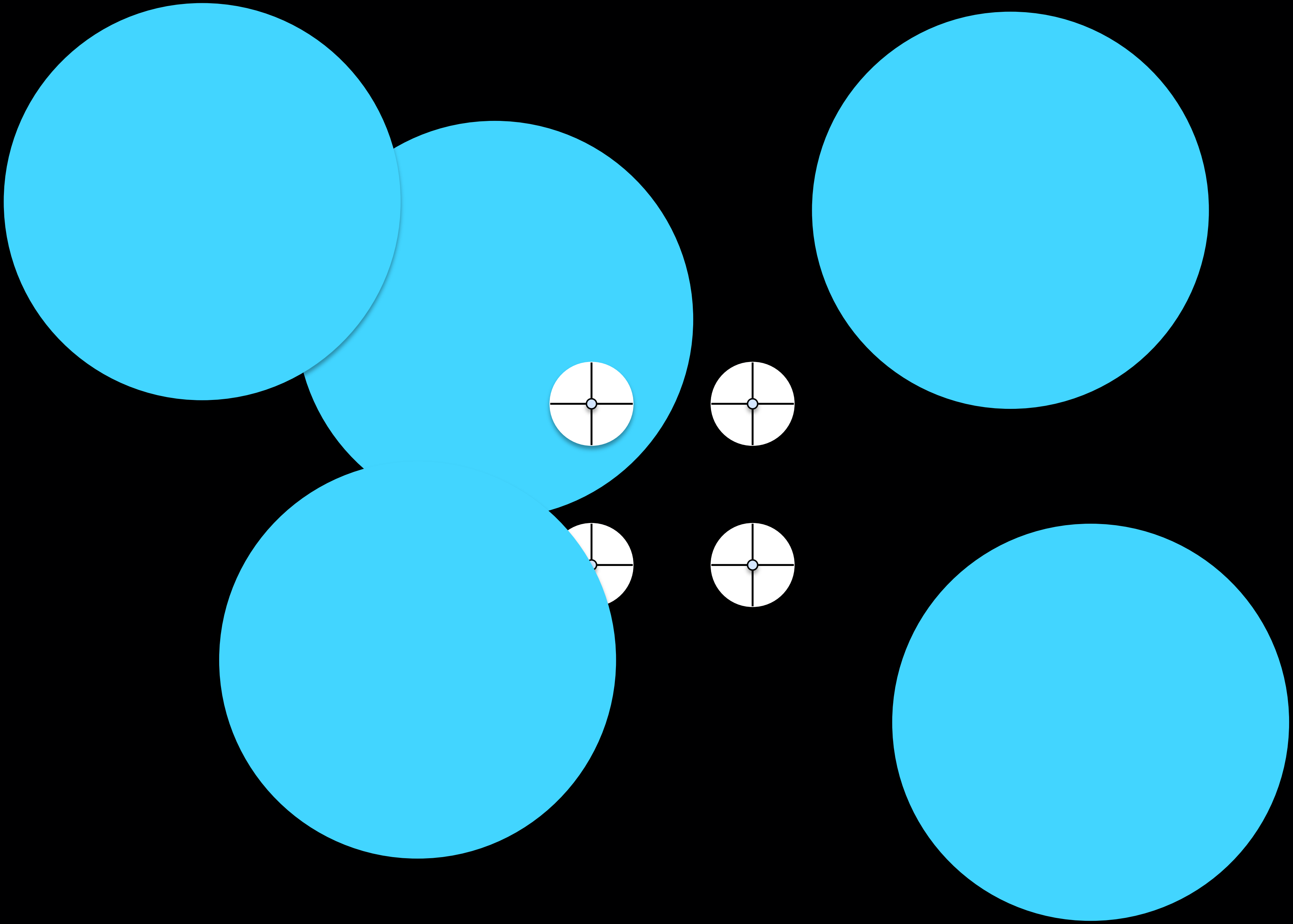
Energy Threshold ~ 80 GeV

Energy Threshold ~ 20 GeV

PART II
Cherenkov Telescope Array Observatory



Credits to W. Hoffmann



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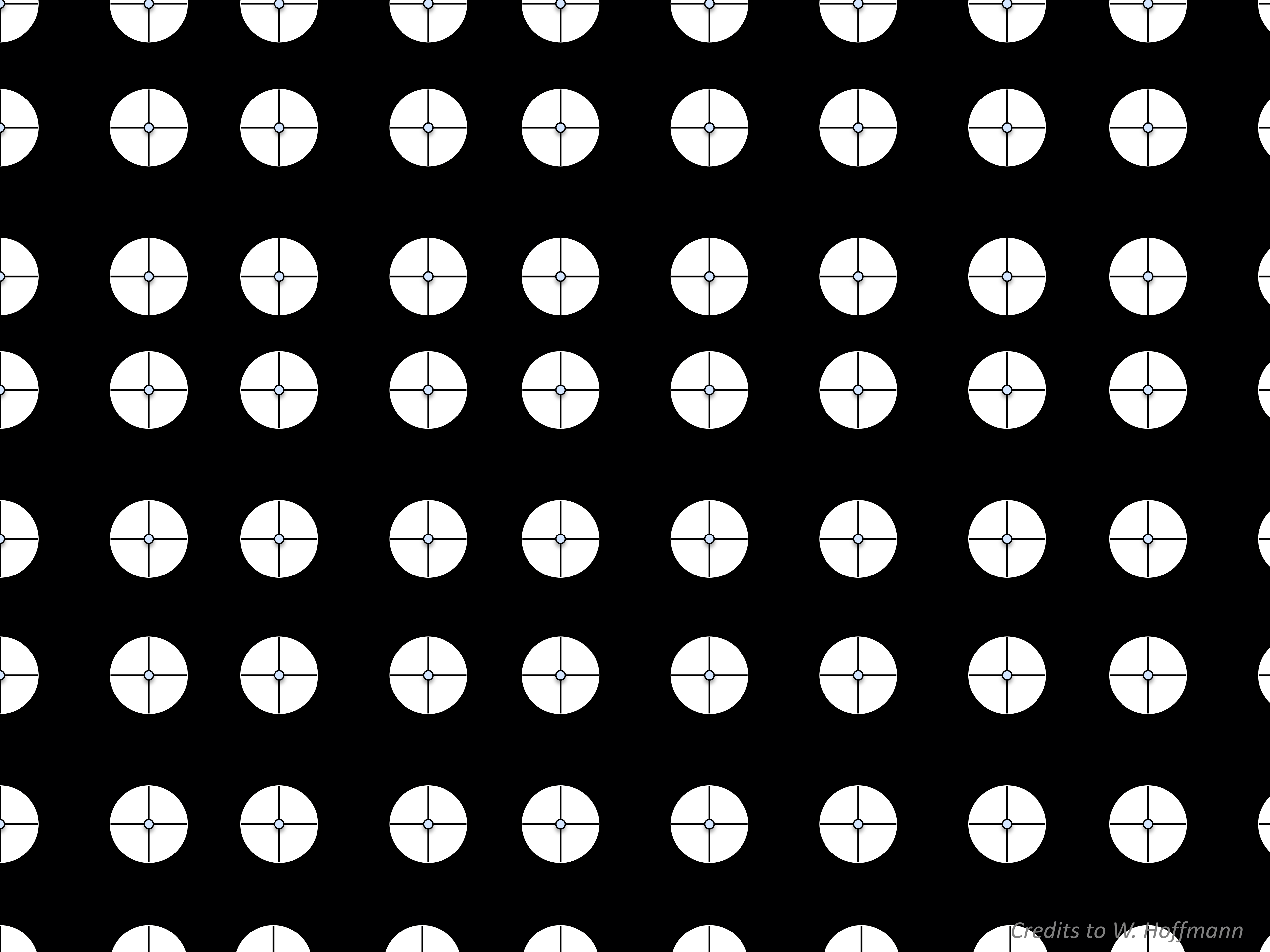
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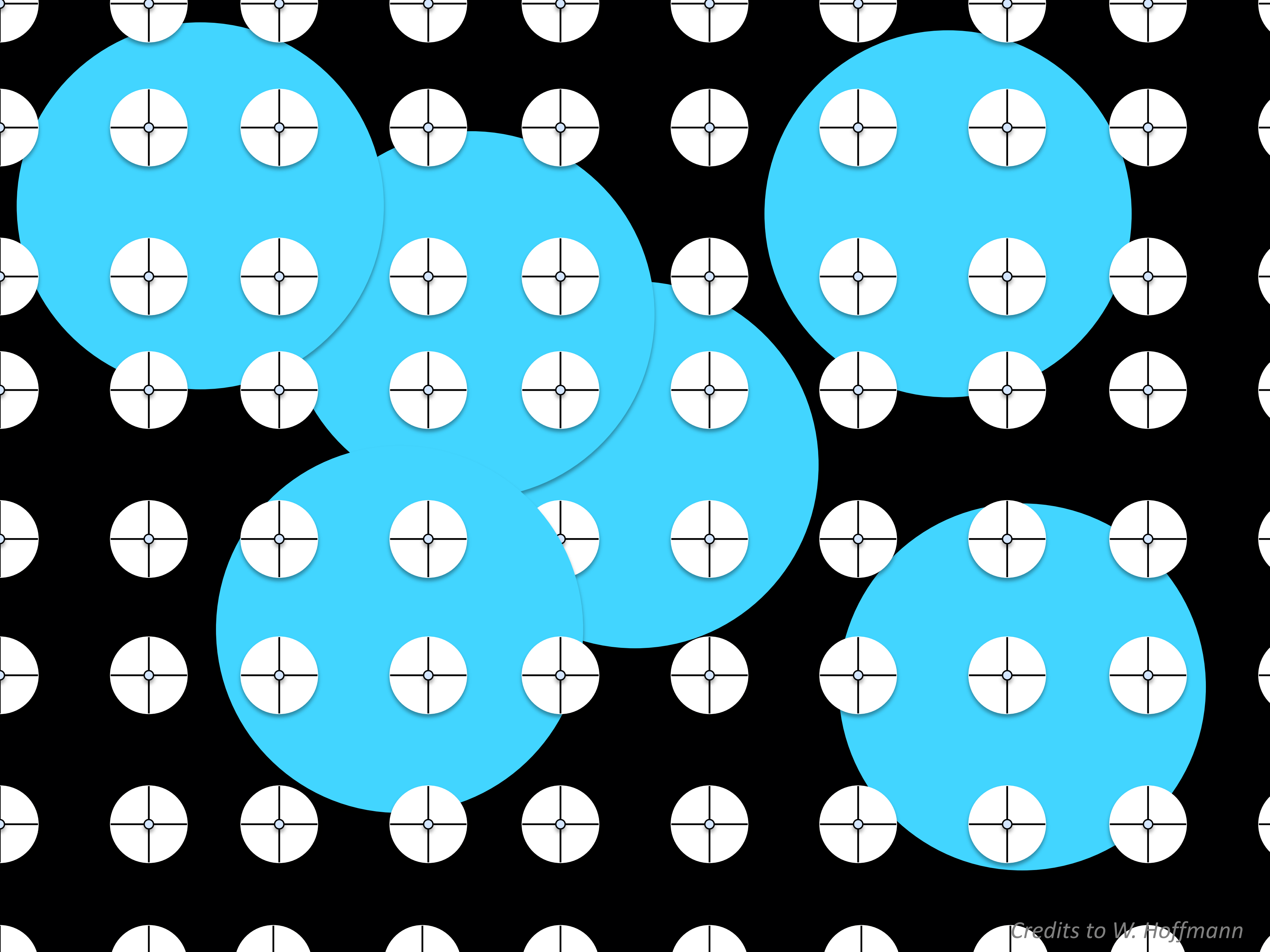
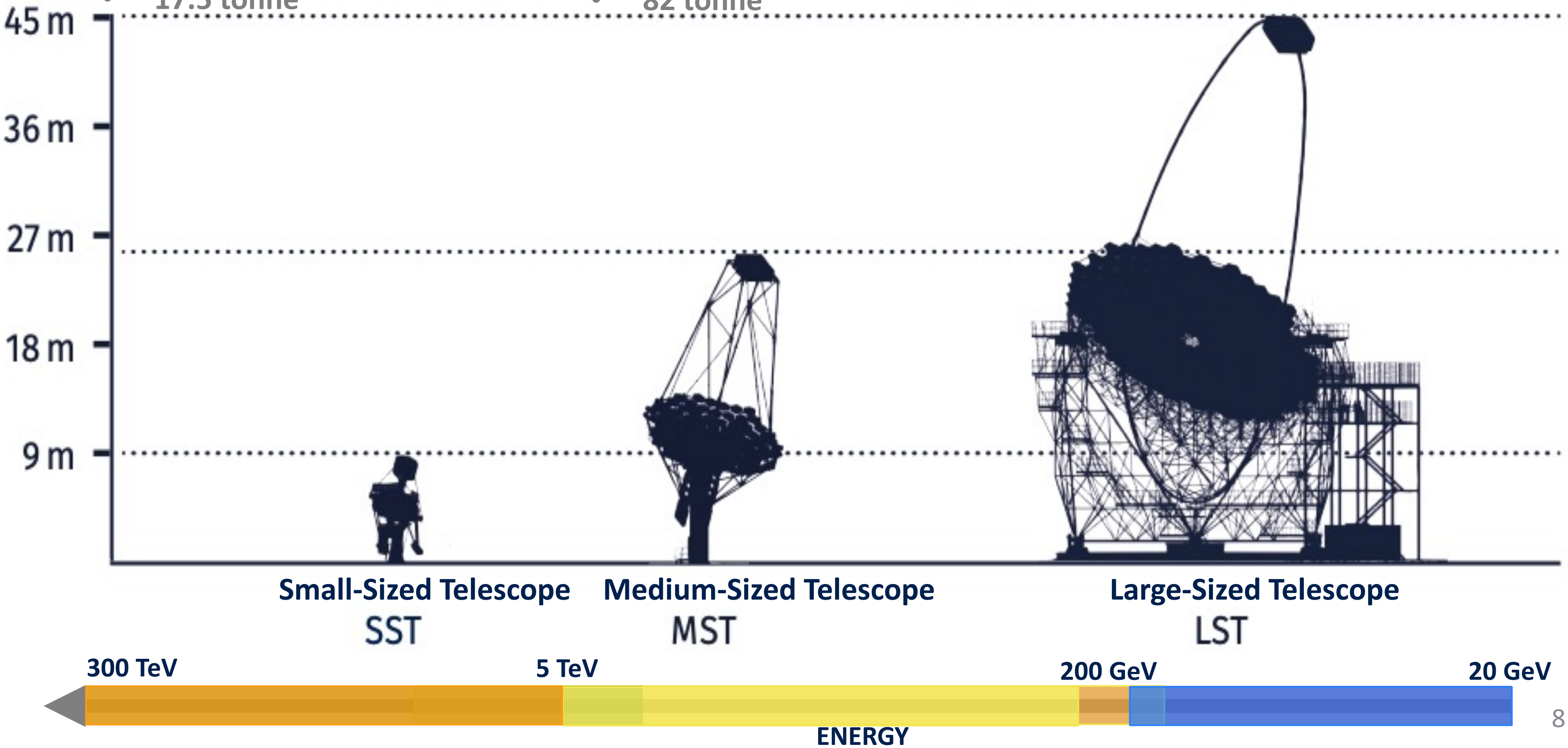

