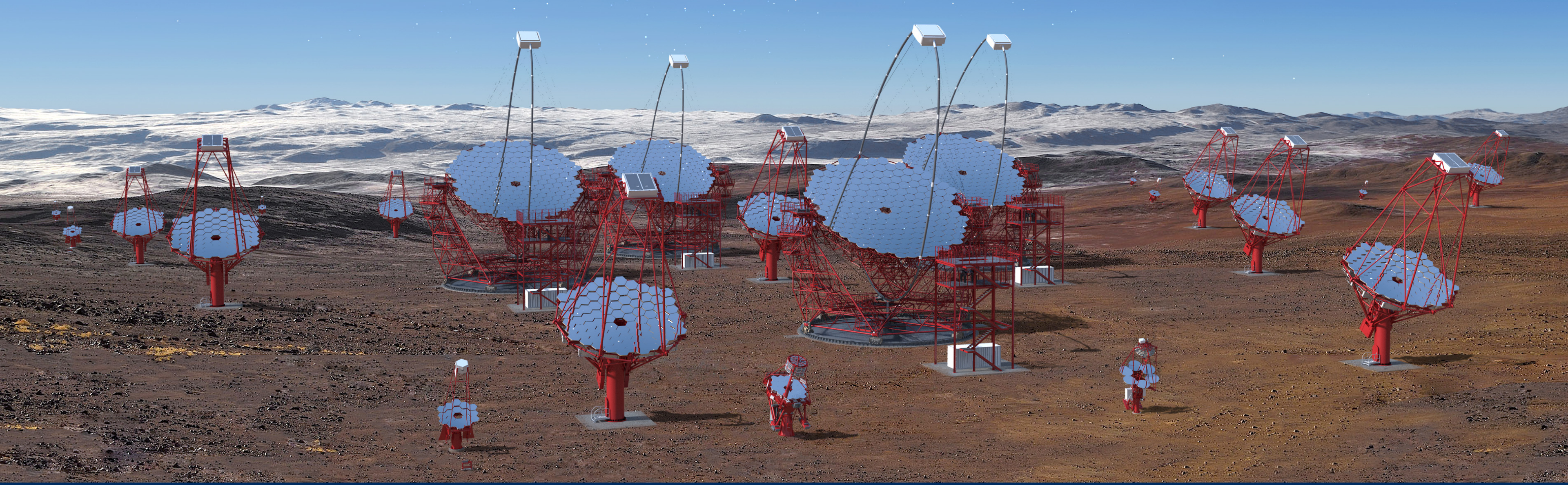
cherenkov telescope array

Il Cherenkov Telescope Array: un Osservatorio sull'Universo estremo



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INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Outline

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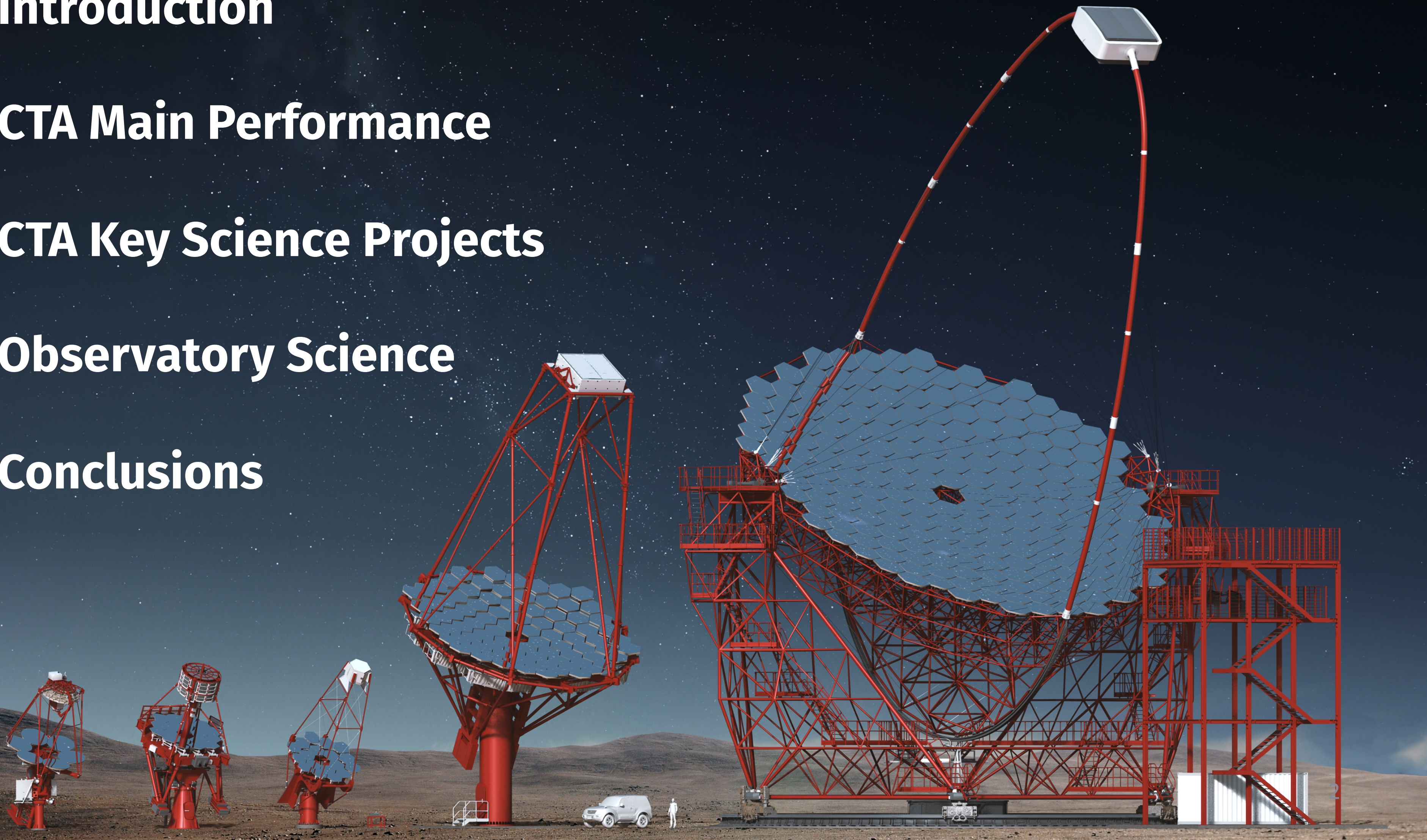
CTA Main Performance

CTA Key Science Projects

Observatory Science

Conclusions



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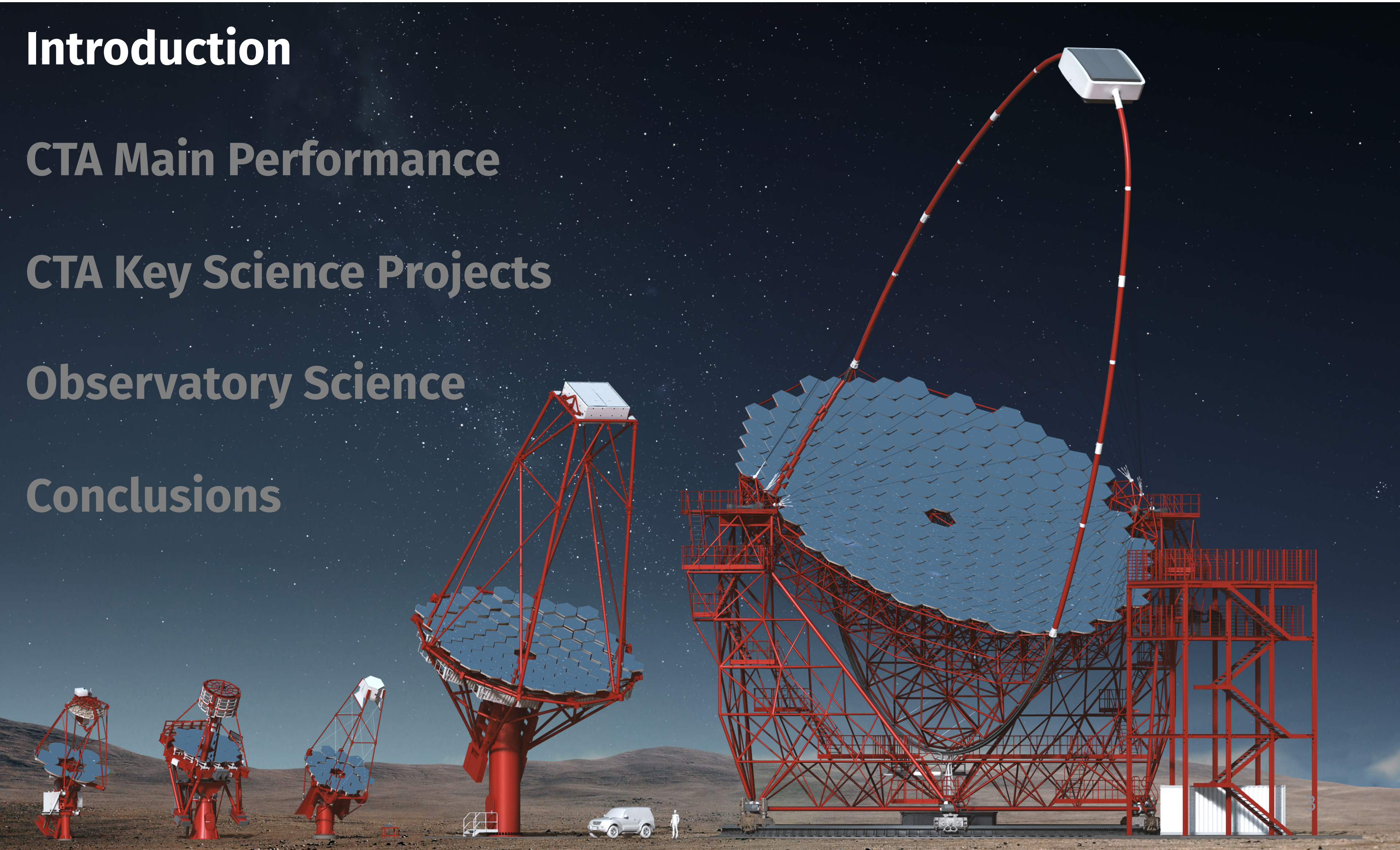

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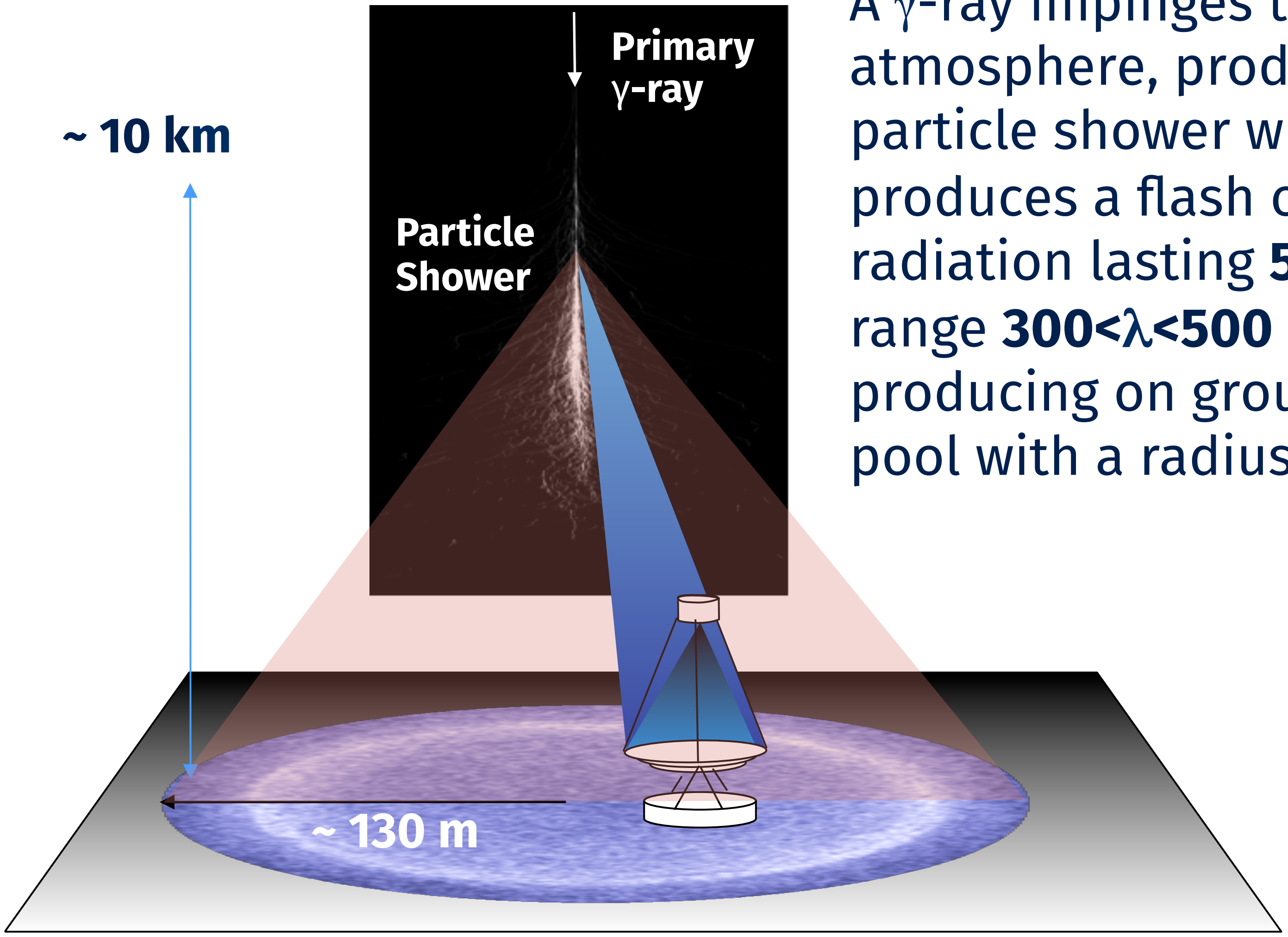
The Cherenkov Telescopes



A γ-ray impinges the atmosphere, producing a particle shower which, in turns, produces a flash of Cherenkov radiation lasting **5-20 ns** in the range **$300<\lambda<500$ nm** and producing on ground a light pool with a radius of ~**130m**.

