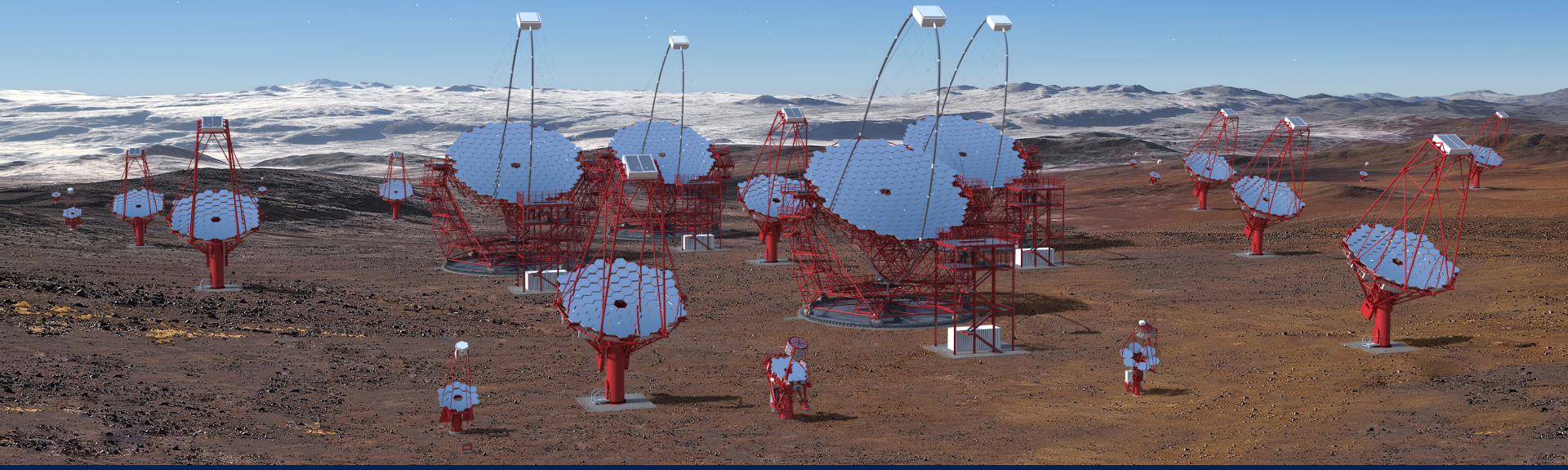
cherenkov telescope array

Synergies between SKA and the Cherenkov Telescope Array



Stefano Vercellone (INAF – OA Brera) stefano.vercellone@brera.inaf.it
for the CTA Consortium

2nd National Workshop of SKA science and technology

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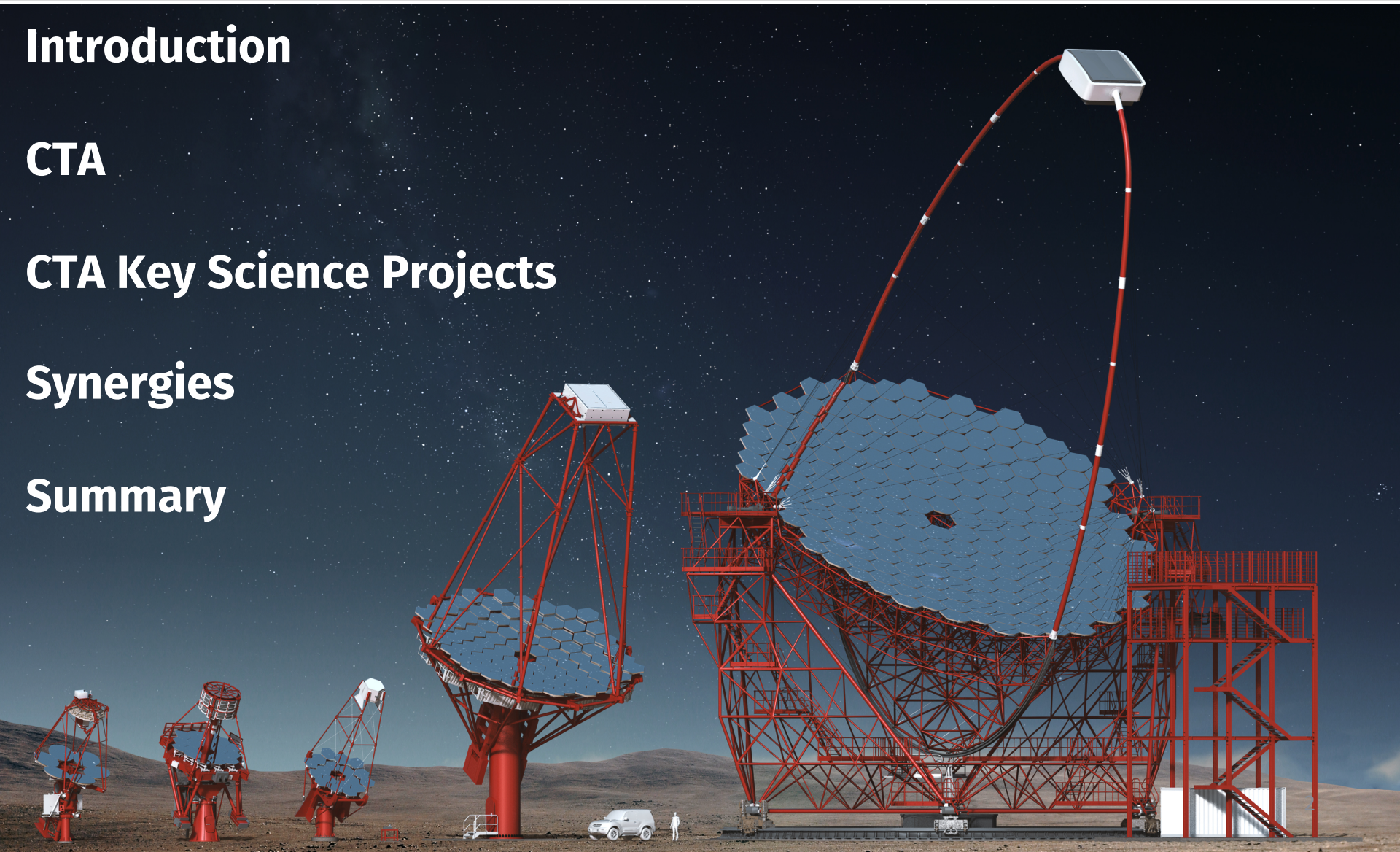

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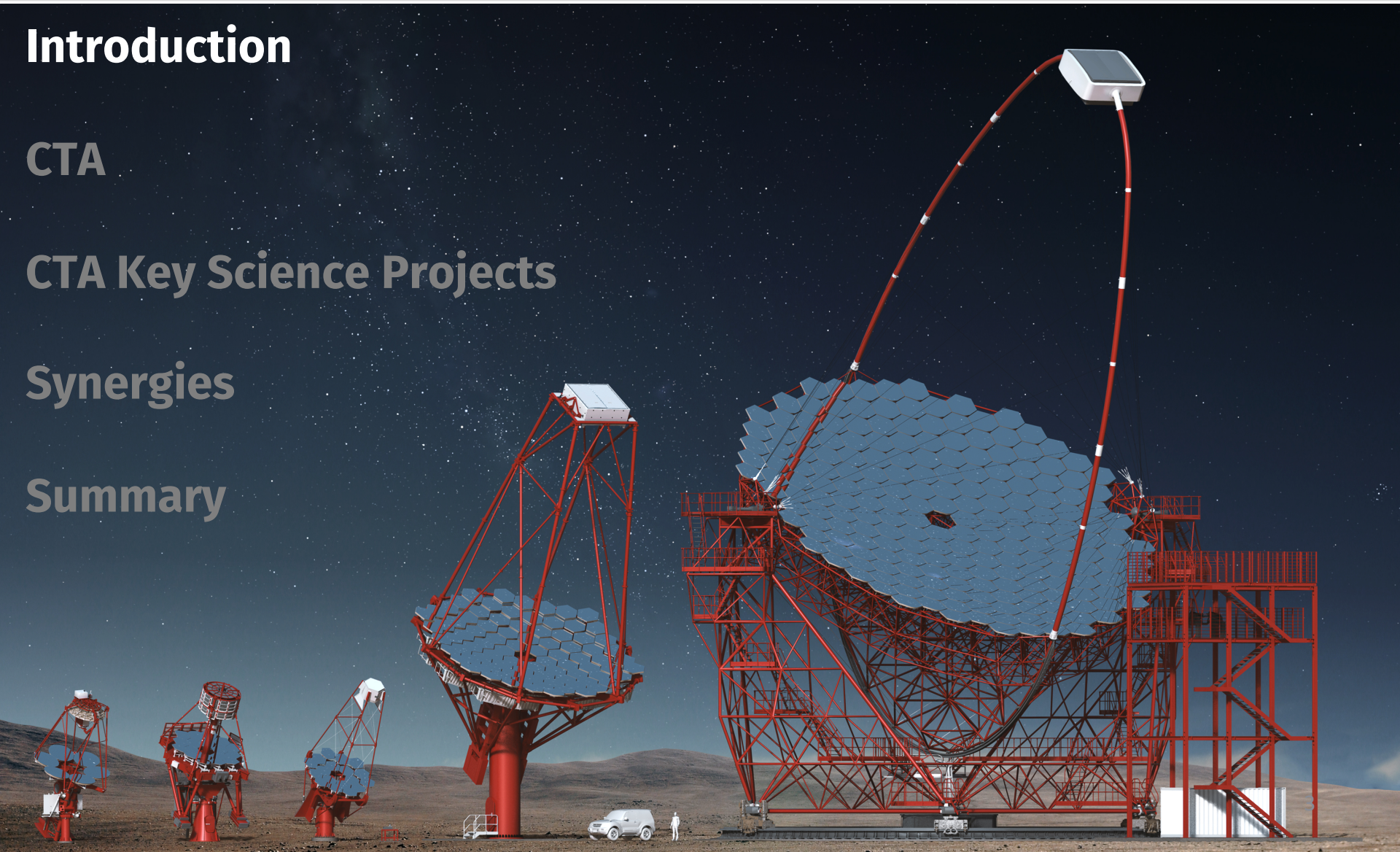