Credits to W. Hoffmann

3 telescope designs

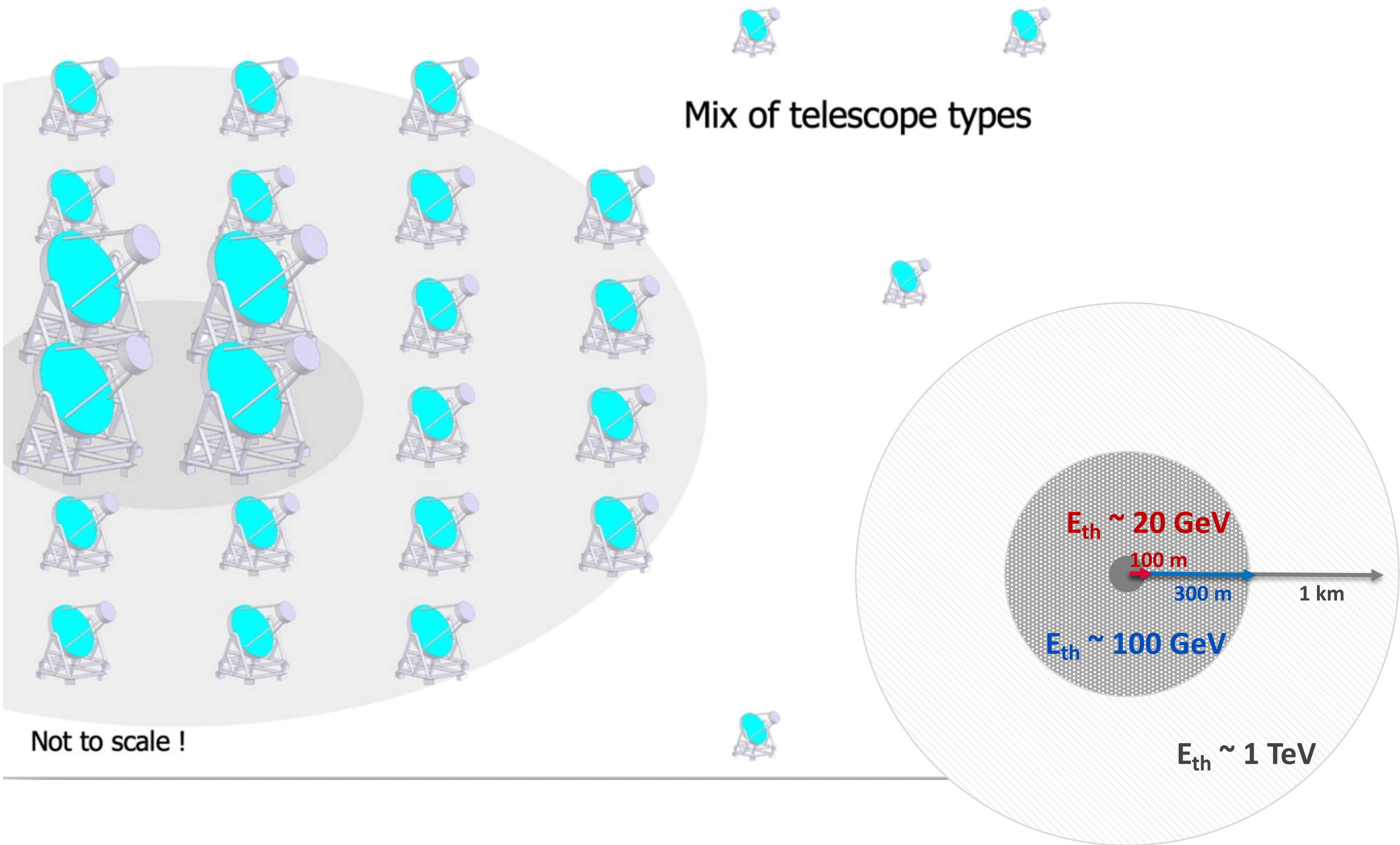
- 2-mirror Schwarzschild-Couder optical design
- 4.3 m ∅ primary reflective surface
- SiPM camera: 2048 pixels (0.16 °)
- 8.8° FoV
- 17.5 tonne

- Davies-Cotton optical design
- 12 m ∅ reflective surface
- PMT camera – 2 designs:
    - NectarCam: 1855 pixels
    - FlashCam: 1764 pixels
- ~7° FoV
- 82 tonne

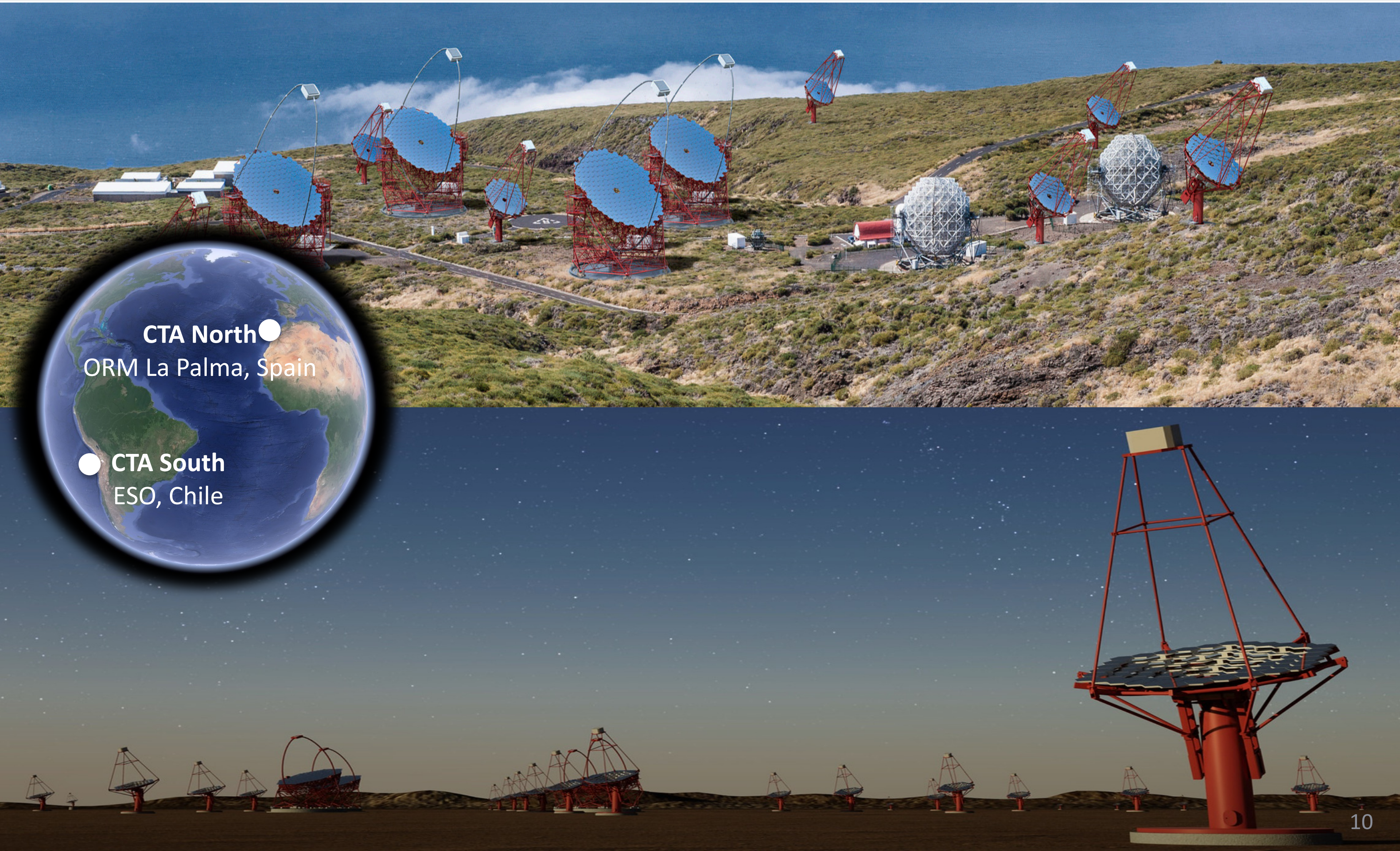
- Parabolic optical design
- 23 m ∅ reflective surface
- PMT camera: 1855 pixels (0.1°)
- 4.3° FoV
- 110 tonne