The Cherenkov Telescopes

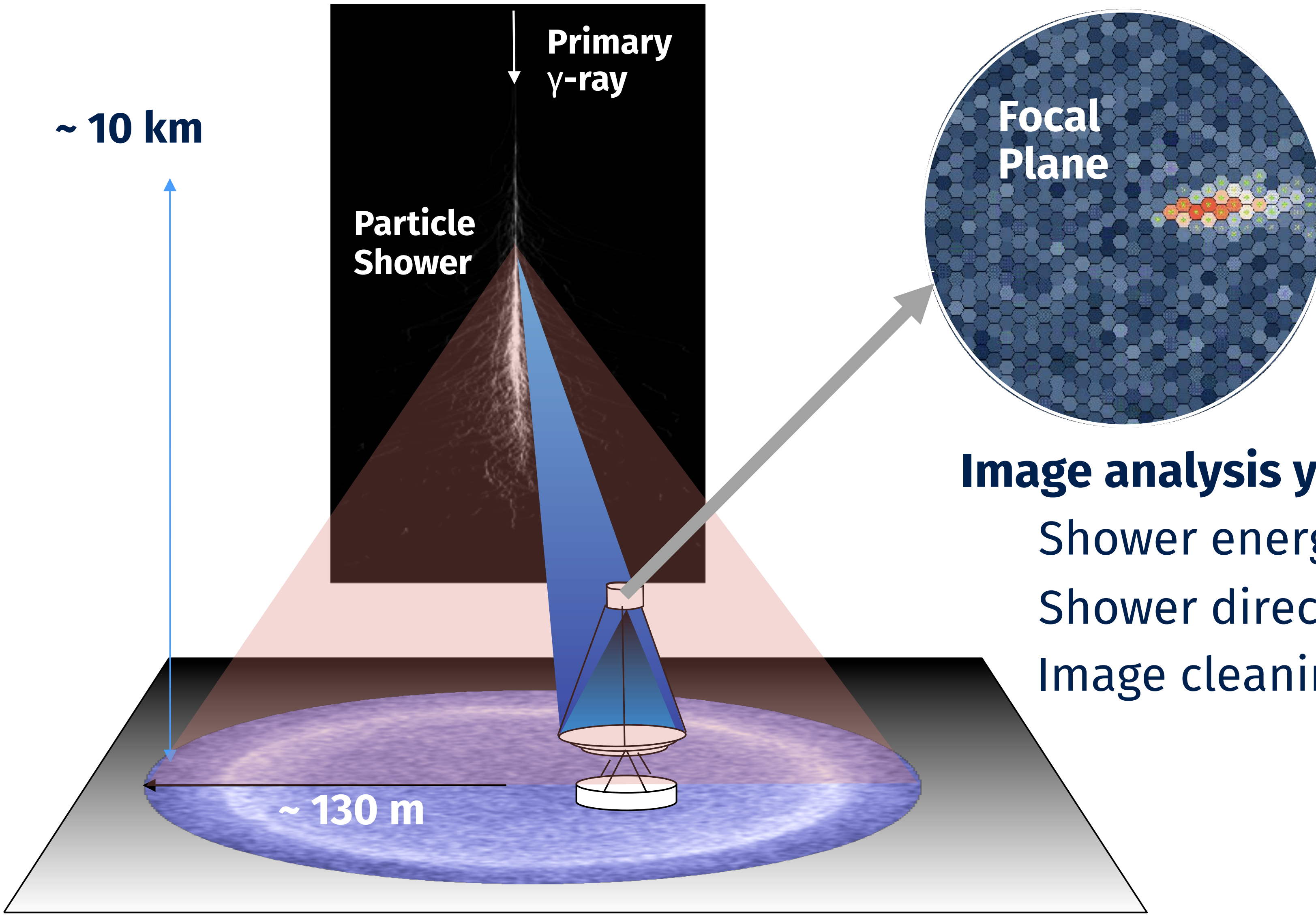


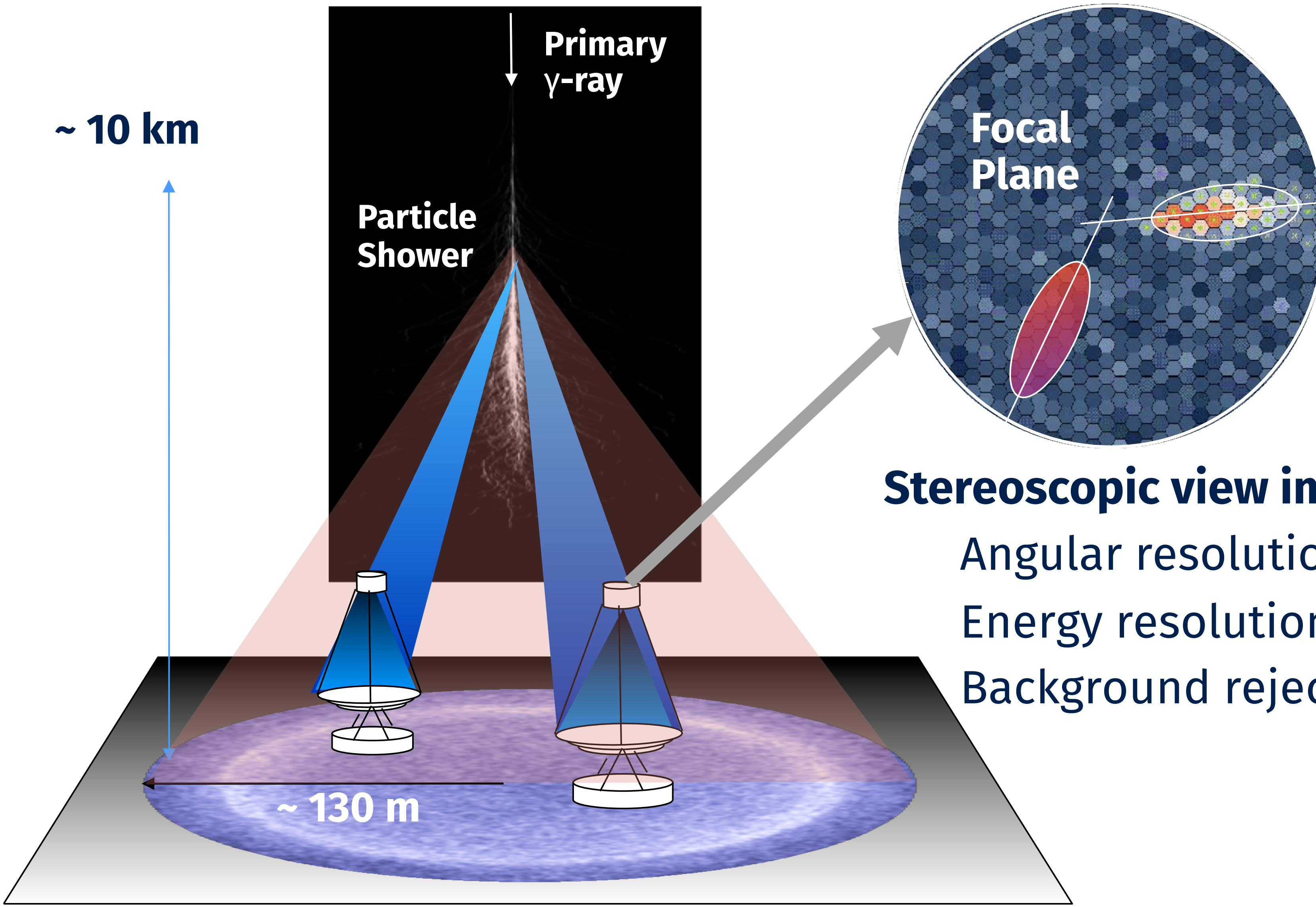
Image analysis yields

Shower energy

Shower direction

Image cleaning

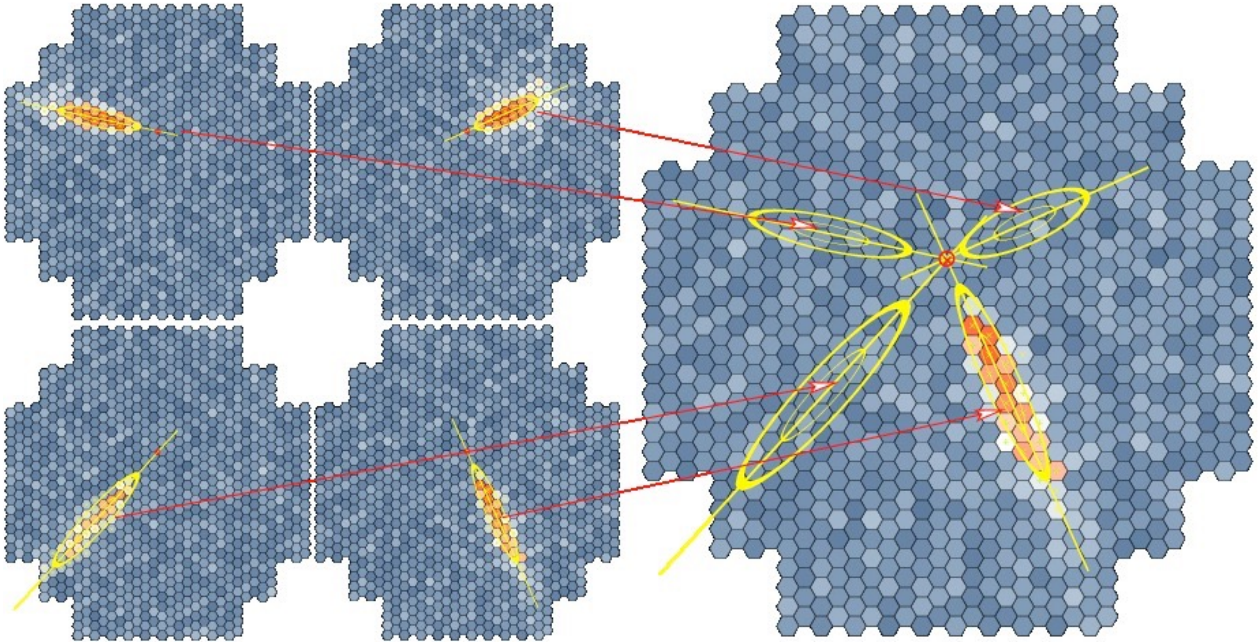
The Cherenkov Telescopes



Stereoscopic view improves

- Angular resolution
- Energy resolution
- Background rejection

The Cherenkov Telescopes

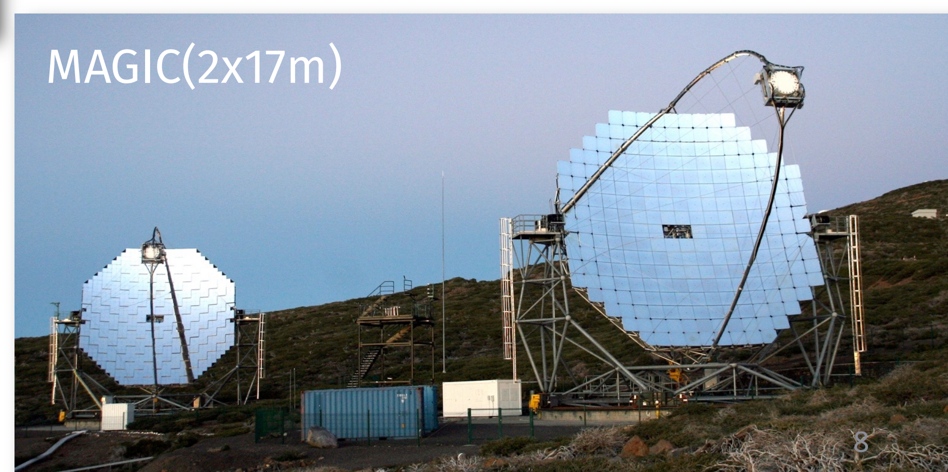


The intersection of major axes on the common FOV gives source position on the sky.

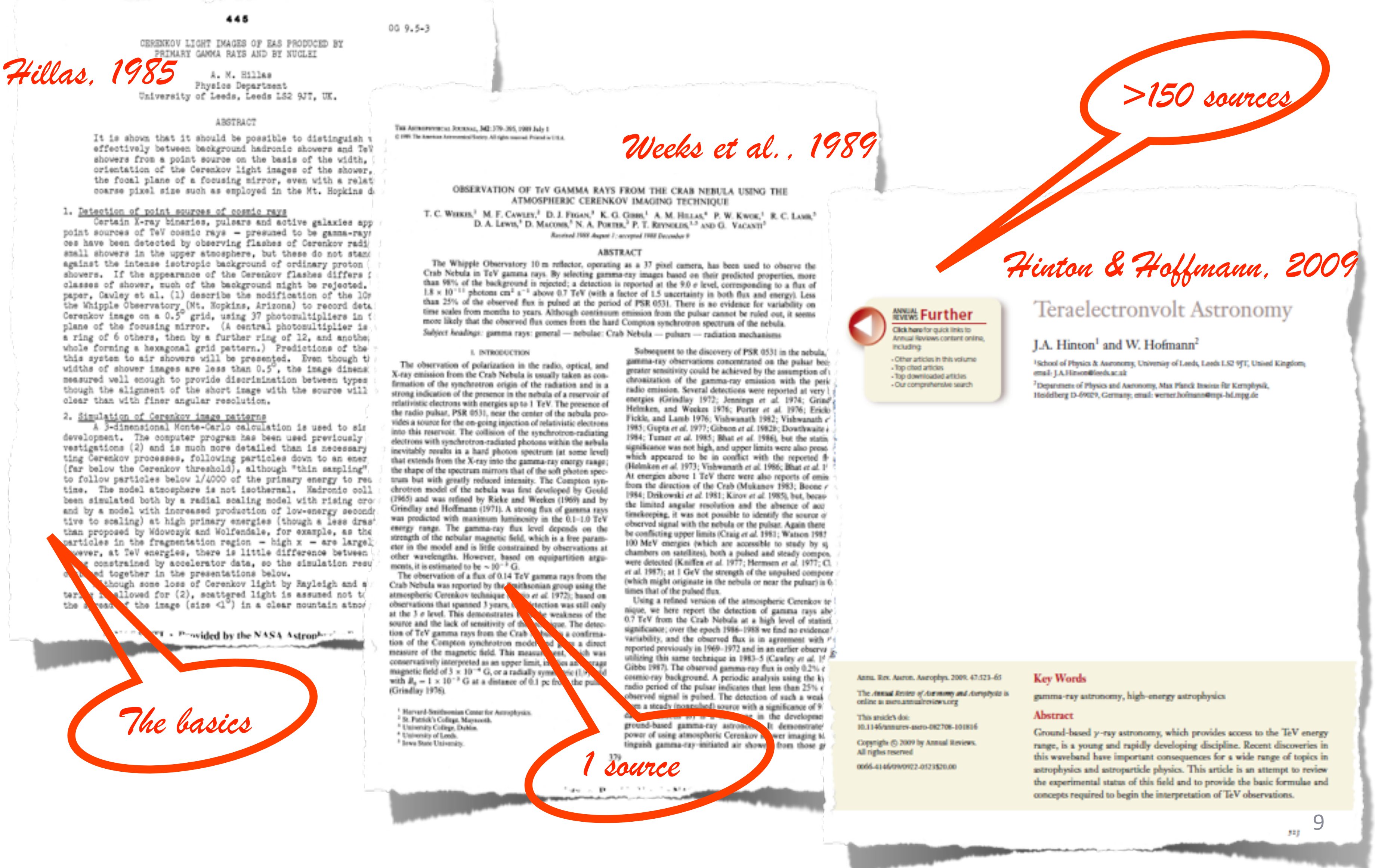
More on the Cherenkov technique, sources and physics in:

Hinton & Hofmann, 2009, ARAA, 47, 523

The current IACT status



VHE high-level timeline



445

OG 9.5-3

CERENKOV LIGHT IMAGES OF EAS PRODUCED BY PRIMARY GAMMA RAYS AND BY NUCLEI

A. M. Hillas
Physics Department
University of Leeds, Leeds LS2 9JT, UK.

ABSTRACT

It is shown that it should be possible to distinguish … effectively between background hadronic showers and TeV … showers from a point source on the basis of the width, … orientation of the Cerenkov light images of the shower, … the focal plane of a focusing mirror, even with a relat… coarse pixel size such as employed in the Mt. Hopkins d…

1. Detection of point sources of cosmic rays

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

T. C. Weekes, M. F. Cawley, D. J. Fegan, K. G. Gibbs, A. M. Hillas, P. W. Kwok, R. C. Lamb, D. A. Lewis, D. Macomb, N. A. Porter, P. T. Reynolds, and G. Vacanti

ABSTRACT

The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detection is reported at the 9.0 σ level, corresponding to a flux of 1.8×10^{-11} photons cm^{-2} s^{-1} above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula.

