



cherenkov  
telescope  
array

# The Cherenkov Telescope Array

## Status and perspectives

Francesco Longo

On behalf of the CTA Consortium and the CTA Observatory

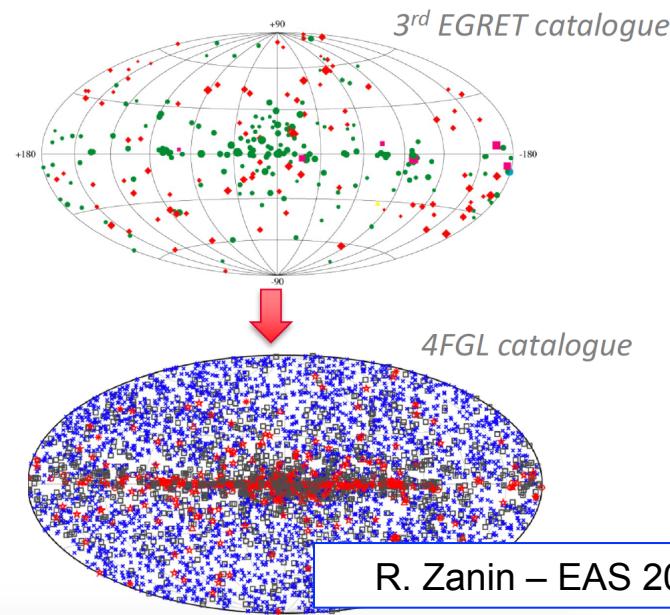
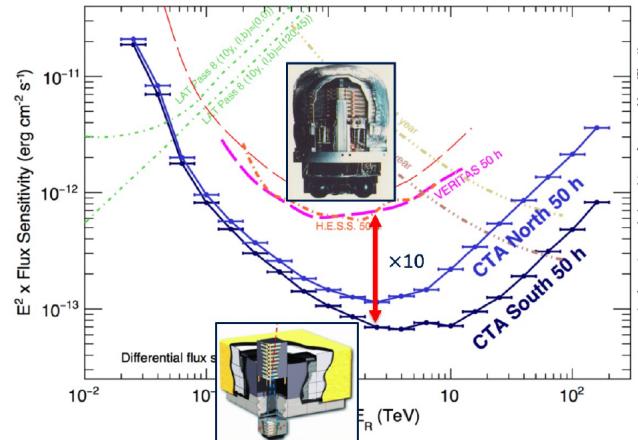
Tenth Fermi Symposium – October 2022

# Take away messages ...



## 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



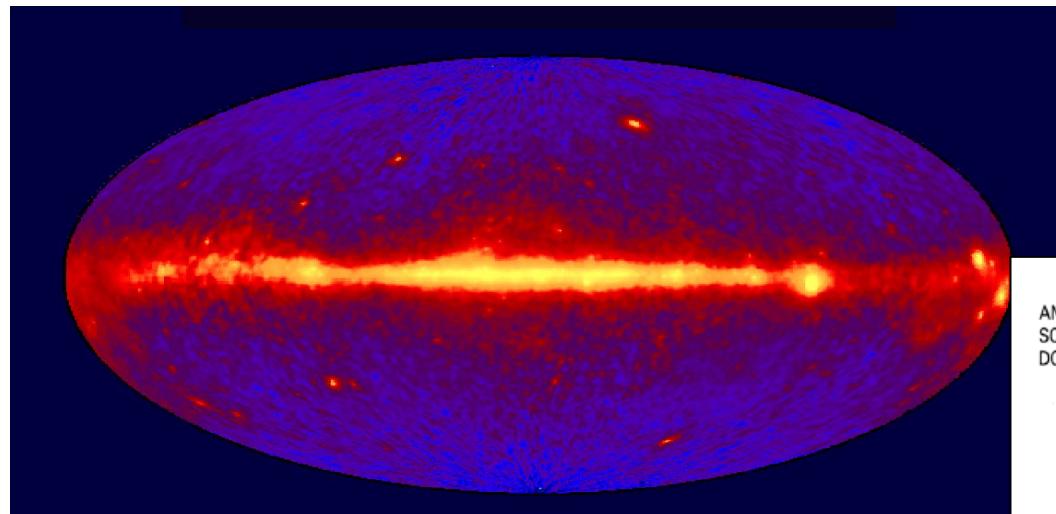


## Summary

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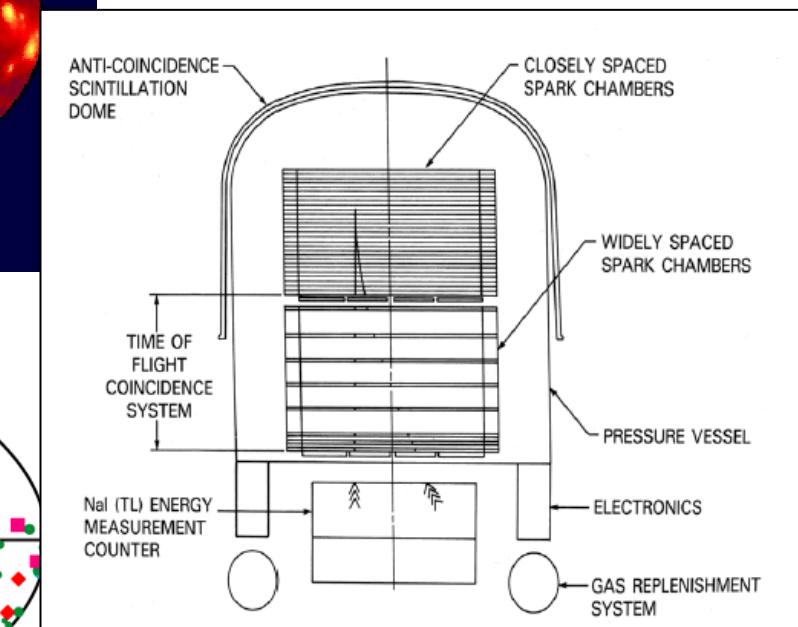
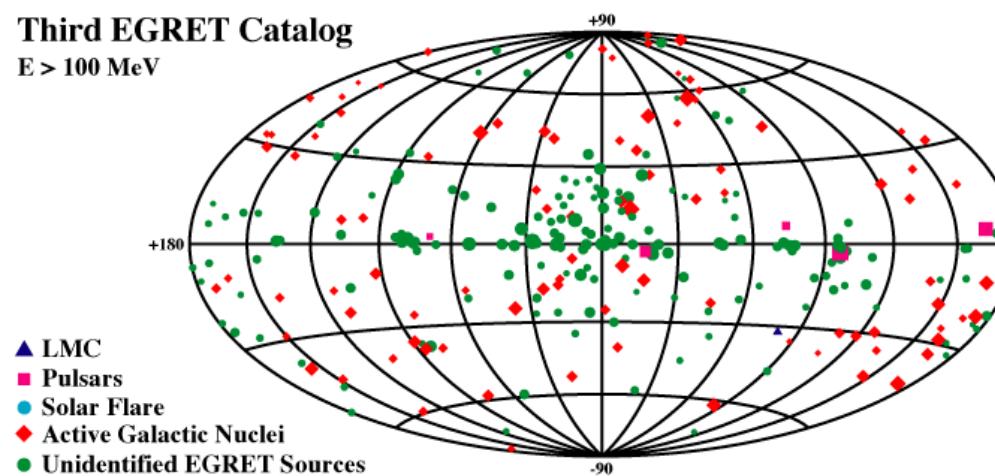
- Lessons learned by Fermi/LAT...
- The Cherenkov Telescope Array
- The actual status of the array
- Key Science Topics
- Opportunities ...

# The EGRET era (1991-2000)

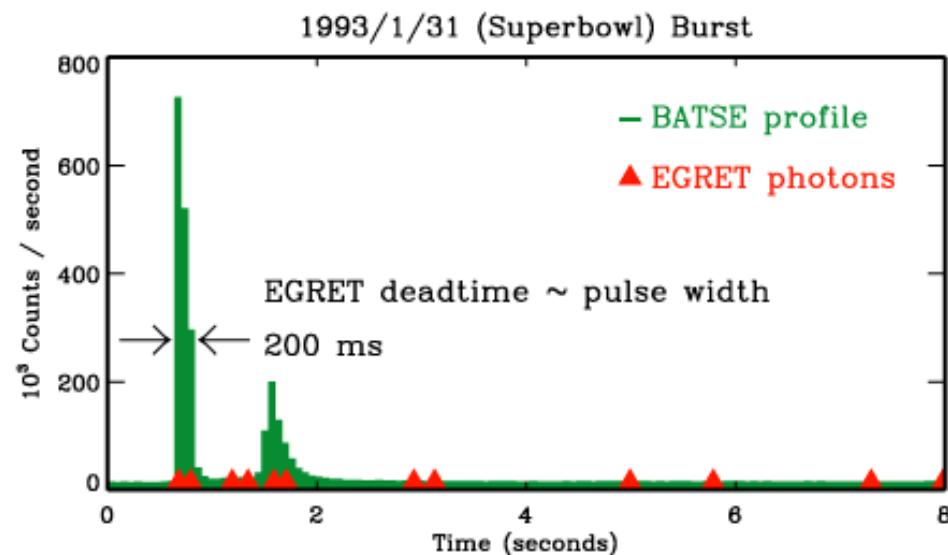


Third EGRET Catalog

$E > 100$  MeV

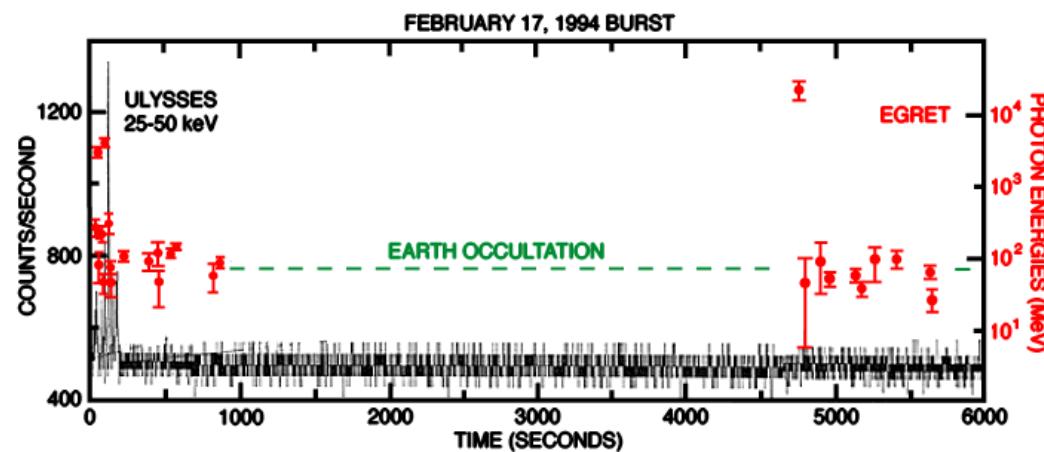


# GRBs in the EGRET era

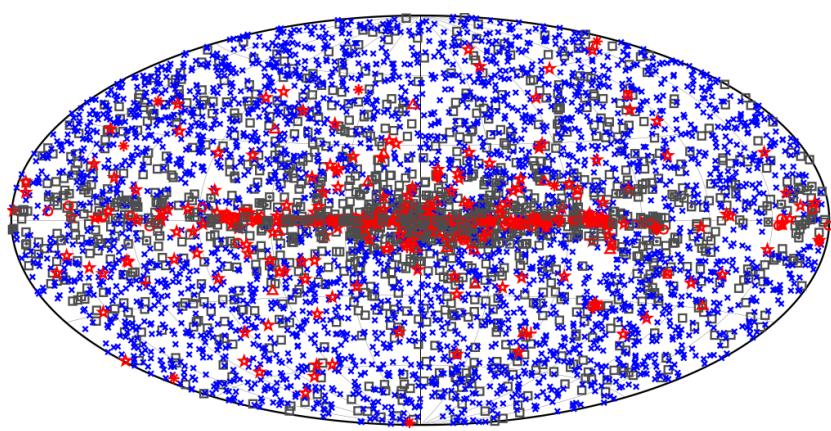
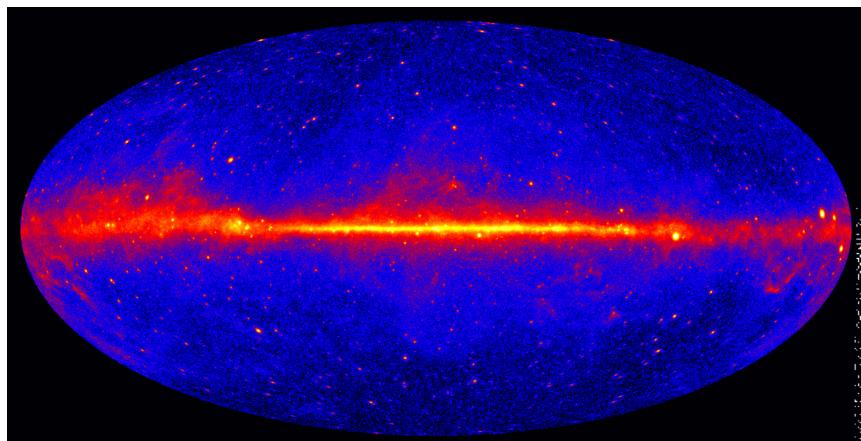