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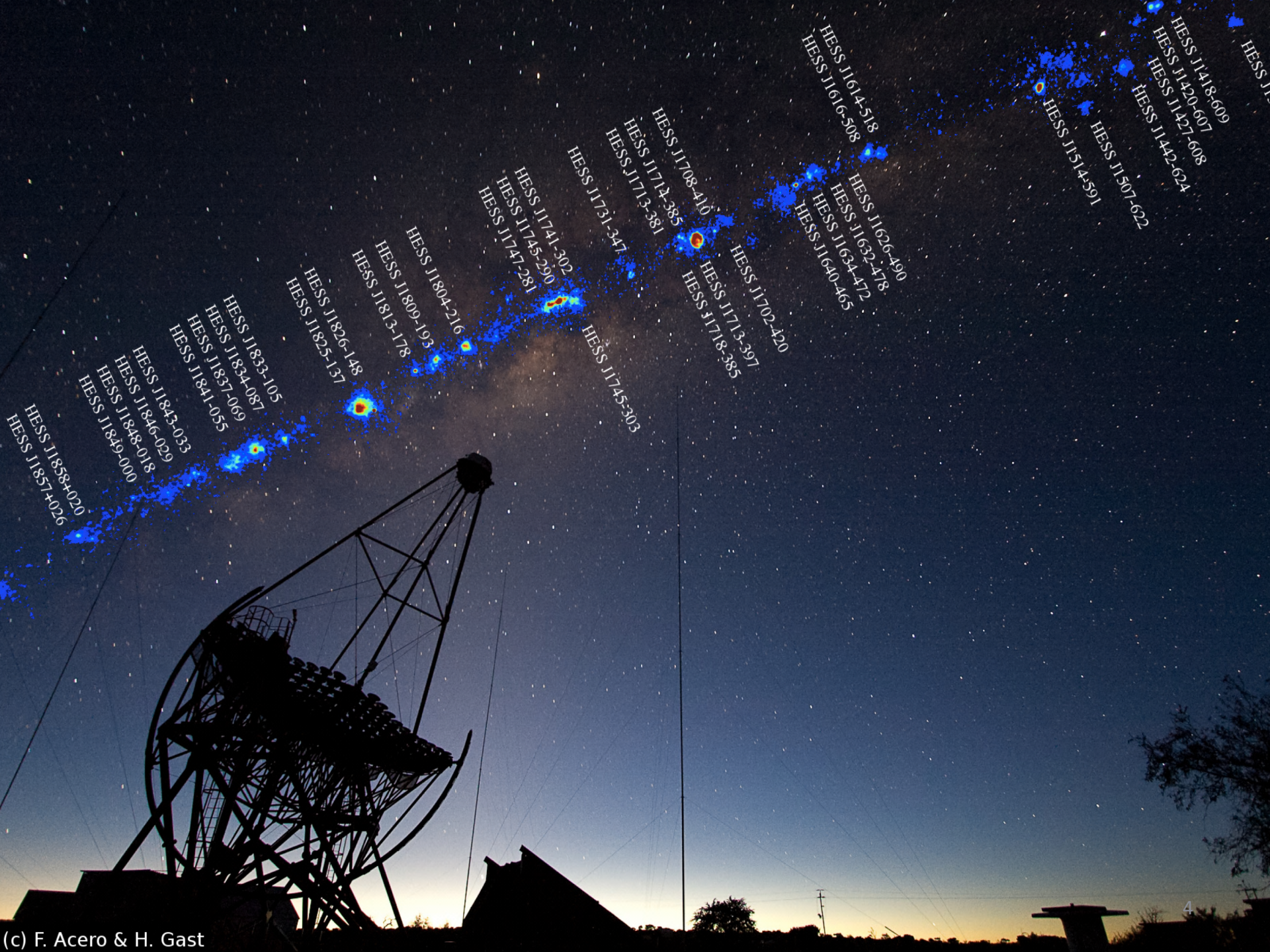
HESS J1858+020
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HESS J1837-069
HESS J1834-087
HESS J1833-105
HESS J1826-148
HESS J1825-137
HESS J1813-178
HESS J1809-193
HESS J1804-216
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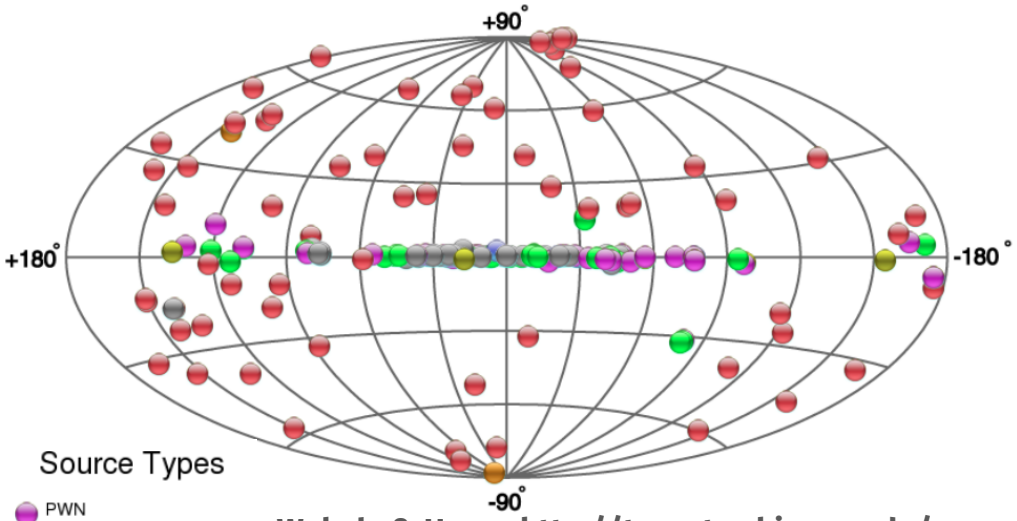
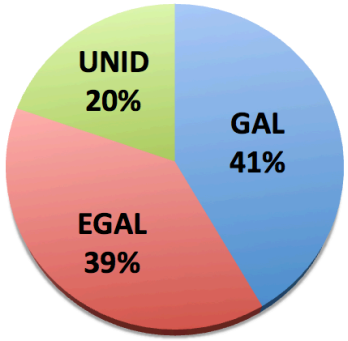
HESS J1741-302
HESS J1745-303
HESS J1731-347
HESS J1712-381
HESS J1714-385
HESS J1708-410
HESS J1718-385
HESS J1713-397
HESS J1702-420
HESS J1640-465
HESS J1634-472
HESS J1632-478
HESS J1626-490
HESS J1616-508
HESS J1614-518
HESS J1514-591
HESS J1507-622
HESS J1442-624
HESS J1427-608
HESS J1420-607
HESS J1418-609
(c) F. Acero & H. Gast

The sky above 50 GeV



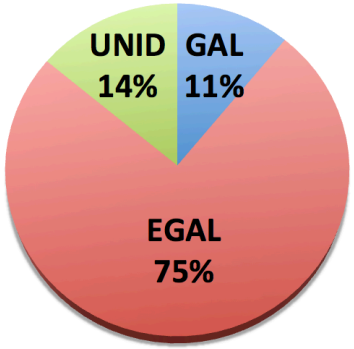
Wakely & Horan http://tevcat.uchicago.edu/

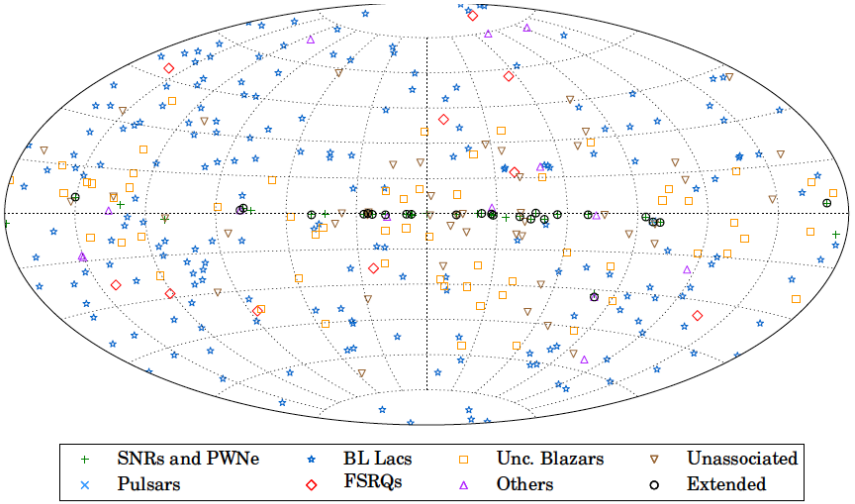
~220 TeVCat sources



H.E.S.S.
MAGIC
VERITAS

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.