Subject headings: gamma rays: general — nebulae: Crab Nebula — pulsars — radiation mechanisms

Teraelectronvolt Astronomy

J.A. Hinton[1] and W. Hofmann[2]

Annu. Rev. Astron. Astrophys. 2009. 47:523–65

Key Words

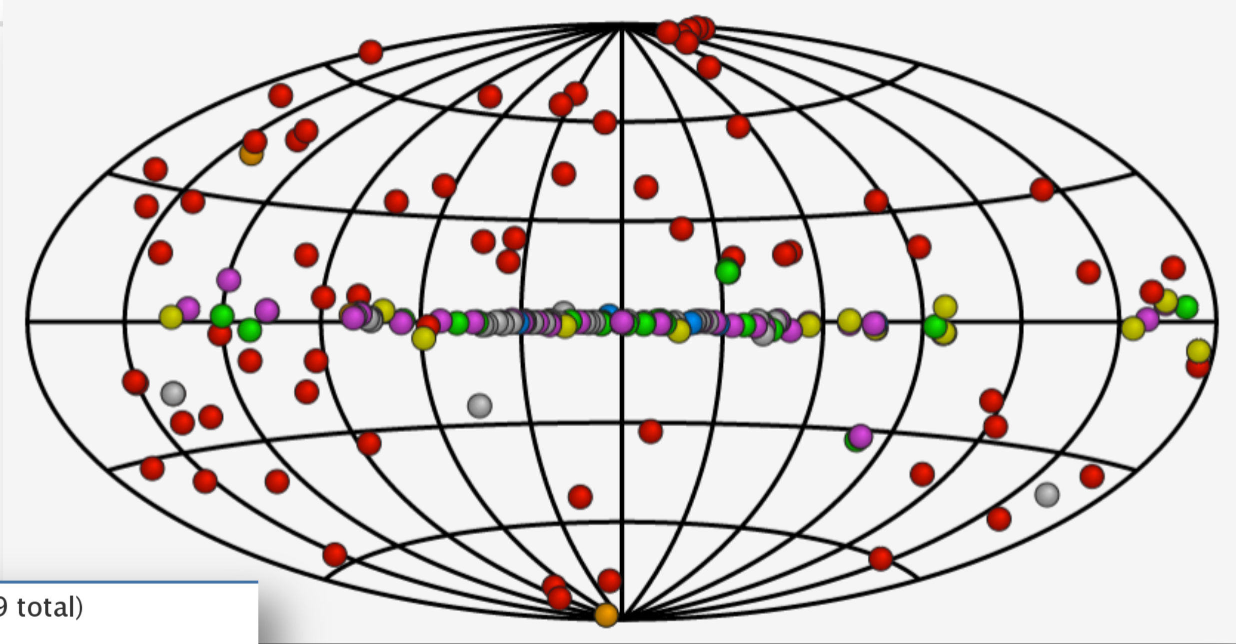
gamma-ray astronomy, high-energy astrophysics

Abstract

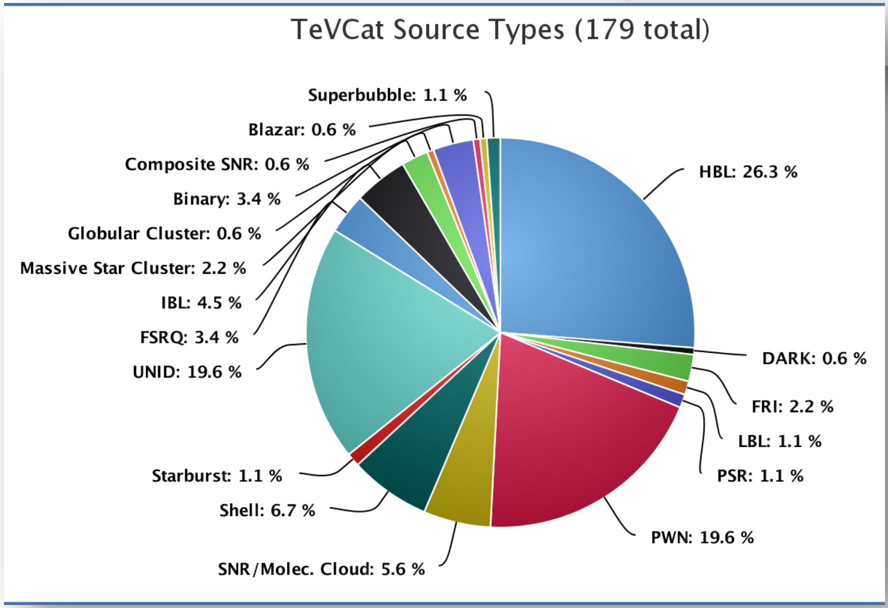
Ground-based γ-ray astronomy, which provides access to the TeV energy range, is a young and rapidly developing discipline. Recent discoveries in this waveband have important consequences for a wide range of topics in astrophysics and astroparticle physics. This article is an attempt to review the experimental status of this field and to provide the basic formulae and concepts required to begin the interpretation of TeV observations.

100 GeV – 50 TeV sky

TeVCat 2
H.E.S.S., MAGIC, VERITAS
~180 sources
E>100 GeV



Wakely & Horan+16



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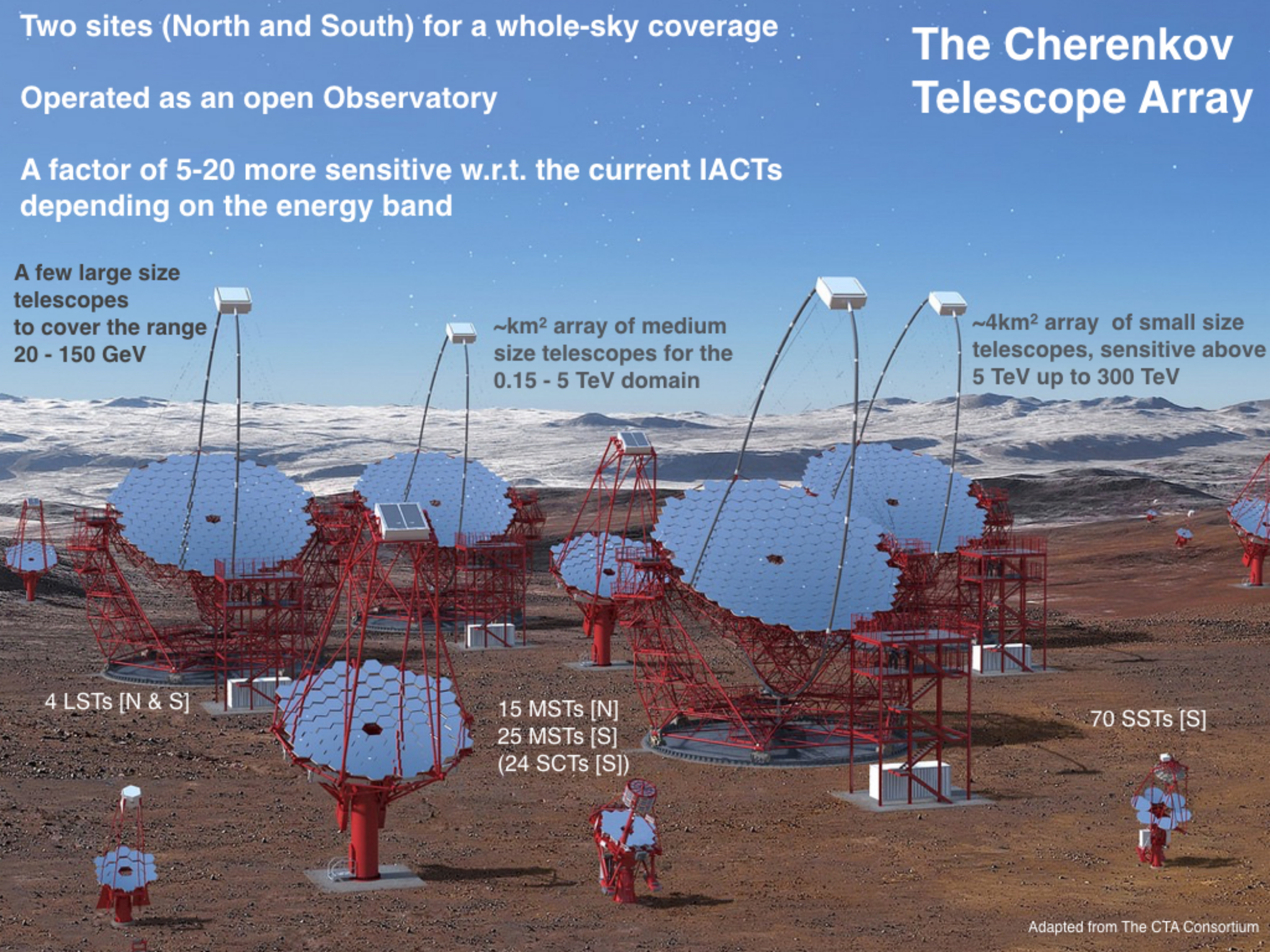

The Cherenkov Telescope Array
Two sites (North and South) for a whole-sky coverage
Operated as an open Observatory
A factor of 5-20 more sensitive w.r.t. the current IACTs depending on the energy band
A few large size telescopes to cover the range 20 - 150 GeV
~km² array of medium size telescopes for the 0.15 - 5 TeV domain
~4km² array of small size telescopes, sensitive above 5 TeV up to 300 TeV
4 LSTs [N & S]
15 MSTs [N]
25 MSTs [S]
(24 SCTs [S])
70 SSTs [S]
Adapted from The CTA Consortium

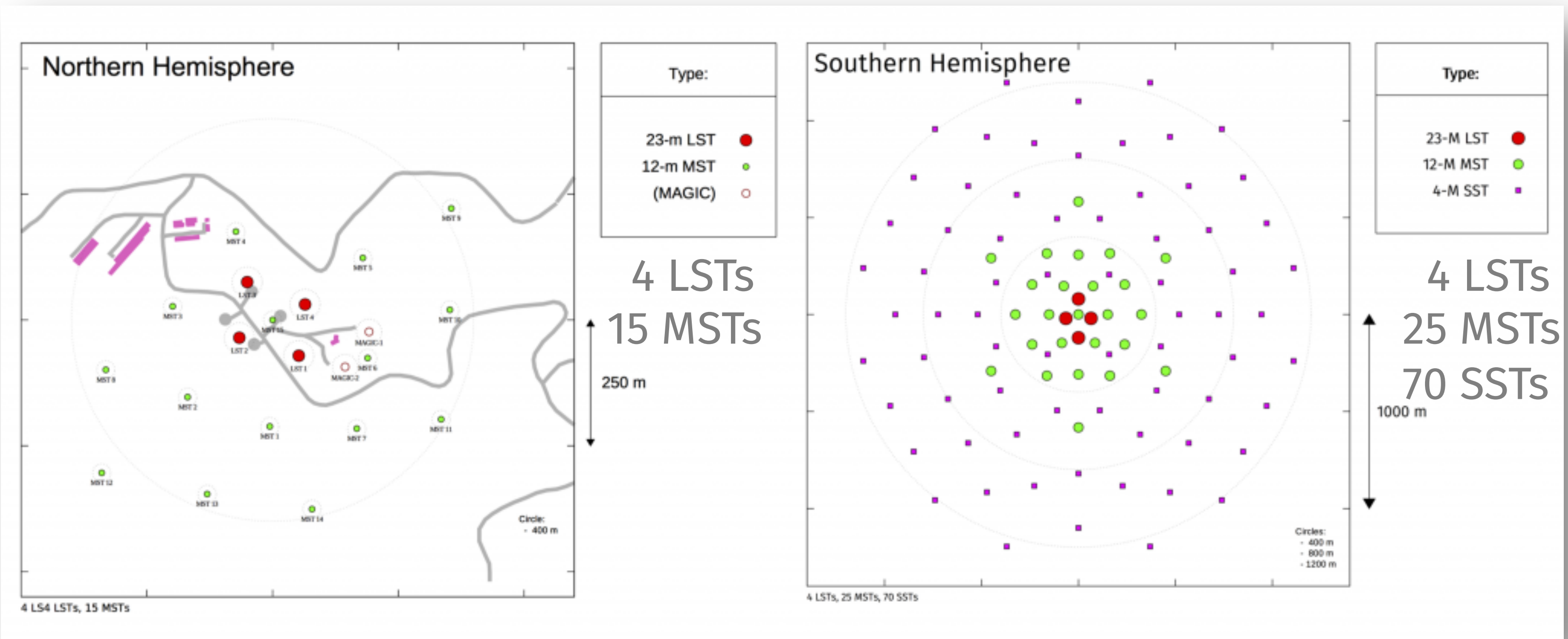
Where to find us

High-level timeline and proposed layout

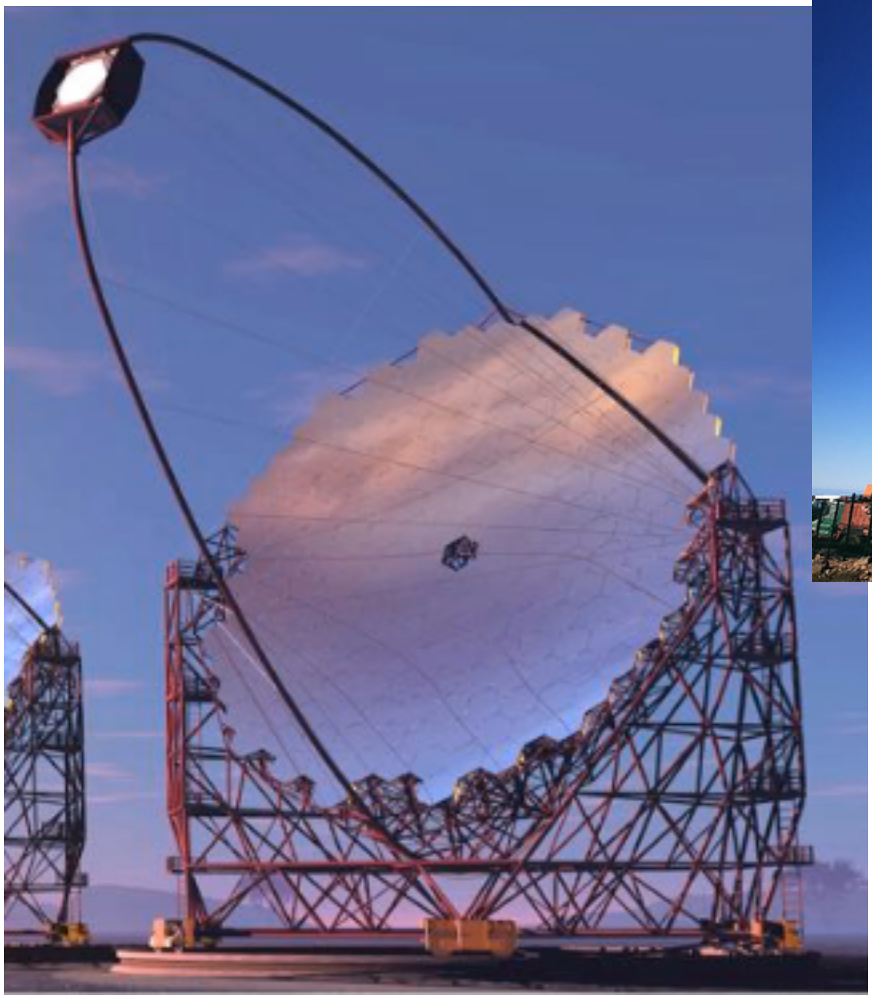
Project Phases

Pre-Construction	Pre-Production	Production
Current Phase	2019-2021	2021-2025

First Pre-Production Telescopes on Site



Large Size Telescope

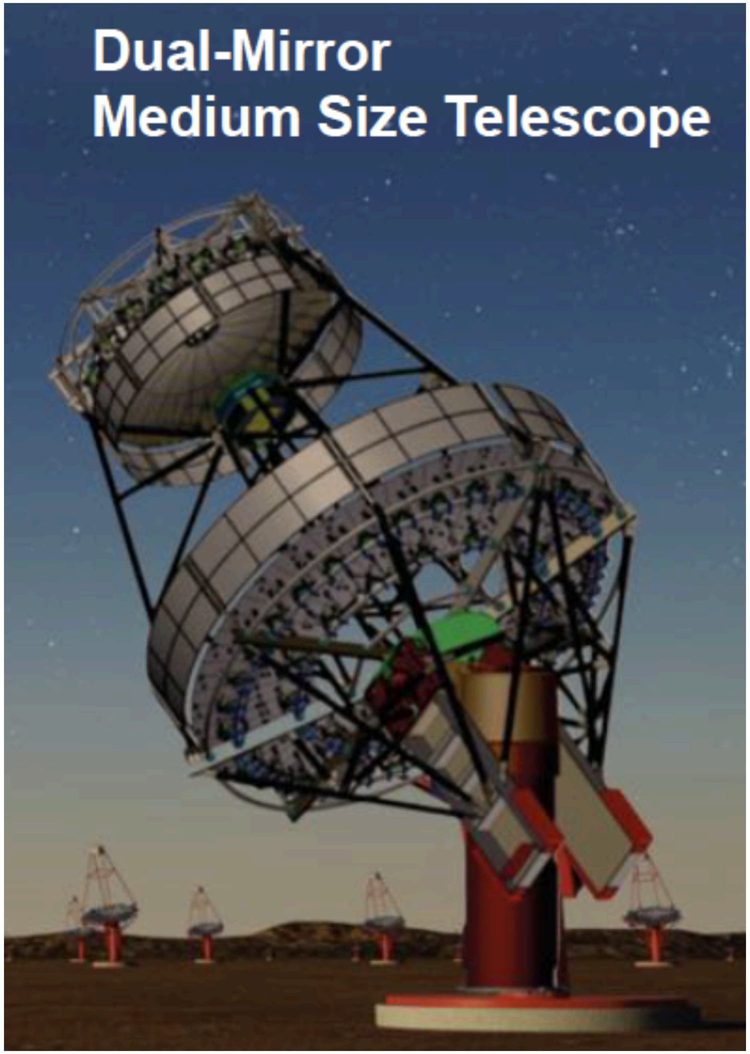


- La Palma LST-1 prototype operational in 2018.
- http://www.lst1.iac.es/webcams/