Hurley et al. 1994

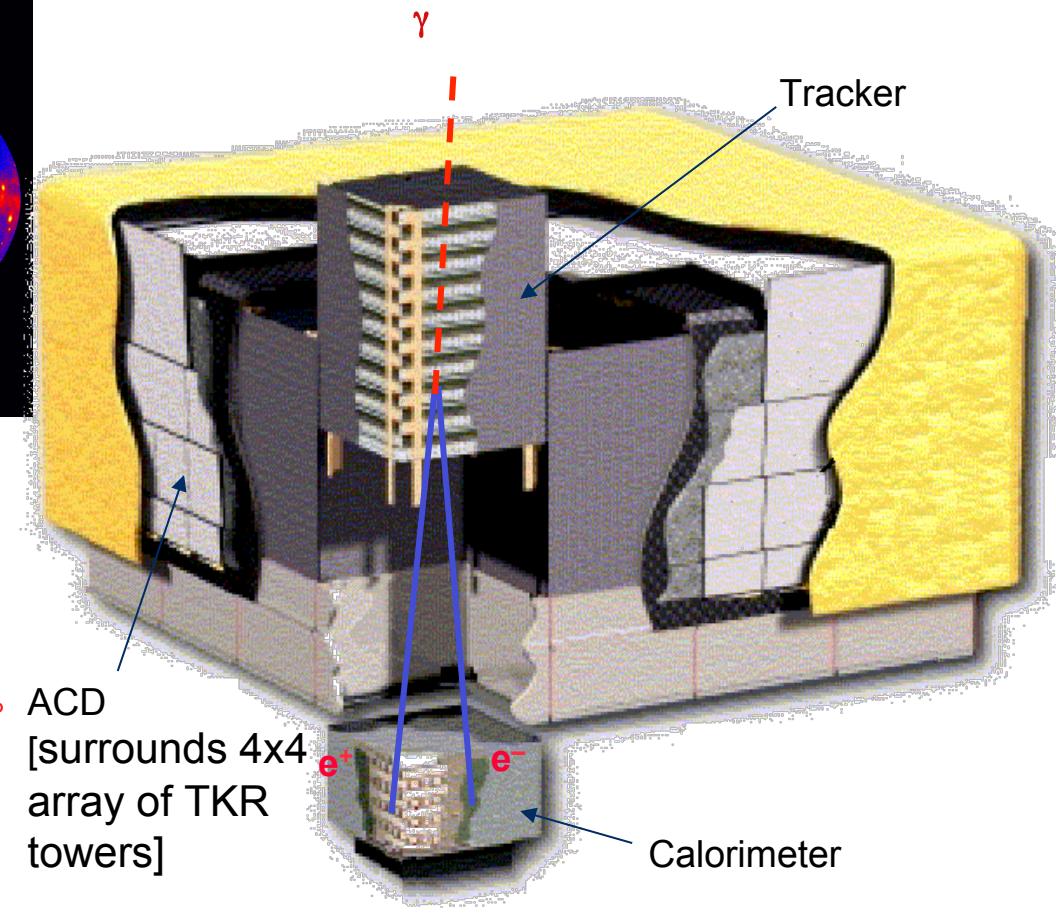
Kouveliotou et al 1994  
Sommer et al. 1994



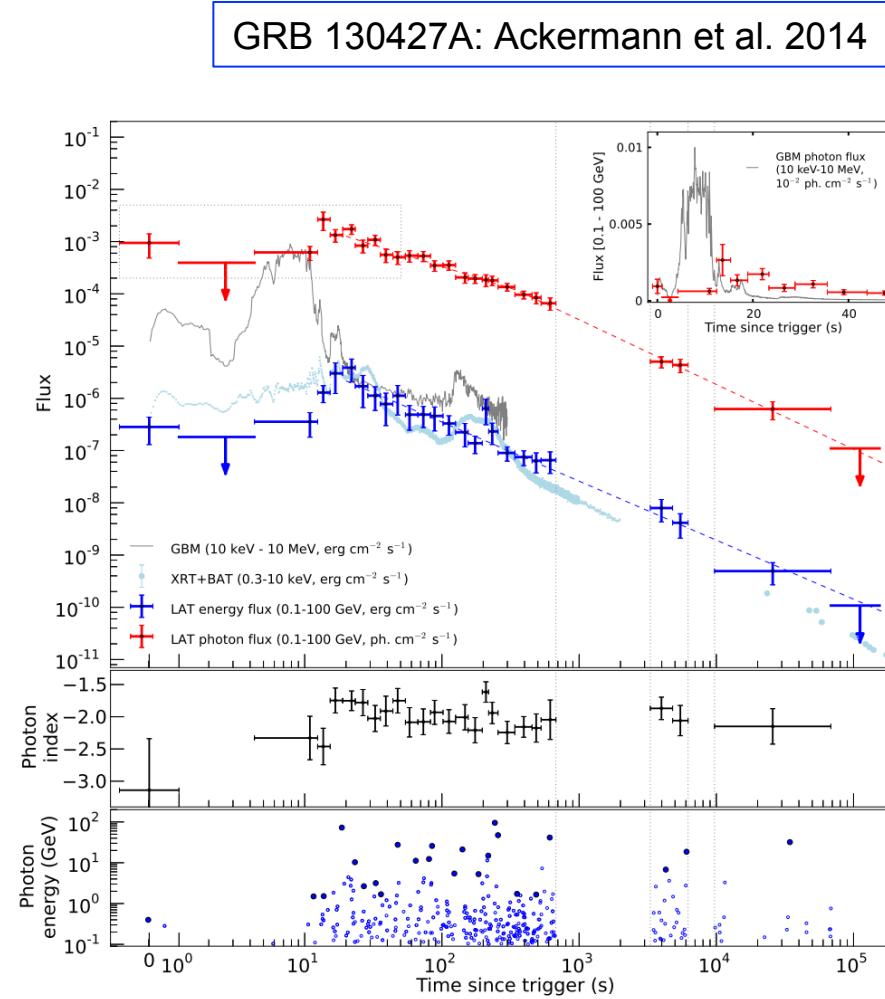
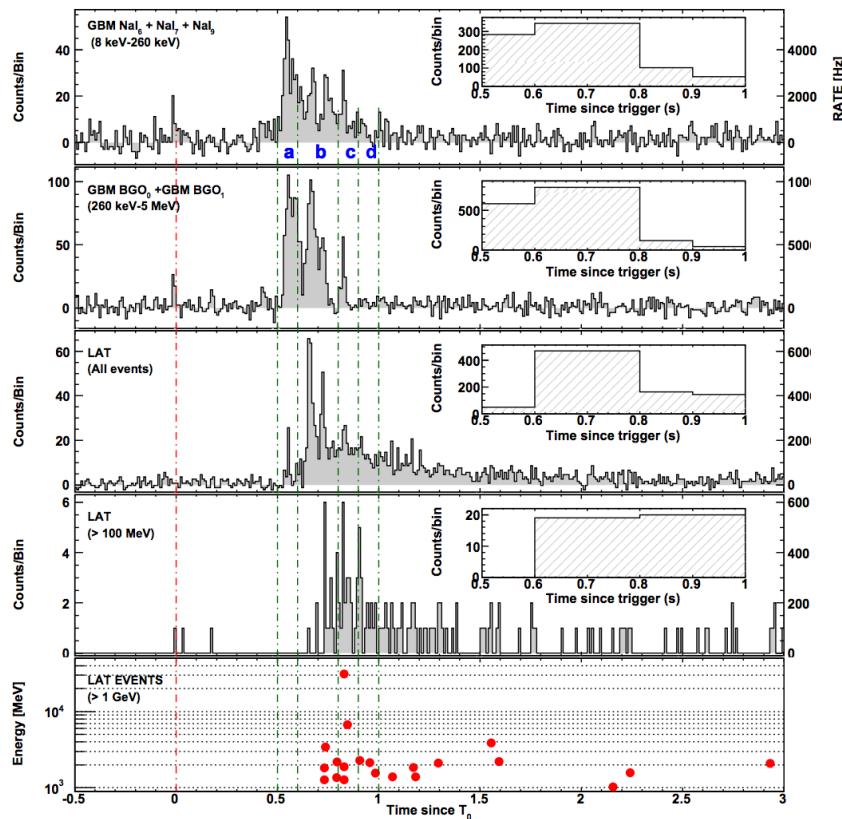
# The Fermi/LAT era (2008-...)



□ No association	■ Possible association with SNR or PWN	* AGN
★ Pulsar	△ Globular cluster	* Starburst Galaxy
▣ Binary	+ Galaxy	◊ PWN
* Star-forming region	□ Unclassified source	○ SNR
		◆ Nova



# GRBs in the Fermi era



# Astronomy with IACTs

## TeV Astronomy is an indirect technique

- The large effective areas provided by the air-showers ( $10^5 \text{ m}^2$ ) improve photon statistics at extreme energies
- Lowest achievable energy threshold of few 10s GeV
- Pointing instruments, good angular resolution ( $\sim 0.1^\circ$ )

$\gamma$ -ray enters the atmosphere

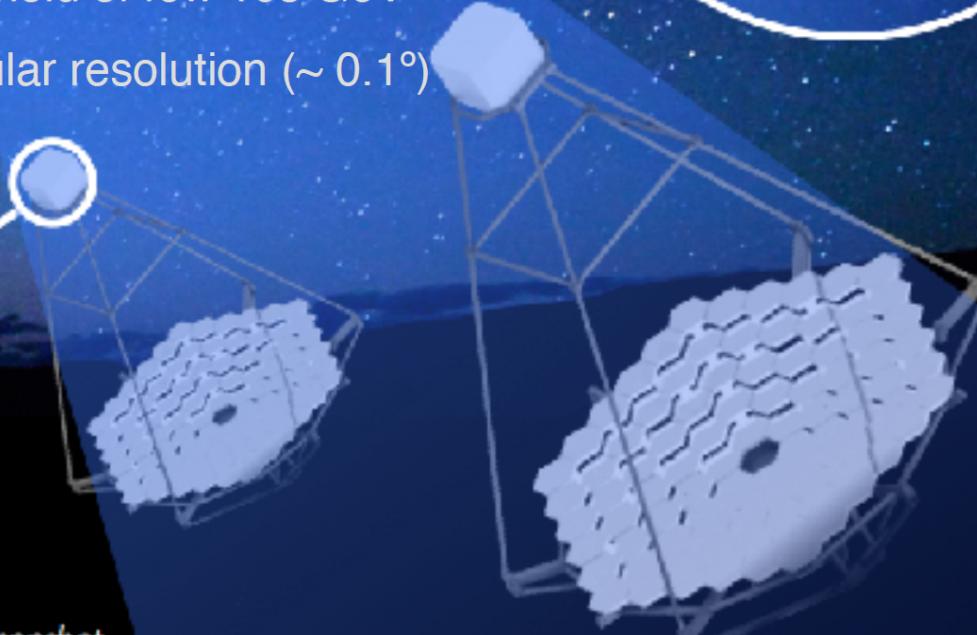
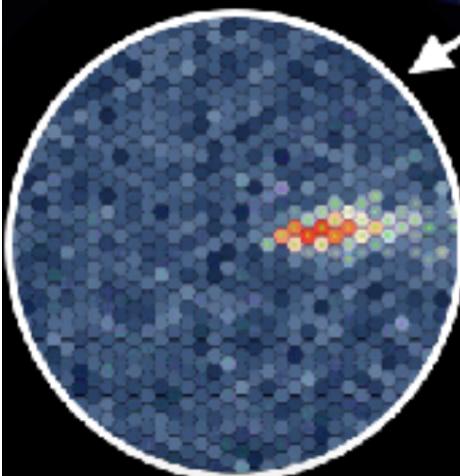
Electromagnetic cascade