Array design



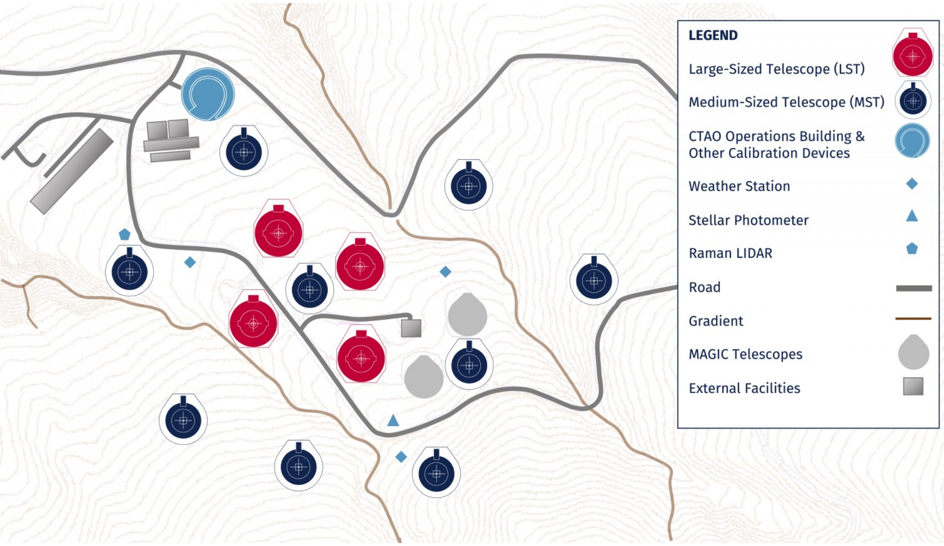
Full sky coverage



The two initial CTAO arrays: the Alpha Configuration

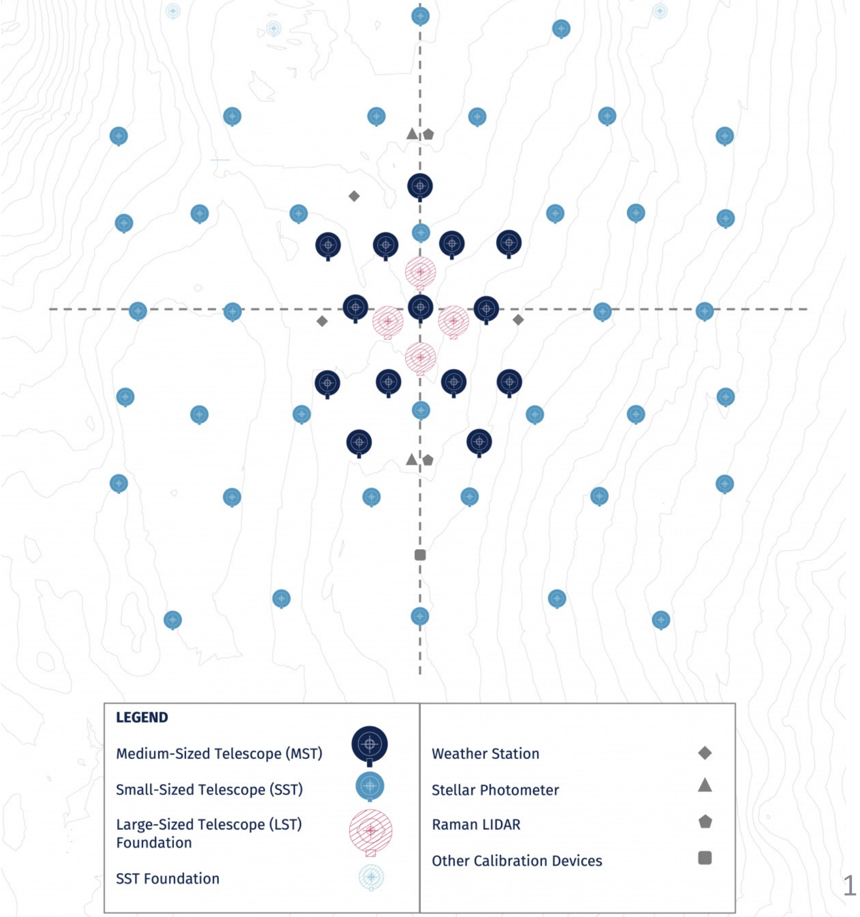
CTAO Northern Array

- **4 LSTs + 9 MSTs**
- 0,25 km² footprint
- focus on extra-Galactic science

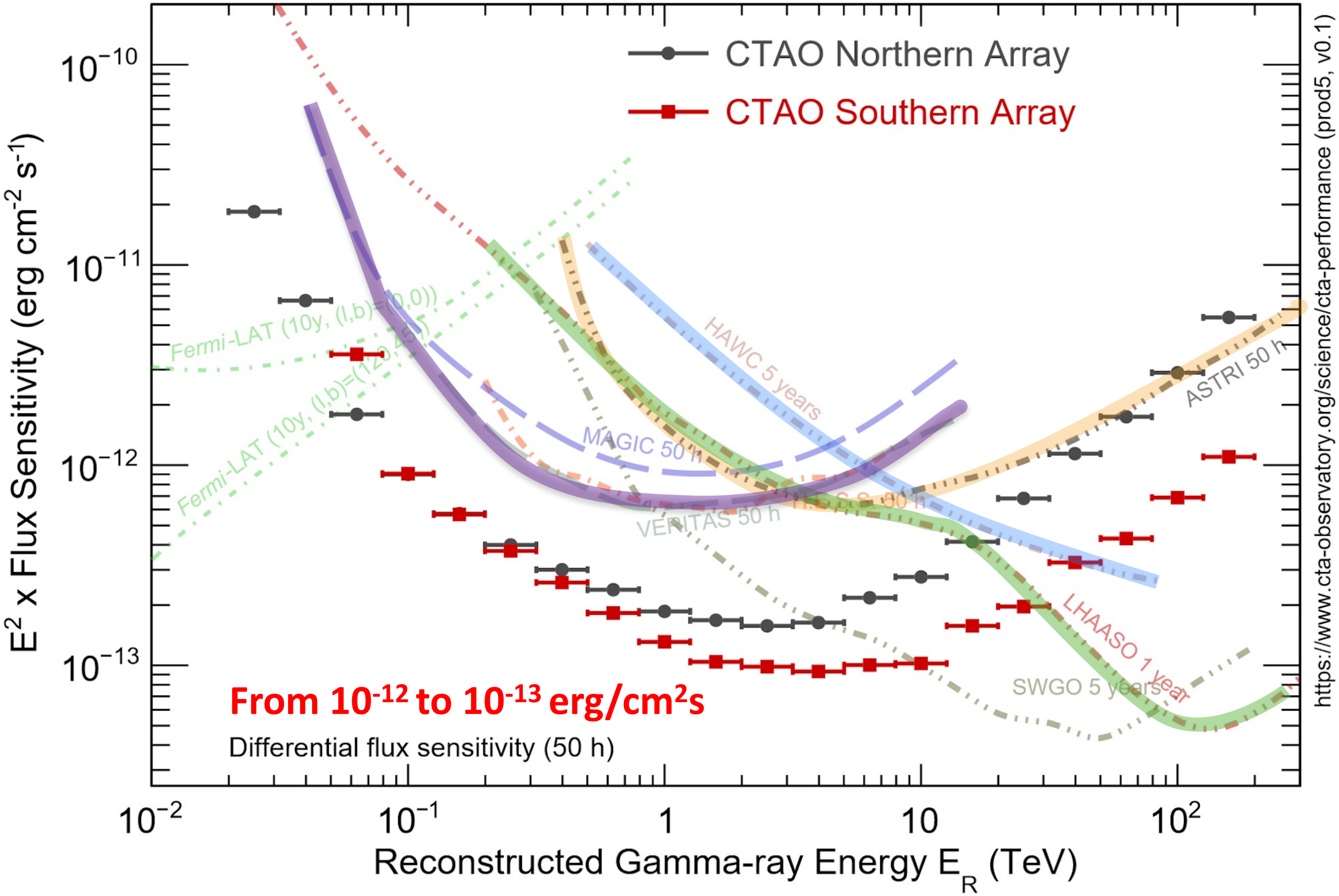


CTAO Southern Array

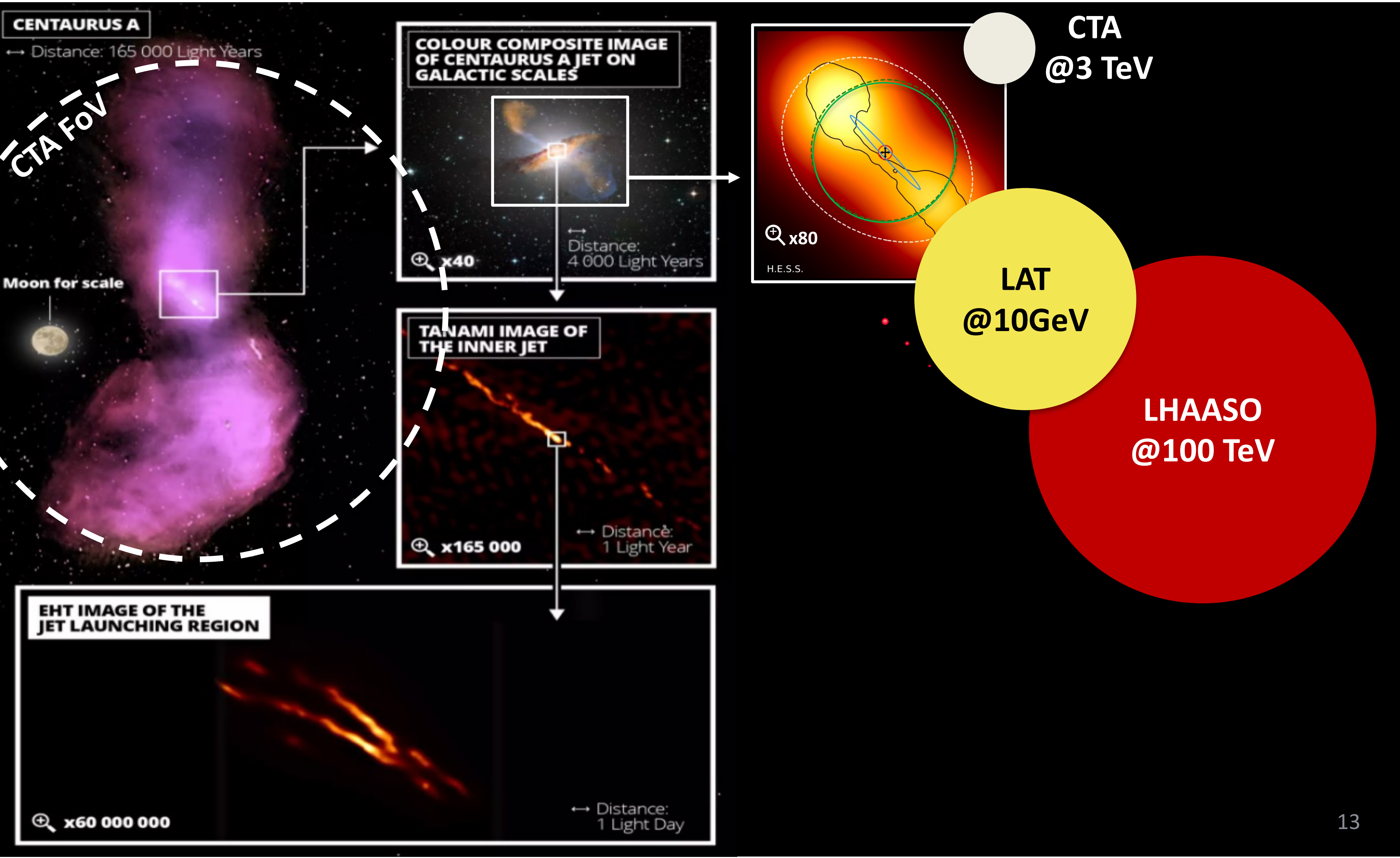
- **14 MSTs + 37 SSTs**
- 3 km² footprint
- focus on Galactic science



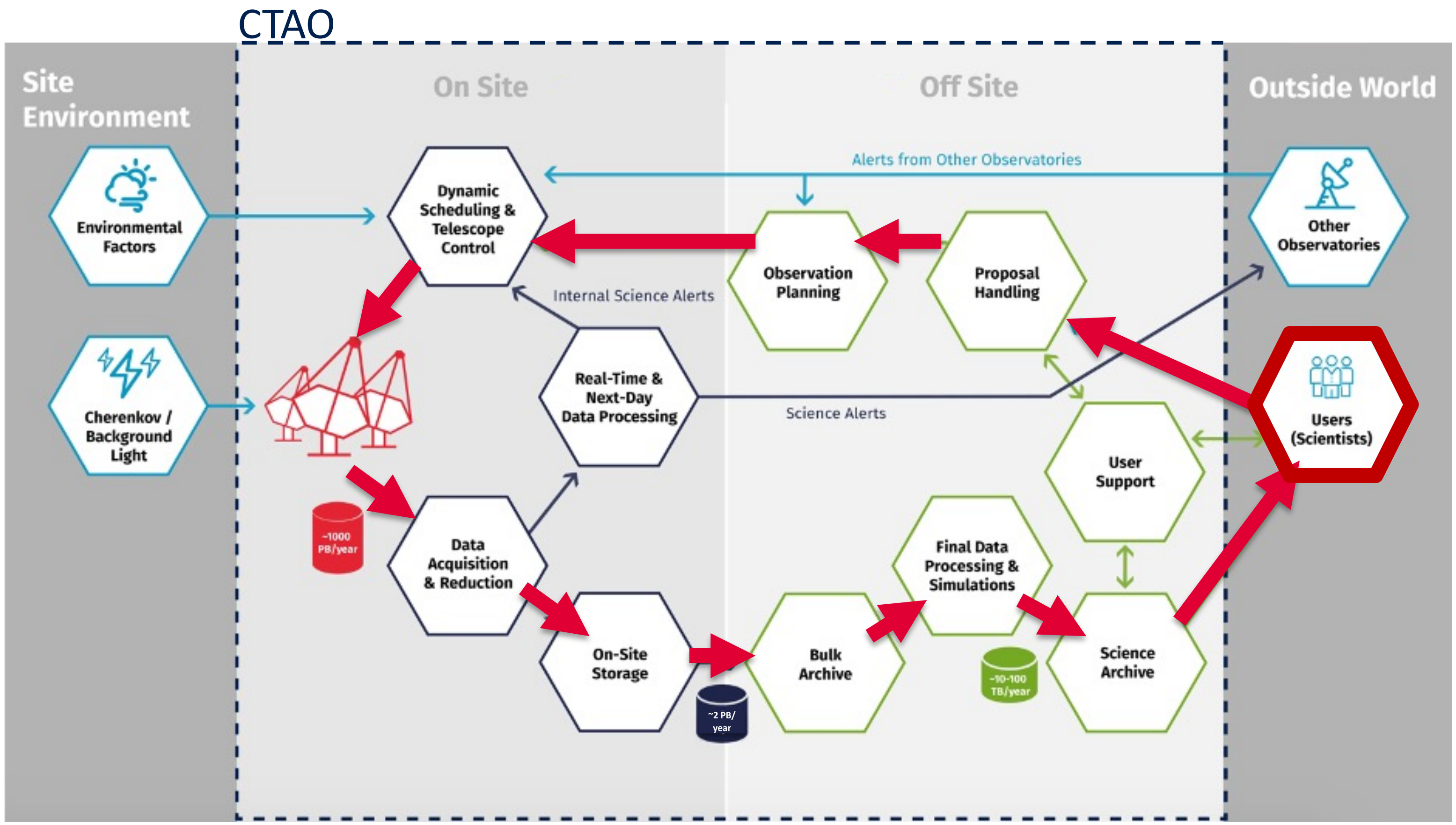
CTAO performance (Alpha Configuration)



CTAO performance (Alpha Configuration)



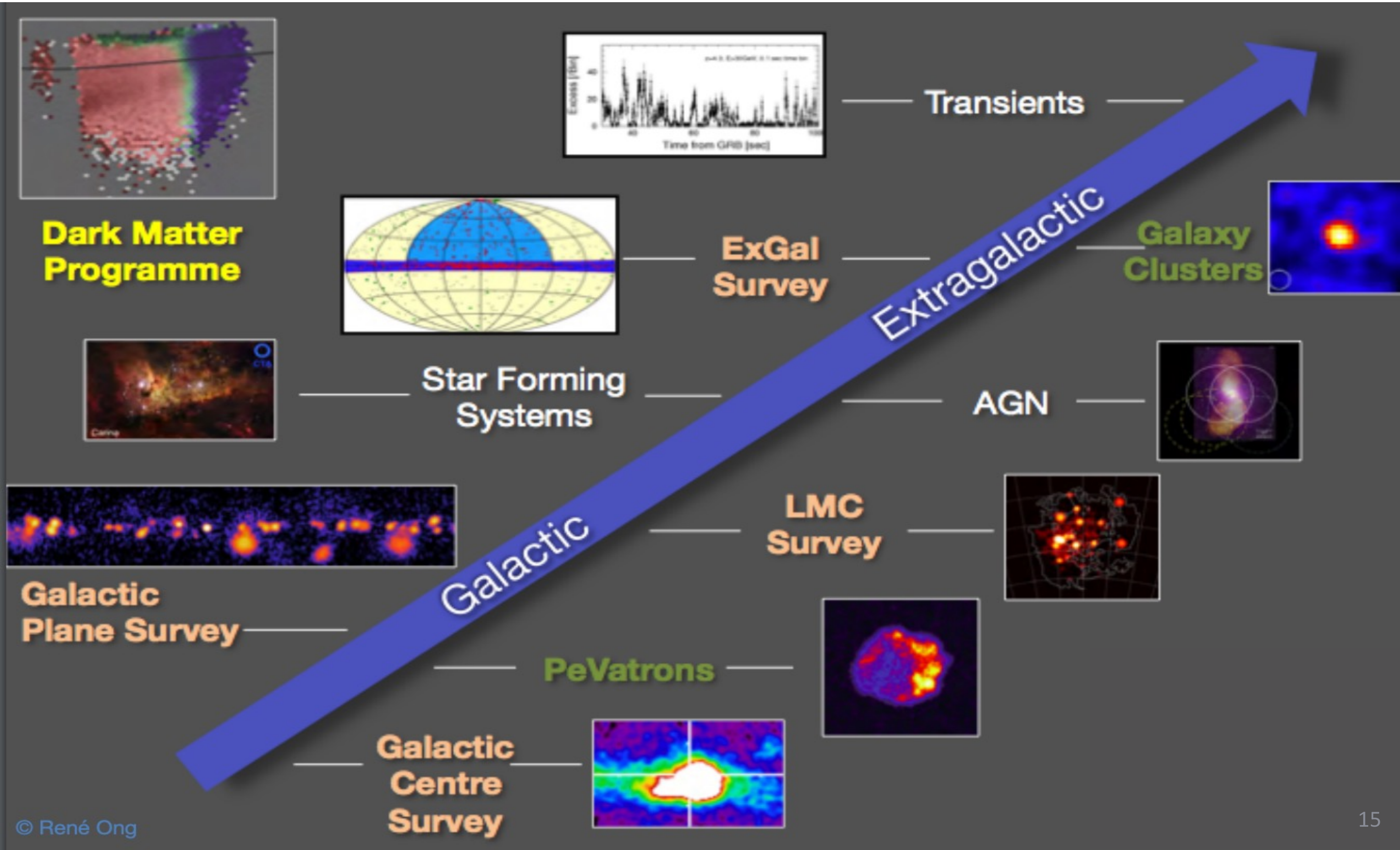
CTA Observatory



- **Proposal driven observatory**: standard proposals & long and large proposals (including Key Science Projects)
- **Proposals evaluated on scientific merits** by a Time Allocation Committee