Credits: The CTA Consortium

Medium Size Telescope Prototype

Dual-mirror MST prototype



Credits: The CTA Consortium

Small size telescope prototypes

SST-2M GCT prototype in Paris

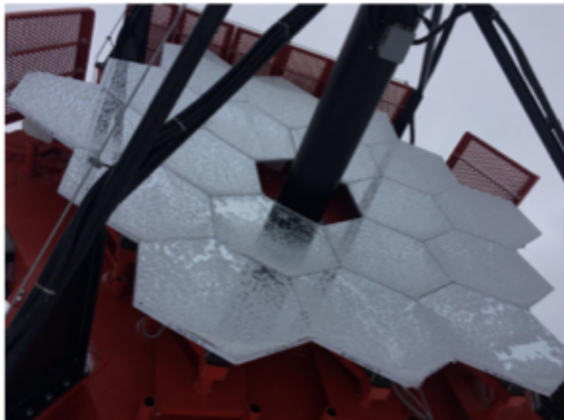
SST-1M prototype in Krakow

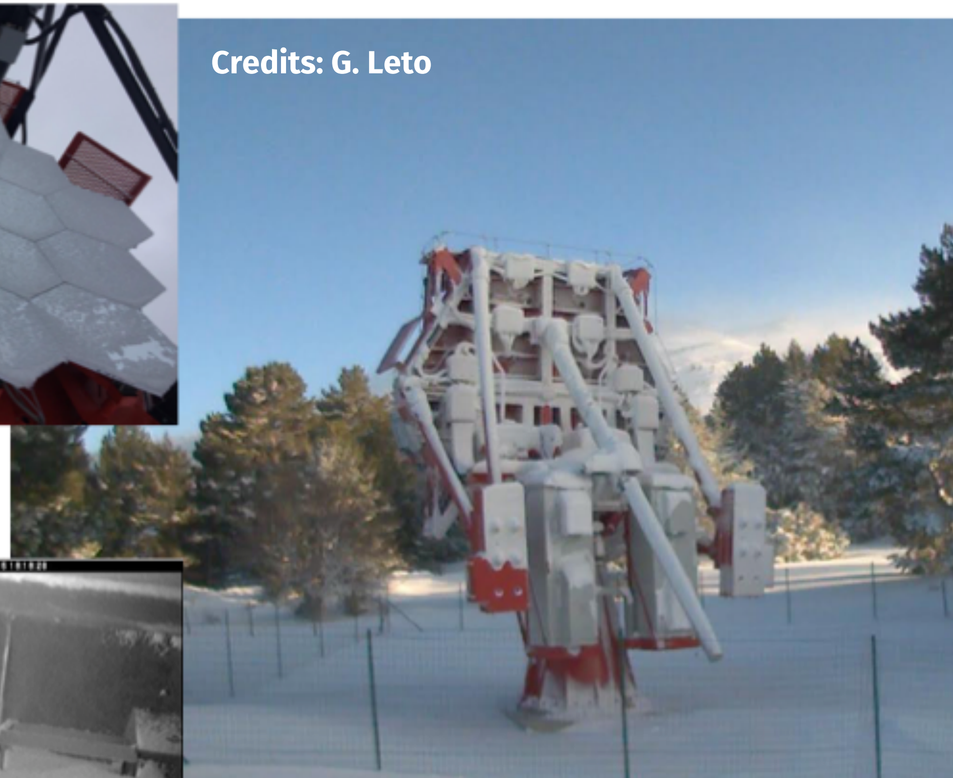
SST-2M ASTRI prototype on Mt. Etna (Sicily)

ASTRI: Etna is an astronomical site...

... in a peculiar environment...

... where Winter may be severe...

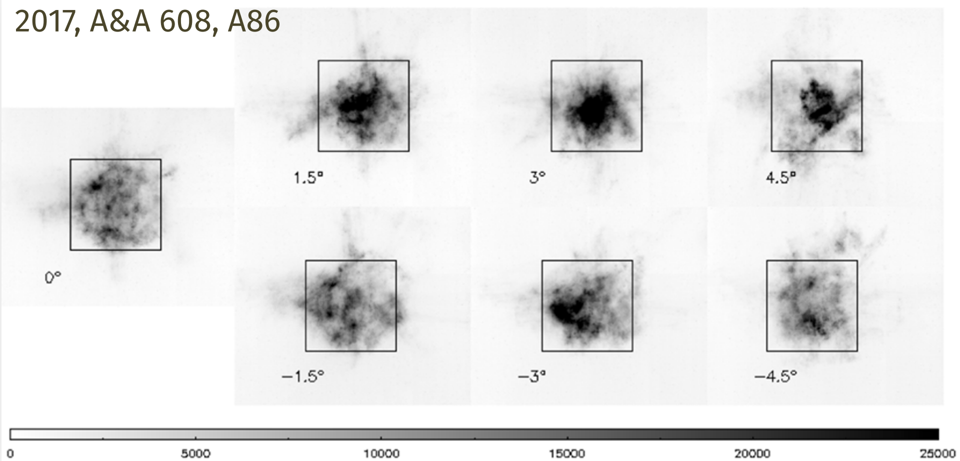




Winter 2014- 2015

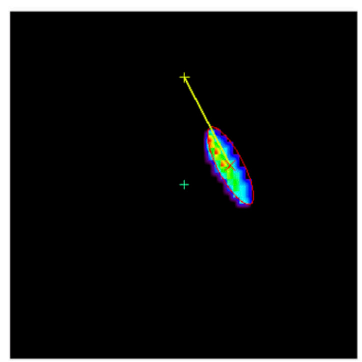
... which we pass in full colours !

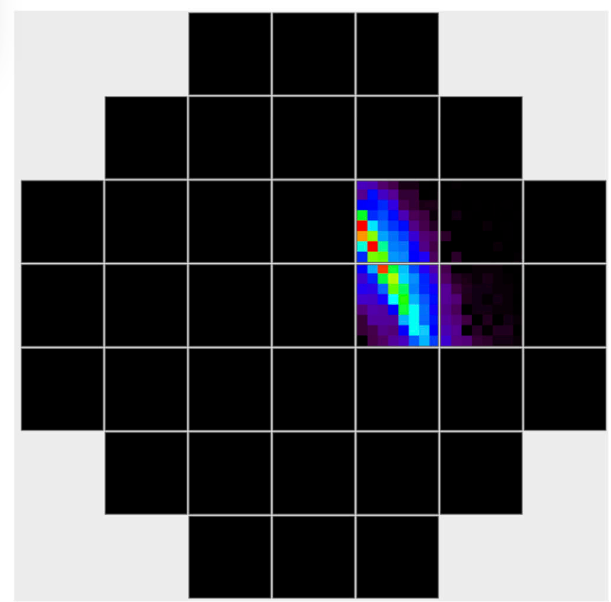
Giro, Canestrari, Sironi et al.
2017, A&A 608, A86



First ever optical characterization of a Schwarzschild-Couder telescope up to 4.5° off-axis.

First Cherenkov light acquired by the ASTRI camera of a shower generated by cosmic rays in the Earth's atmosphere.



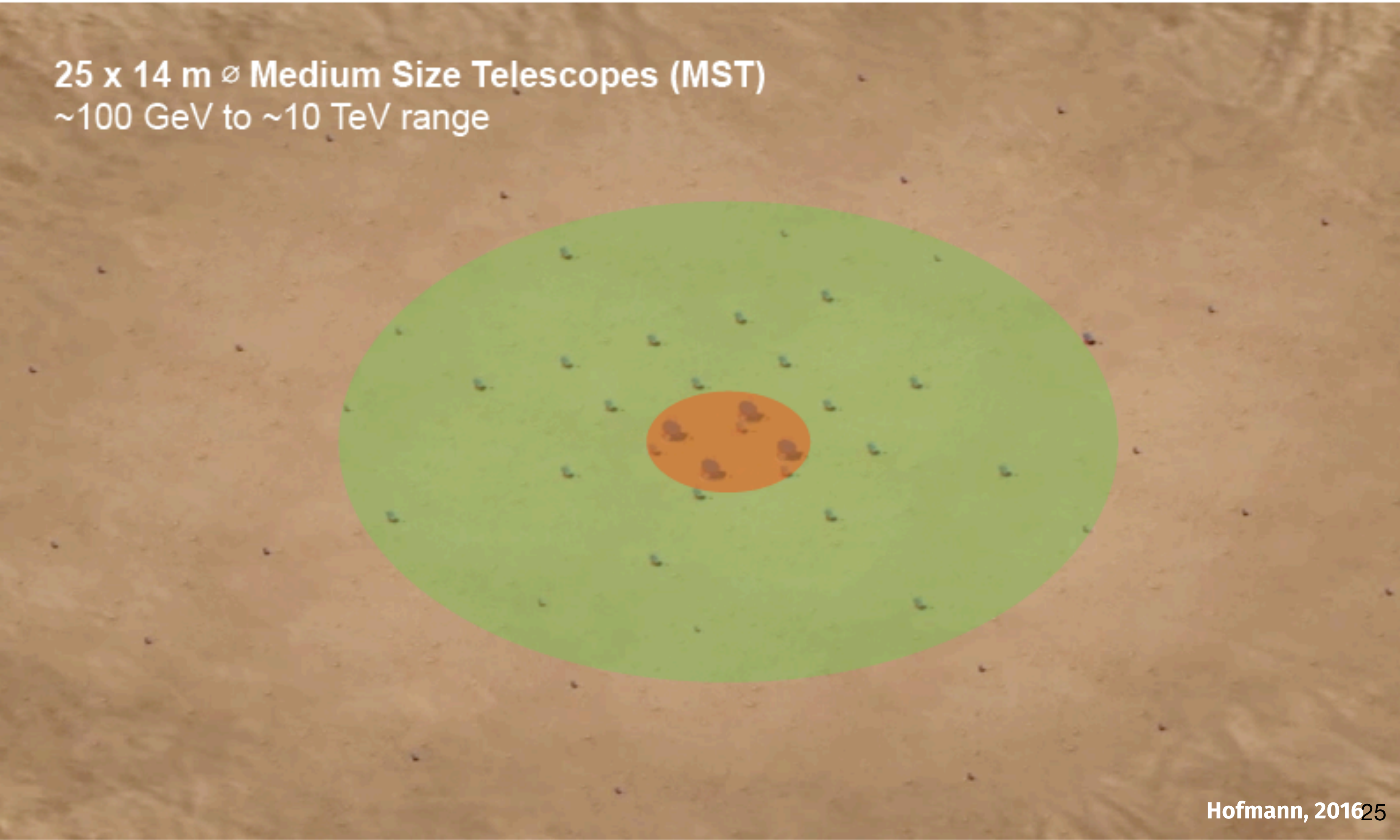


Credits: ASTRI Team, May 2017

The Cherenkov Telescope Array
(South Site)

The Cherenkov Telescope Array
(South Site)

The Cherenkov Telescope Array
(South Site)

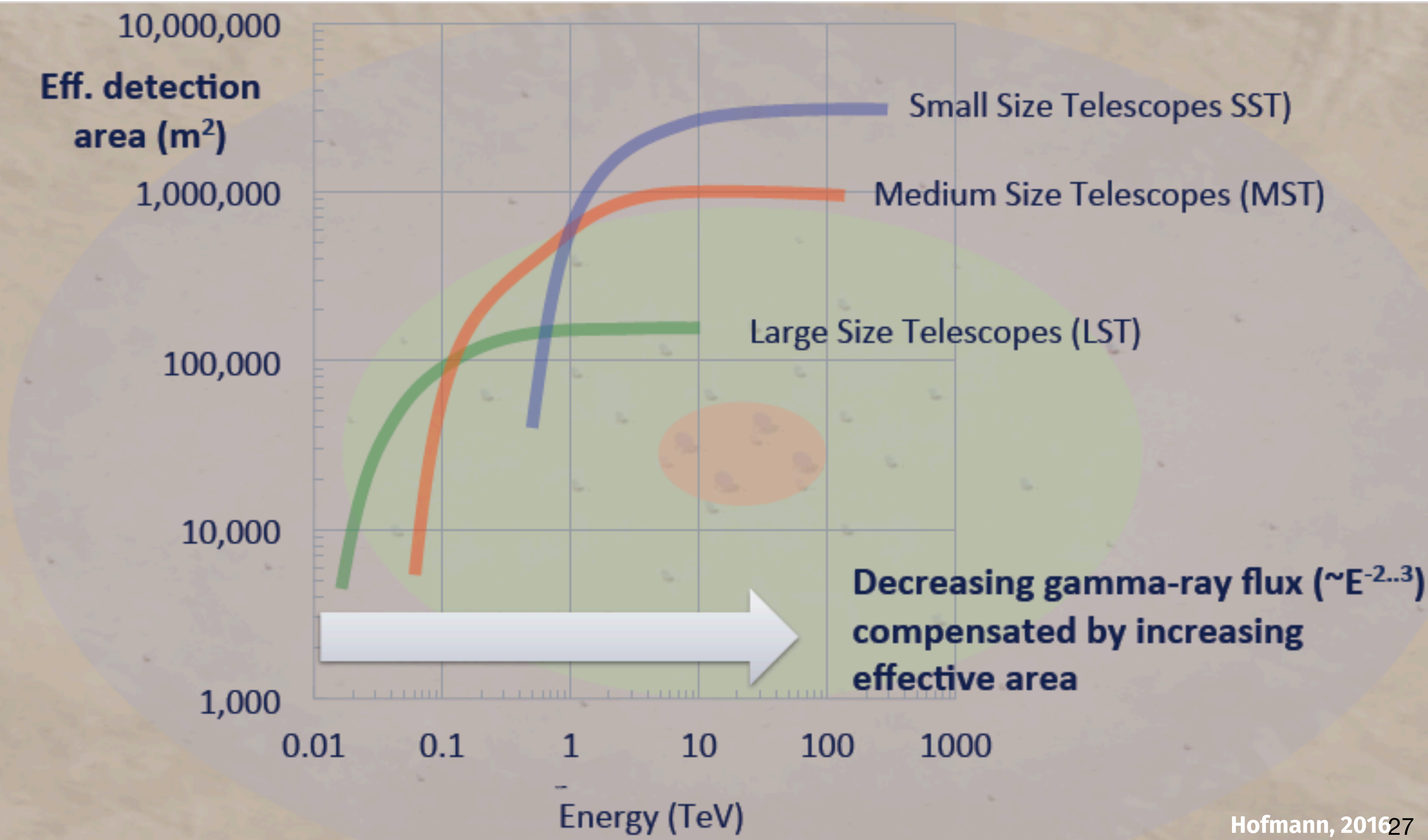


The Cherenkov Telescope Array
(South Site)