Primary  $\gamma$



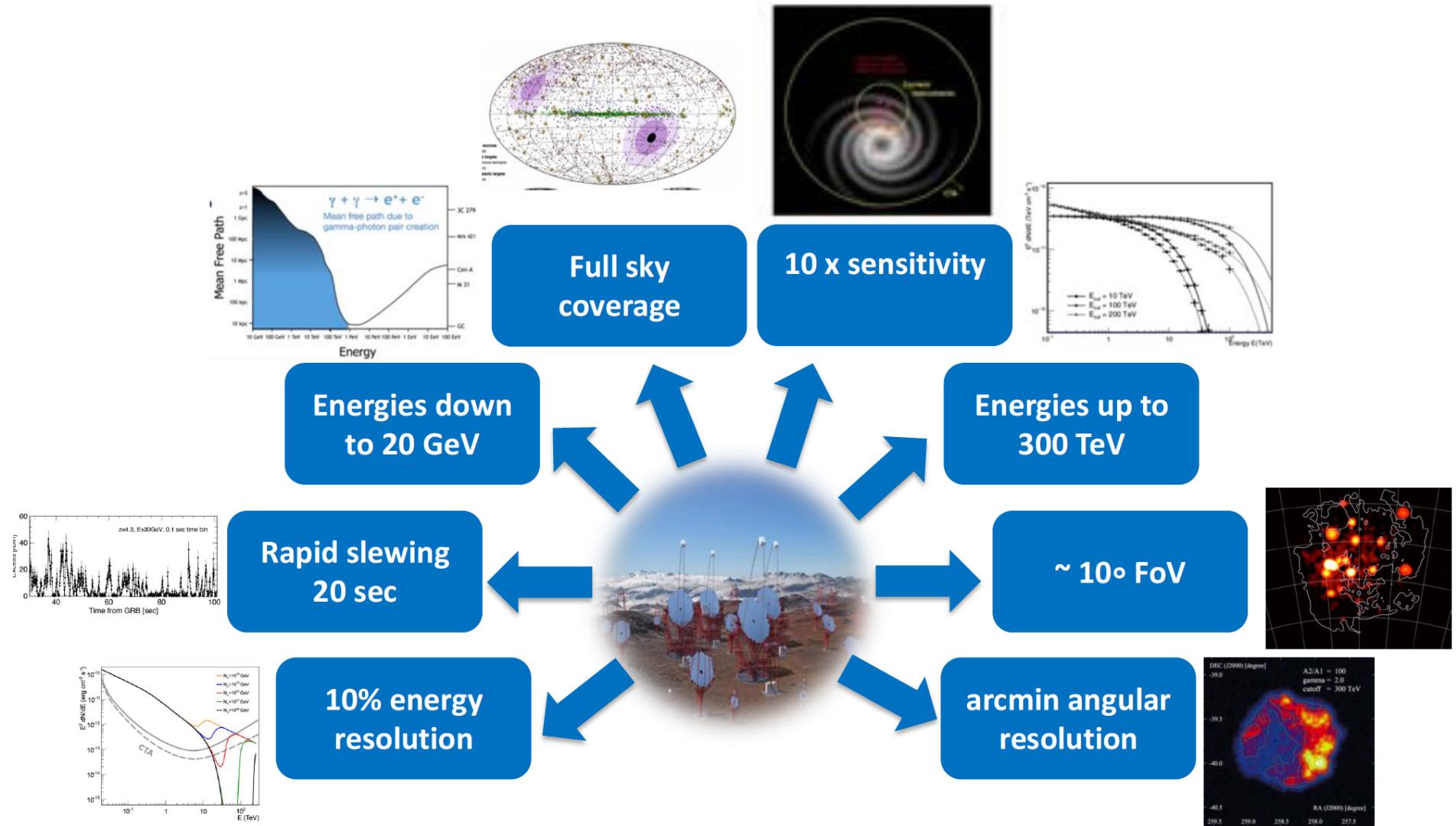
10 nanosecond snapshot

0.1  $\text{km}^2$  "light pool", a few photons per  $\text{m}^2$ .

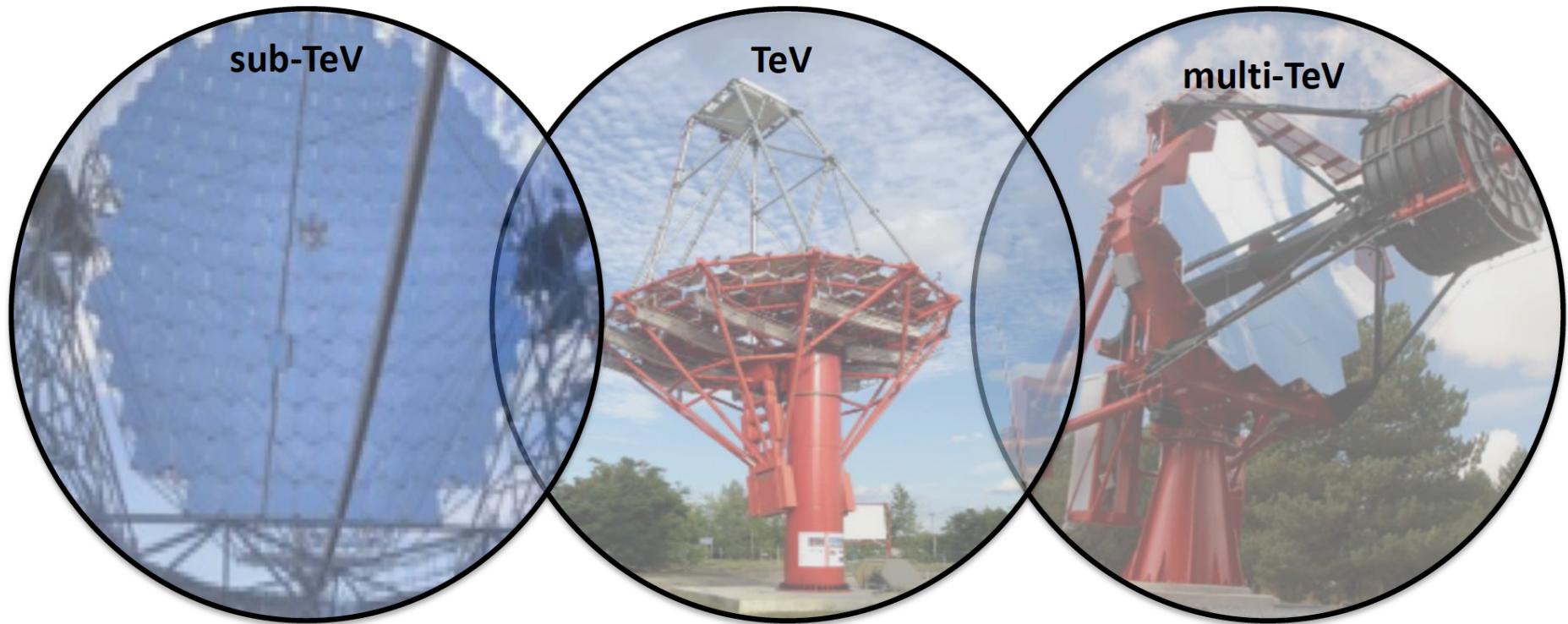


- **The first ground-based gamma-ray observatory**
  - serve large user community data & science tools in fair way
  - **Proposal driven observatory**
- **30 yr of lifetime**
  - Significant effort for maintenance and operations costs optimization
- **One legal entity: CTAO GmbH in the process to become an ERIC with HQ in Bologna (Italy)**
- **Two Telescope arrays, one Observatory**
  - Inter-site coordination
  - Uniform approach to scientific operations
- **The Science Data Mgmt Center in Zeuthen (Germany)**

# Design drivers



# Science cases and design



- Lowest energies (tens of GeV)  
→ **cosmological sources**
    - deepest sensitivity ever
    - arcmin angular resolution
    - large FoV
  - Deepest sensitivity for short timescale phenomena  
→ **Time domain unexplored**
- Surveys & precision studies
- R.Zanin – TeVPa 2019
- Precision measurements in a still little explored energy range
    - **100 TeV range unexplored**
    - **precision studies**

# The CTA Sites



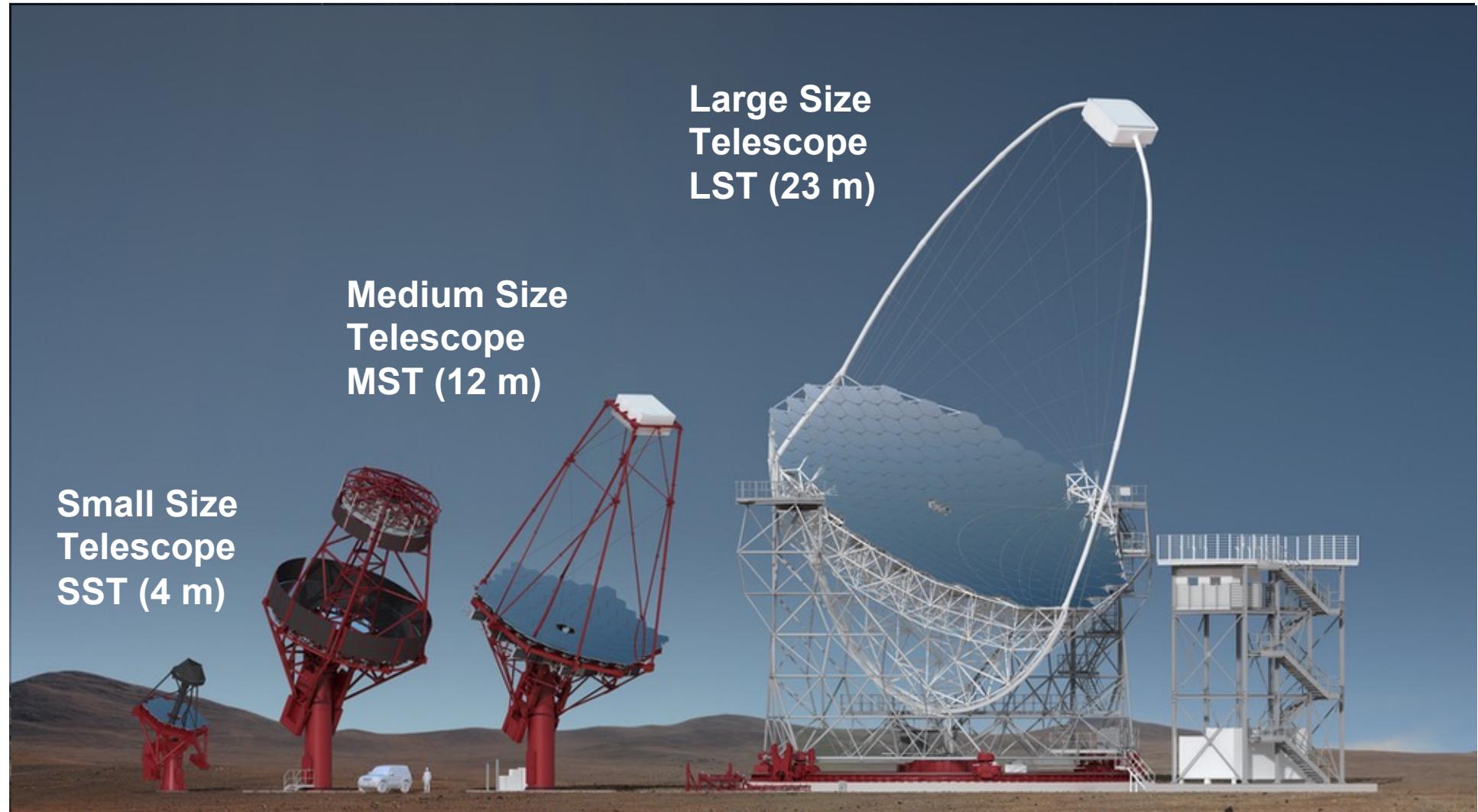
## A Global Observatory...