PART III
CTAO Science Case

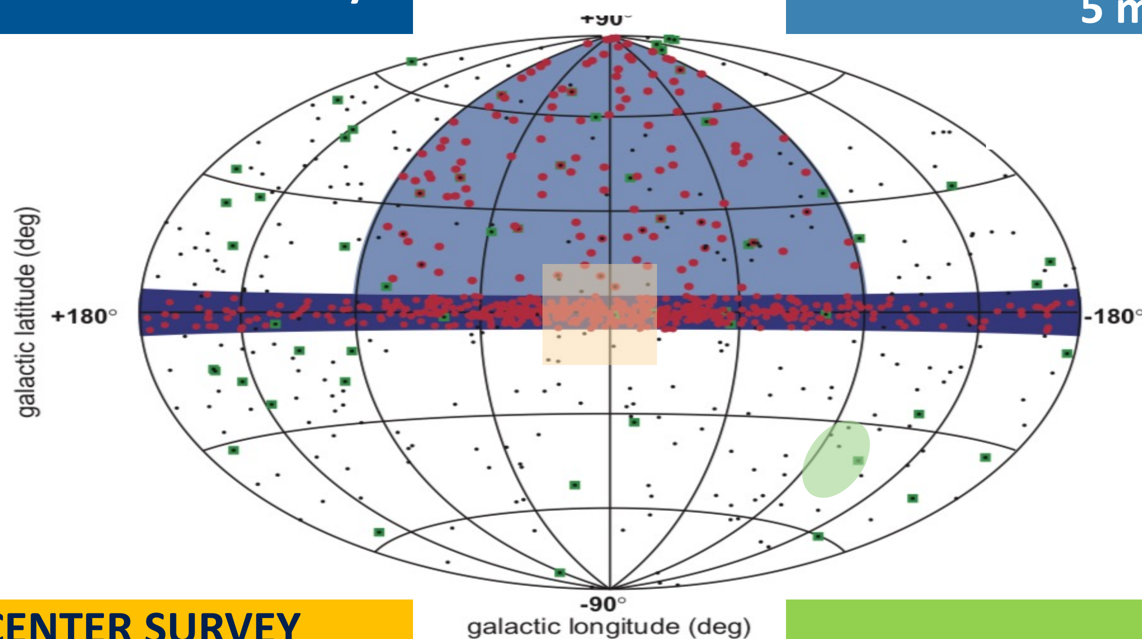
CTAO Science Program



CTAO surveys

GALACTIC PLANE SURVEY
not uniform sensitivity across the plane 2-4 mCrab
pilot survey: first results after ~1 yr

EXTRAGALACTIC SURVEY
unbiased survey of VHE sky → huge discovery space
25% of the sky
5 mCrab

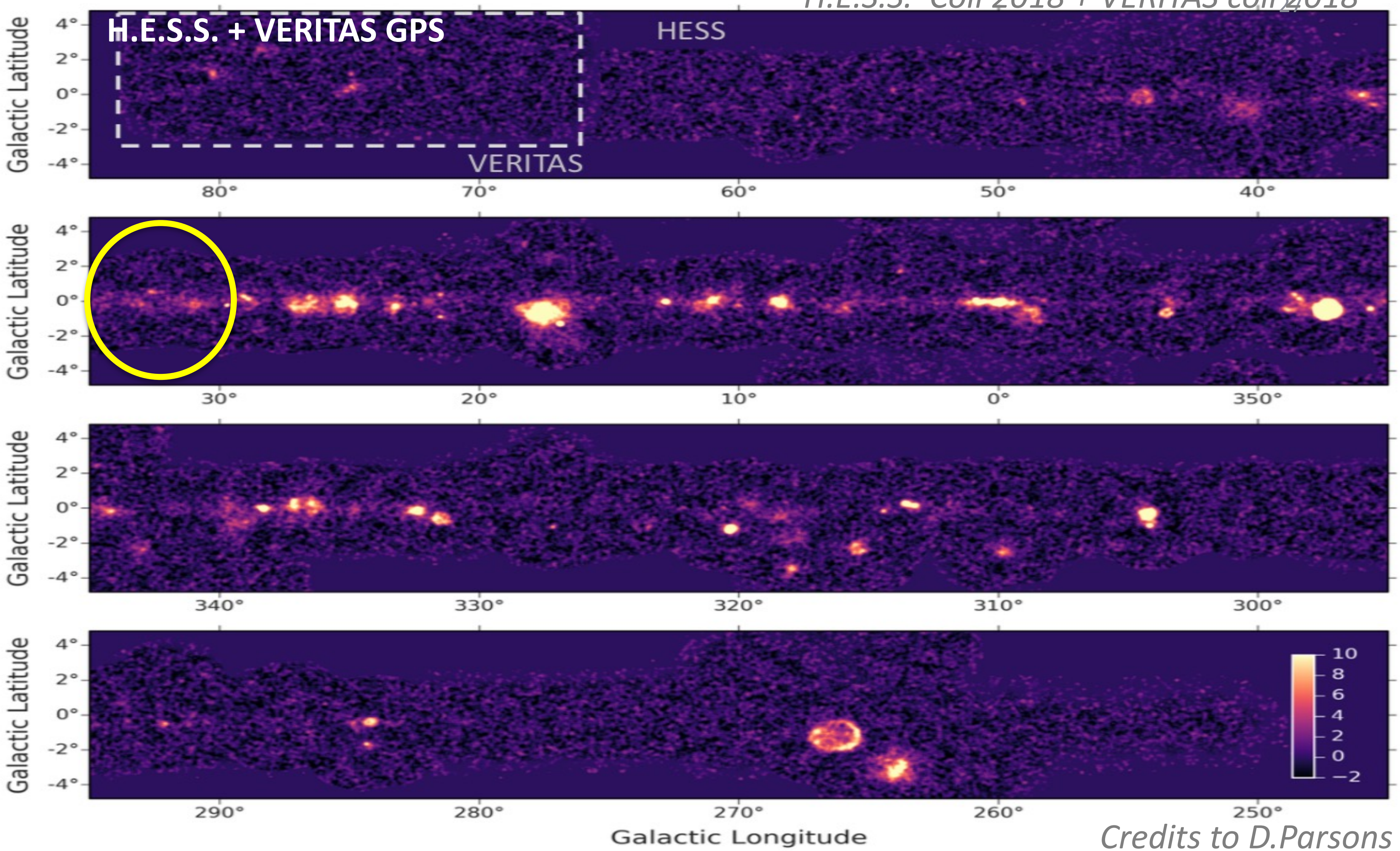


GALACTIC CENTER SURVEY
deeper observations around the GC
10° x 10°
2 mCrab

LARGE MAGELLANIC CLOUD SURVEY
1.5-2 mCrab

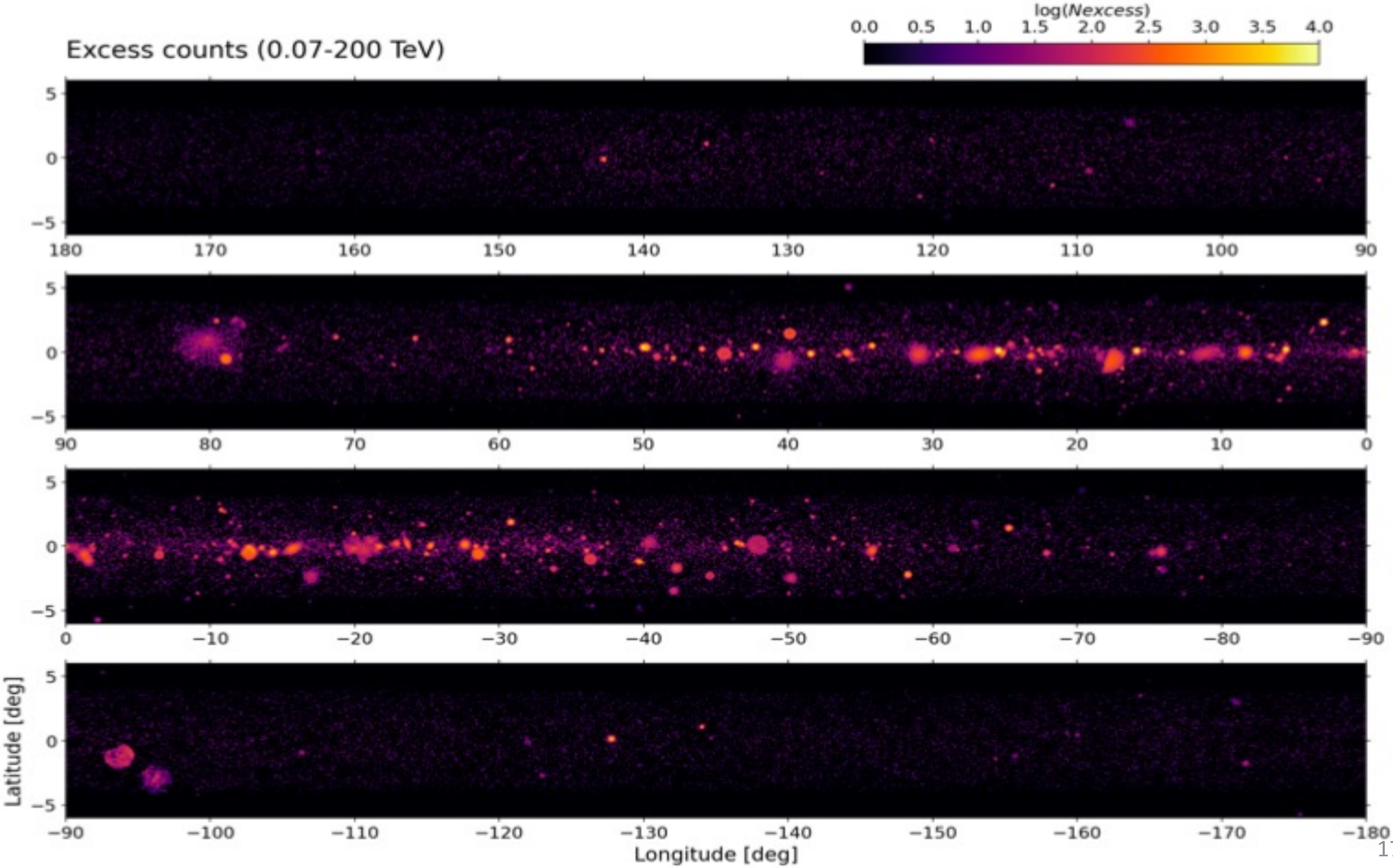
Galactic plane survey

H.E.S.S. Coll 2018 + VERITAS coll 2018



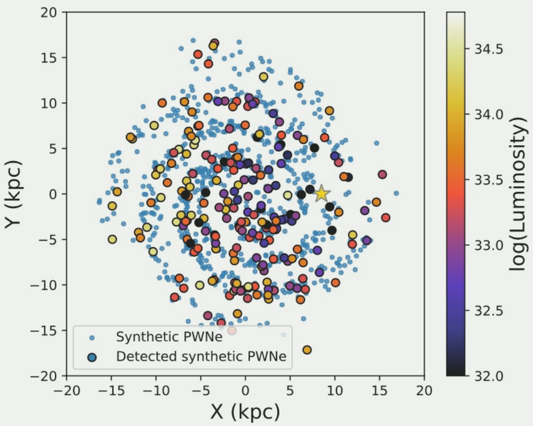
Credits to D.Parsons

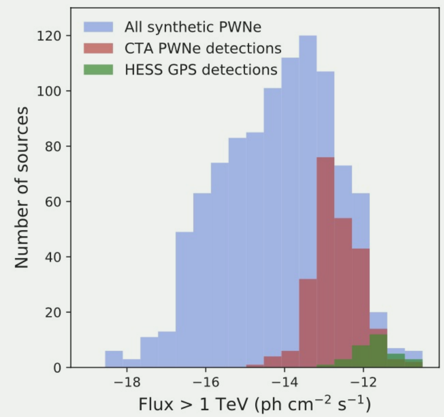
Galactic Plane Survey



Source population studies

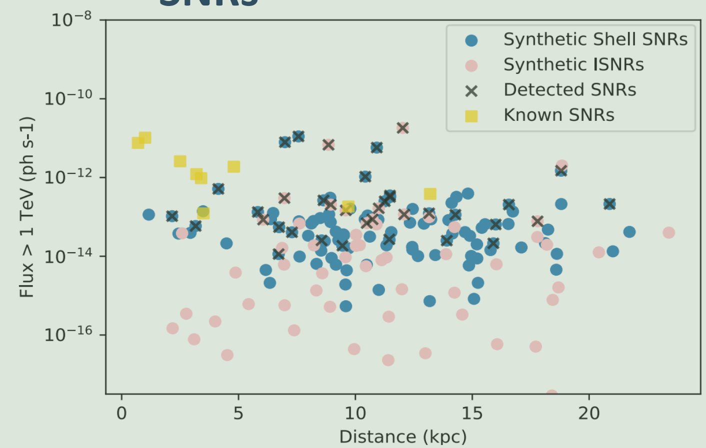
PWNe





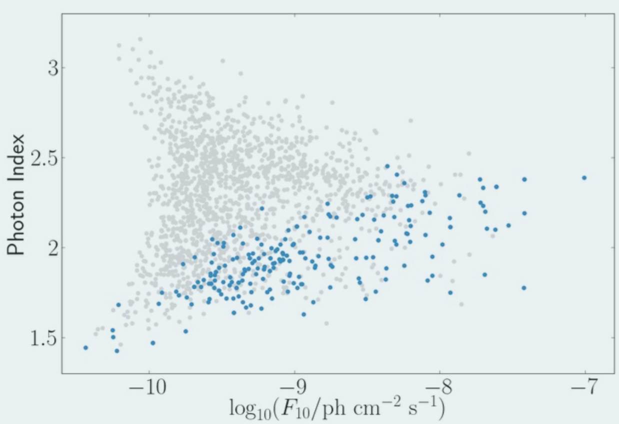
- transformational jump in population size to the PWNe field