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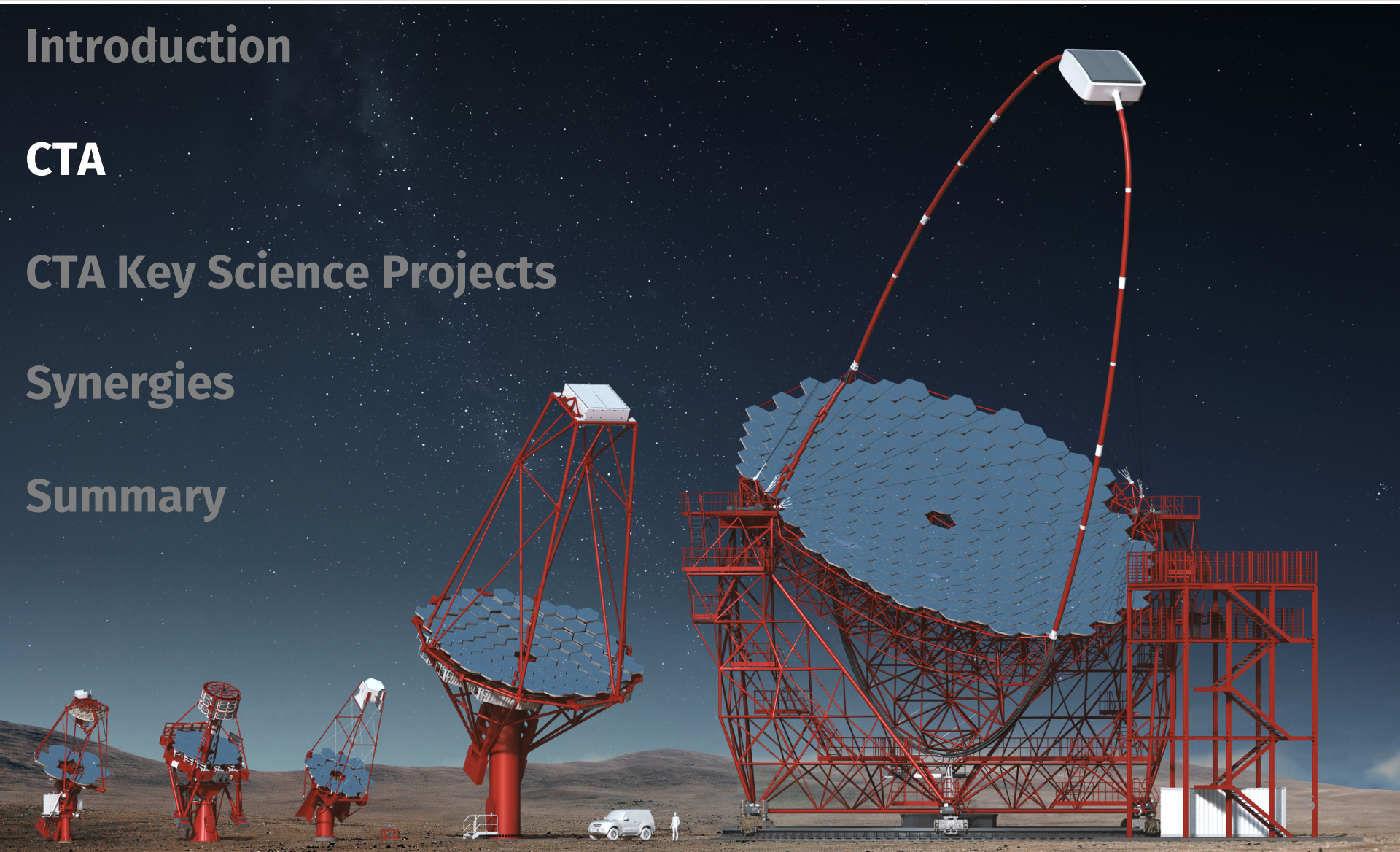
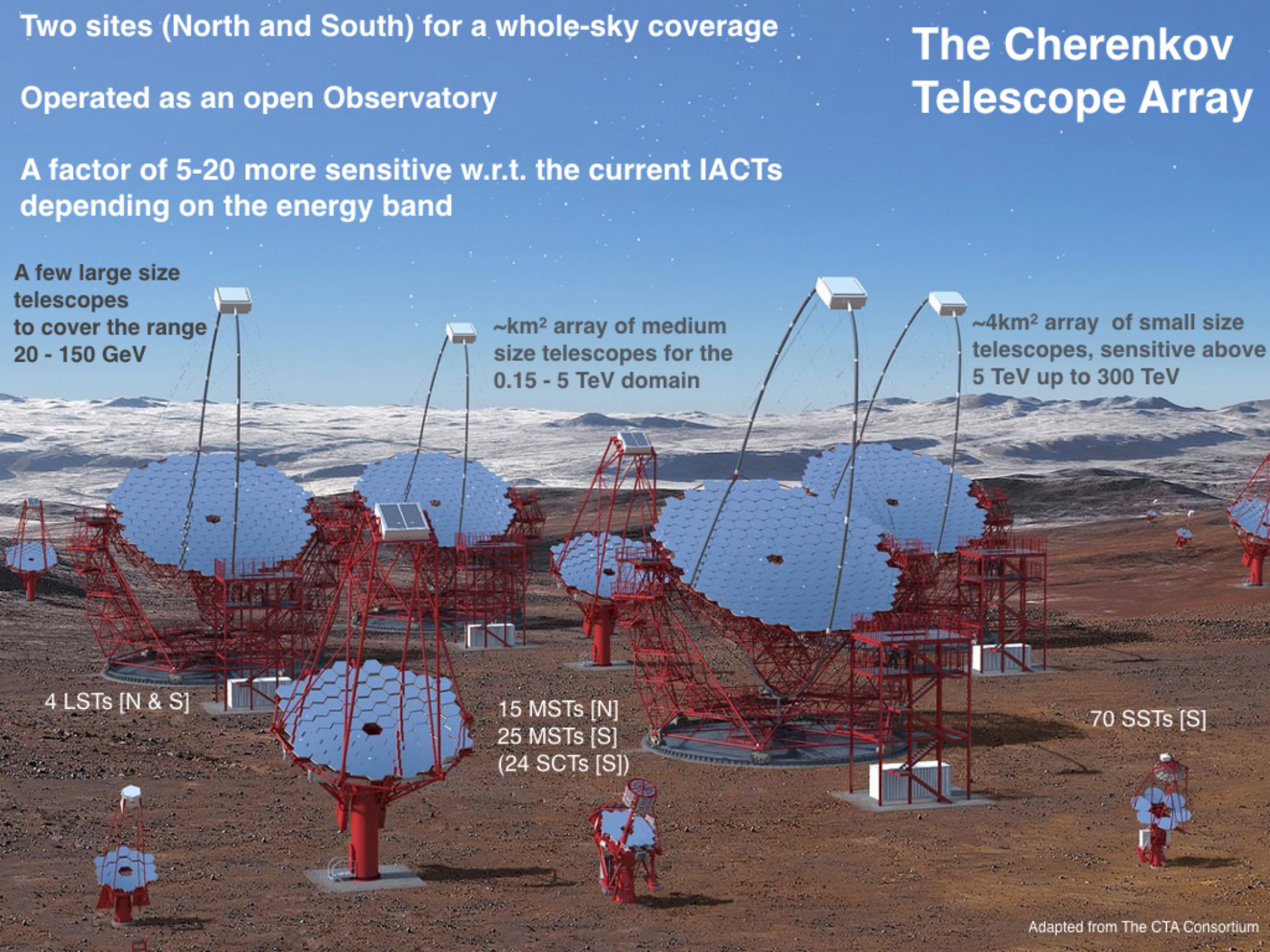