# The CTA Telescopes

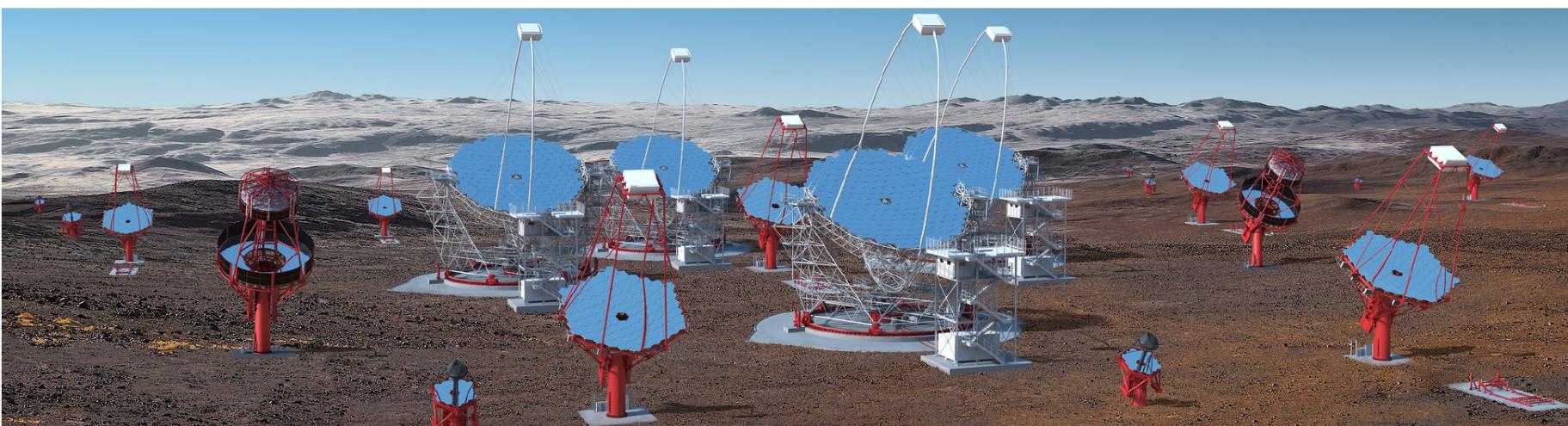
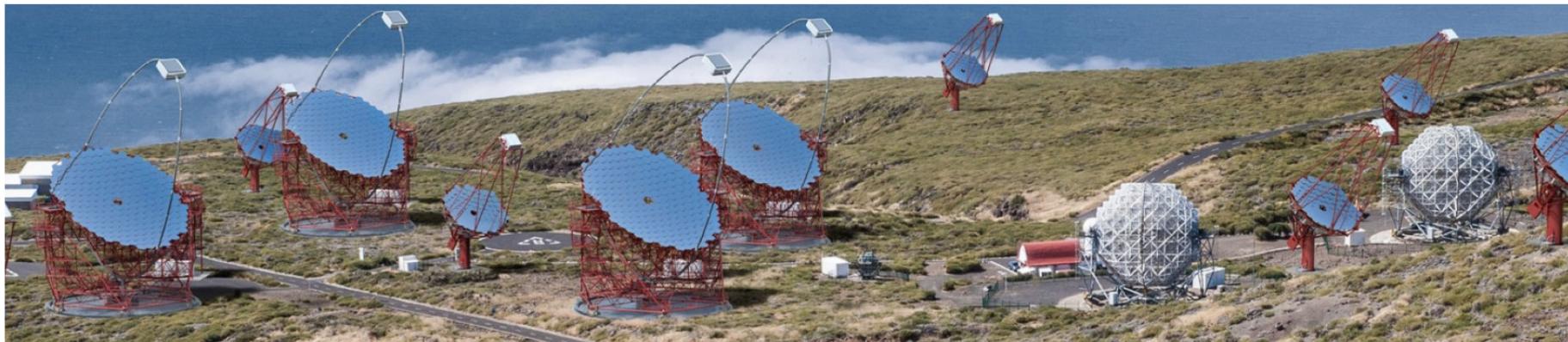


## A Hybrid Observatory...



# CTA North & CTA South

Alpha		CTA Construction
Northern Array	Number of LSTs	4
	Number of MSTs	9
Southern Array	Number of LSTs	0
	Number of MSTs	14
	Number of SSTs	37
Total		74



# CTA Alpha Layout

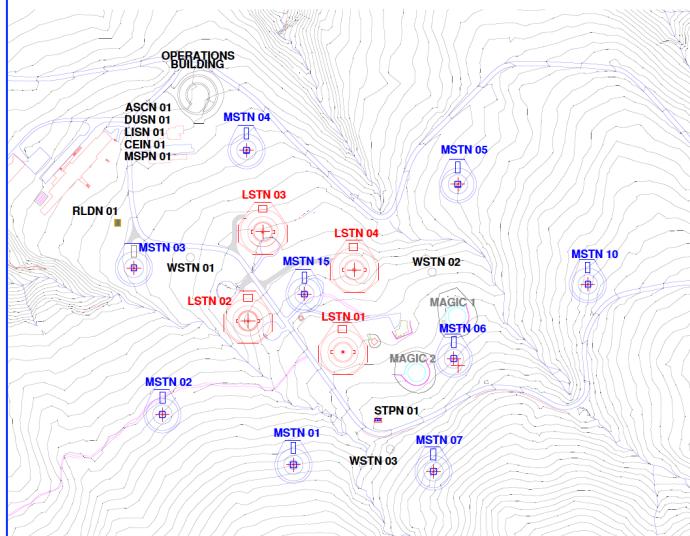


## The two initial CTAO arrays: the Alpha Configuration



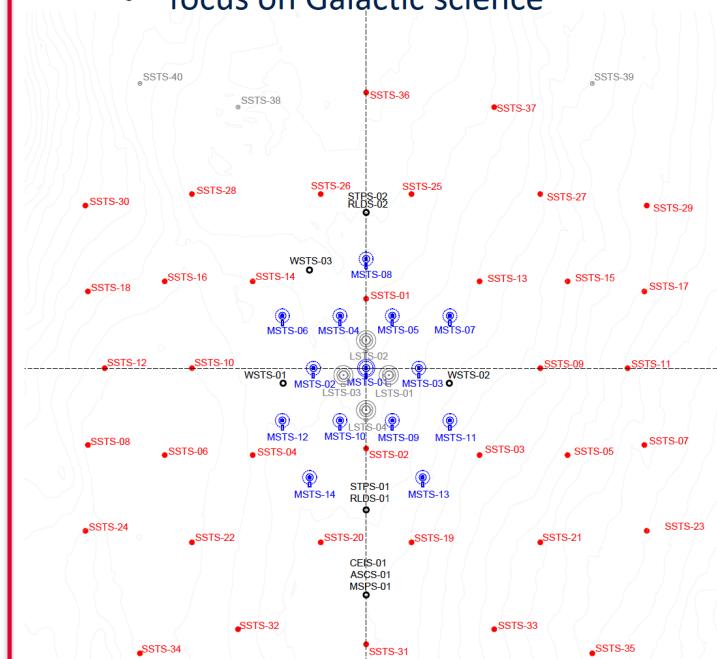
### CTAO Northern Array

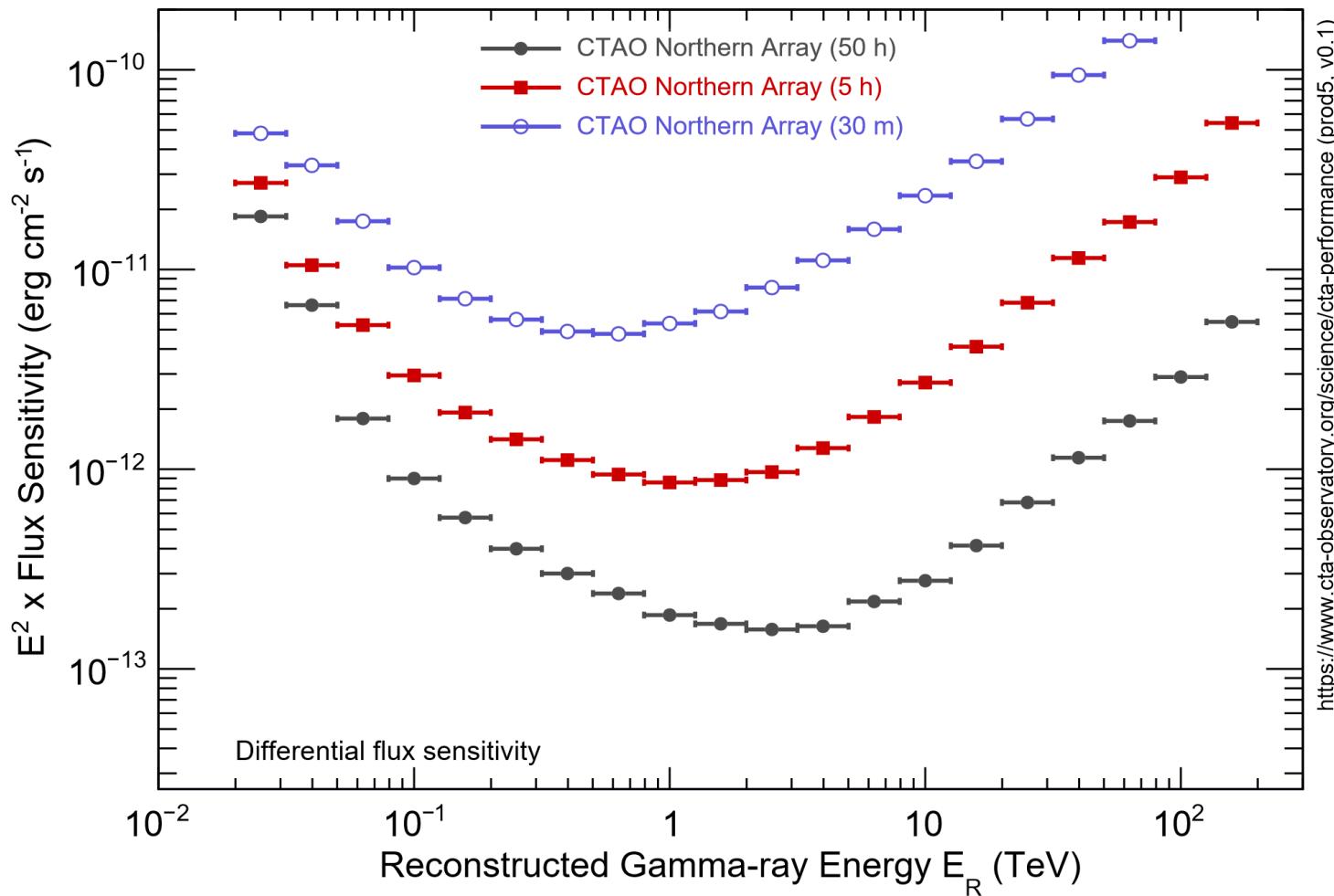
- 4 LSTs + 9 MSTs
- 0,25 km<sup>2</sup> footprint
- focus on extra-Galactic science