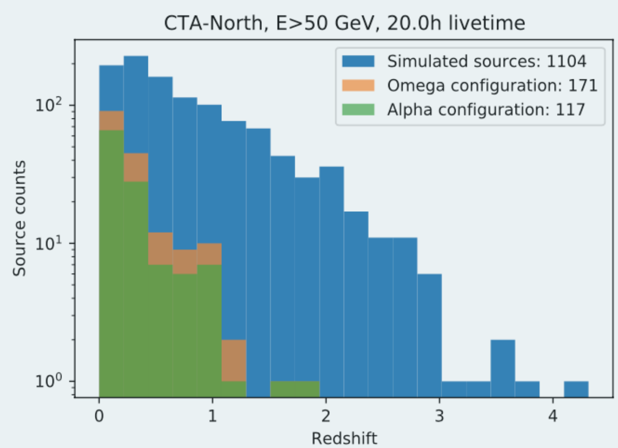
SNRs



- SNRs up to other side of the Galaxy
- 5-10 times better flux sensitivity

AGNs

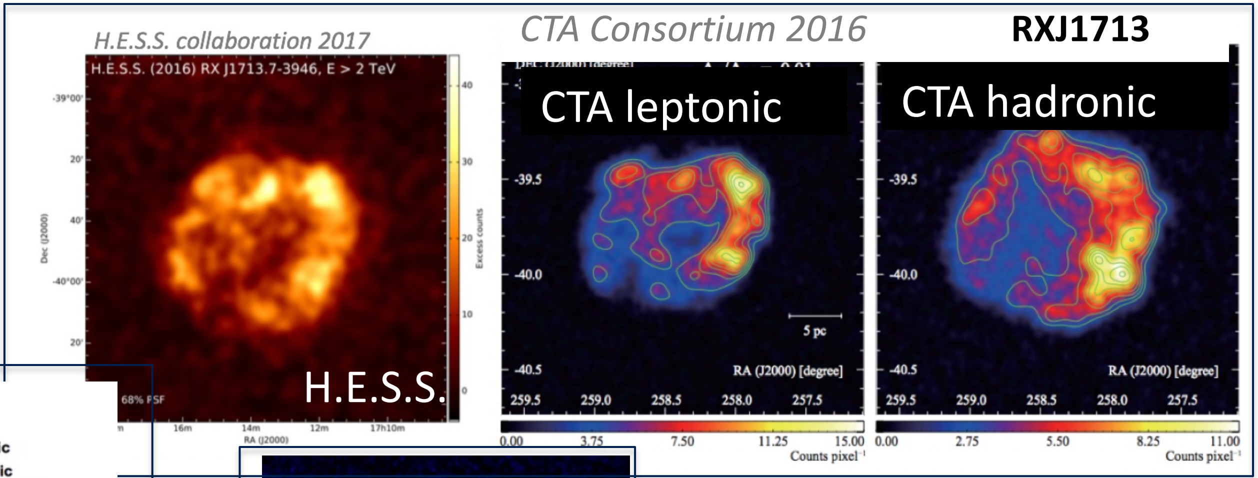


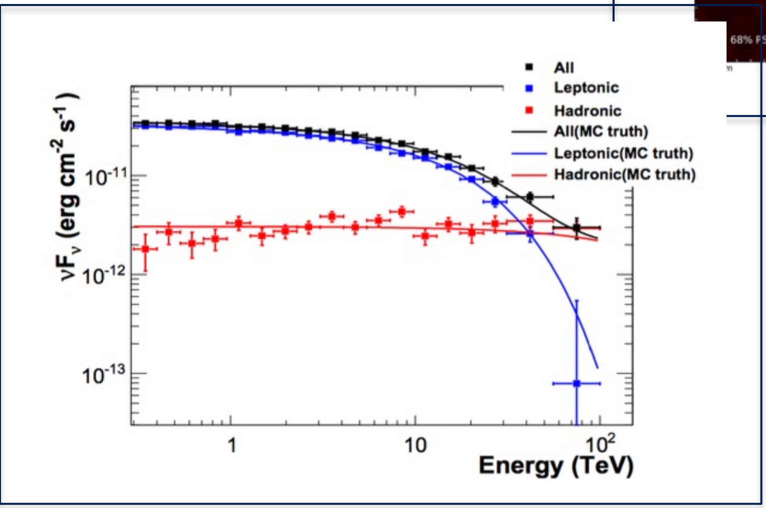


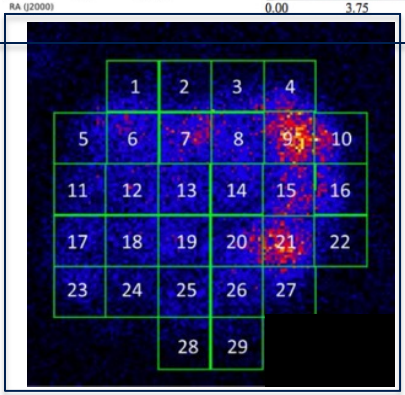
- factor >2 detected non-flaring AGNs
- enlarge the γ-ray horizon up to z≃2

Probing extreme environments

- **precision morphological and spectral studies allow to discriminate between emission models and probe acceleration regions**
- **when combined with lower frequency data gamma-ray observations can shed light on still-open astrophysical questions**

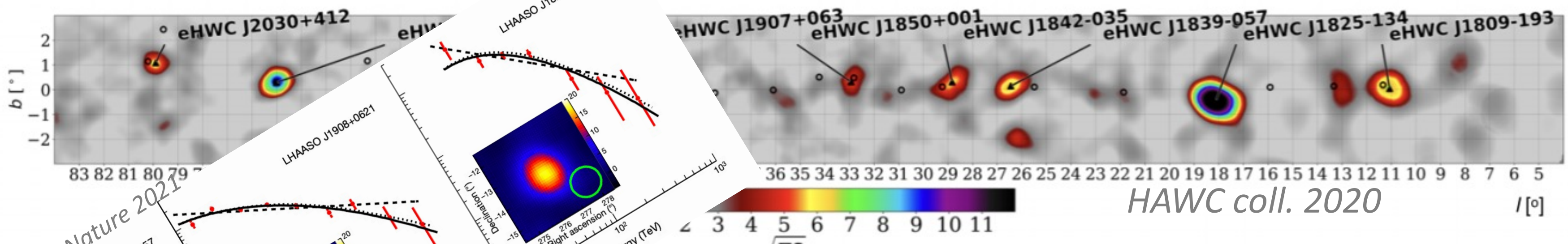




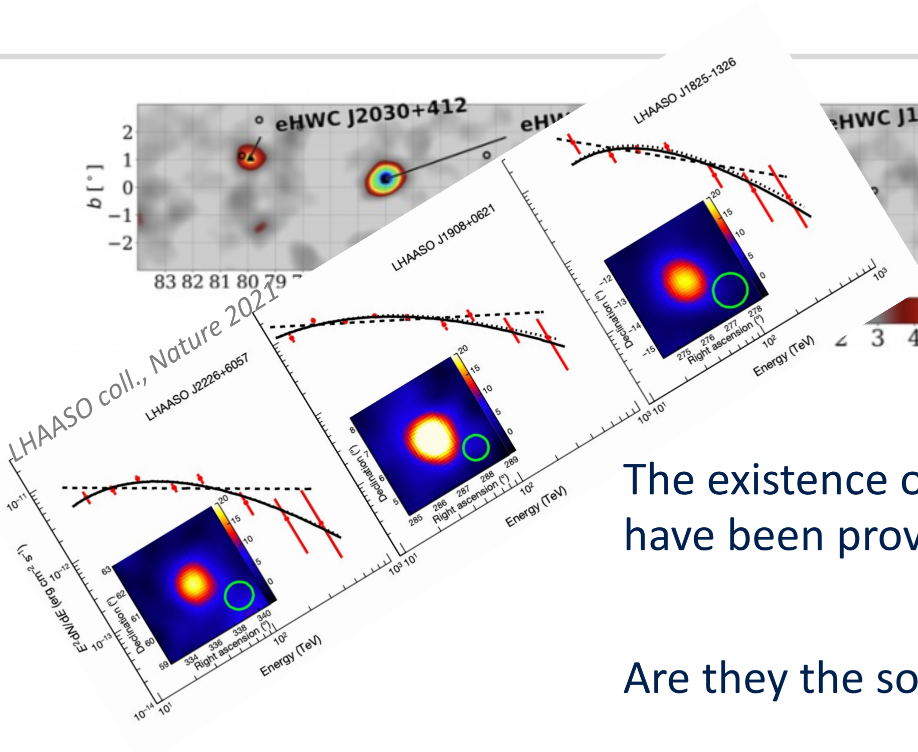


- **sub-arcminute resolution**
- **spatial resolved spectroscopy**
- **<10% energy resolution**

Origin of Galactic Cosmic Rays



HAWC coll. 2020



LHAASO coll., Nature 2021

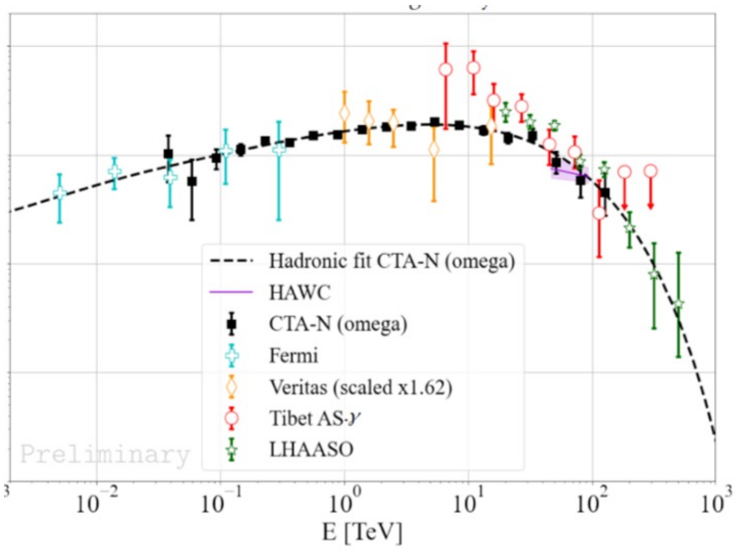
The existence of sources emitting at more than 100 TeV have been proven by by HAWC, LHAASO and Tibet Array

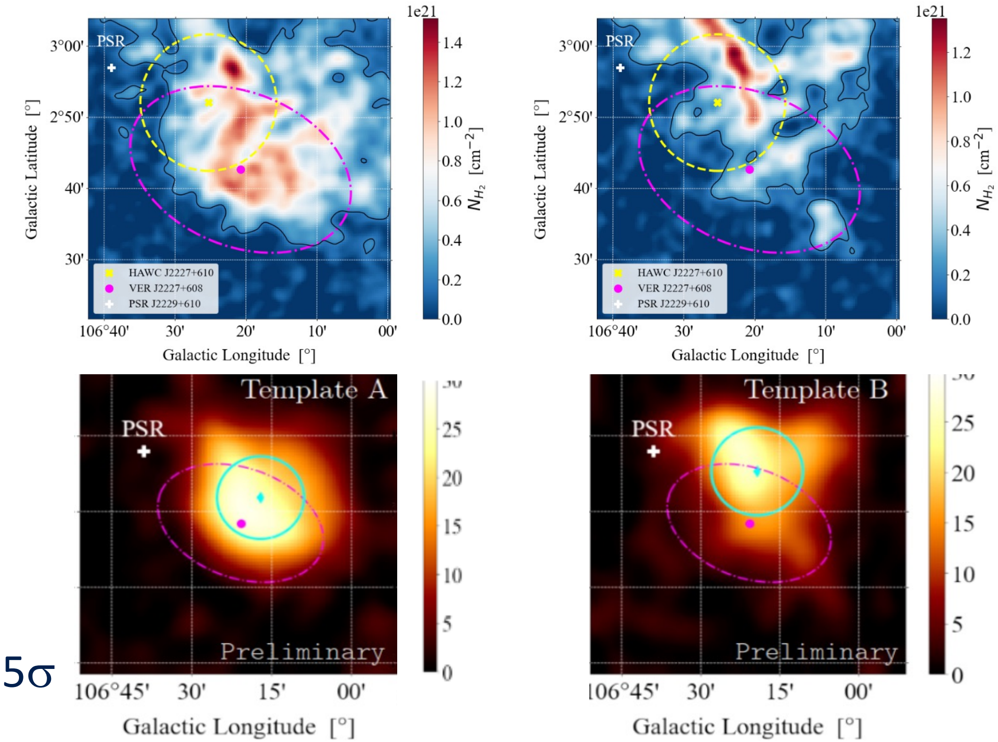
Are they the sources of CRs contributing to the “knee” region?

Only the synergy between these instruments and IACTs, specifically CTAO, and neutrino experiments can provide a univocal answer to this question

Origin of Galactic Cosmic Rays

Test case: G106.3+2.7
Is the emission seen by HAWC/LHAASO/Tibet Array of hadronic or leptonic origin?