70 x 4 m ⌀ Small Size Telescopes (SST)
few TeV to few 100 TeV range

Hofmann, 2016

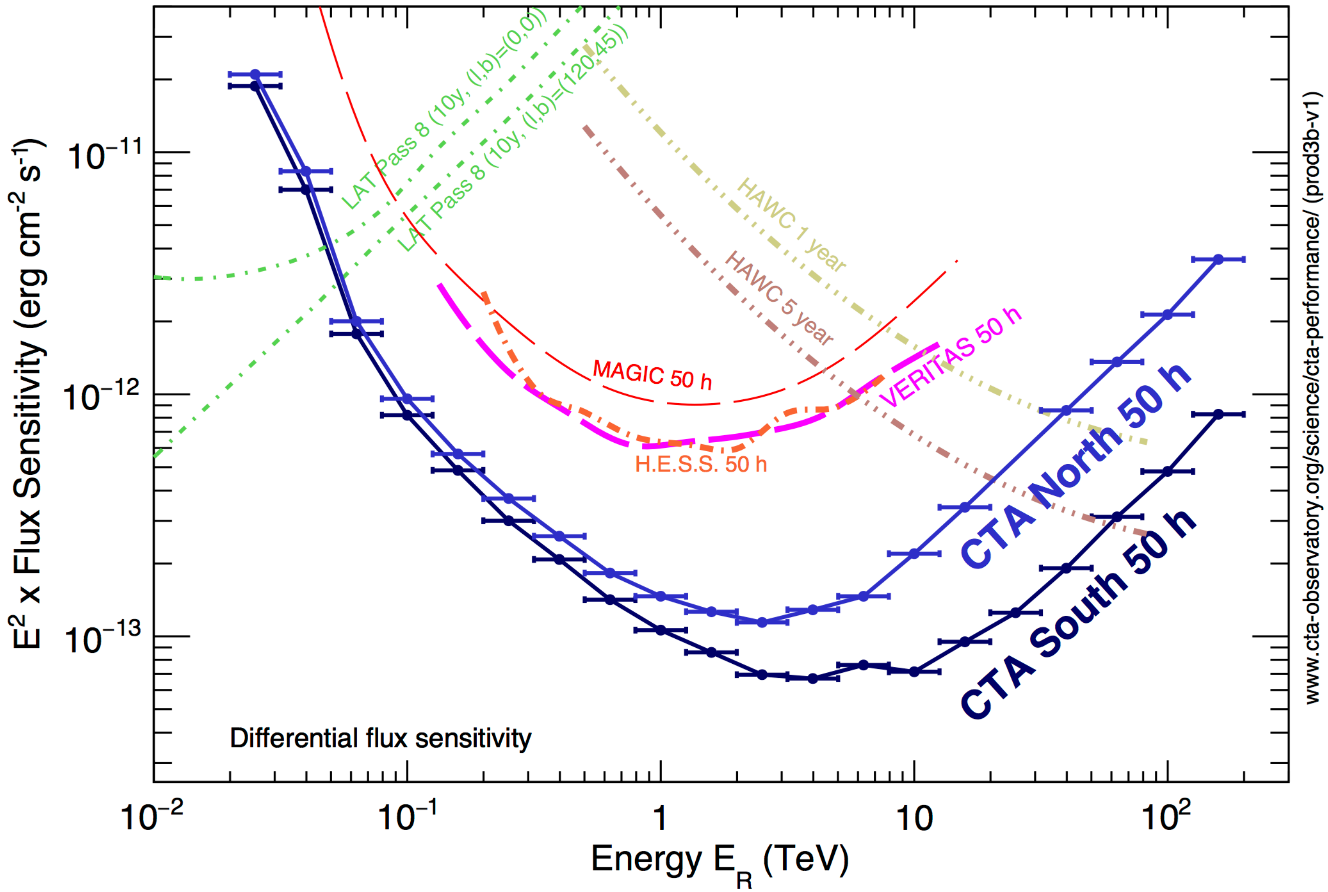
EFFECTIVE AREA FOR GAMMA-RAY DETECTION



Hofmann, 2016

CTA Performance

Differential Sensitivity



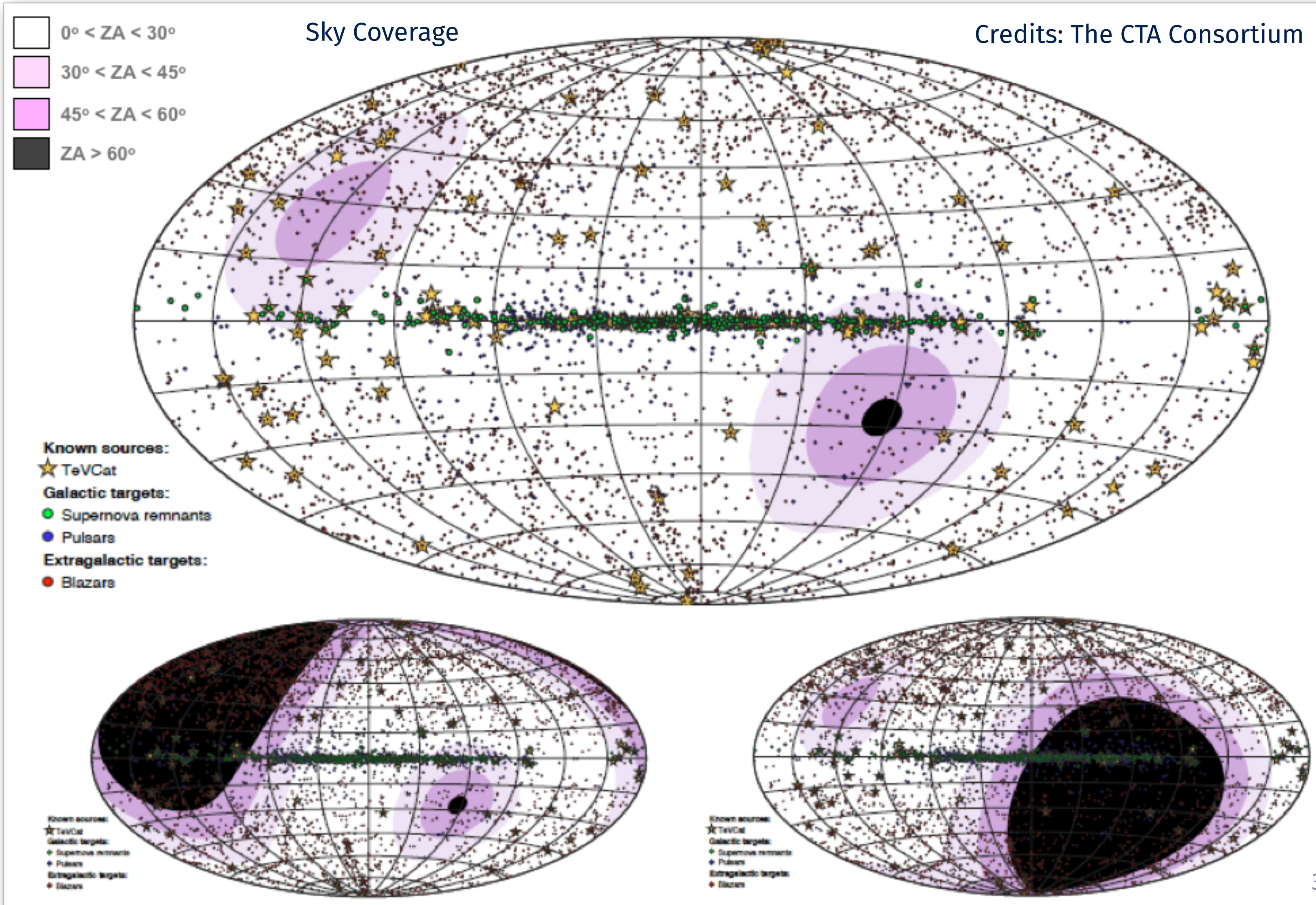
A factor of **5-20 improvement** in sensitivity depending on energy, relative to current IACTs.

Extension of the accessible energy range from **well below 100 GeV to above 100 TeV.**

https://www.cta-observatory.org/science/cta-performance/

CTA Possible Observing Strategy

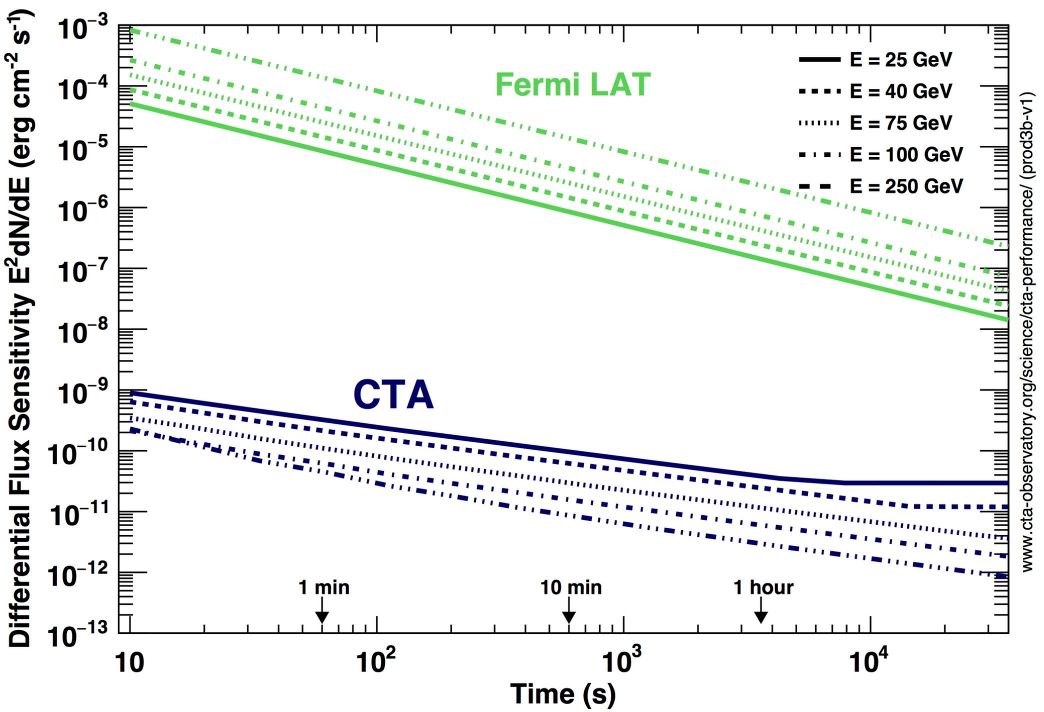
CTA as an *all-sky* Observatory



CTA as a *transient factory*

- **Huge advantage over Fermi** in energy range of overlap for ~minute to ~day timescale phenomena
  - Explosive transients
  - AGN flares
  - Binary systems

- **Disadvantage over Fermi**
  - Limited FoV (compared to Fermi)
  - Prompt reaction to external trigger is critical



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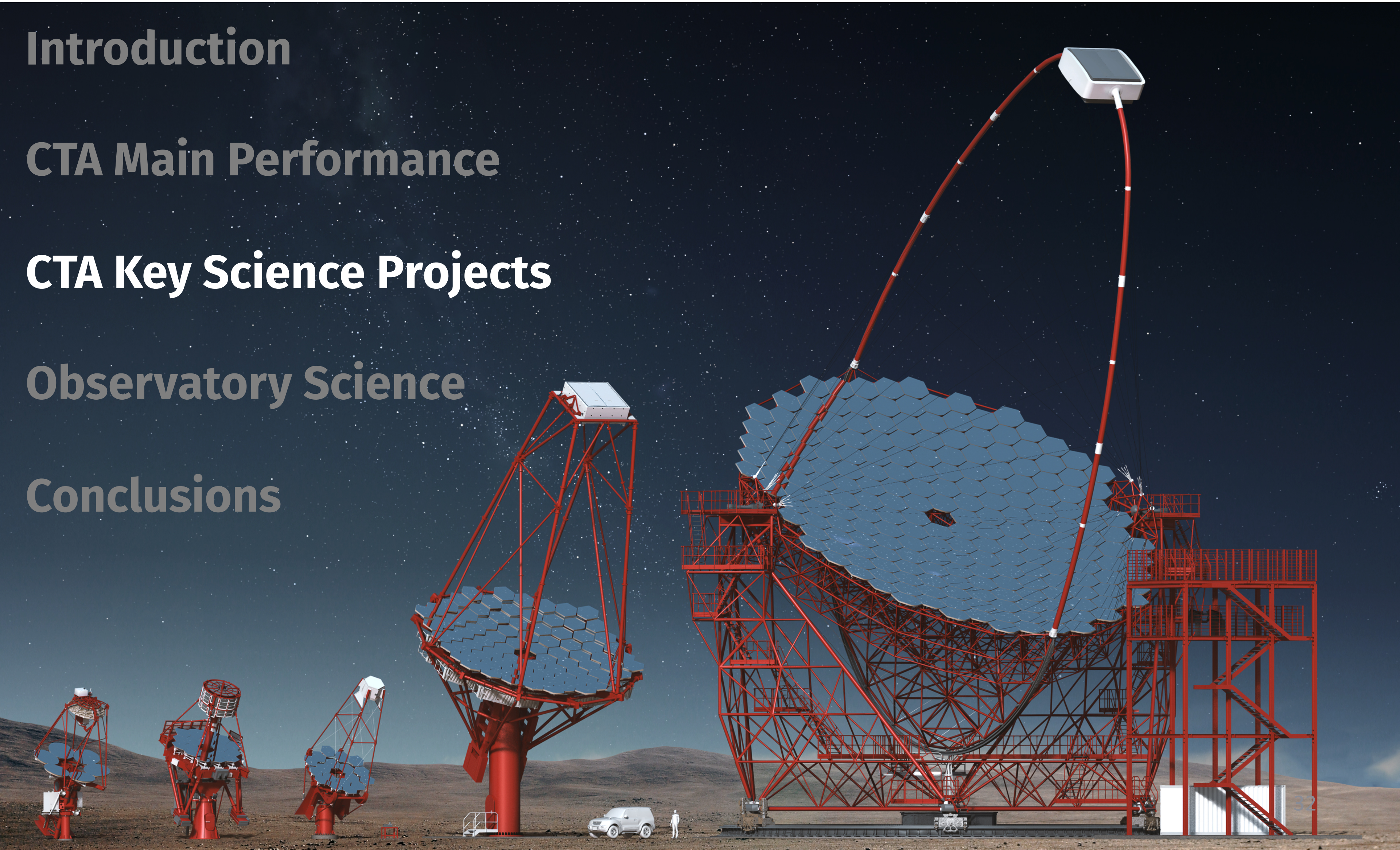


Science Themes

Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Theme 2: Probing Extreme Environments

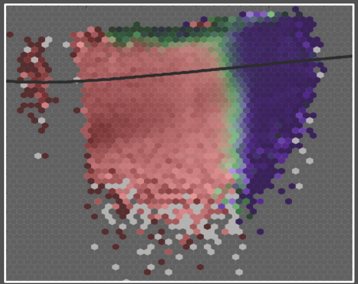
- Processes close to neutron stars and black holes?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

Theme 3: Physics Frontiers – beyond the SM

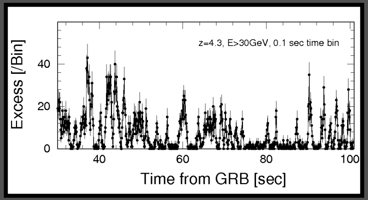
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

CTA Observing Programme

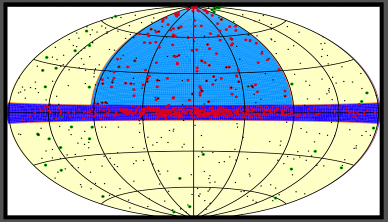
- Core Programme (baseline CTA)
  - **9 Key Science Projects** (KSPs) and **1 DM Programme**
  - Focused on **major legacy projects**: surveys & population studies (providing legacy data-sets), large classes of sources, and a few iconic objects
  - Large potential for **guest observer proposals** – building on results from the KSP surveys



Dark Matter Programme

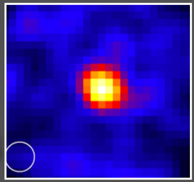


Transients



ExGal Survey

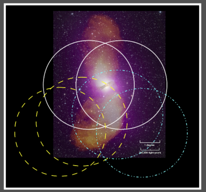
Galaxy Clusters

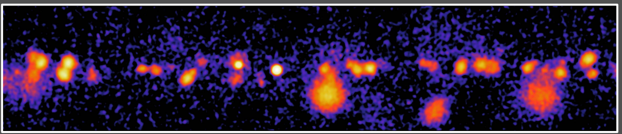


Extragalactic

Star Forming Systems

AGN

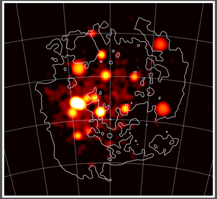




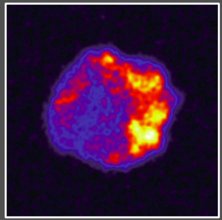
Galactic Plane Survey

Galactic

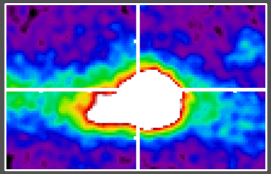
LMC Survey



PeVatrons



Galactic Centre Survey



cta
cherenkov telescope array

Mapping Science → Observations

Theme			Question	Dark Matter Programme	Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra-galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
1	Understanding the Origin and Role of Relativistic Cosmic Particles	1.1	What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔✔
		1.2	What are the mechanisms for cosmic particle acceleration?		✔	✔	✔		✔✔	✔✔	✔	✔✔	✔
		1.3	What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔		✔				✔✔	✔	✔
2	Probing Extreme Environments	2.1	What physical processes are at work close to neutron stars and black holes?		✔	✔	✔			✔✔		✔✔	
		2.2	What are the characteristics of relativistic jets, winds and explosions?		✔	✔	✔	✔	✔✔	✔✔		✔✔	
		2.3	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔	✔			✔✔	
3	Exploring Frontiers in Physics	3.1	What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔		✔						✔
		3.2	Are there quantum gravitational effects on photon propagation?						✔✔	✔		✔✔	
		3.3	Do Axion-like particles exist?					✔	✔			✔✔	

DM ← → KSPs

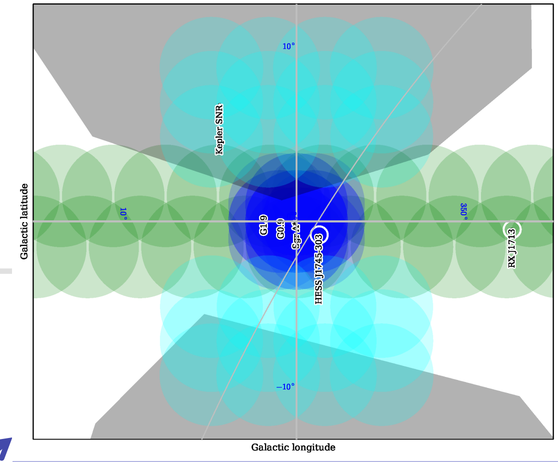
- **KSPs are sets of observations** addressing multiple science questions within CTA themes.
- **Check-marks →** impact of each KSP on a particular science question.
- **The DM Programme** has a transversal nature (GC, LMC, Galaxy Clusters).