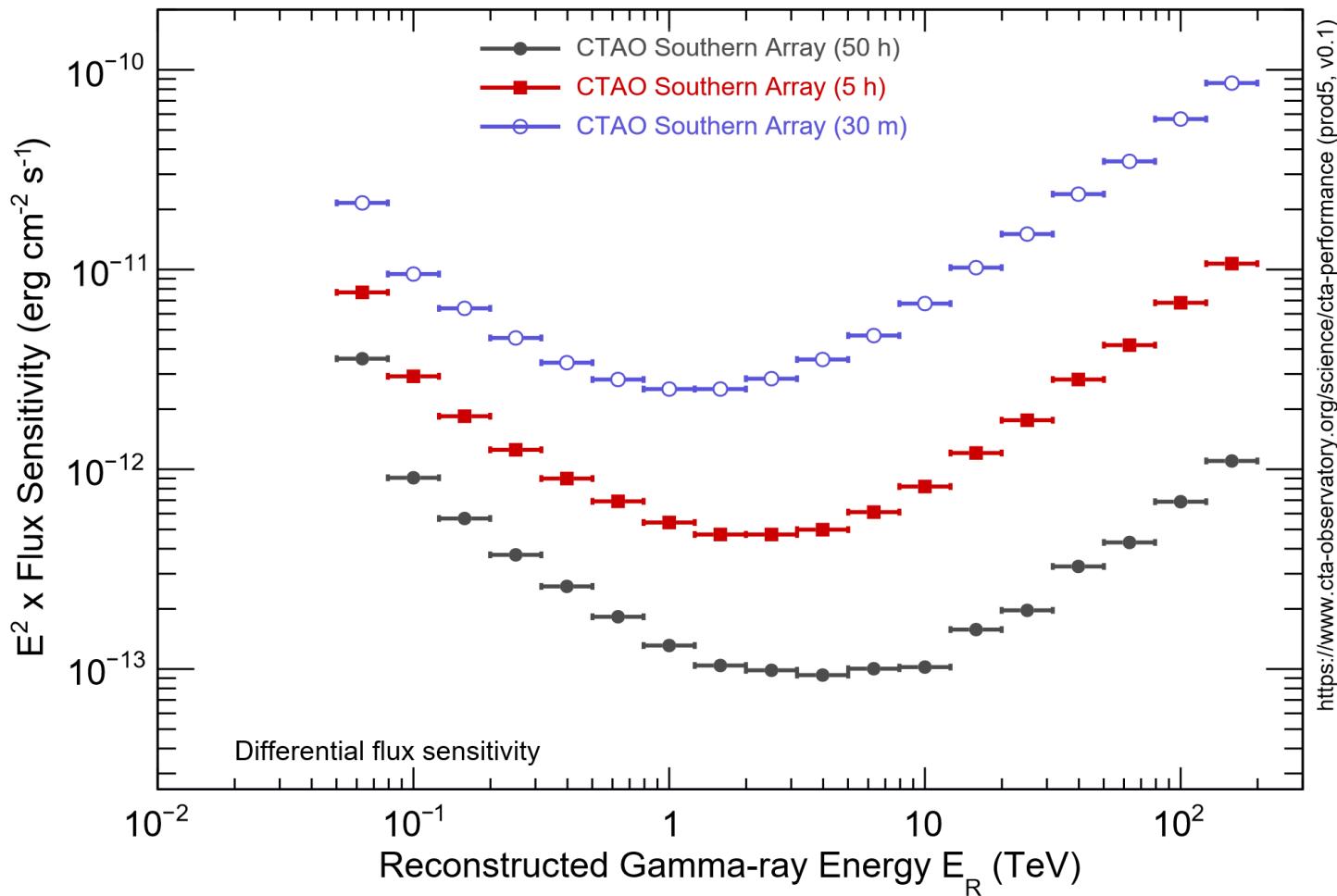


### CTAO Southern Array

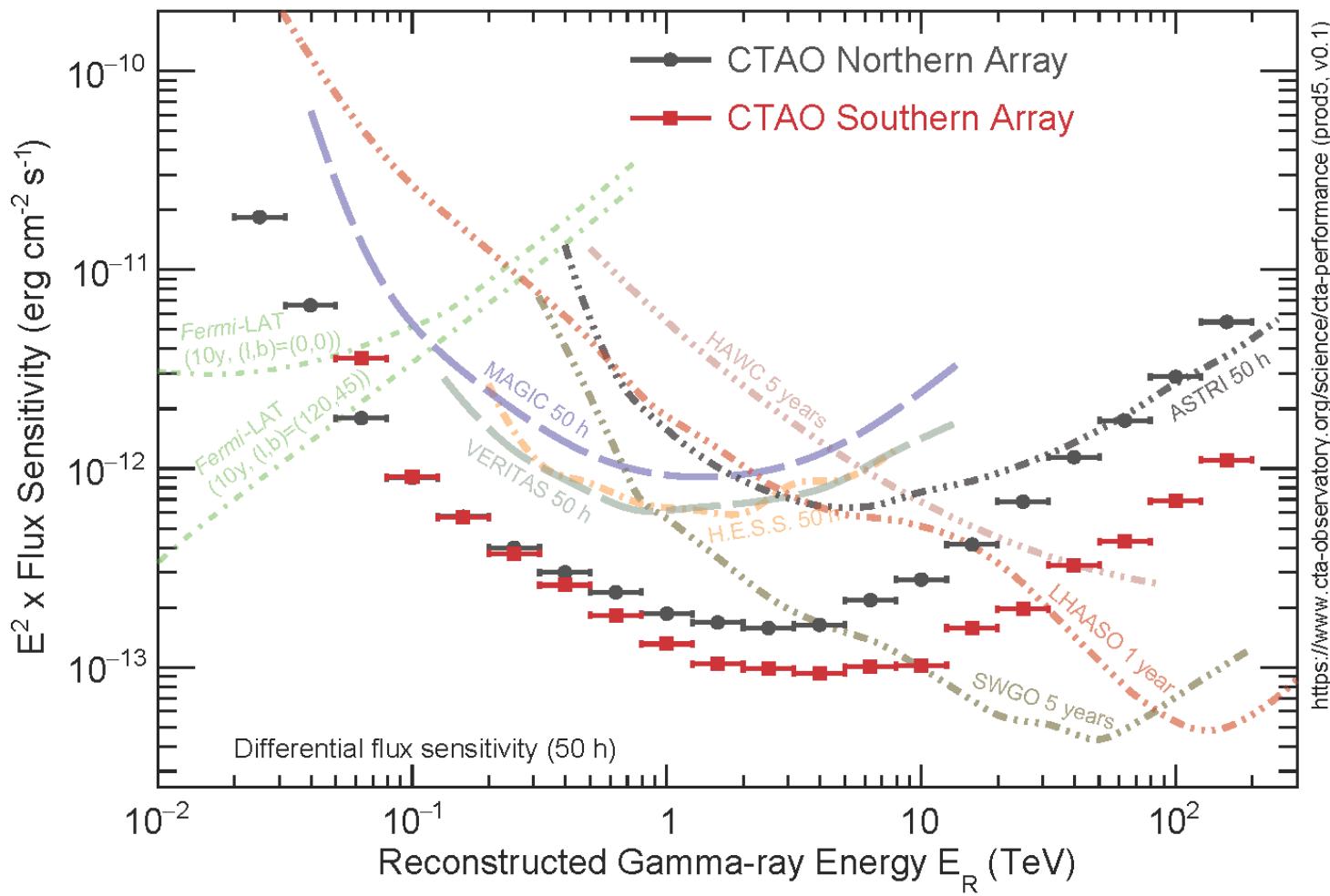
- 14 MSTs + 37 SSTs
- 3 km<sup>2</sup> footprint
- focus on Galactic science