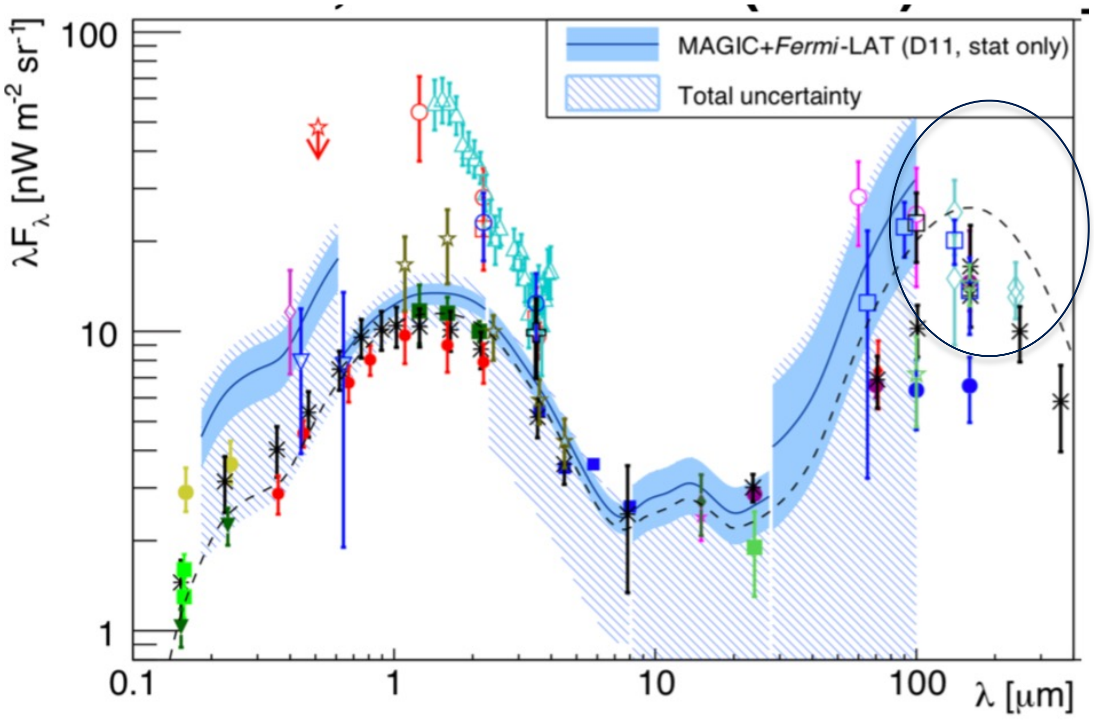
CTA will be able to detect the spectral cut-off at ~50 TeV in 50 hr at more than 5σ

not enough to disentangle between hadronic or leptonic origin

morphological studies will provide important clues given the CTA's excellent angular resolution

γ-ray cosmology: EBL measurements

MAGIC coll. 2019



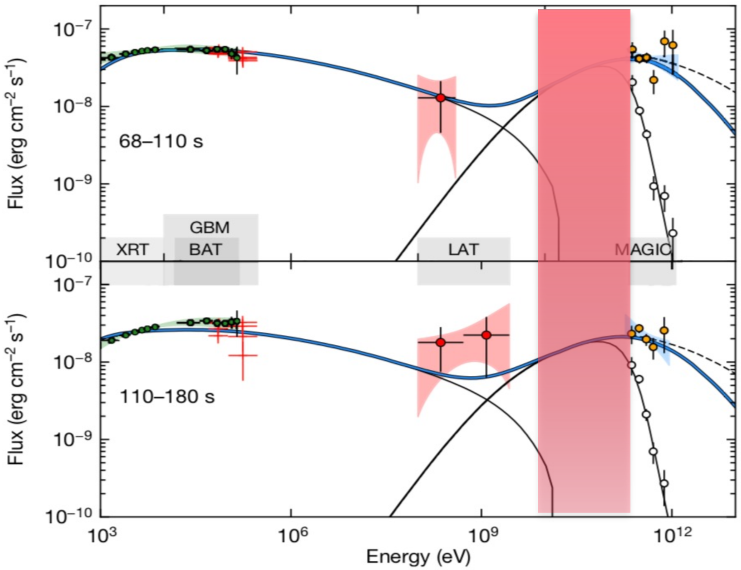
improve precision in the IR range by looking at absorption features in the AGN spectra

- CTAO with its large energy coverage has the unique capability **to measure unabsorbed intrisic (GeV) and attenuated (TeV)** part of the spectra
- CTAO will detect a large sample of sources at different z

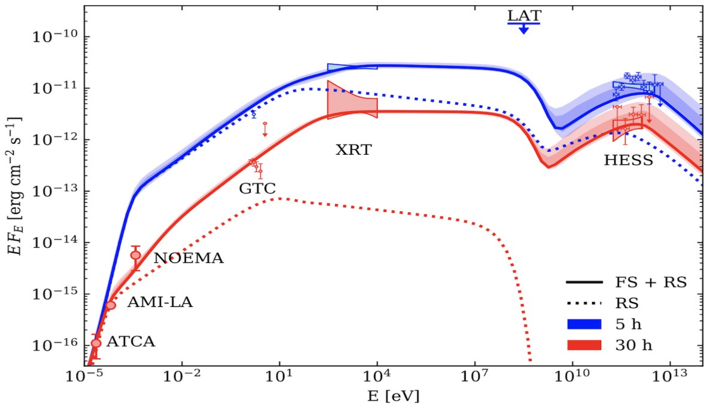
Time-domain astronomy: the case of GRBs

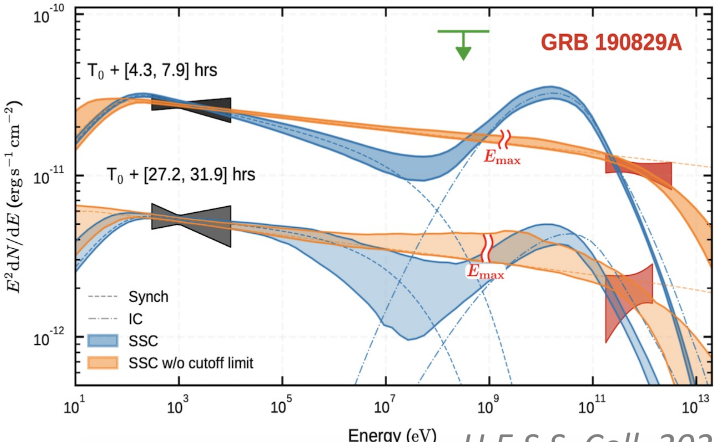
- In the multi-messanger/multi-wavelength era it is important to have all pieces of the puzzle

MAGIC Coll. 2021



Salafia+2022



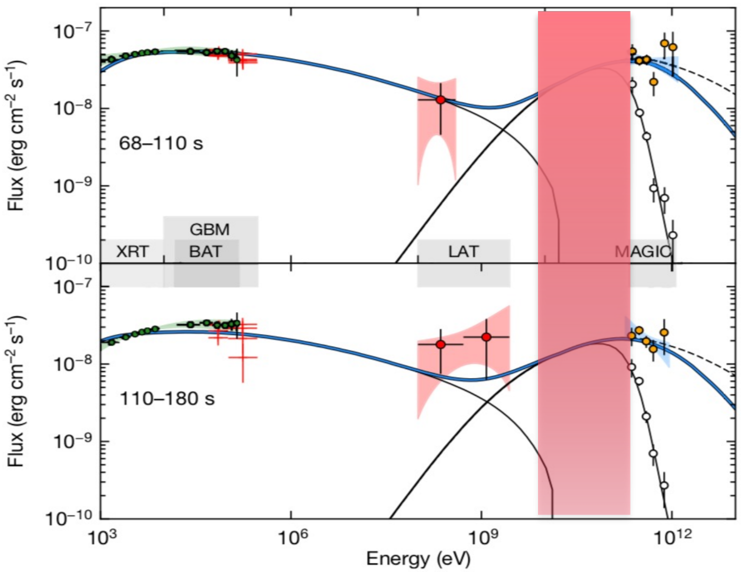


H.E.S.S. Coll. 2022

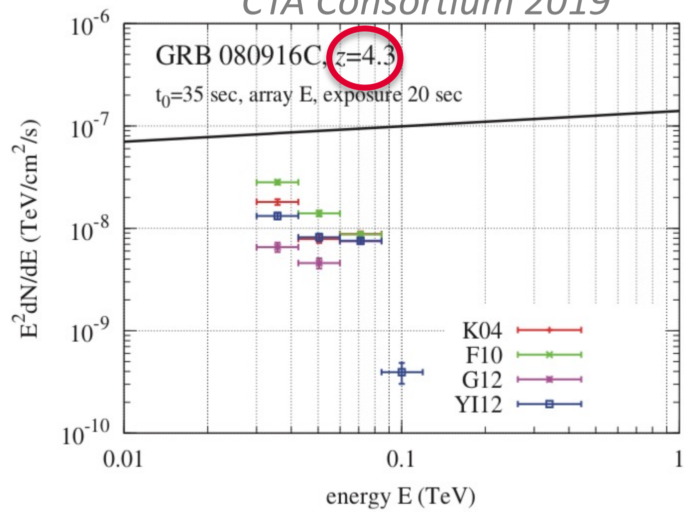
Time-domain astronomy: the case of GRBs

- In the multi-messanger/multi-wavelength era it is important to have all pieces of the puzzle

MAGIC Coll. 2021



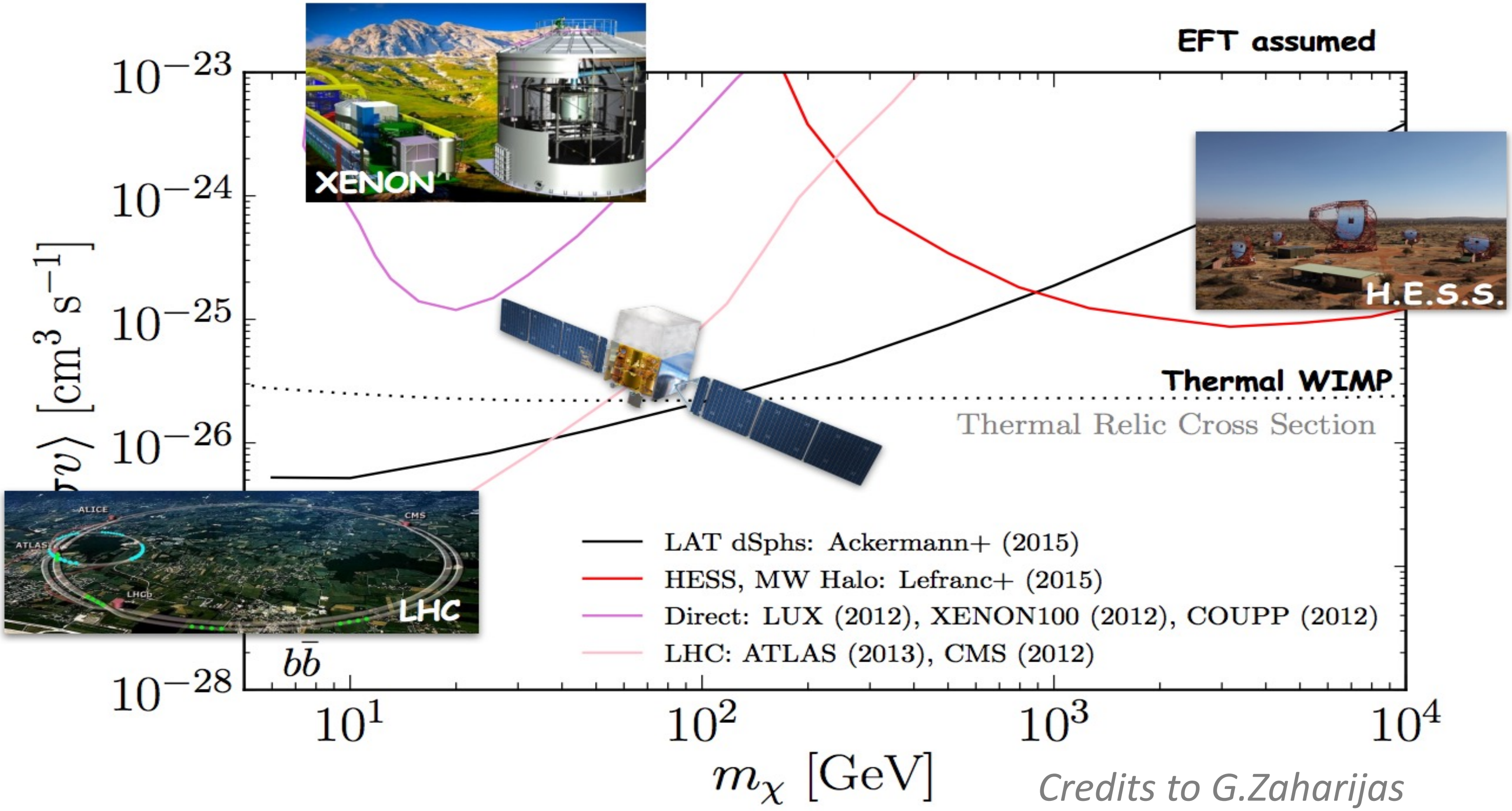
CTA Consortium 2019



high-z are at reach!

2-3 GRB per year!