Science with CTA

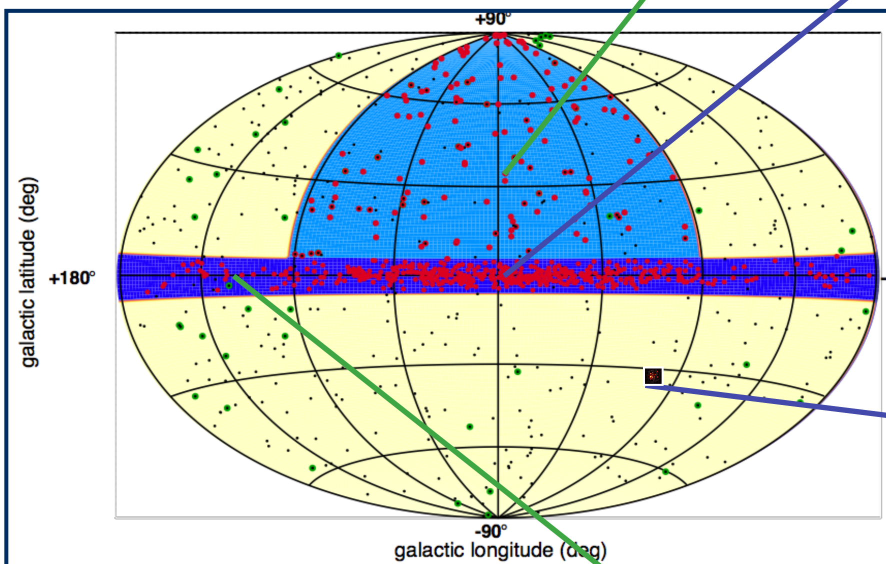
arXiv:1709.07997

To be published as a book & open-access online version by World Scientific.

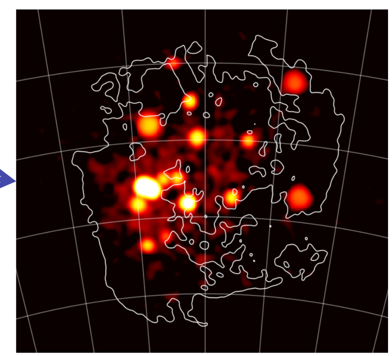
The Survey KSPs



Extragalactic Survey:
Unbiased survey of ¼ sky to ~6 mCrab
VHE population study, duty cycle
New, unknown sources; 1000 h



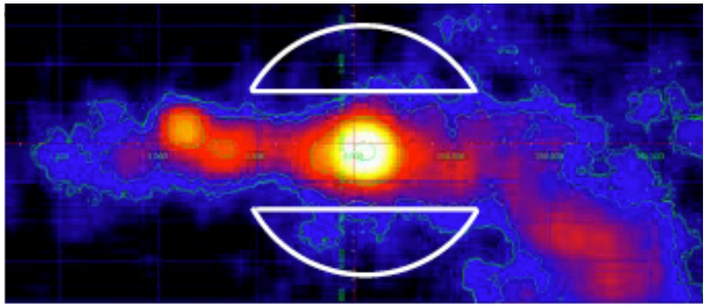
Galactic Centre Survey:
ID of the central source
Spectrum, morphology of diffuse emission
Deep DM search; base of the Fermi Bubbles
Central exposure: 525 h, 10°x10° : 300 h

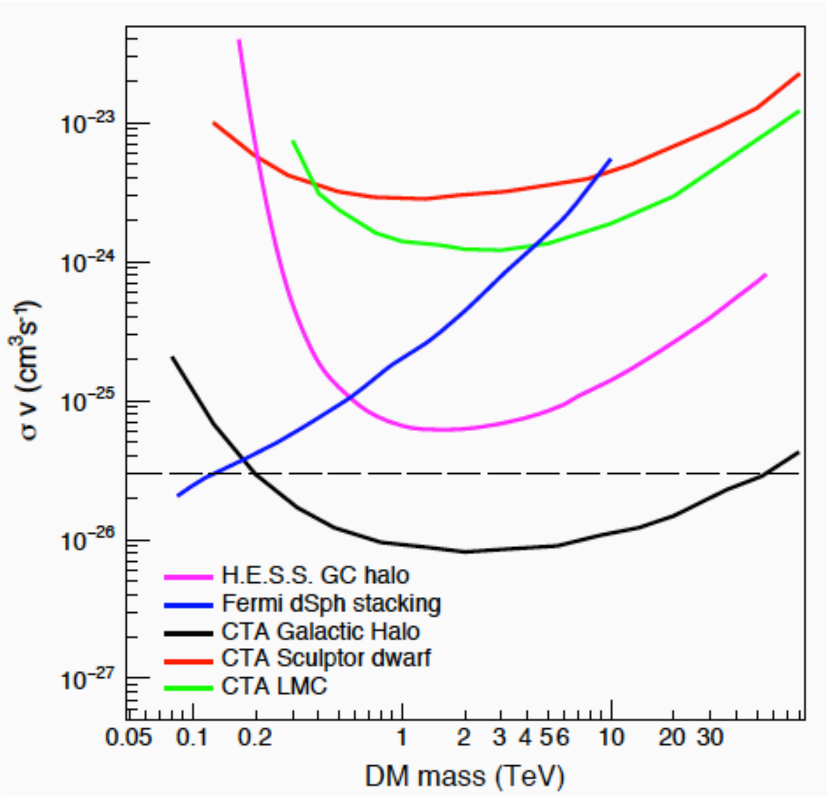


Galactic Plane Survey:
Survey of entire plane to ~2 mCrab
Galactic source population: SNRs, PWNe, etc.
PeVatron candidates, early view of GC, 1620 h

Large Magellanic Cloud Survey:
Face-on satellite galaxy with high SFR
Extreme Gal. sources, diffuse emission (CRs)
DM search; 340 h in six pointings

The Dark Matter Programme

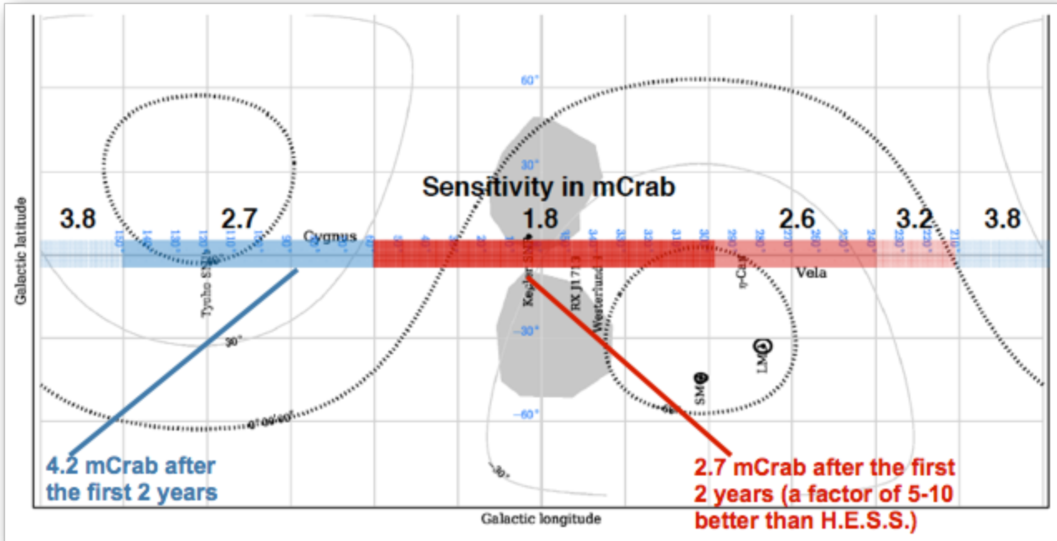




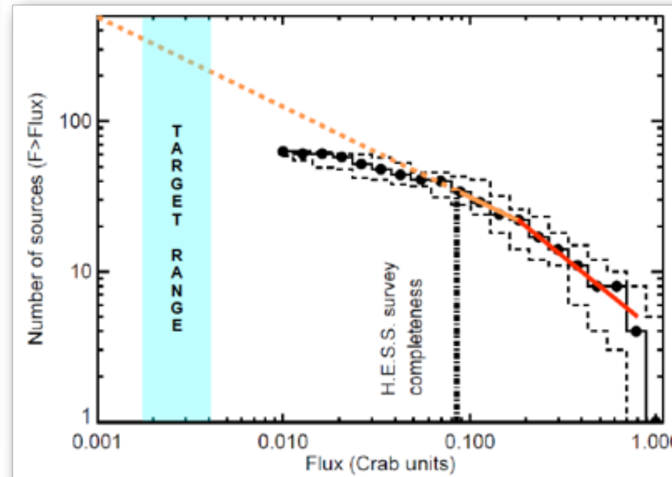
- **Key target: Galactic Centre halo**
  - Deep observation (525 h) to reach canonical thermal cross-section for wide WIMP mass range

- **Complementary observations**
  - Dwarf Sph. Galaxies (100 h)
  - LMC (340 h)
  - Perseus Gal. Cluster (300 h)
  - Expect strategy to evolve with new information

Galactic Plane Survey



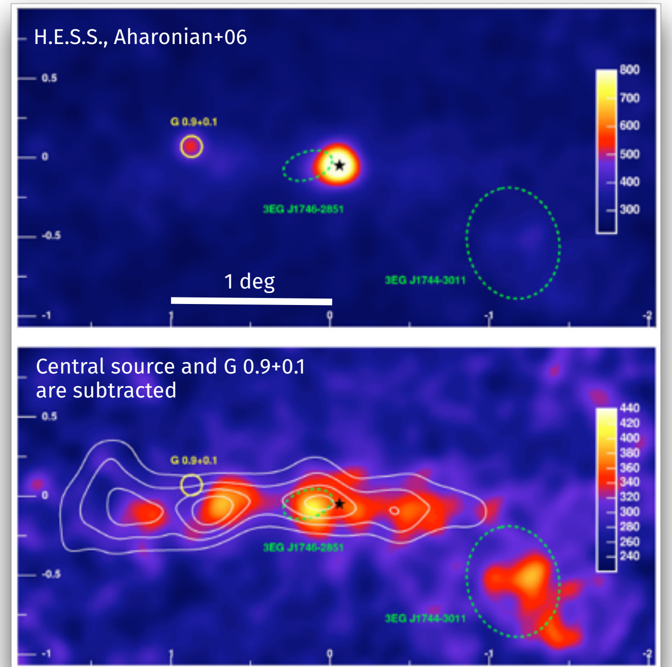
The CTA Consortium

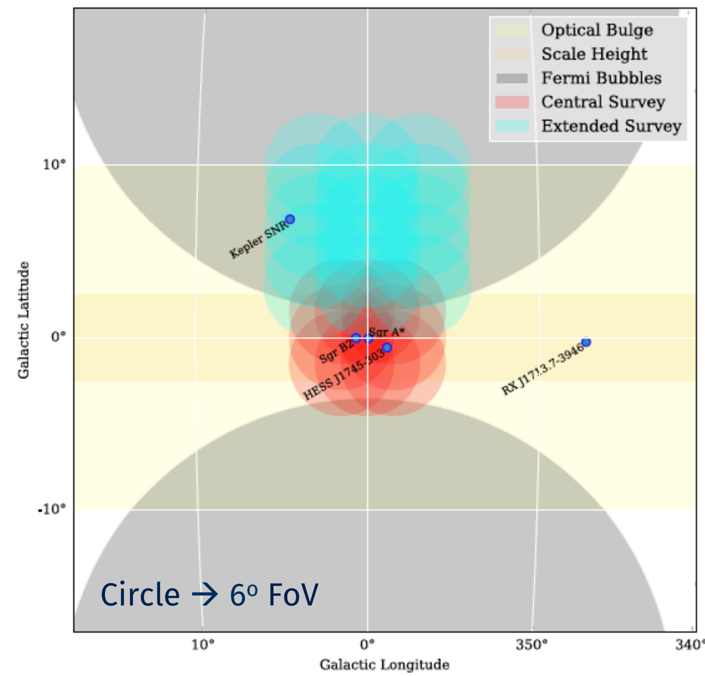


Expected results

- Discovery of new and unexpected phenomena in the Galaxy
- **Discovery of PeVatron candidates ➡ origin of cosmic rays**
- **Detection of many new VHE sources O(300 – 500), particularly PWNe and SNRs**
- Measurement of the large-scale diffuse VHE gamma-ray emission
- **Discovery of new VHE gamma-ray binaries**
- **Production of a multi-purpose legacy data set**
- The GPS will produce and periodically release sky maps and catalogues

Galactic Centre Survey





The CTA Consortium

Expected results

- **Determination of the nature of the central source**
- **A detailed view of the VHE diffuse emission**
- Resolving new, previously undetectable sources
- **Search for variability in the VHE source near Sgr A***
- Studying the interaction of the central source with neighbouring clouds