# CTA performance



# The CTA Telescopes

LST-1 La Palma



SST - ASTRI



MST-SCT

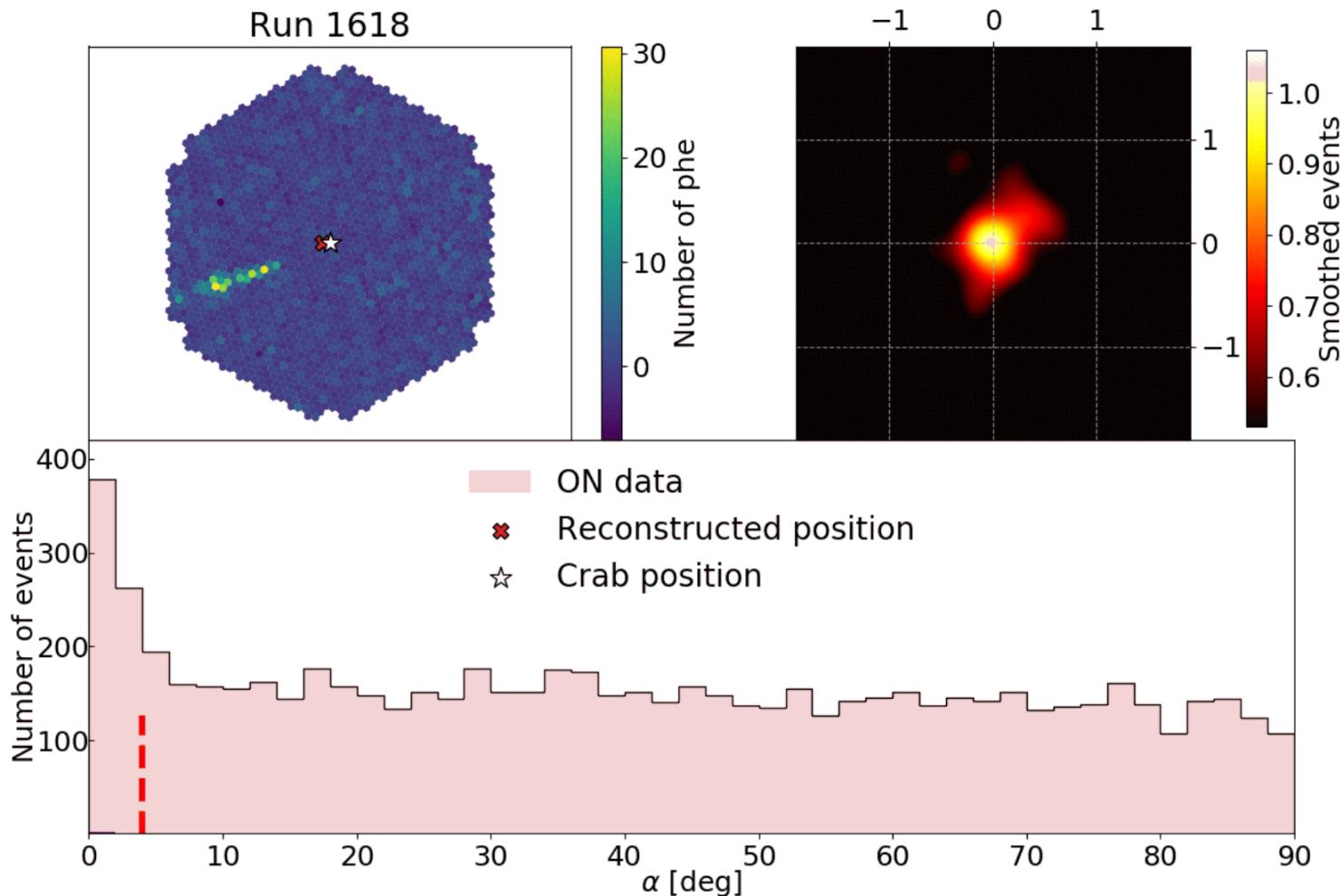


MST

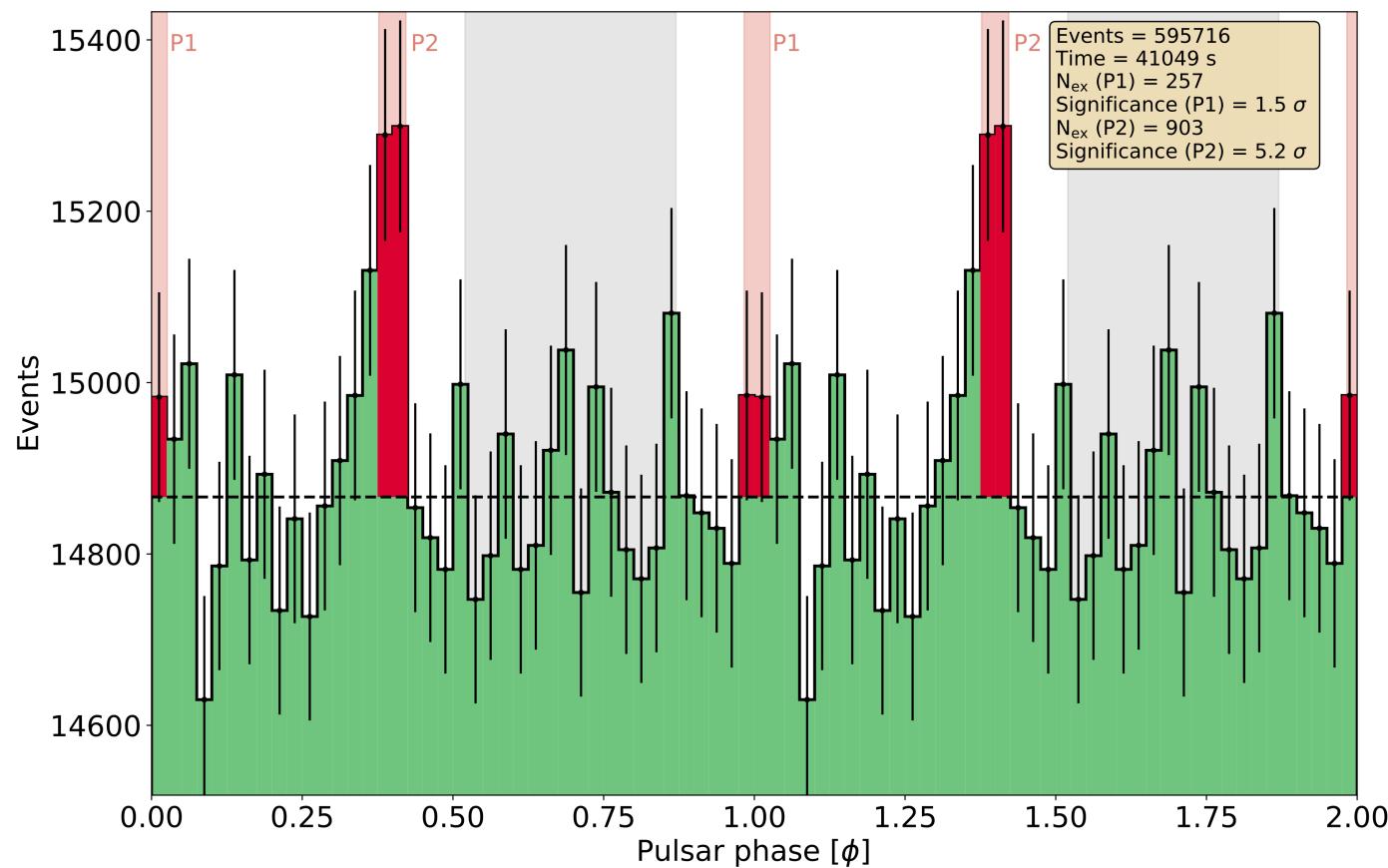


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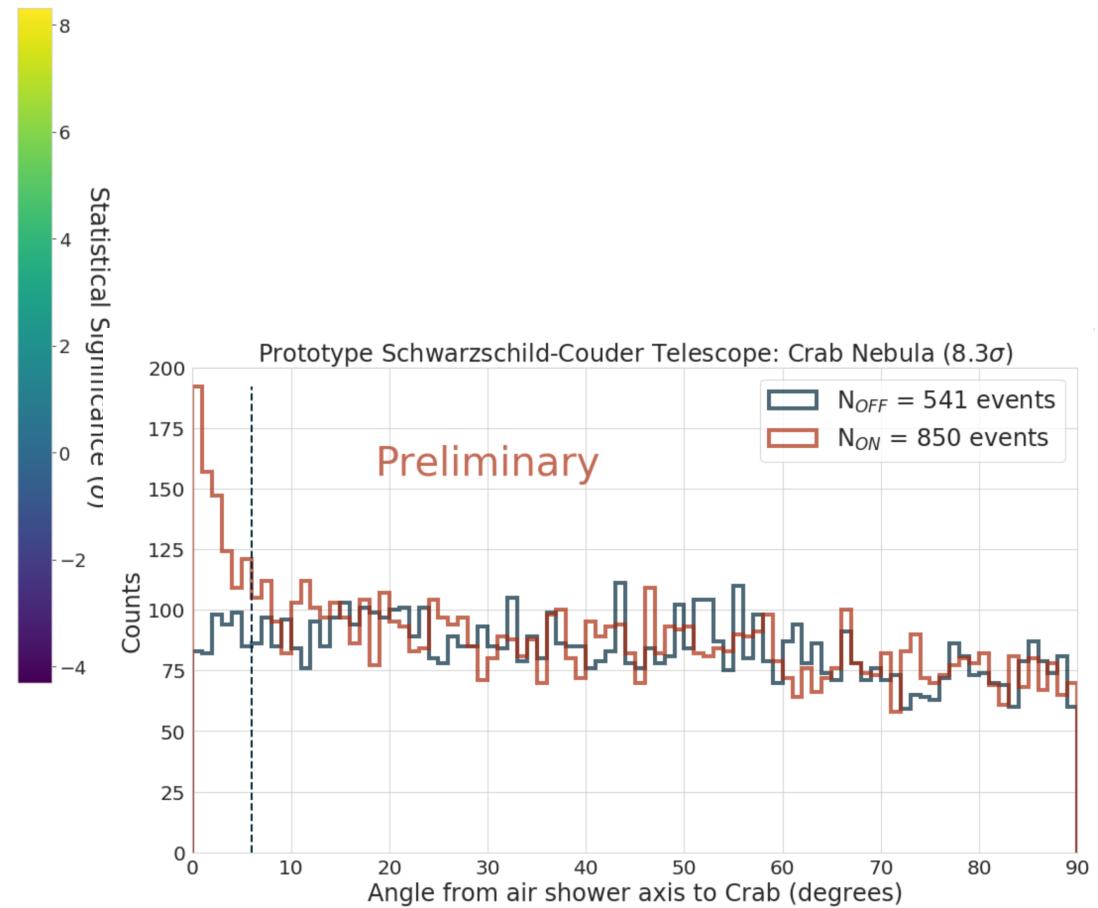
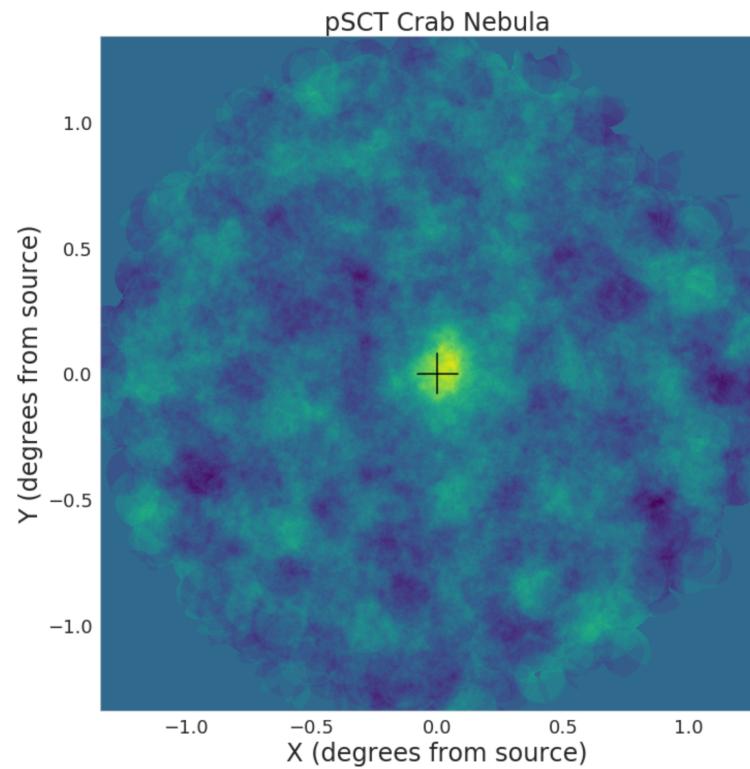
# CTA telescopes – first results



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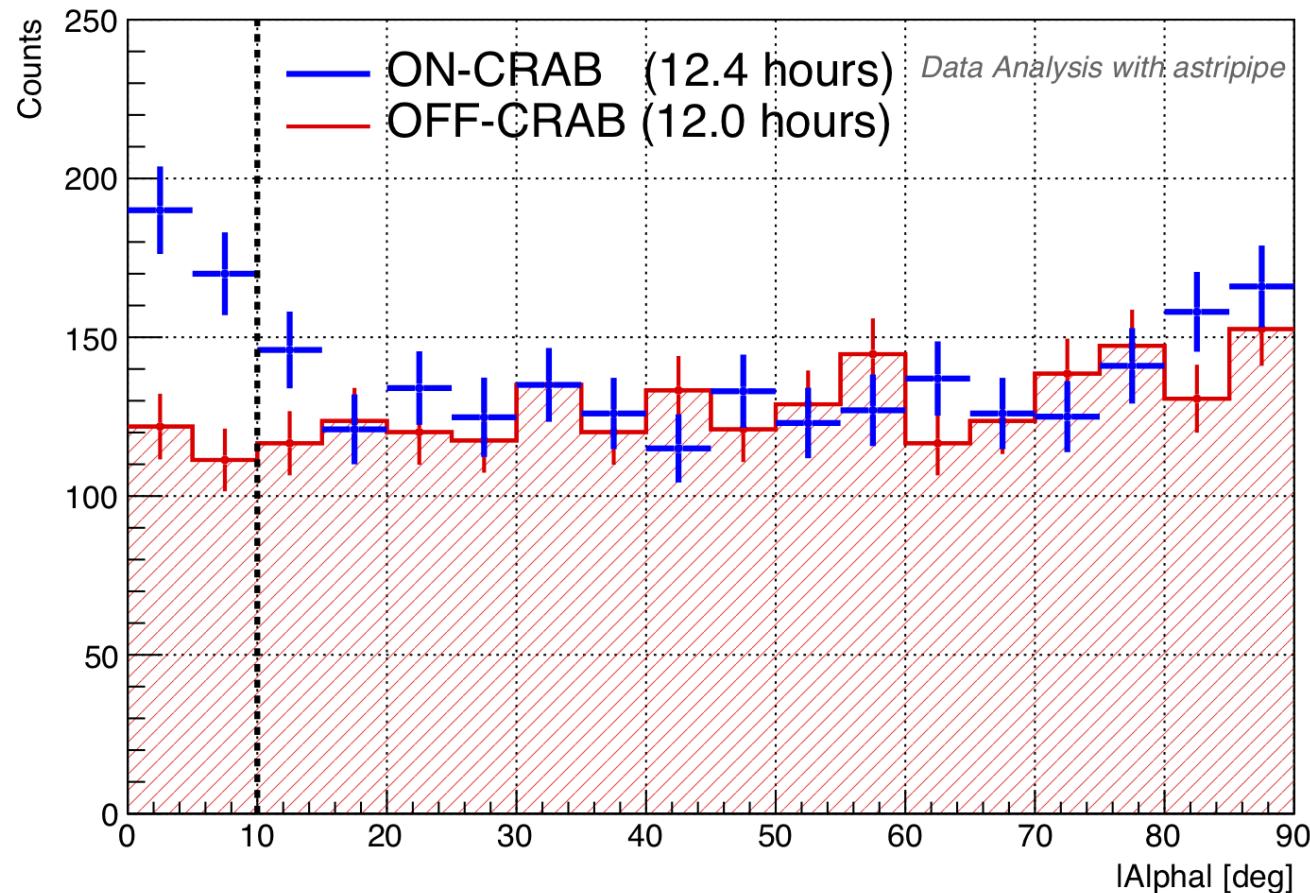
# CTA telescopes – first results



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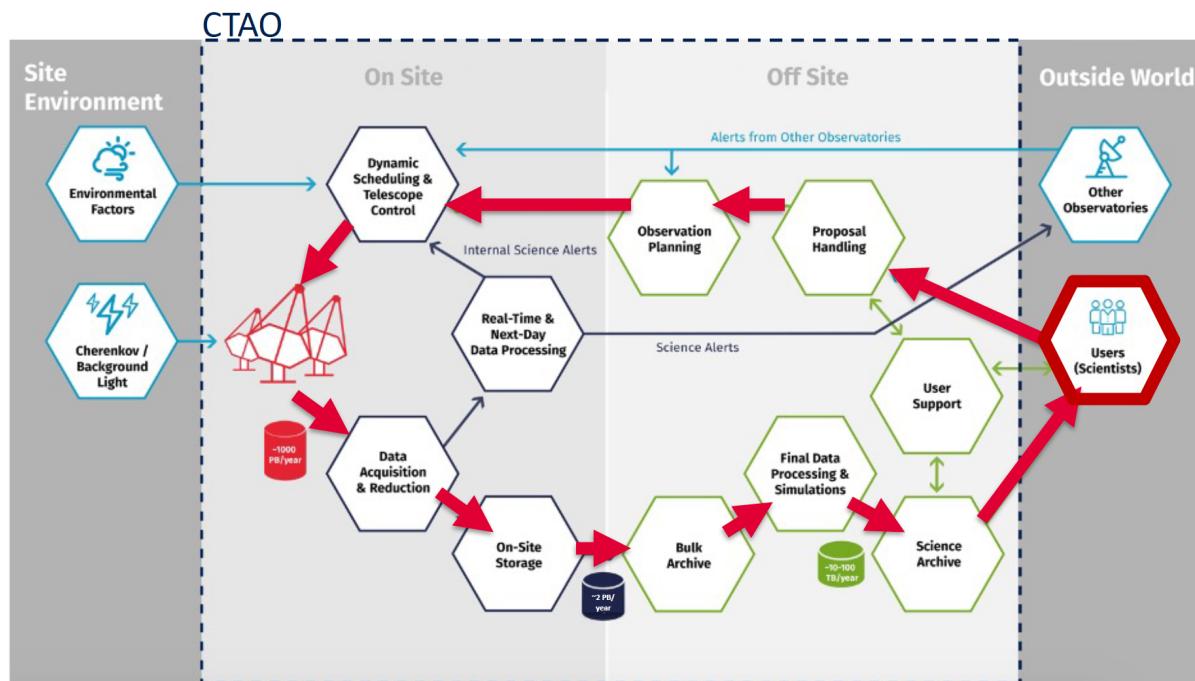
ASTRI SST-2M prototype, December 2018



# CTA as an observatory

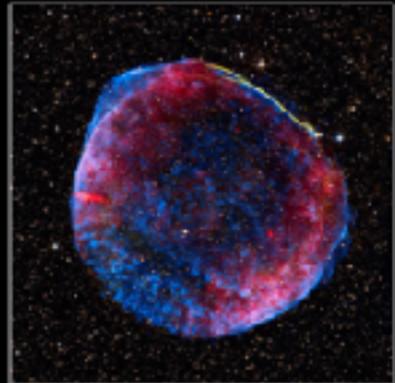


## CTA Observatory



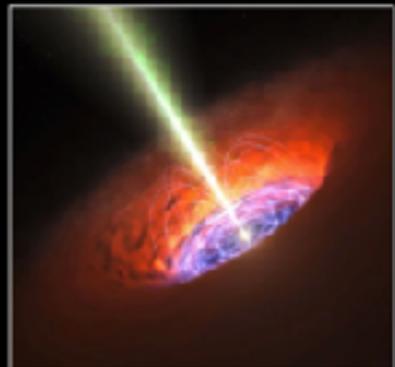
- **Proposal driven observatory:** standard proposals & long and large proposals (including Key Science Projects)
- **Proposals evaluated on scientific merits** by a Time Allocation Committee

# Astrophysics with IACTs



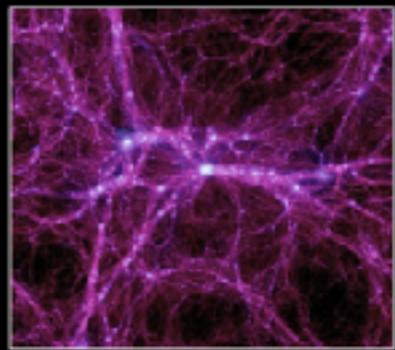
- **COSMIC PARTICLE ACCELERATION**

What are the sites and mechanisms of particle acceleration in the cosmos?



- **EXTREME ASTROPHYSICAL ENVIRONMENTS**

The physics of neutron stars, black holes and their energetic environments, such as relativistic jets, winds and stellar explosions.