Dark matter search

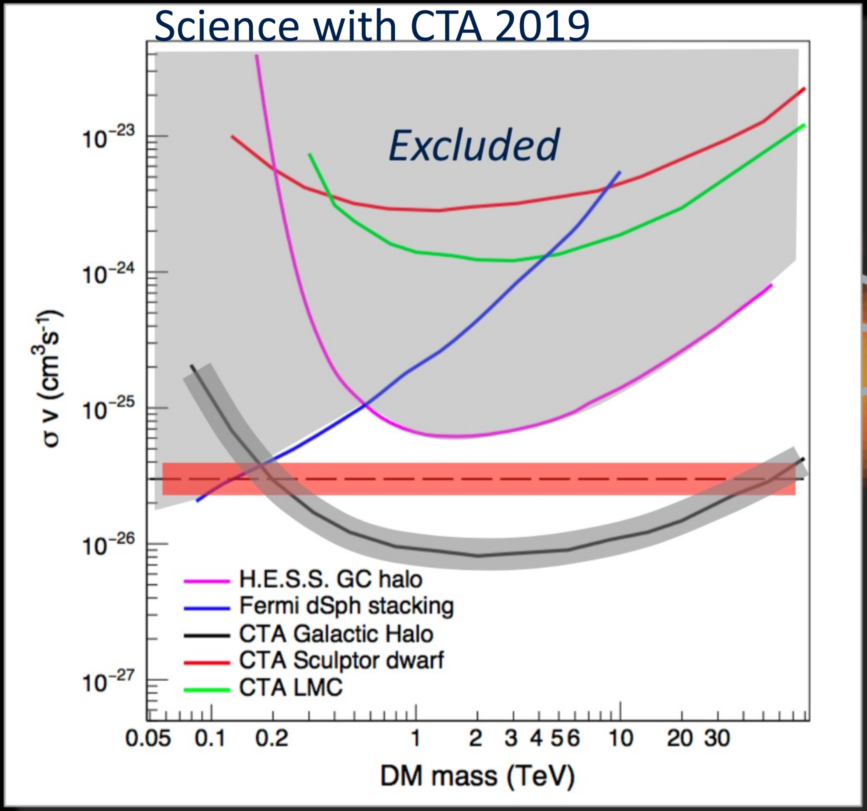


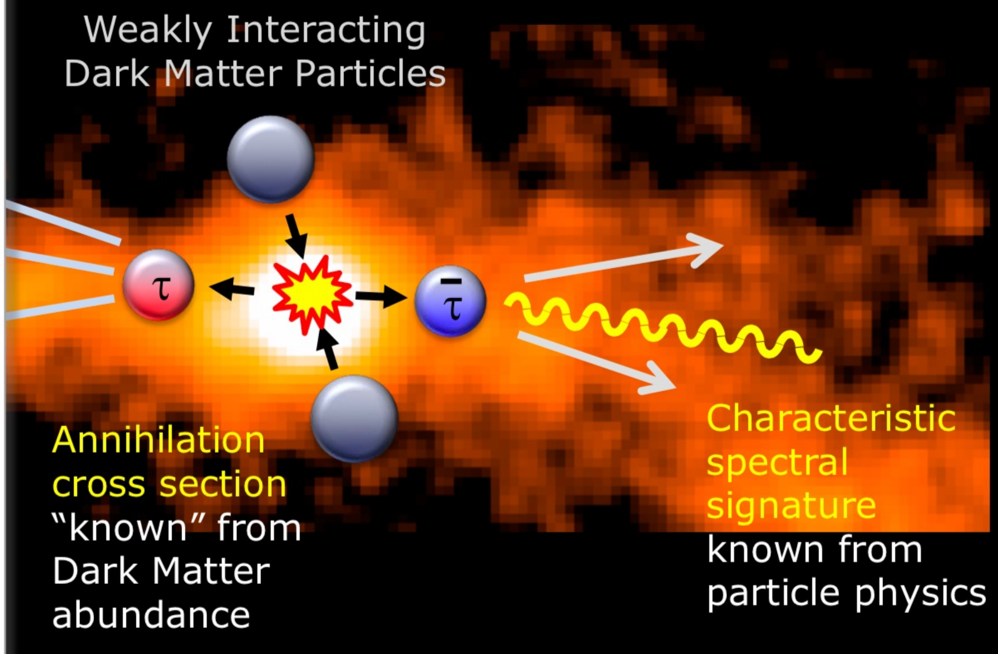
Credits to G.Zaharijas

- WIMP is not ruled out *(Leane+ 2018)*
- The TeV mass domain is unexplored

Dark matter search

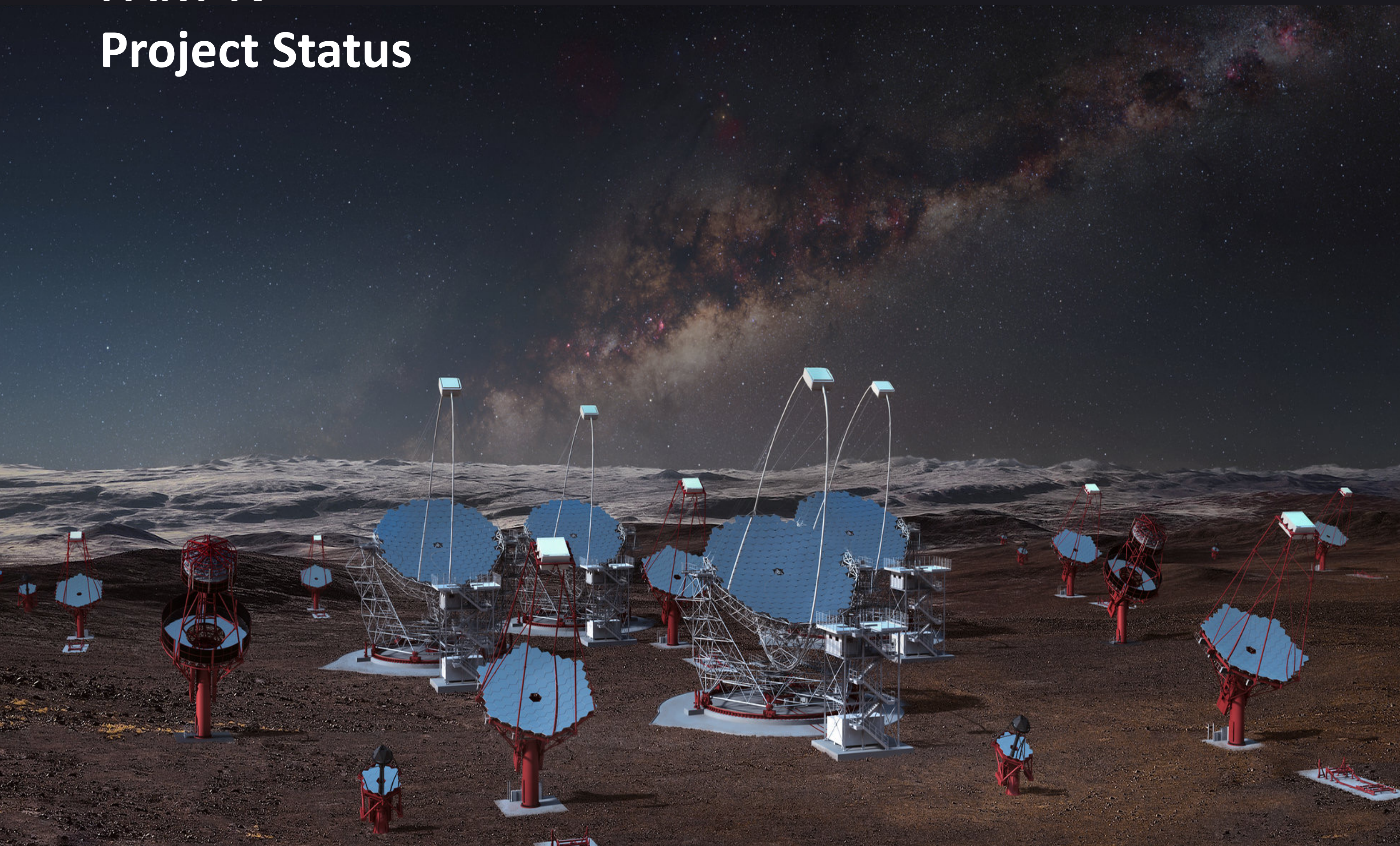
- CTAO will constrain the WIMP paradigma in case of non-detection





from: Science with CTA
www.worldscientific.com/worldscibooks/10.1142/10986

PART IV
Project Status



CTAO Construction phase is about to start

- **CTAO construction scope is agreed**
- The construction phase will start with the establishment of the final legal entity:
  CTAO European Research Infrastructure Consortium (ERIC)
  - Q1 2023
  - last about 5 yr
- **Early science operations foreseen during the construction phase**

Announcement
2021-June-25

The Board of Governmental Representatives Approves the CTAO's Cost Book and Scientific & Technical Description

geographically distributed:
- **headquarters in Bologna (Italy)**
- **science data management center in Zeuthen (Germany)**
- **two observation stations**

CTAO-North

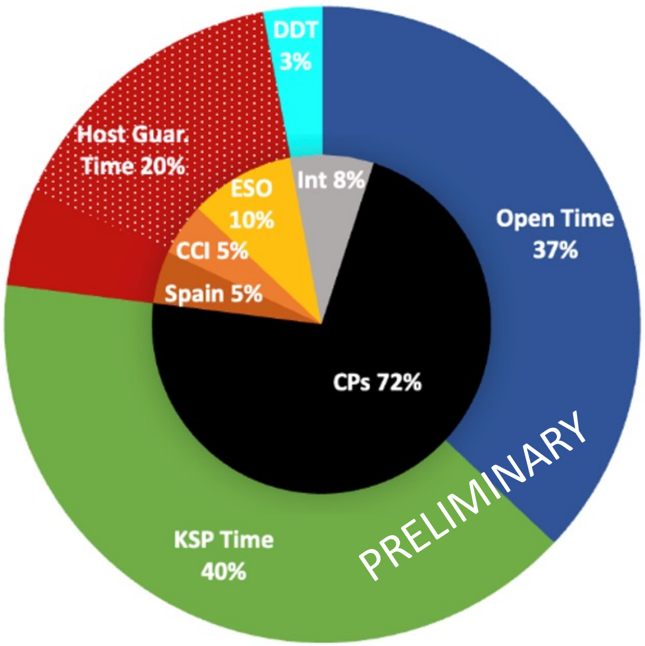

INAUGURATED IN OCTOBER 2018


>800 hr of GAMMA-RAY OBSERVATIONS ALREADY TAKEN
FIRST SCIENTIFIC RESULTS ALREADY PRESENTED

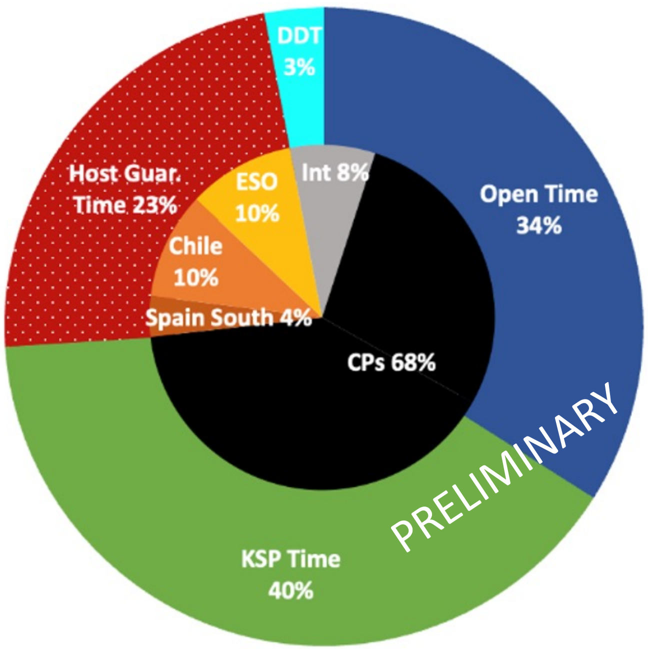
CTAO-South

Observing time

CTAO-North
(integrated over the first 10 OPs of the Operation phase)



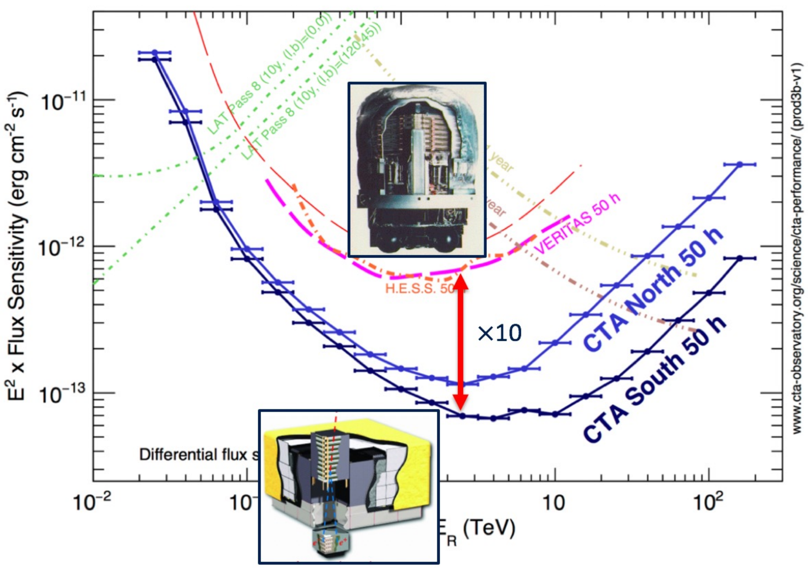
CTAO-South
(integrated over the first 10 OPs of the Operation Phase)



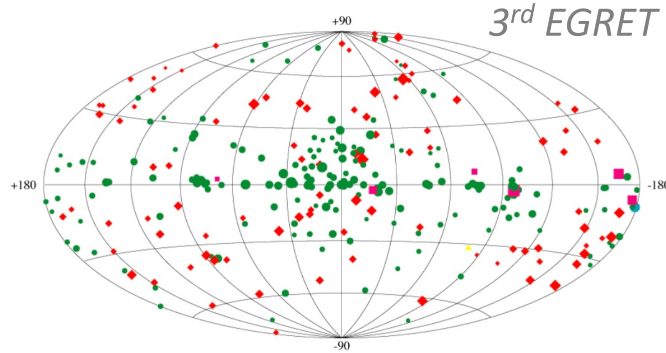
- about 20% of observing time reserved to scientistics from host countries/organizations
- most of the observing time ~ 70% reserved to scientists from contributing parties (CP)
    - about half of it as GTOs as reward for contributions to the construction project to run Key Science Projects (KSPs)
- a small fraction of international community observing time (ICOT)

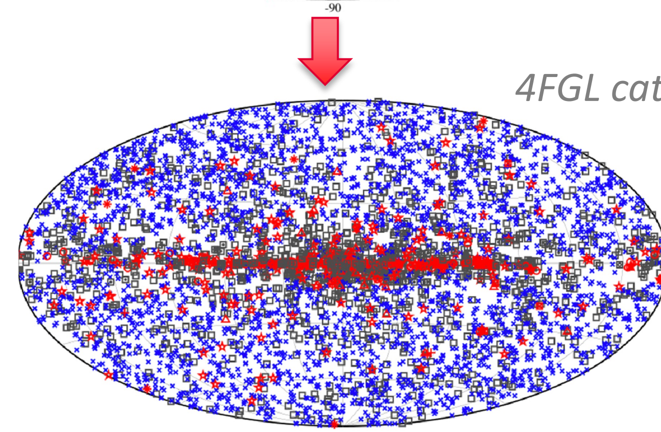
Conclusions

- **CTAO will be the first gamma-ray ground-based observatory, openly delivering data to the community**
- **CTAO will usher in a new era in VHE Astrophysics**
  - **Rich science program answering many open questions**
  - **Large new discovery space**