The Cherenkov Telescope Array

Two sites (North and South) for a whole-sky coverage

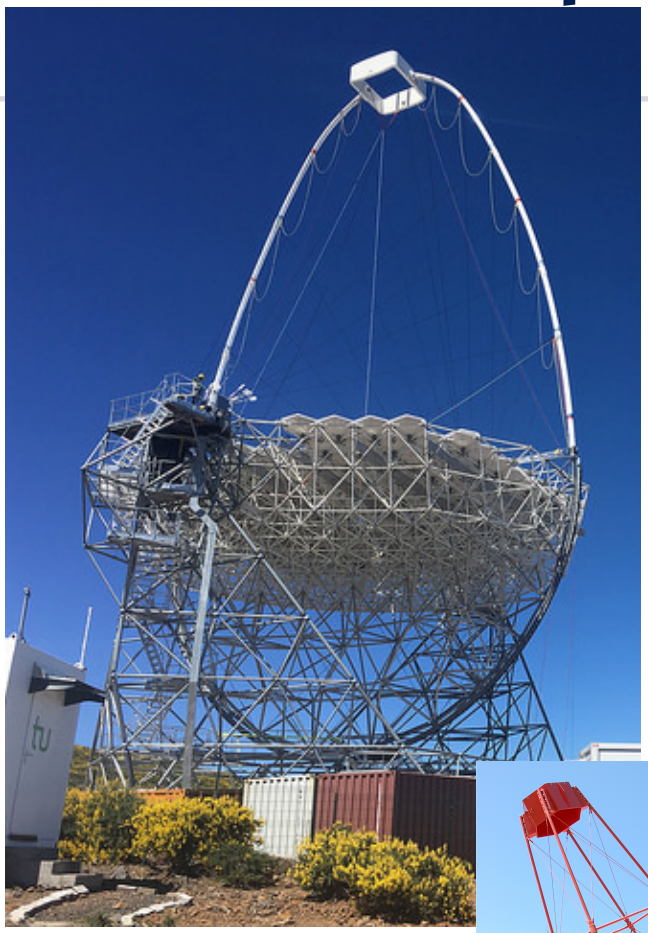
Operated as an open Observatory

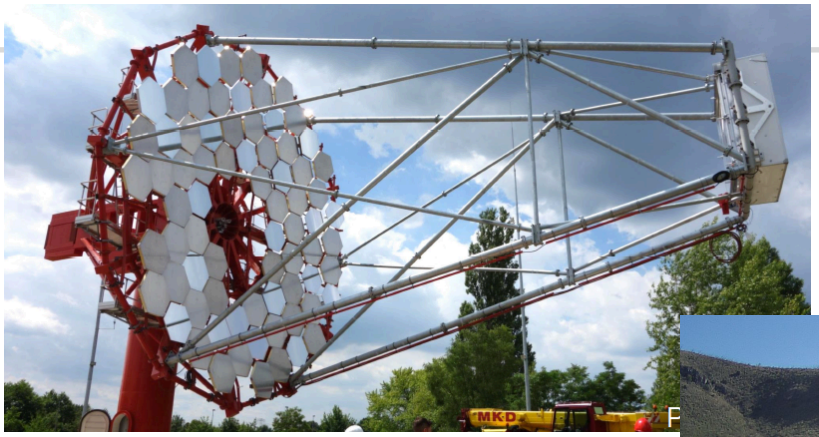
A factor of 5-20 more sensitive w.r.t. the current IACTs depending on the energy band