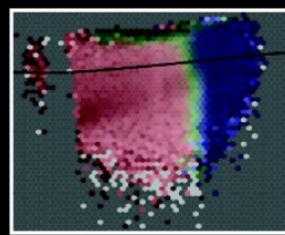
- **FUNDAMENTAL PHYSICS FRONTIERS**

Probing the nature of Dark Matter, the existence of axion-like particles, and Lorentz invariance violation

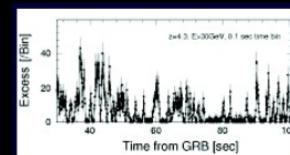
# A Census of particle accelerators across all cosmic scales



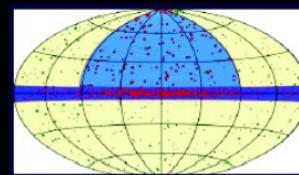
## KEY SCIENCE PROJECTS



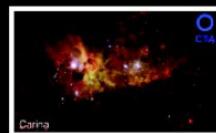
Dark Matter  
Programme



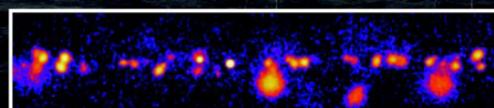
Transients



ExGal  
Survey



Star Forming  
Systems



Galactic  
Plane Survey

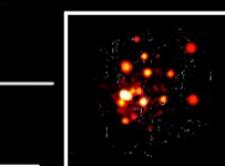
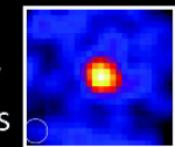
Galactic

PeVatrons

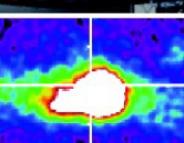
Galactic  
Centre

Extragalactic

Galaxy  
Clusters



LMC  
Survey



U.Barres – COSPAR 2020

# Science with CTA



CTA will have important synergies with many of the new generation of major astronomical and astroparticle observatories. Multi-wavelength and multi-messenger approaches combining CTA data with those from other instruments will lead to a deeper understanding of the broad-band non-thermal properties of target sources, elucidating the nature, environment, and distance of gamma-ray emitters. Details of synergies in each waveband are presented.

<https://arxiv.org/abs/1709.07997>

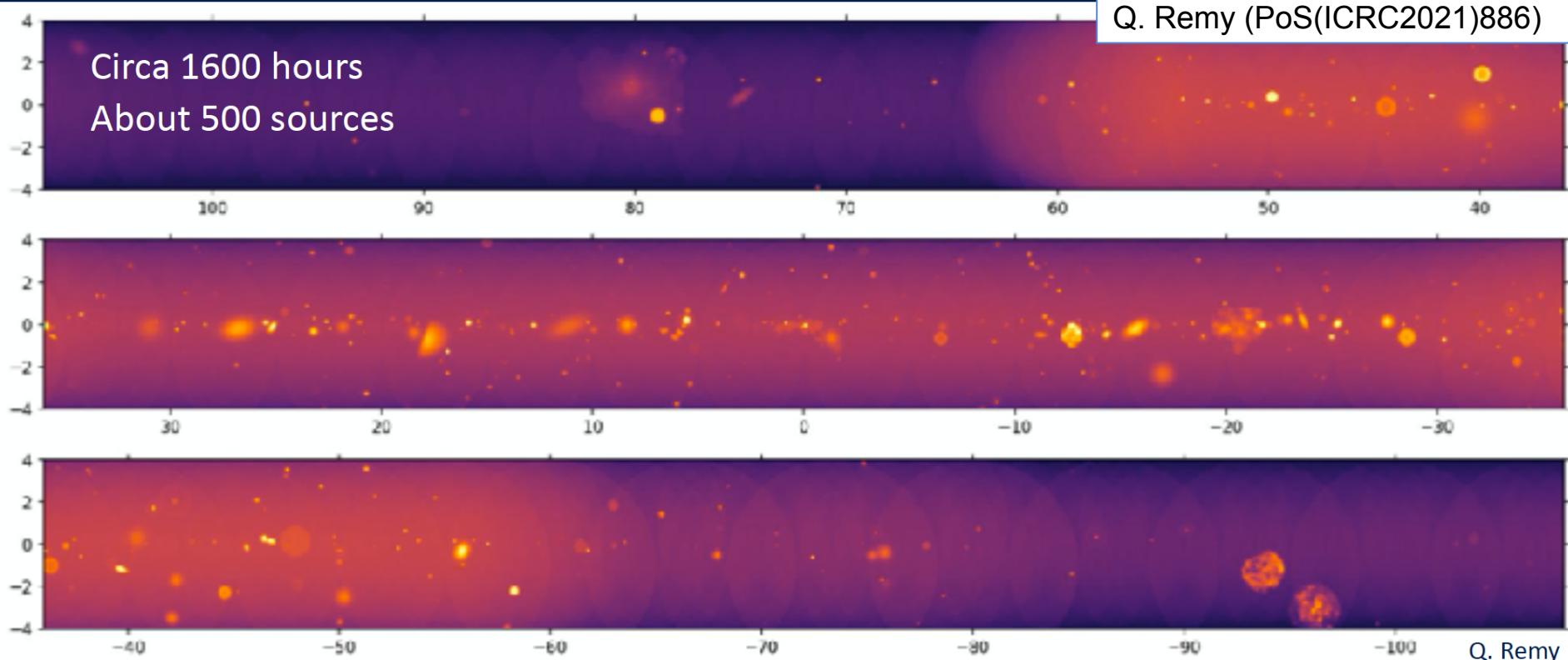




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# CTA Galactic Science

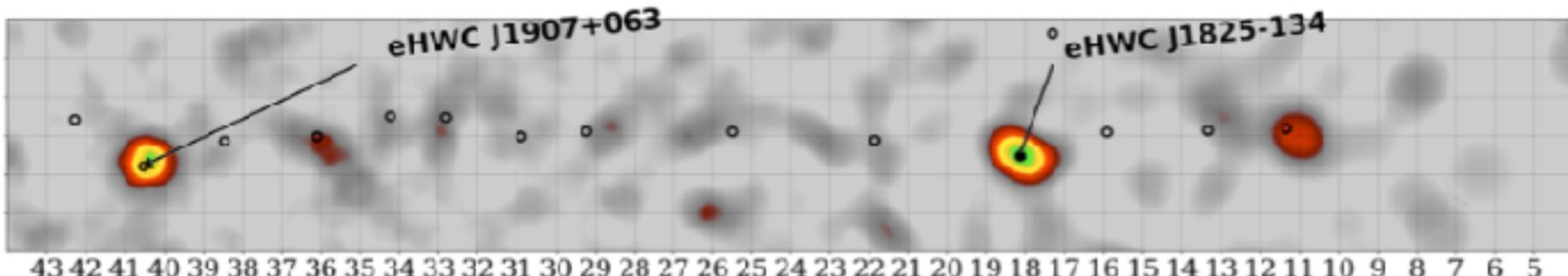
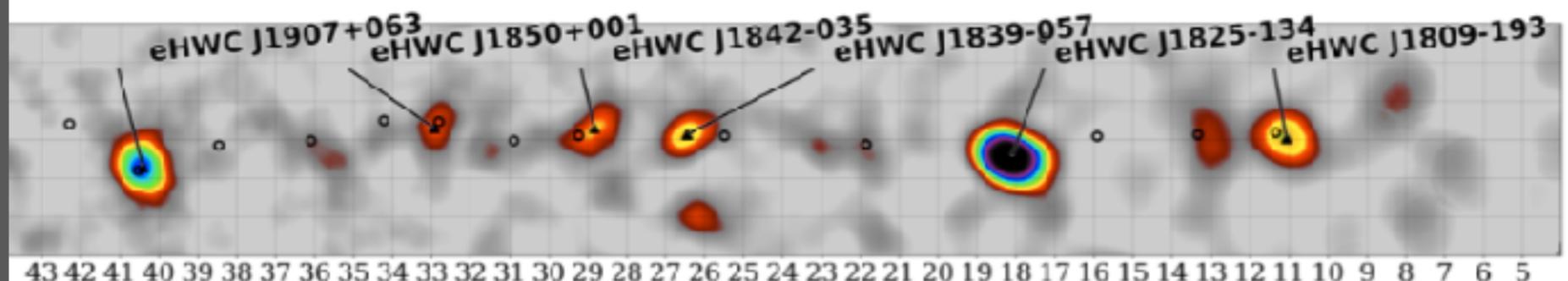
- Survey speed about 300x greater than H.E.S.S.
- Much deeper reach, to scan the entire galaxy for PWNe and SNRs, as opposed to the few-kpc reach of current instruments.



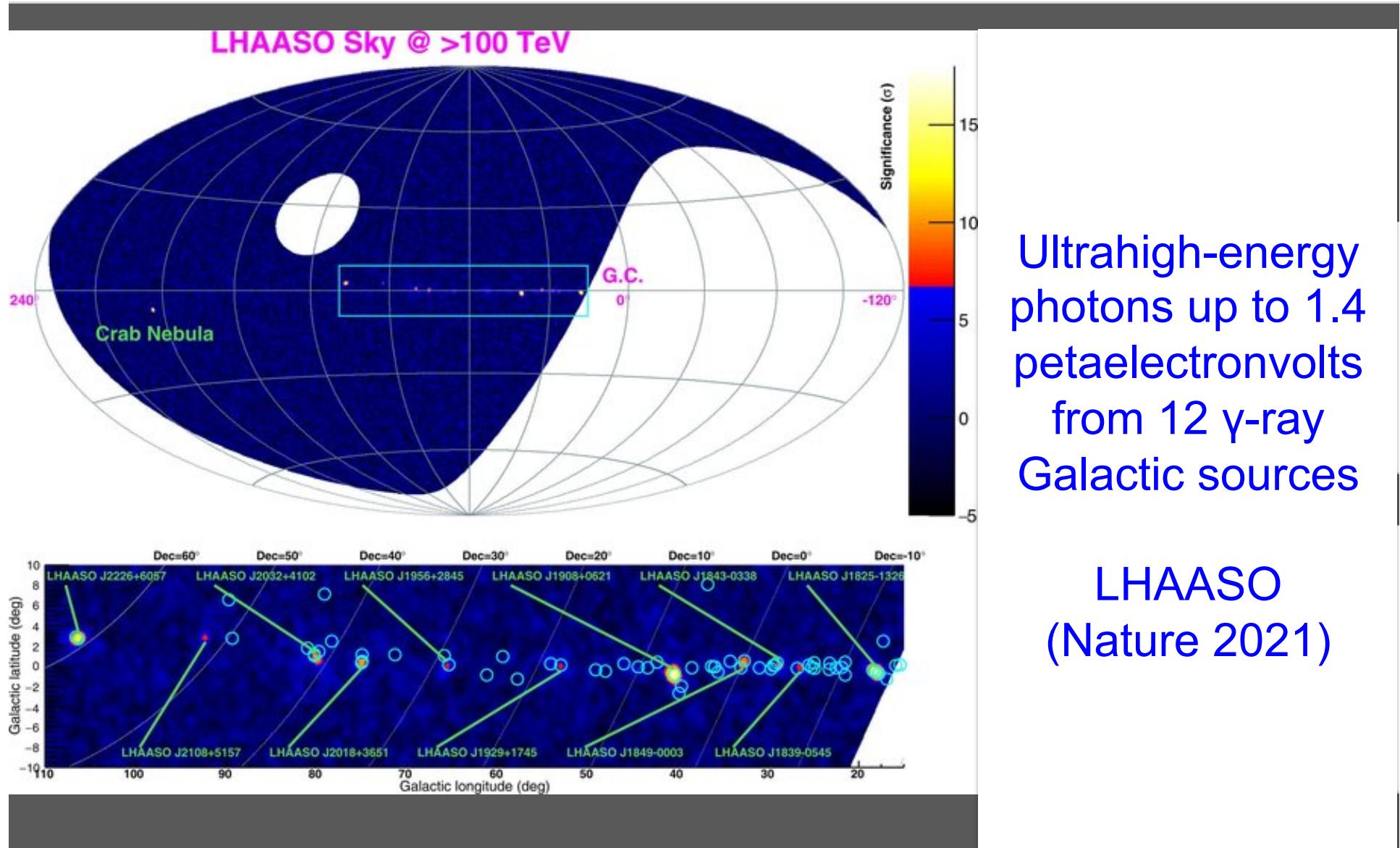
# PeVatrons: the extreme energy frontier



HAWC (arXiv:1909.08609) has opened a window into the PeVatron frontier that can be extensively probed and expanded by CTA



# PeVatrons: the extreme energy frontier





# The new window of VHE Gamma-ray Bursts

## First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; **Razmik Mirzoyan on behalf of the MAGIC Collaboration**  
on 15 Jan 2019; 01:03 UT