LMC Survey

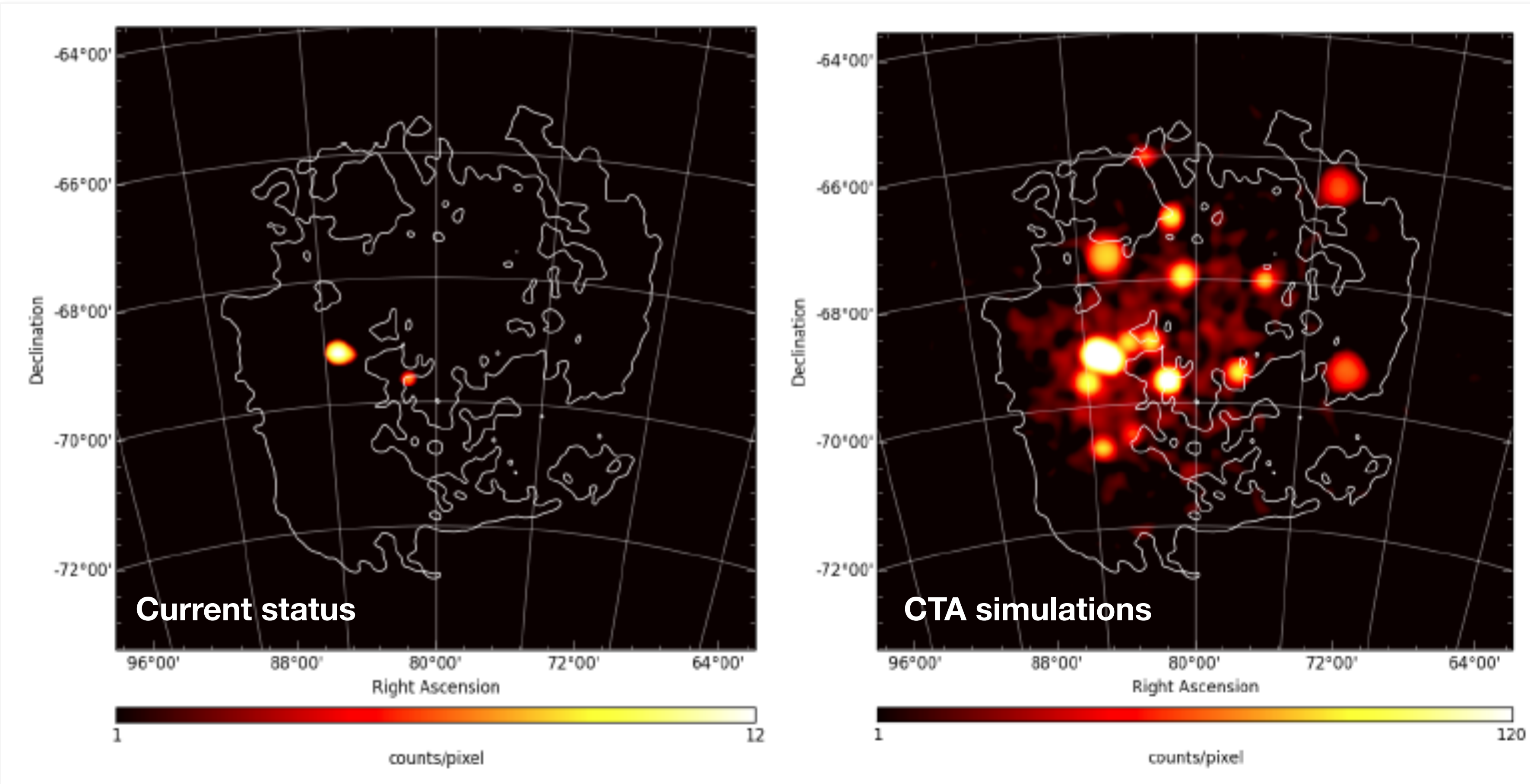
Credits: Schaefer 2015

The **Large Magellanic Cloud (LMC)** is one of the nearest **star-forming galaxies**, at a distance of 50 kpc (± 2% → important for source energetics).

Its activity is attested by more than 60 supernova remnants, dozens to hundreds of HII regions, bubbles and shells observed at various wavelengths.

It is a unique place to obtain a resolved, global view of a star-forming galaxy at TeV energies.

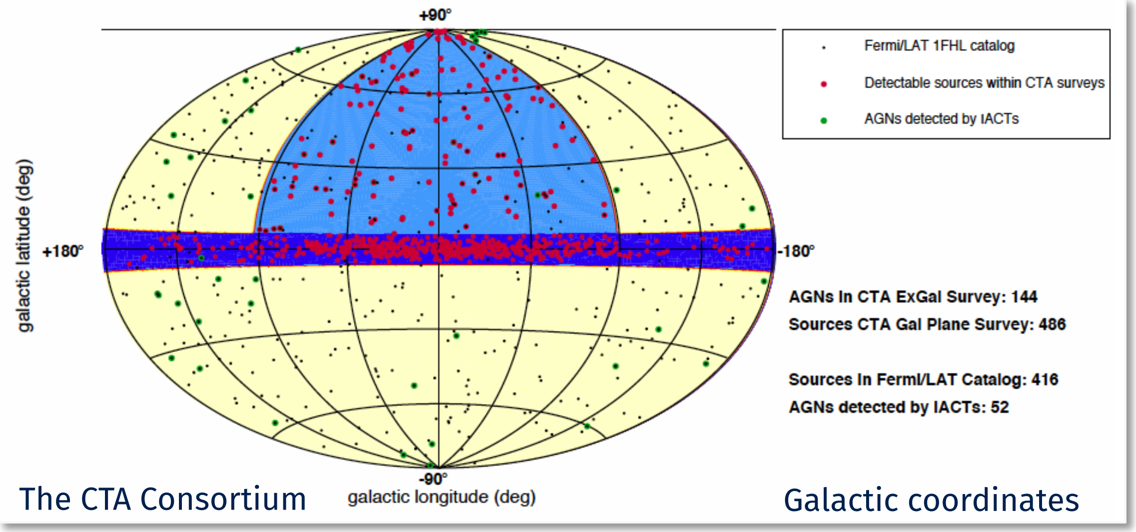
LMC Survey



Simulation includes currently detected sources, plus ten point-like sources with $L_{(E > 1\ \mathrm{TeV})}$ ~10^{34} erg s^{-1}, and a handful of regions enriched in cosmic rays.

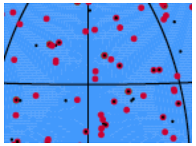
Credits: The CTA Consortium

Extra-galactic Survey



The CTA Consortium

Galactic coordinates



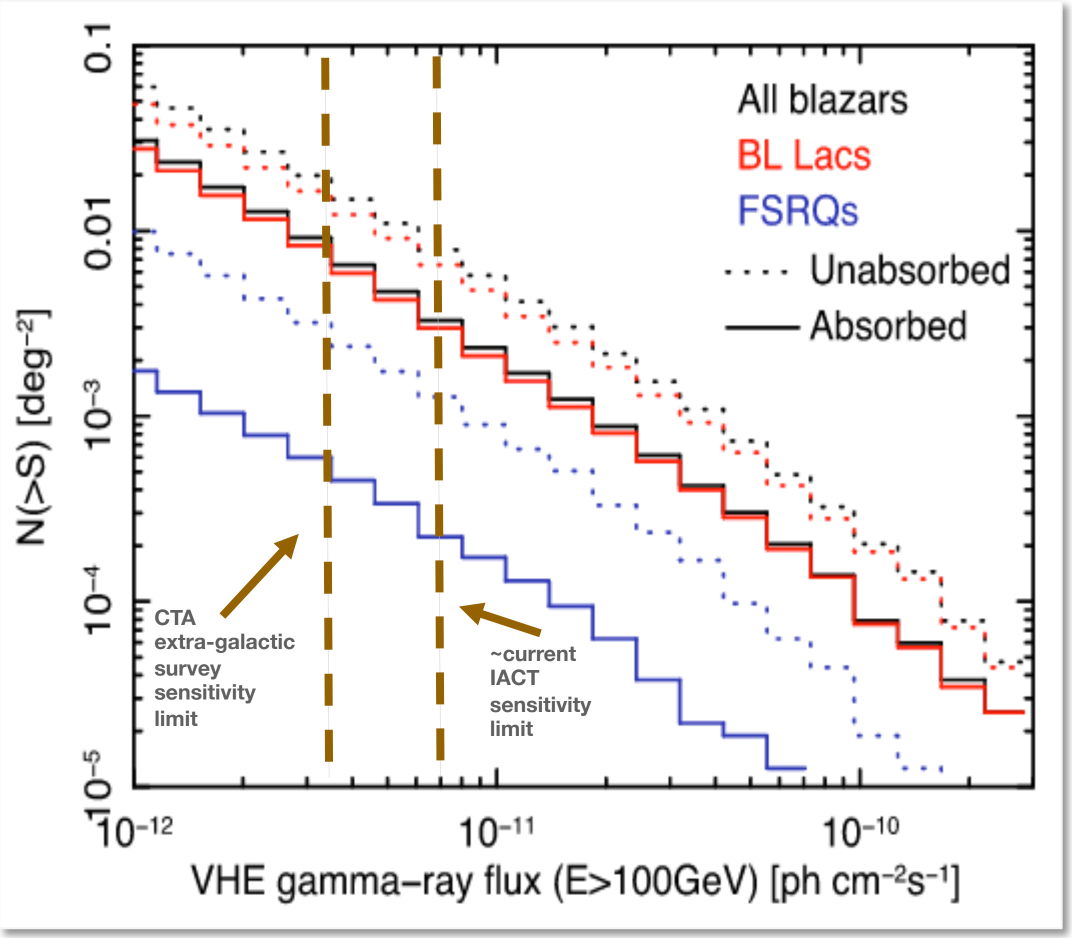
1/4 of the sky (~10^4 deg^2)
Limiting flux ~ 5 mCrab

The survey would connect with the Galactic Plane Survey (|b| < 5°) over Galactic longitude −90° < l < 90°.

Several highly interesting regions such as the Virgo & Coma clusters, the Fermi Bubbles (North) and Cen A (South) will be covered by the proposed survey.
The EGAL survey will be useful to investigate dark matter sub-halos.

Current simulations suggest that a wide-field, shallow survey should detect more sources than a narrow-field, deep survey (given an equal survey time).

Extra-galactic Survey



Padovani & Giommi (2015)

Padovani & Giommi (2015) derived the expected number of blazars on the sky in the GeV–TeV domain.

With the 5 mCrab sensitivity during the proposed survey**, CTA should detect around 100 sources in 10,000 deg².**

Multi-messenger Astrophysics window is open !

Detection of a gravitational wave event following a GRBs onset and its MWL follow-up

```
TITLE:    GCN CIRCULAR
NUMBER:   21916
SUBJECT:  IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE:     17/09/23 01:09:26 GMT
FROM:     Erik Blaufuss at U. Maryland/IceCube  <blaufuss@icecube.umd.edu>
```

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel

Credential

Subjects: Optical, Gam

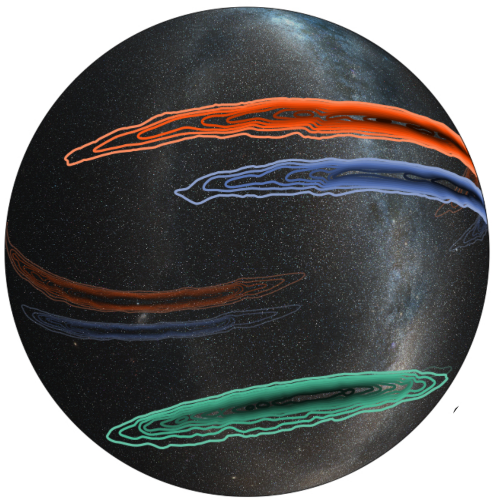
Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Possible association of an extra-galactic source with an IceCube neutrino event.

Transients



Credits: The LIGO Scientific Collaboration

Transients are a diverse population of astrophysical objects. Some are known to be prominent **emitters of high-energy gamma-rays,** while others are sources of non-photonic, multi-messenger signals such as cosmic rays, **neutrinos and/or gravitational waves** (GW → MoU already signed).

		Observation times (h yr^{-1} $site^{-1}$)			
Priority	Target class	Early phase	Years 1–2	Years 3–10	Years 1–10
1	GW transients	20	5	5	
2	HE neutrino transients	20	5	5	
3	Serendipitous VHE transients	100	25	25	
4	GRBs	50	50	50	
5	X-ray/optical/radio transients	50	10	10	
6	Galactic transients	150	30	0(?)	

Follow-up priority	Target class	Detected @ HE	Trigger	Rate (yr^{-1})	Urgency	Activity duration	Obs. time (h) /night	Total time (h)	Site
1	Magnetar giant flares	–	MeV	0.1	1 min	1–2 d	Max. 1	10	A/B
2	PWN flares: Crab nebula	Y	HE	1	1 d	5–20 d (HE)	4	50	S&N
3	HMXB microquasars: Cyg X-3	Y	HE/X-ray	0.5	1 d	50–70 d (HE)	Max. 1	50	N
	Cyg X-1	Y	HE/X-ray	0.2	1 d	1–10 d ?	Max. 1	30	N
4	Unidentified HE transients	Y	HE	1	1 d	?	2	20	A/B
5	LMXB microquasars	?	X-ray/radio	1	1 d	Weeks	2	20	A/B
6	Novae	Y	HE/opt.	2	1 d	Weeks	2	20	A/B
7	Transitional pulsars	Y	Radio/opt.	0.5	1 d	Weeks	2	20	A/B
8	Be/X-ray binary pulsars	N	X-ray	1	1 d	Weeks	2	20	A/B

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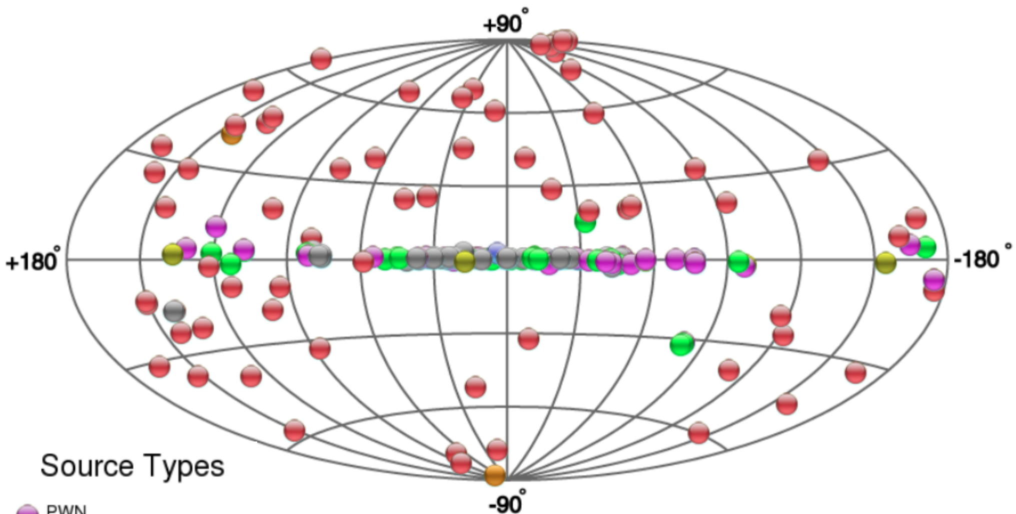
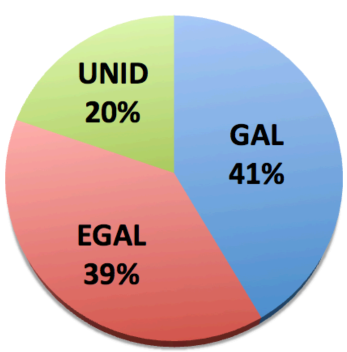
The sky above 50 GeV

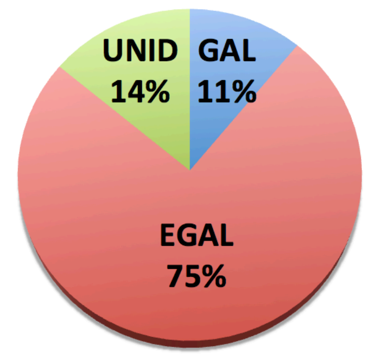


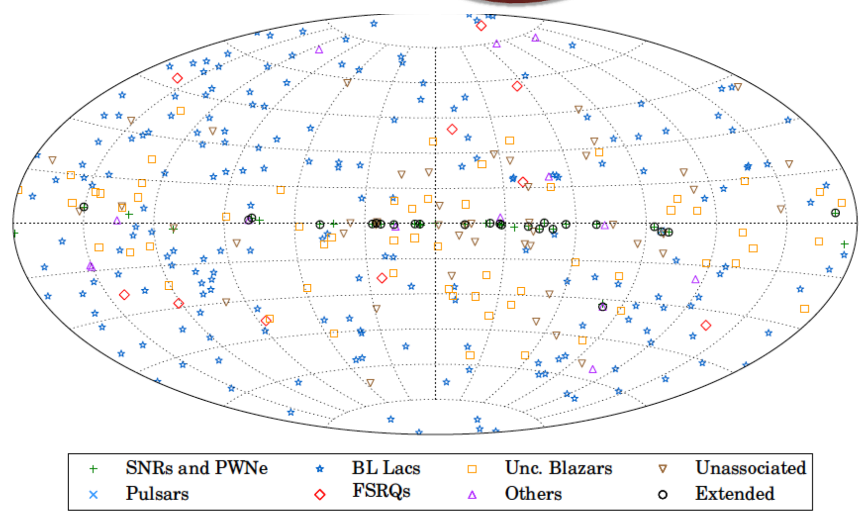
Wakely & Horan http://tevcat.uchicago.edu/