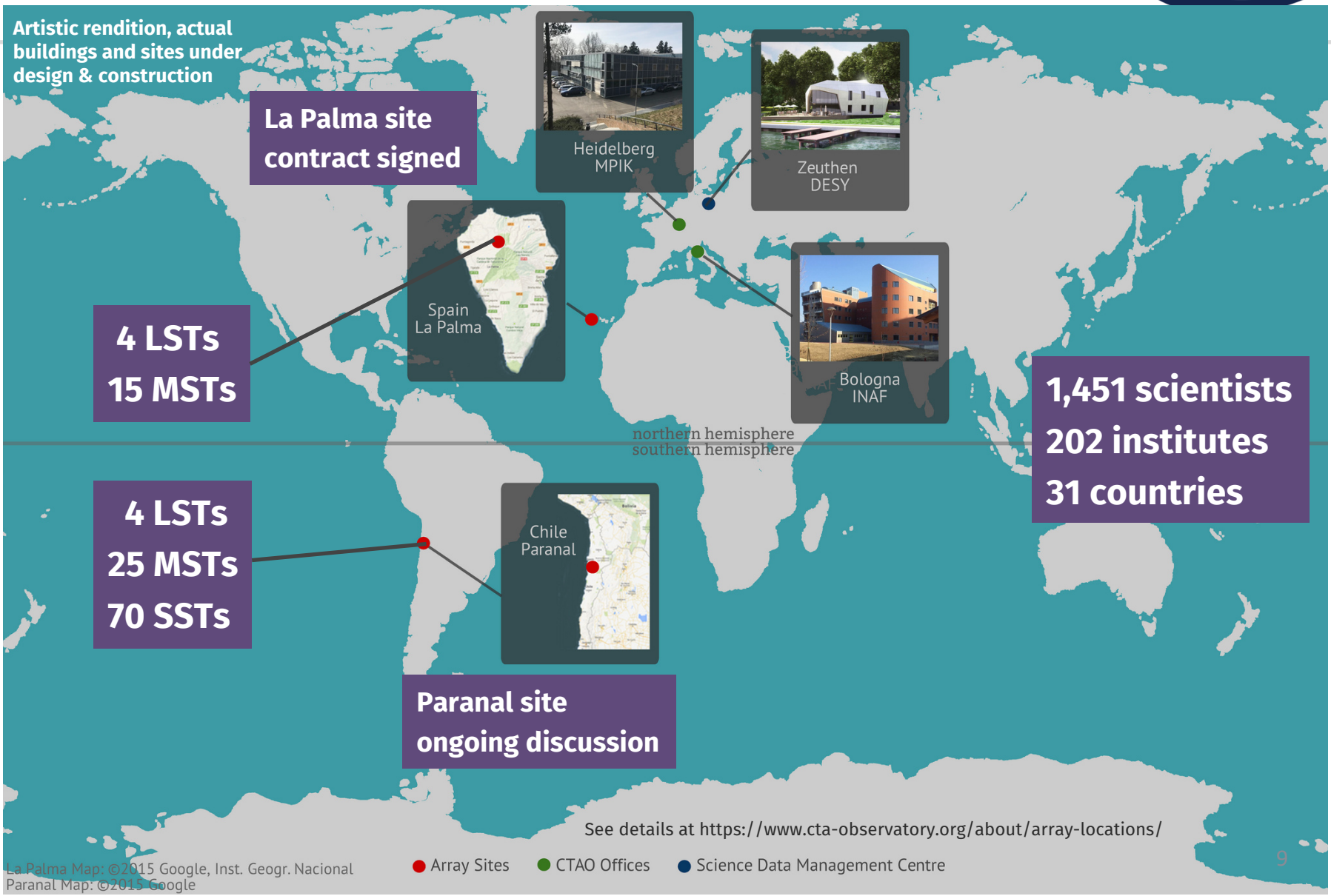
Adapted from The CTA Consortium

CTA current prototypes





CTA locations



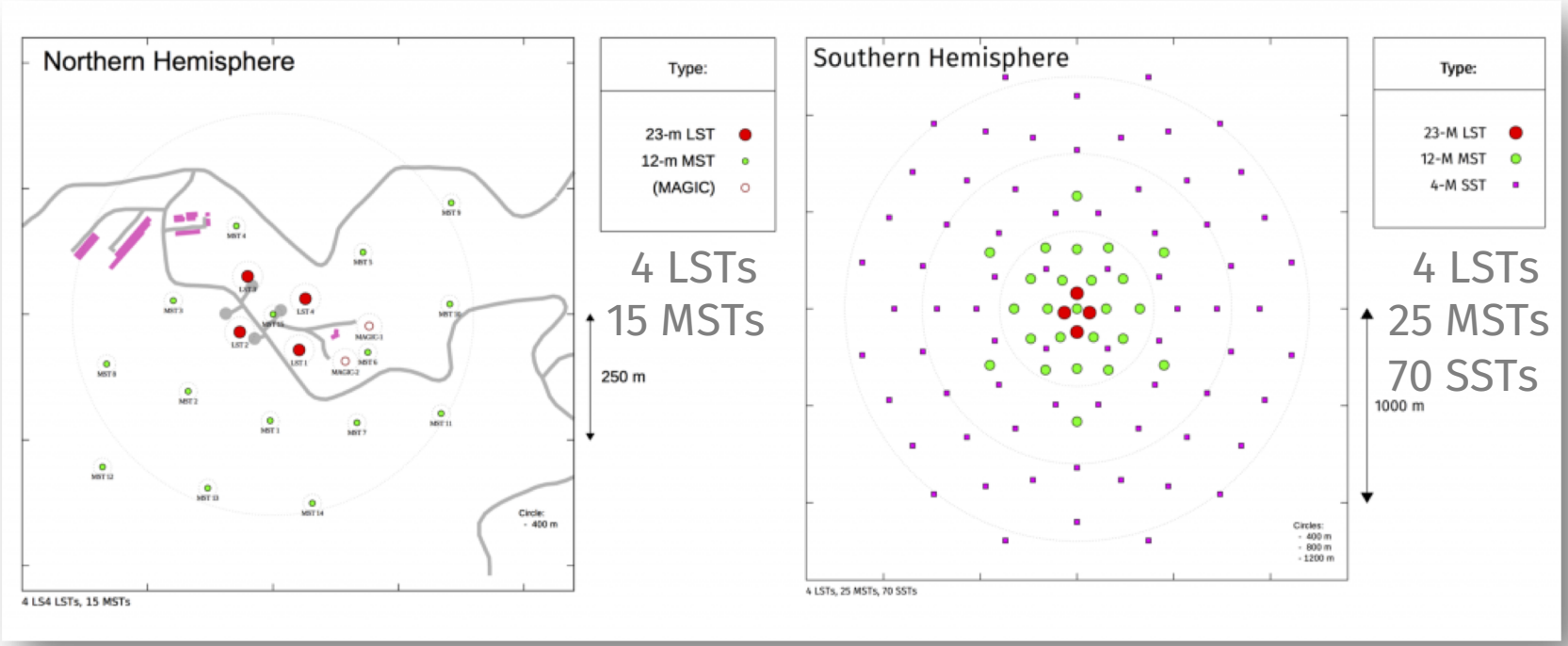
High-level timeline and proposed layout

Project Phases

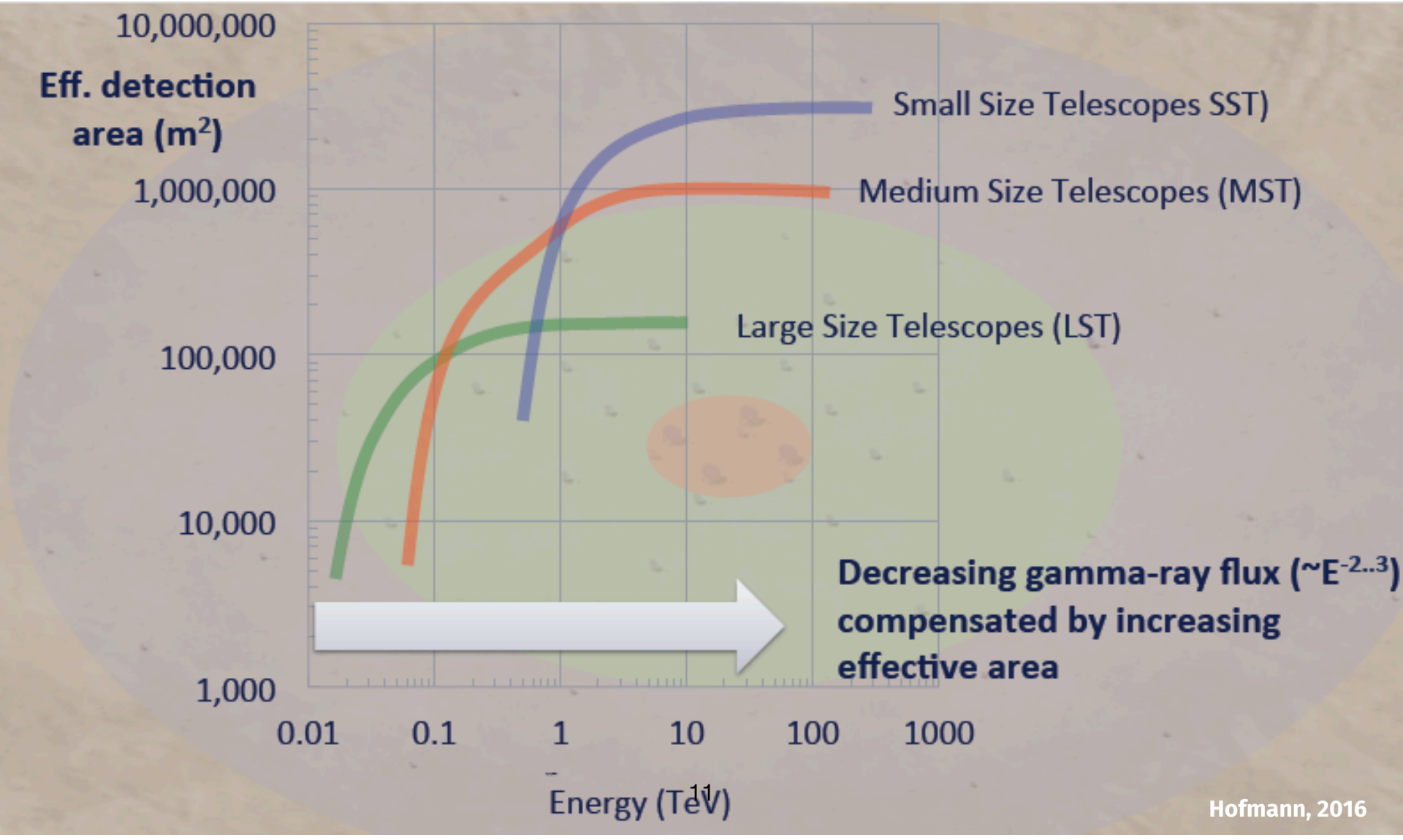
Pre-Construction	Pre-Production	Production
Current Phase	2019-2021	2021-2025