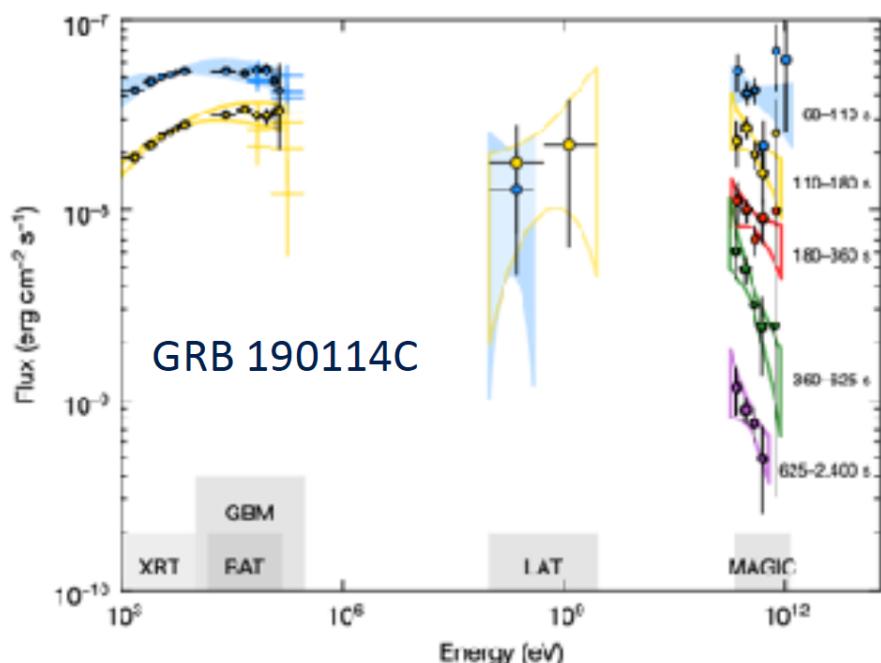
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-RAT alert. we started



Three long GRBs detections announced in the past two years:

GRB 180720B ( $z=0.65$ )

GRB 190114C ( $z=0.42$ )

Afterglow detected > 300 GeV  
Huge statistics (1000s gammas)  
Sub-minute timescale spectra

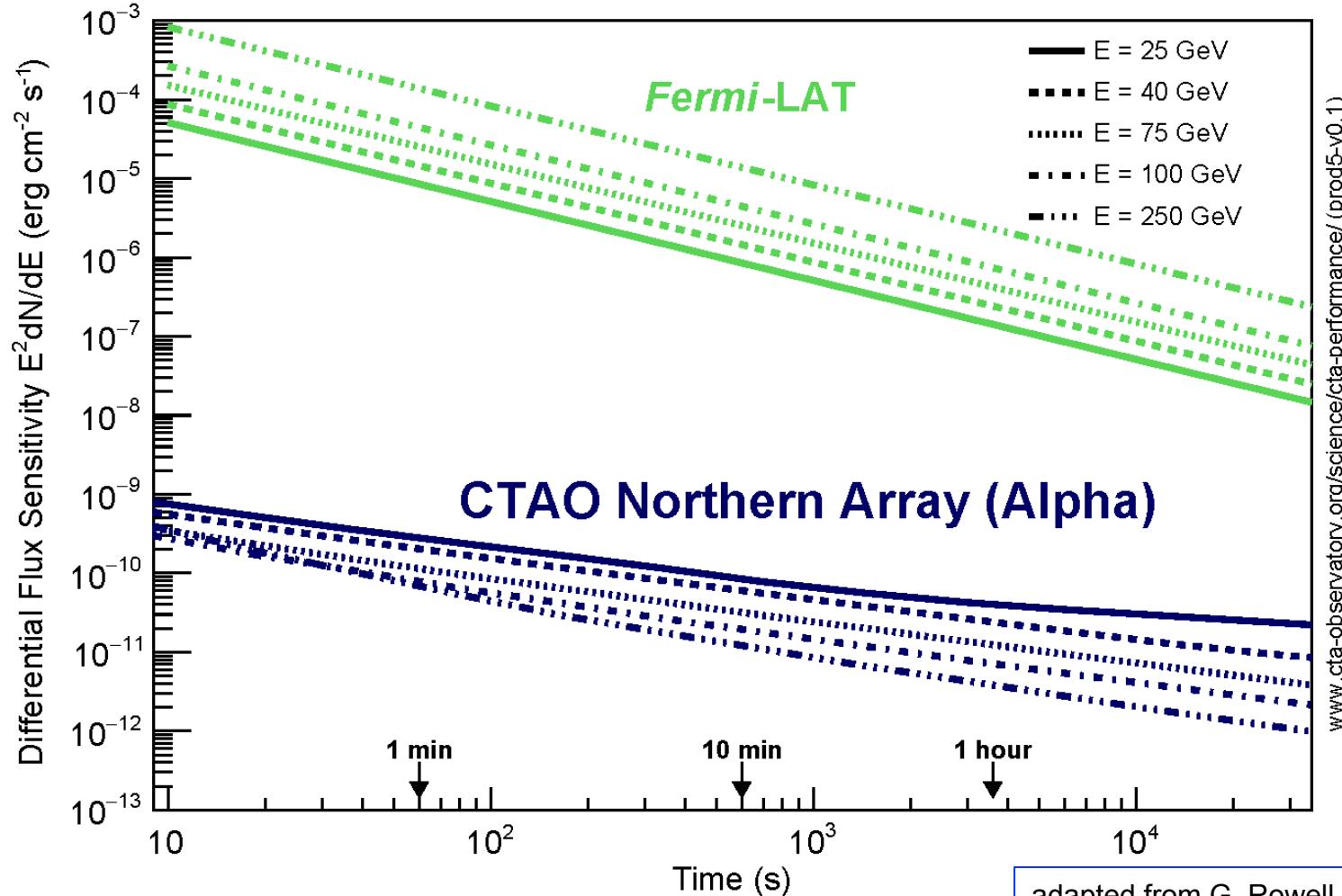
GRB 190829A ( $z=0.08$ )

+ GRB 201216C ( $z = 1.1$ )  
+ GRB 221009A ( $z=0.15$ )

Strong MWL and MM synergies for spectral and variability studies

# Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)

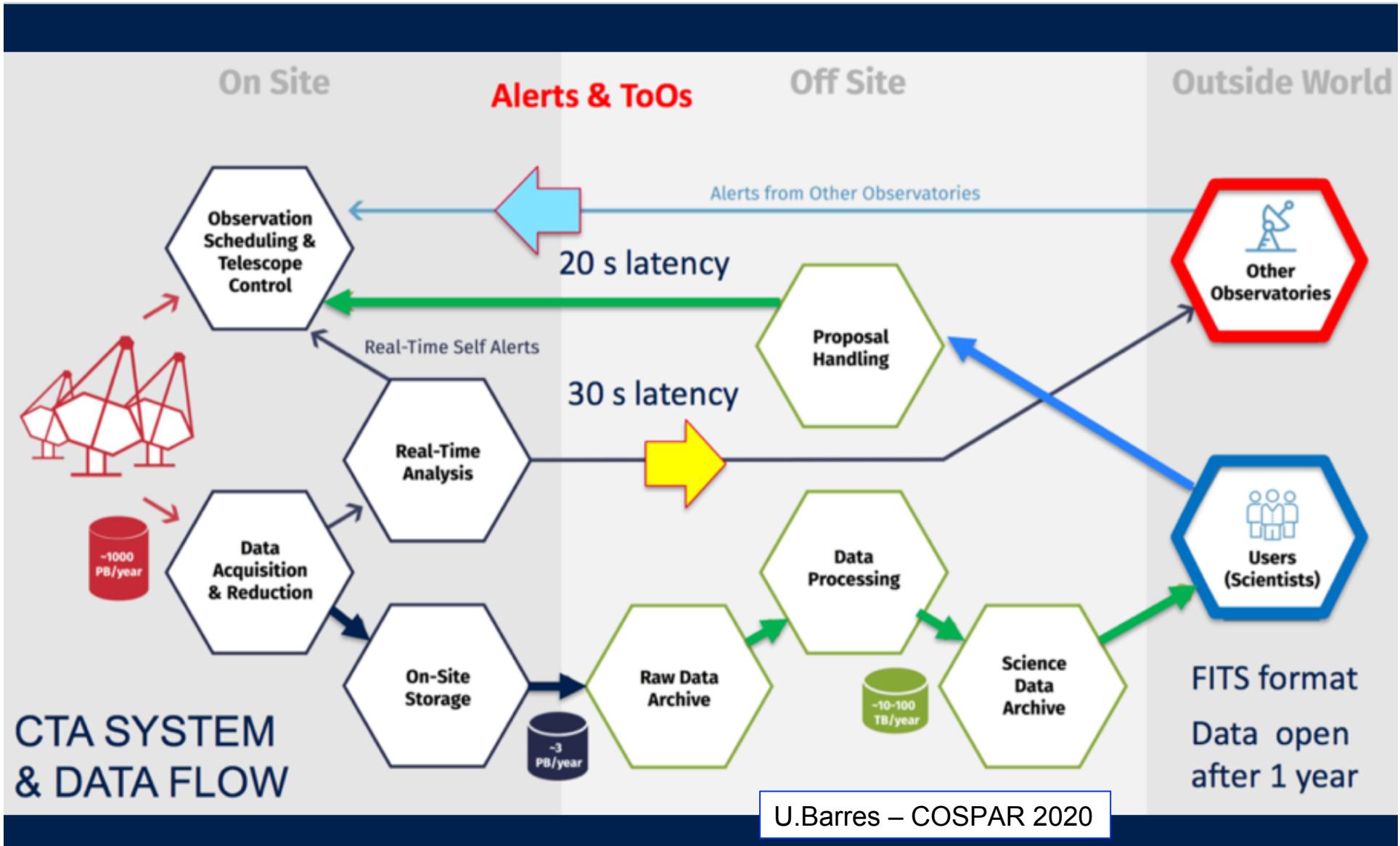


CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range  
→ GRBs, AGN, giant pulses, FRBs, GW, SGR bursts.....



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# CTA Transients Science



# The 1<sup>st</sup> CTAO Science Data Challenge



## CTAO Science Data Challenge(s)



- **CTAO Science Data Challenge (SDC):**  
source and large-scale structure finding/characterization data challenges  
on simulated science-ready (DL3) data products\*
- **A series of SDCs with increasing complexity both on the sky realism side  
and on the foreseen goals**

# The 1<sup>st</sup> CTAO Science Data Challenge



## CTAO SDCs: general goals



1. **to allow the broad science community to get familiar with the CTAO data products and the CTAO Science Analysis Tools (SATs)**
2. **to serve as a test-bed for driving forward new algorithms and new technologies** (like machine-learning) for source and large-scale structure detection/identification in the context of the source confusion
3. **to serve as intermediate step in the verification process of software packages** that will be used during Observatory operations and data models and formats
4. **to foster the production of good documentation** to be used for users' support

# The 1<sup>st</sup> CTAO Science Data Challenge



## CTAO SDCs: phases



Each SDC consists of 4 phases:

- **Phase 1: definition**
  - definitions of goals, science cases and technical needs
- **Phase 2: preparation**
  - preparation and running of the simulations
- **Phase 3: execution**
  - starts with the opening of the challenge;
  - users can download and explore the data,
  - users can submit their results
- **Phase 4: closing-out**
  - starts when the challenge is closed;
  - it foreseen the scrutiny and score of the submitted results, the nomination of the winners;
  - it includes the writing-up of a closing-out document (peer-reviewed paper under discussion)

# External Needs Matrix



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✓ = important ✓ = critical

Band or Messenger	Astrophysical Probes	Galactic Plane Survey	LMC & SFRs	CRs & Diffuse Emission	Galactic Transients	Starburst & Galaxy Clusters	GRBs	AGNs	Radio Galaxies	Redshifts	GWs & Neutrinos
Radio	Particle and magnetic-field density probe. Transients. Pulsar timing.	✓	✓	✓	✓	✓	✓	✓	✓		✓
(Sub)Millimetre	Interstellar gas mapping. Matter ionisation levels. High-res interferometry.	✓	✓	✓		✓		✓	✓		
IR/Optical	Thermal emission. Variable non-thermal emission. Polarisation.	✓	✓	✓	✓	✓		✓	✓	✓	
Transient Factors	Wide-field monitoring & transients detection. Multi-messenger follow-ups.						✓	✓			✓
X-rays	Accretion and outflows. Particle acceleration. Plasma properties.	✓	✓	✓	✓	✓	✓	✓	✓		✓
MeV-GeV Gamma-rays	High-energy transients. Pion-decay signature. Inverse-Compton process	✓	✓	✓	✓	✓	✓	✓			✓
Other VHE	Particle detectors for 100% duty cycle monitoring of TeV sky.	✓	✓	✓		✓		✓			
Neutrinos	Probe of cosmic-ray acceleration sites. Probe of PeV energy processes.		✓				✓	✓			✓
Gravitational Waves	Mergers of compact objects (Neutron Stars). Gamma-ray Bursts.						✓				✓

# Conclusions

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- CTA will open a new era in VHE astrophysics
  - A rich science program to answer key scientific questions
  - A VHE observatory !
- Clear MM and MWL synergies
- A new Data Challenge is being organised