~180 TeVCat sources



360 *Fermi*-LAT sources E>50 GeV





2FHL Ackermann+16

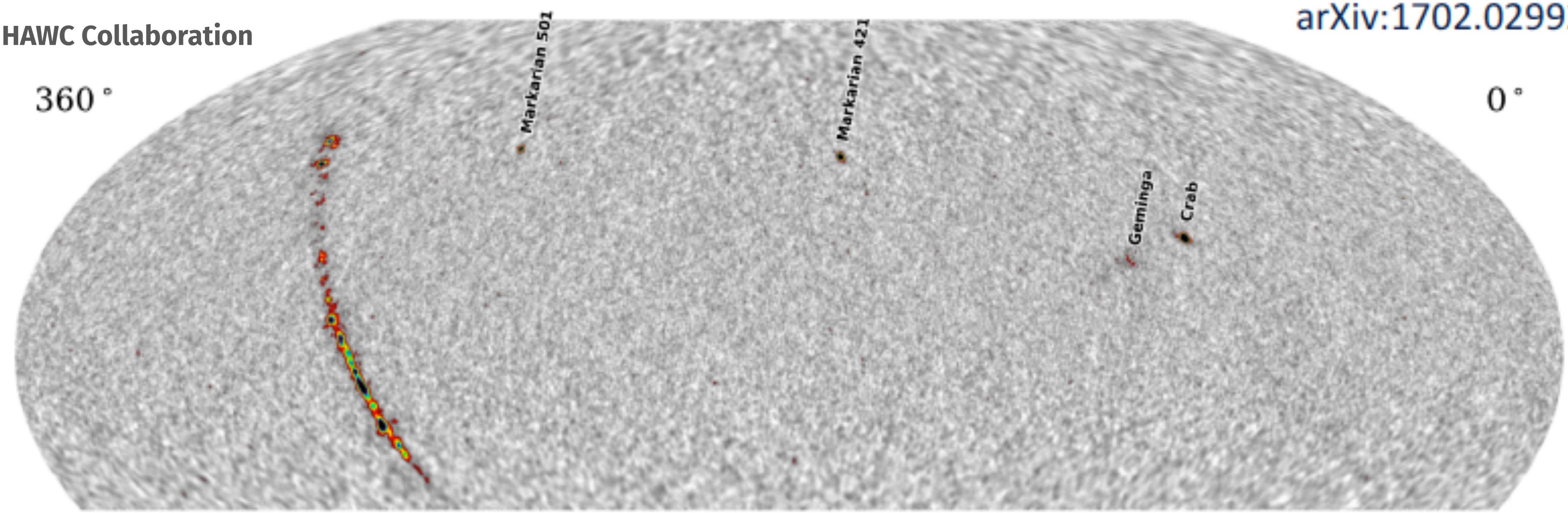
Only ~25% of the 2FHL sources have been previously detected by Cherenkov telescopes.

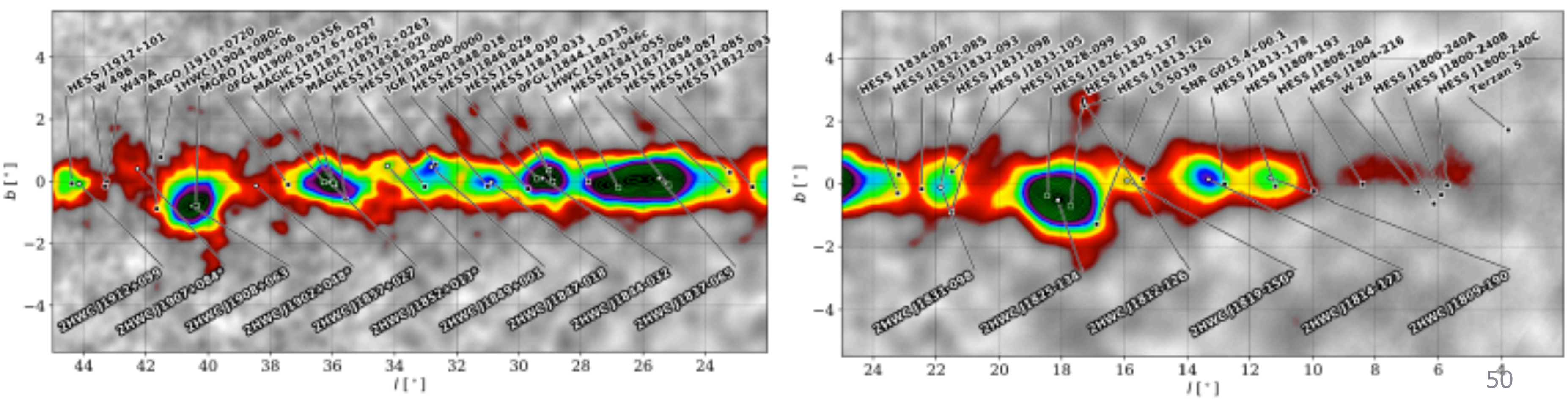
2FHL provides a reservoir of candidates to be followed up at very high energies.

0.1 – 100 TeV sky

HAWC Collaboration

arXiv:1702.02992





KSPs vs. proposal-driven programs

Key Science Projects

- Ensure that important science questions for CTA are addressed in a coherent fashion and with a well-defined strategy,
- Conceived to provide legacy data sets for the entire community

Example: galactic and extragalactic surveys

- Deep investigation of known sources
- Follow-up of KSP discovered sources
- Multiwavelength campaigns
- Follow-up of ToOs from other wavebands / messengers
- Search for new sources
- ...

Proposal-Driven User Programme

Credits: Hofmann, Gamma 2016

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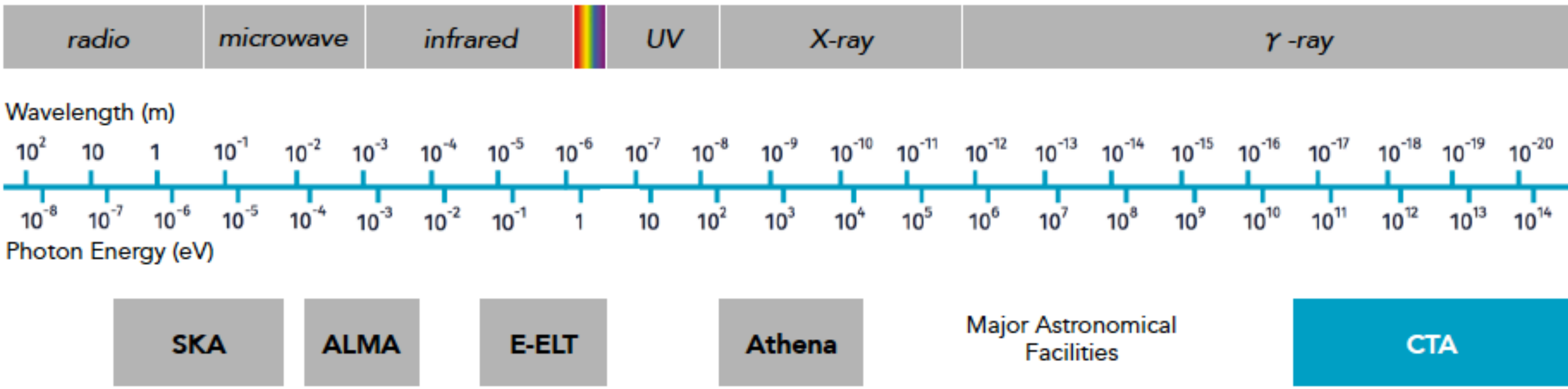
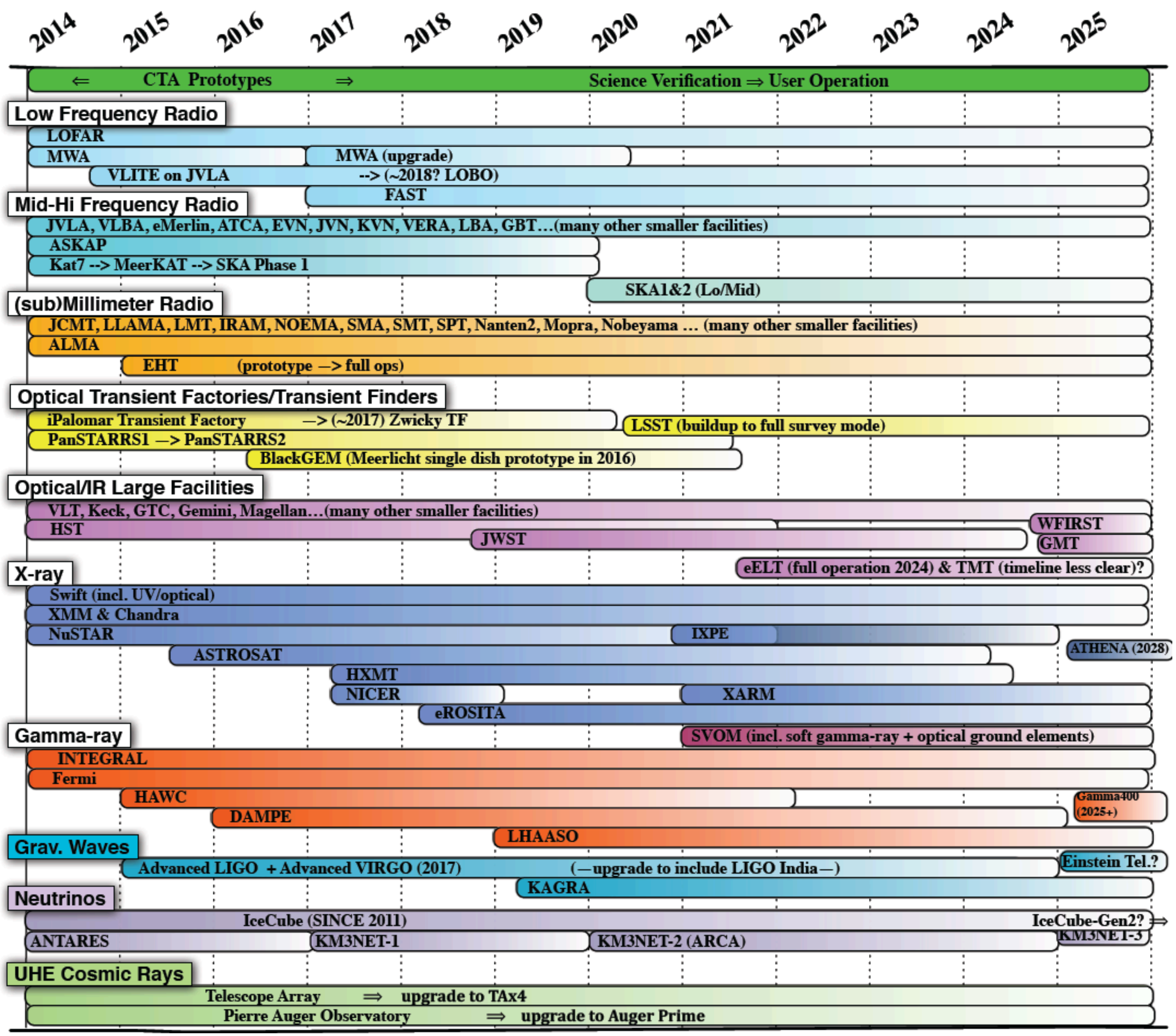
Synergies during CTA operation



These are just a few of the MWL facilities available during the CTA era.

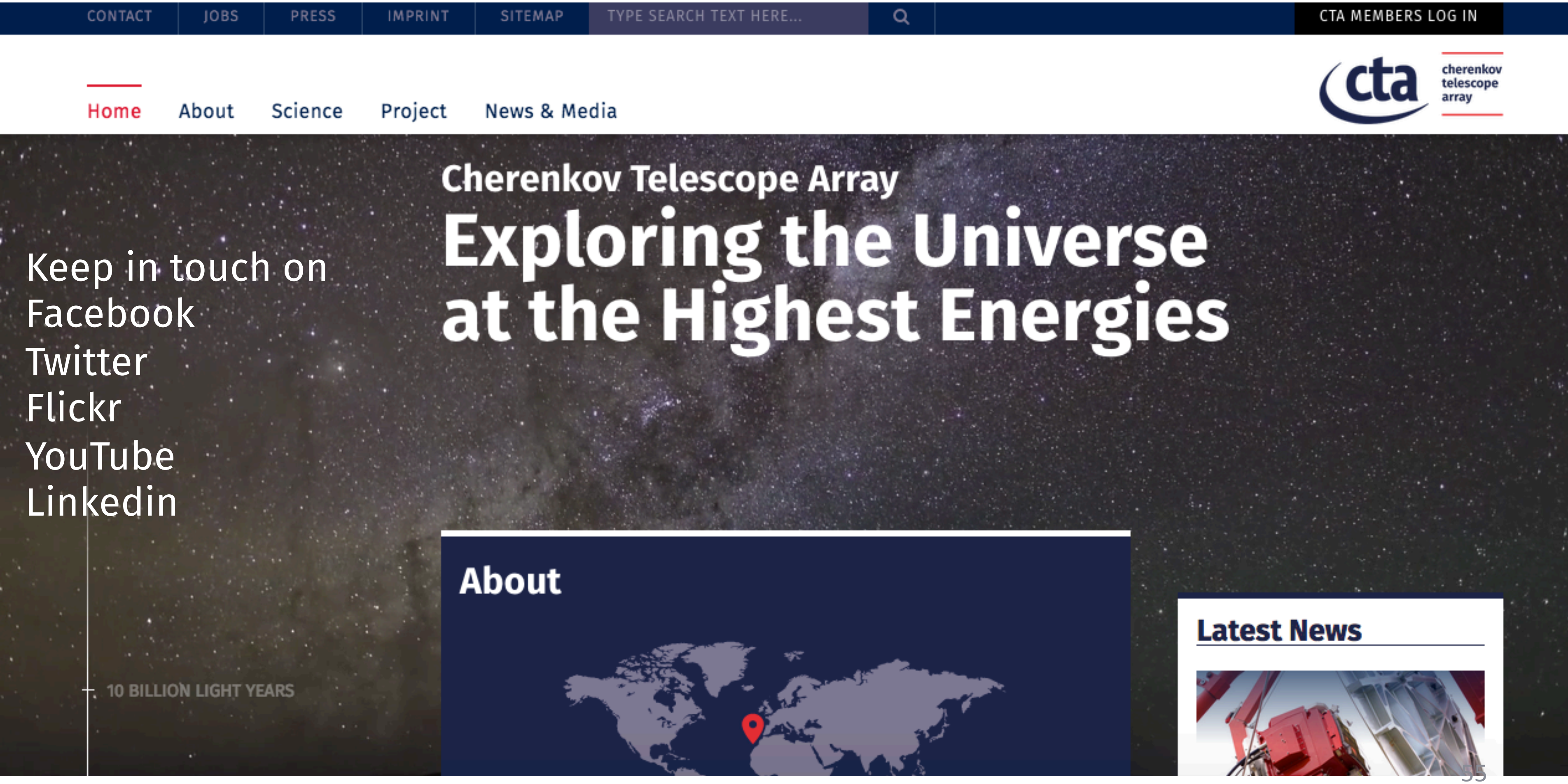
Next slide shows…

Synergies during CTA operation



CTA Main webpage

https://www.cta-observatory.org/



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  - Hinton and Hofmann, Annual Review of Astronomy and Astrophysics, 47, 523 (2009)
- **Seeing the High-Energy Universe with the Cherenkov Telescope Array - The Science Explored with the CTA**
  - Edited by Hinton, Sarkar, Torres and Knapp, Astroparticle Physics Volume 43, Pages 1-356 (March 2013)
- **CTA Contributions to the 2017 ICRC Conference**
  - [https://arxiv.org/html/1709.03483]
- **Science with the Cherenkov Telescope Array**
  - Edited by Hinton, Ong and Torres, arXiv:1709.07997

Summary

CTA will be an **Observatory** open to the scientific community.

Science will focus on cosmic particle acceleration, extreme environments, and physics beyond the standard model.

Proprietary time (significant fraction in the first years) will be articulated in **Key Science Projects.**

Large potential for **Guest Observer proposals** – e.g., building on results from the KSP surveys.

CTA will have important **synergies** with many of the new generation of astronomical and astro-particle observatories.

Thanks !

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