First Pre-Production Telescopes on Site

Operational lifetime ≥ 30 years



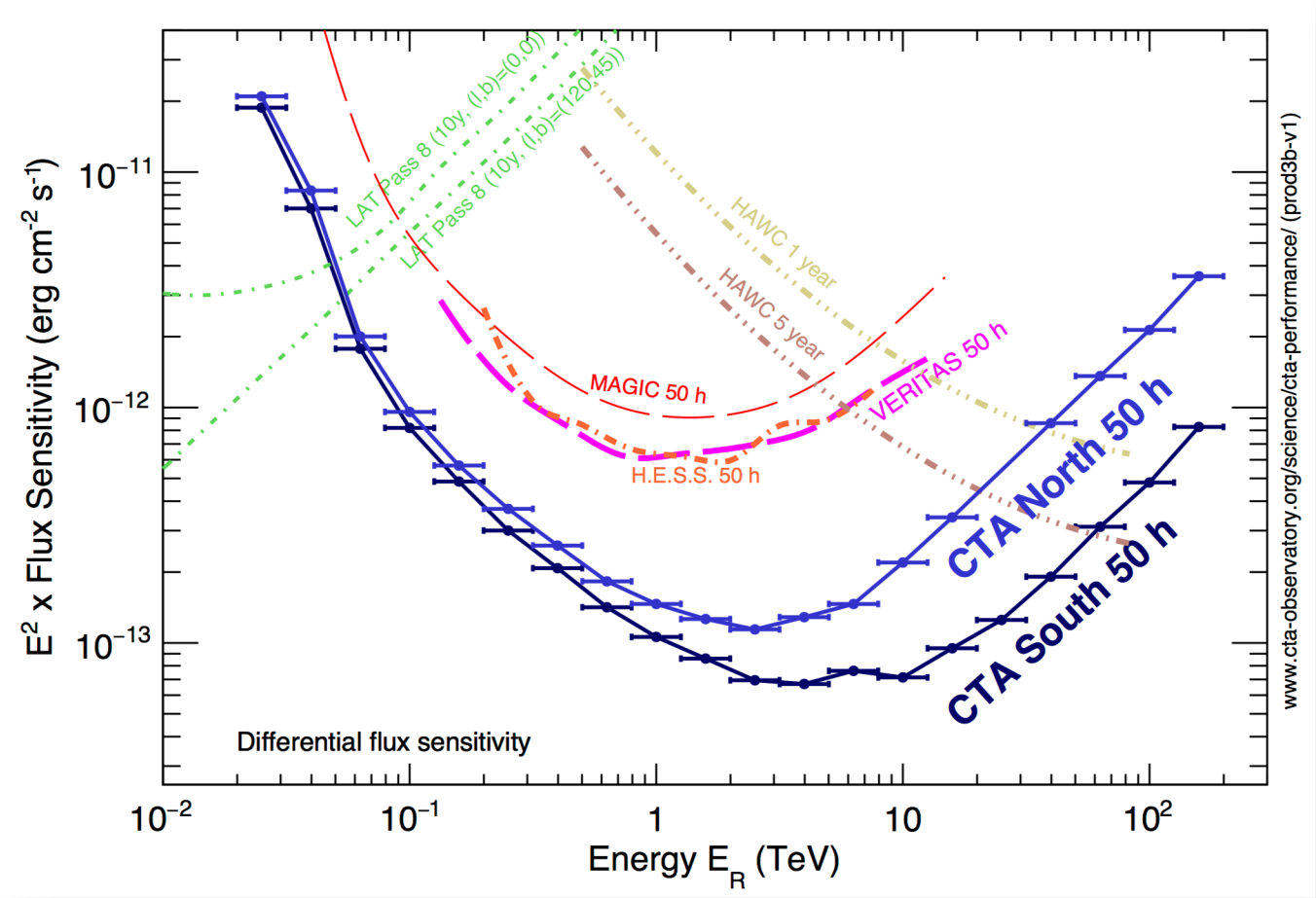
Effective area for gamma-ray detection



Hofmann, 2016

CTA Performance

Differential Sensitivity

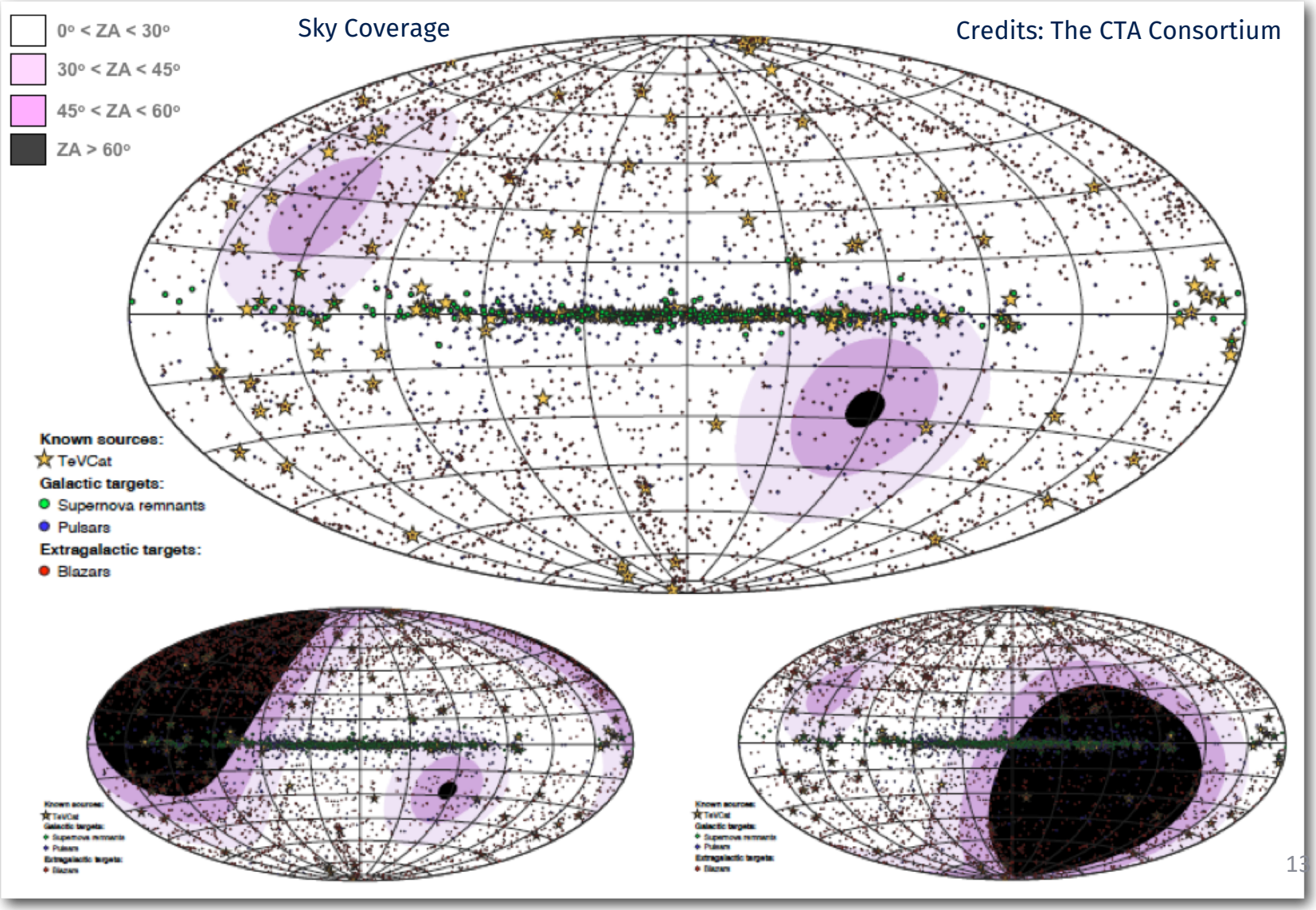


A factor of **5-20 improvement** in sensitivity depending on energy, relative to current IACTs.

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

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

CTA as an *all-sky* Observatory



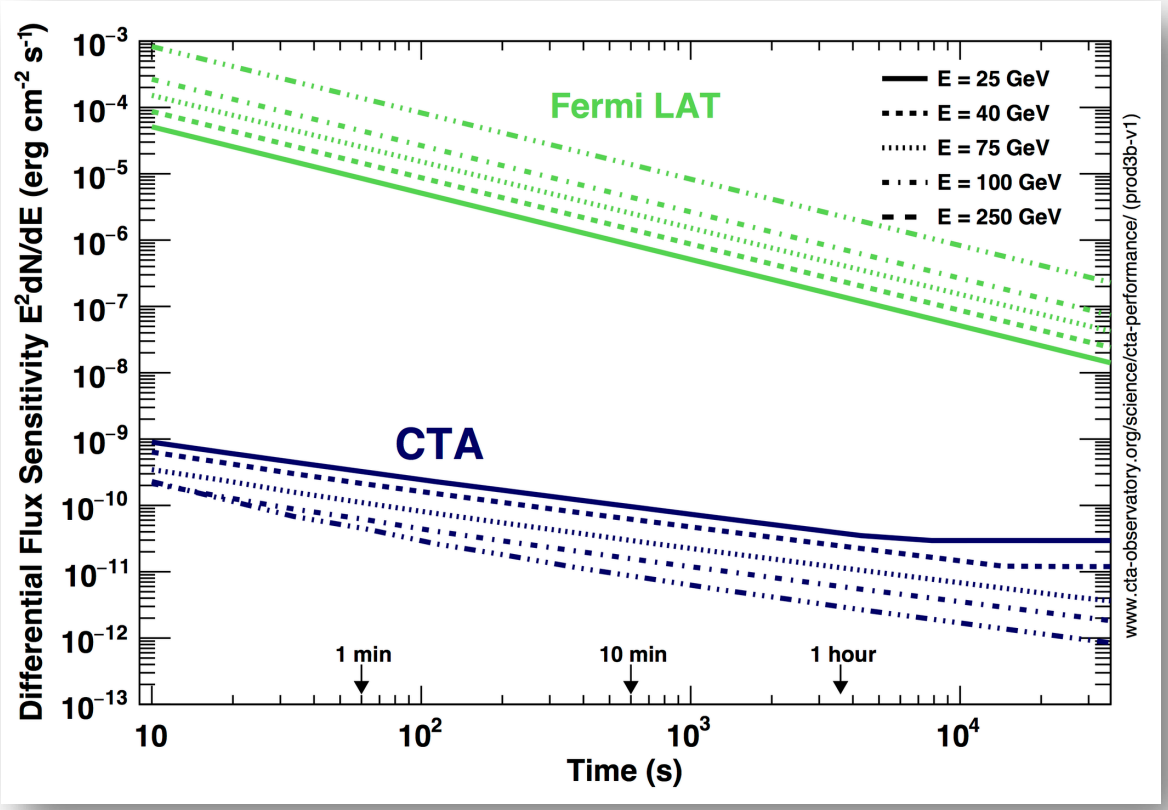
CTA as a *transient factory*

Huge advantage over Fermi in energy range of overlap for ~minute to ~day timescale phenomena

- Explosive transients
- AGN flares
- γ-ray binaries
- ***Real-time analysis SW is crucial***

Disadvantage over Fermi

- Limited FoV (compared to Fermi)
- Prompt reaction to external triggers is critical