3rd EGRET catalogue





4FGL catalogue

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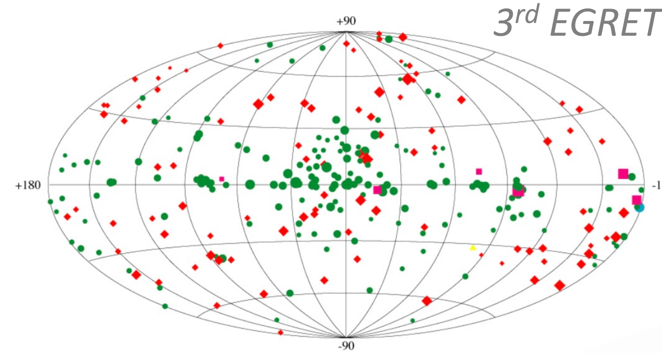
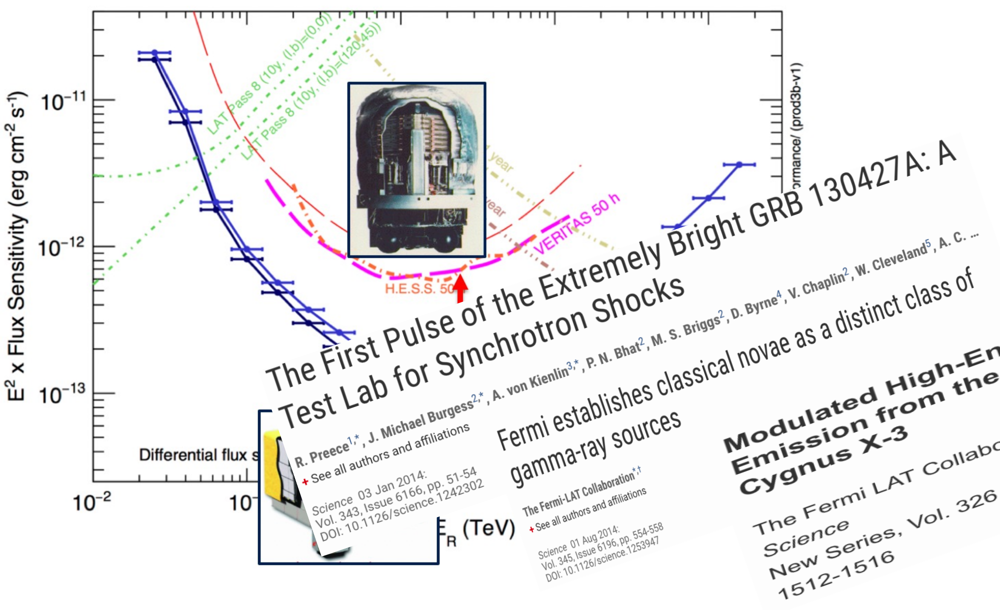
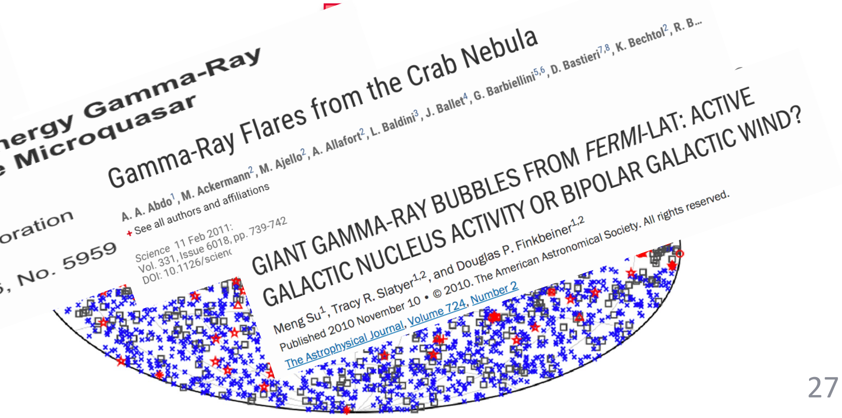
3rd EGRET catalogue



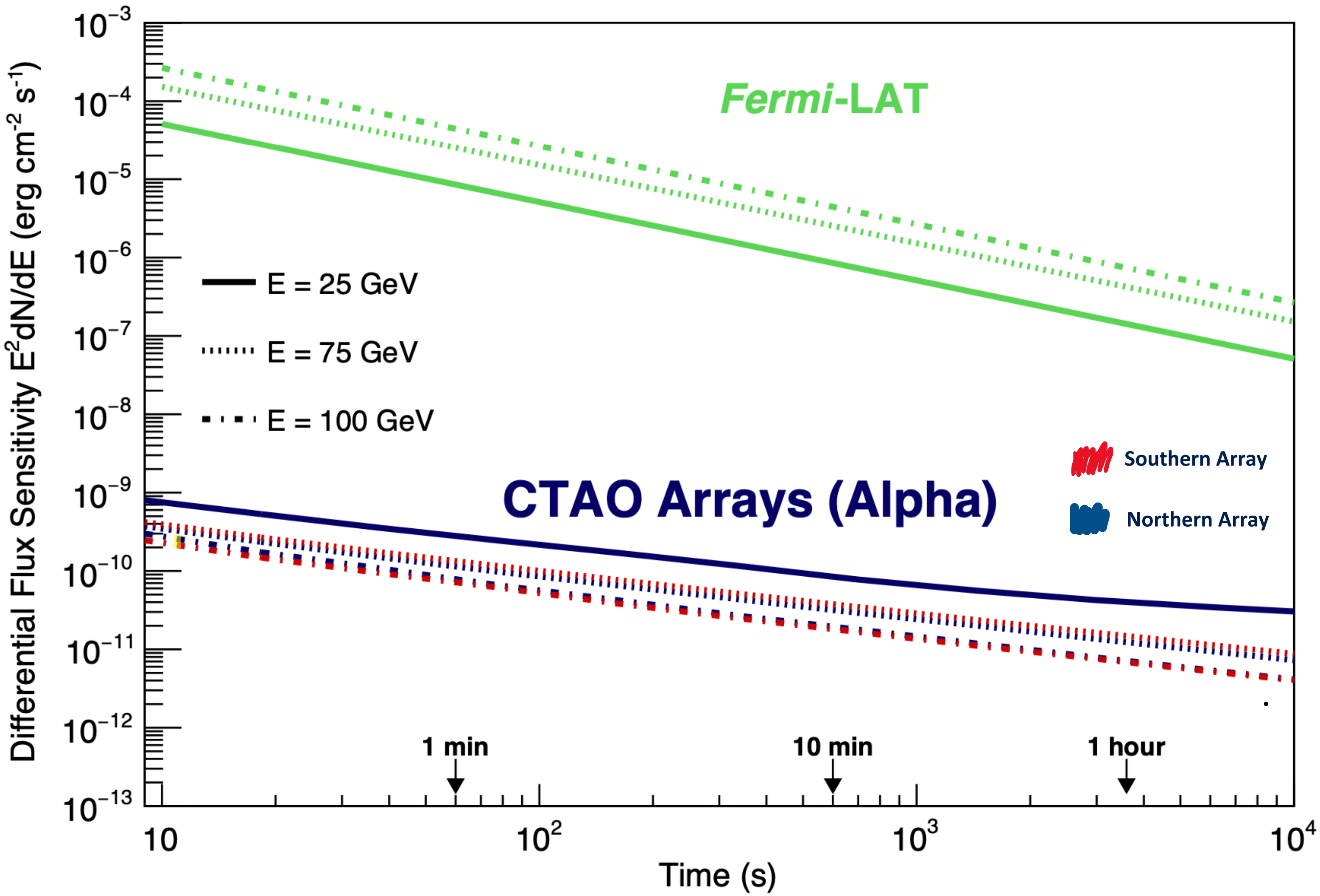




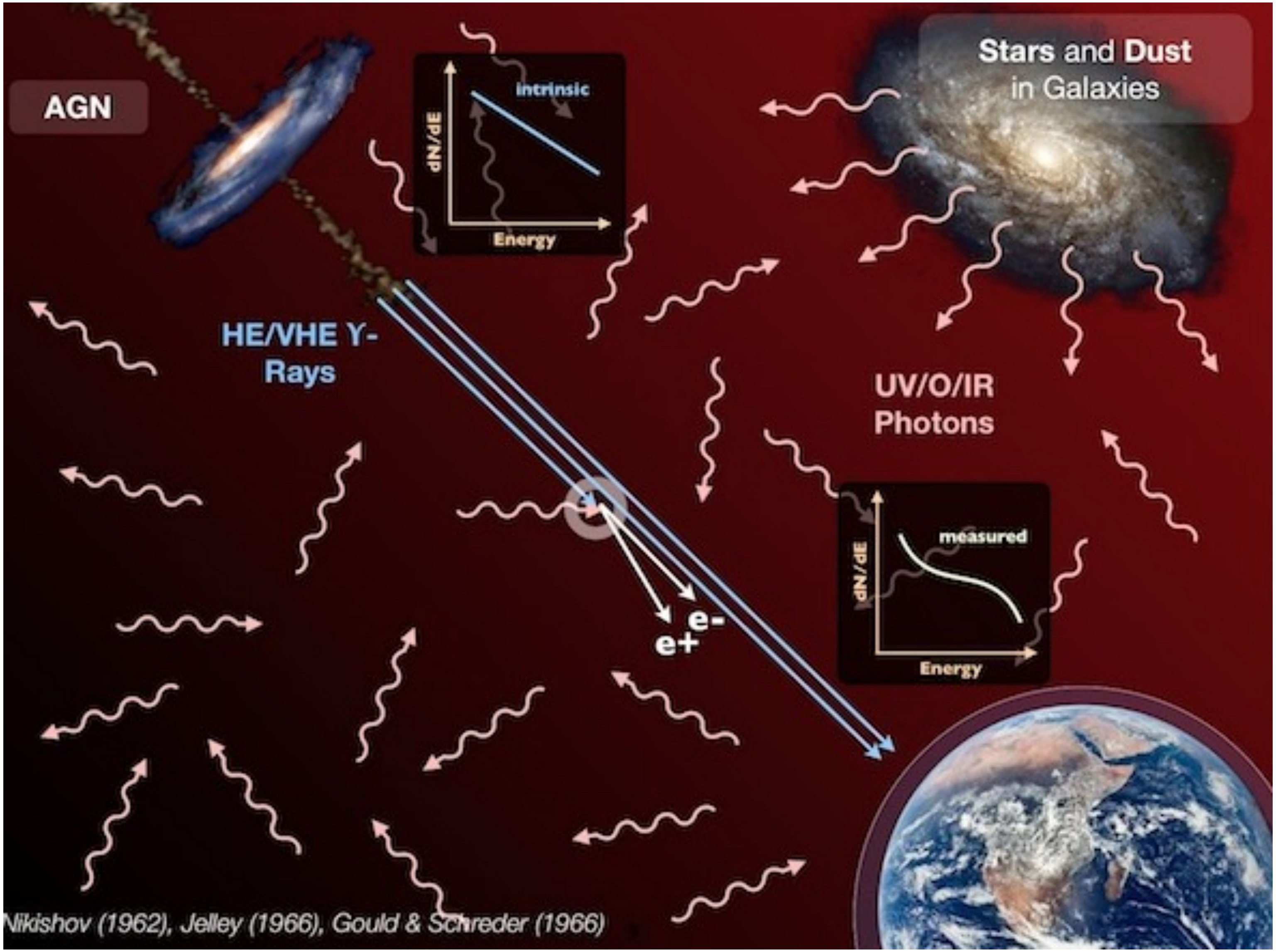
cta cherenkov telescope array

Thank you

CTAO performance (Alpha Configuration)

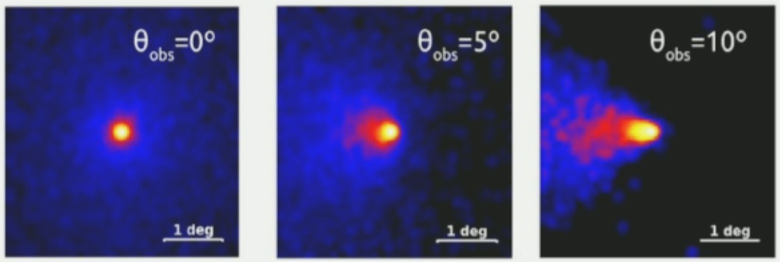


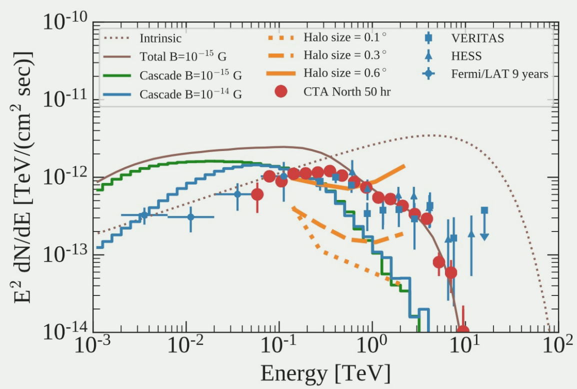
Extragalactic Background Light absorption



Constraining γ-ray propagation

IGMF

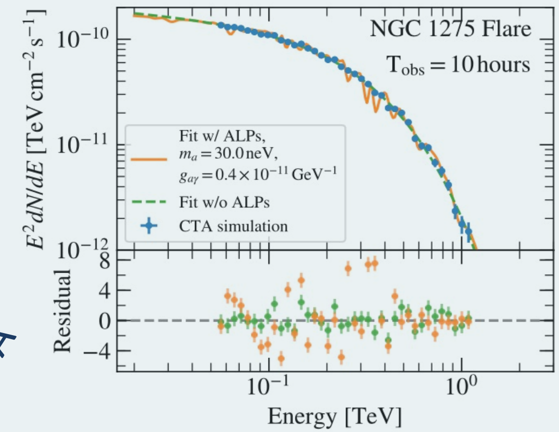




CTA can measure extended halos as well as detect new spectral components at low energies: all smoking guns for measurement of IGMF strength

ALPs

simulated ALP signature



At reach for CTA

LIV

simulated LIV signature