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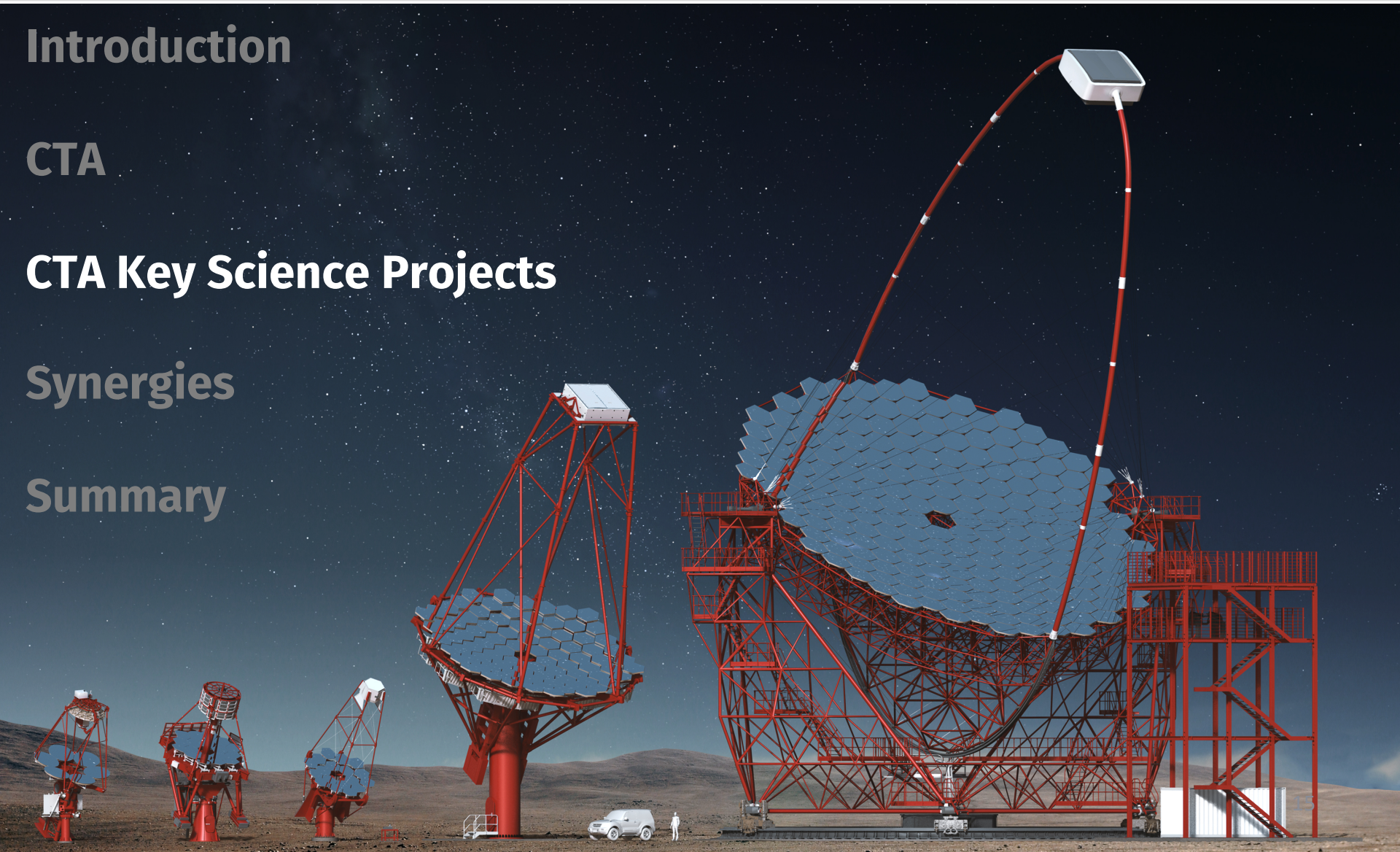


Theme 1: Cosmic Particle Acceleration

- 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

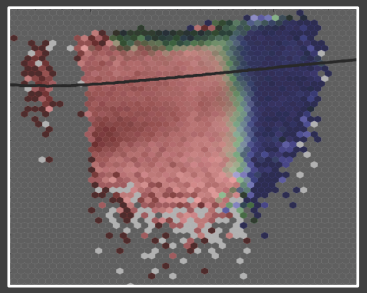
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

CTA Observing Programme

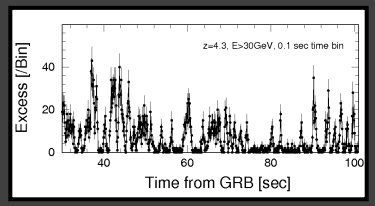
- **9 Key Science Projects** (KSPs) and **1 DM Programme**
  - **KSPs are a sets of observations addressing multiple science questions within CTA themes**

- Focused on **major legacy projects**:
  - surveys & population studies (providing legacy data-sets)
  - large classes of sources
  - a few iconic objects

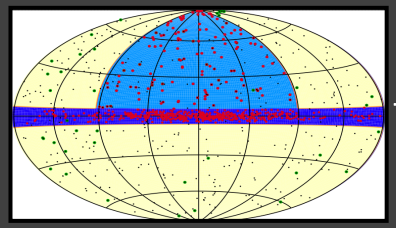
- Large potential for **guest observer proposals**
  - building on results from the KSP surveys



Dark Matter Programme



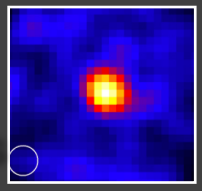
Transients



ExGal Survey

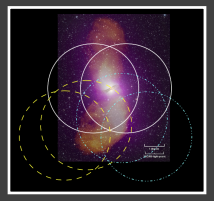
Extragalactic

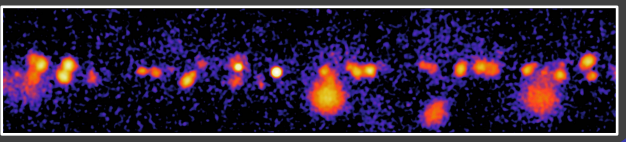
Galaxy Clusters



Star Forming Systems

AGN

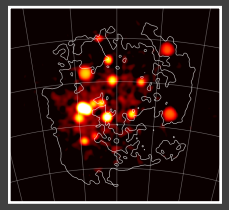




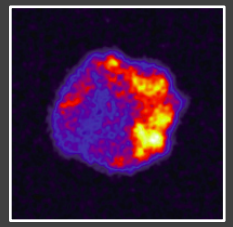
Galactic Plane Survey

Galactic

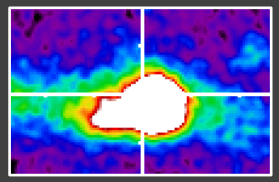
LMC Survey



PeVatrons



Galactic Centre Survey



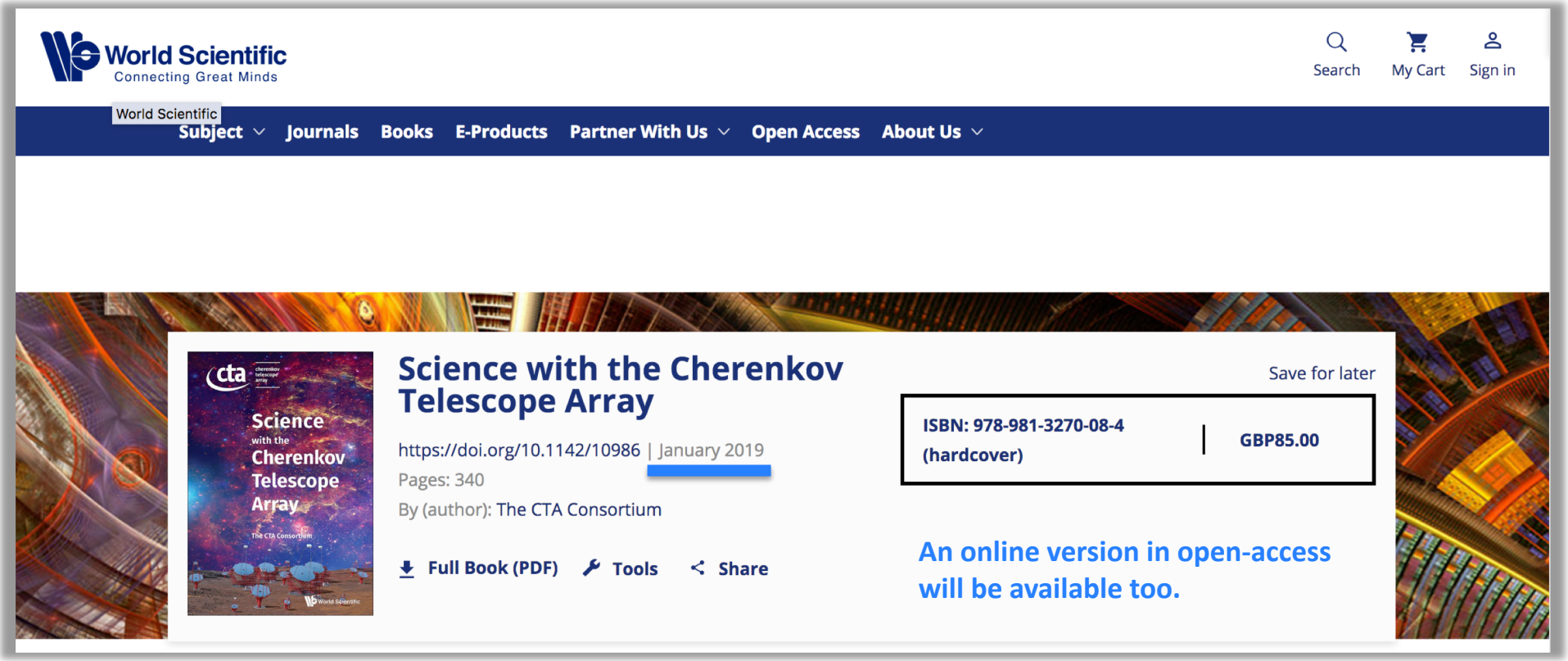
cta
cherenkov telescope array

Science with the CTA

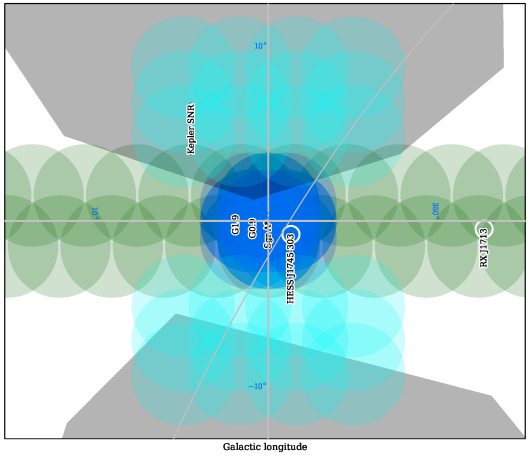
Publication describing the **CTA Science Goals**

arXiv: https://arxiv.org/abs/1709.07997

World Scientific: https://www.worldscientific.com/worldscibooks/10.1142/10986

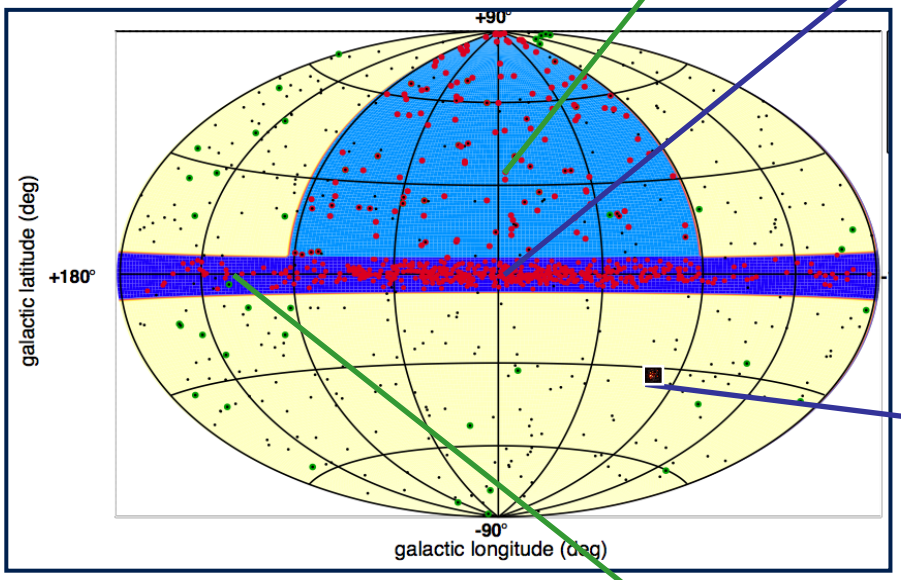


The Survey KSPs



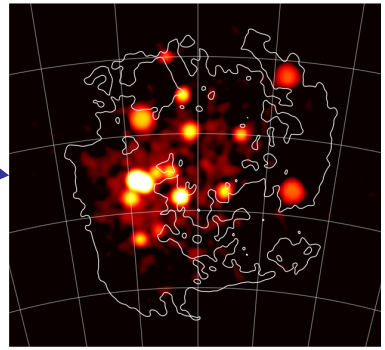
Extragalactic Survey:

Unbiased survey of ¼ sky to ~6 mCrab
VHE population study, duty cycle
New, unknown sources; O(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: O(525) h, 10°x10° : O(300) h



Galactic Plane Survey:

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

Large Magellanic Cloud Survey:

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

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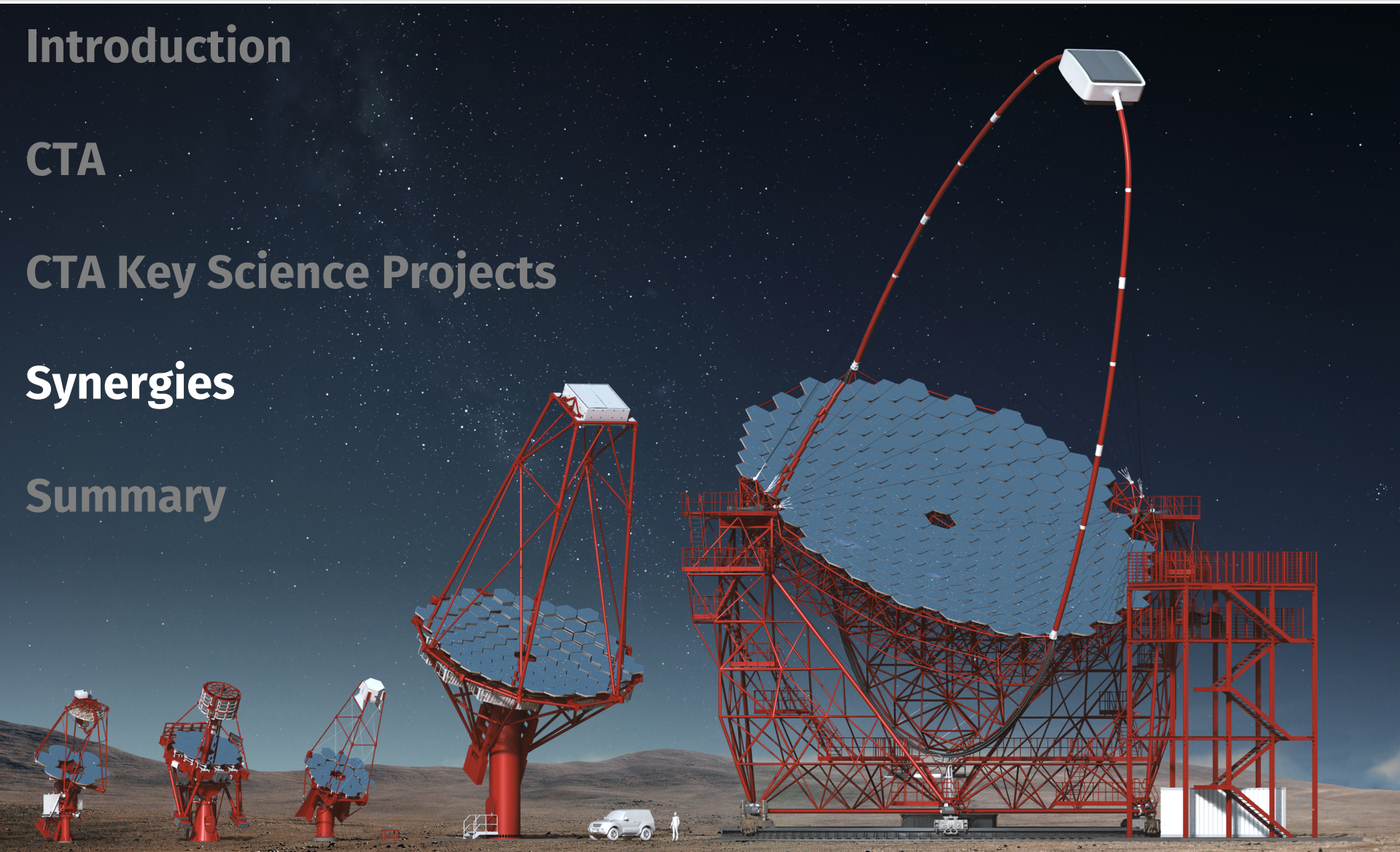
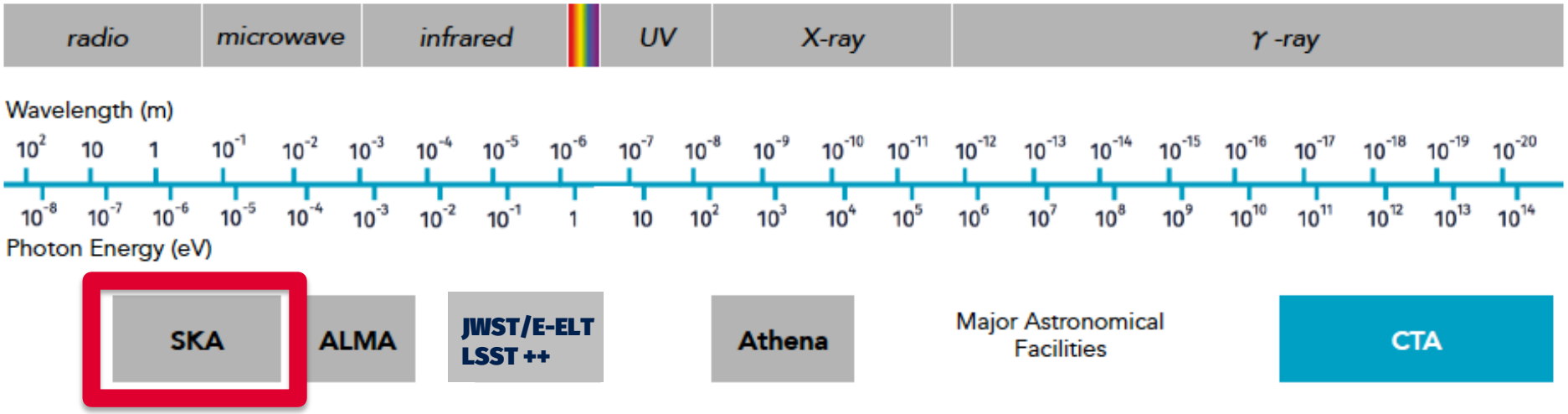


Synergies during CTA operation

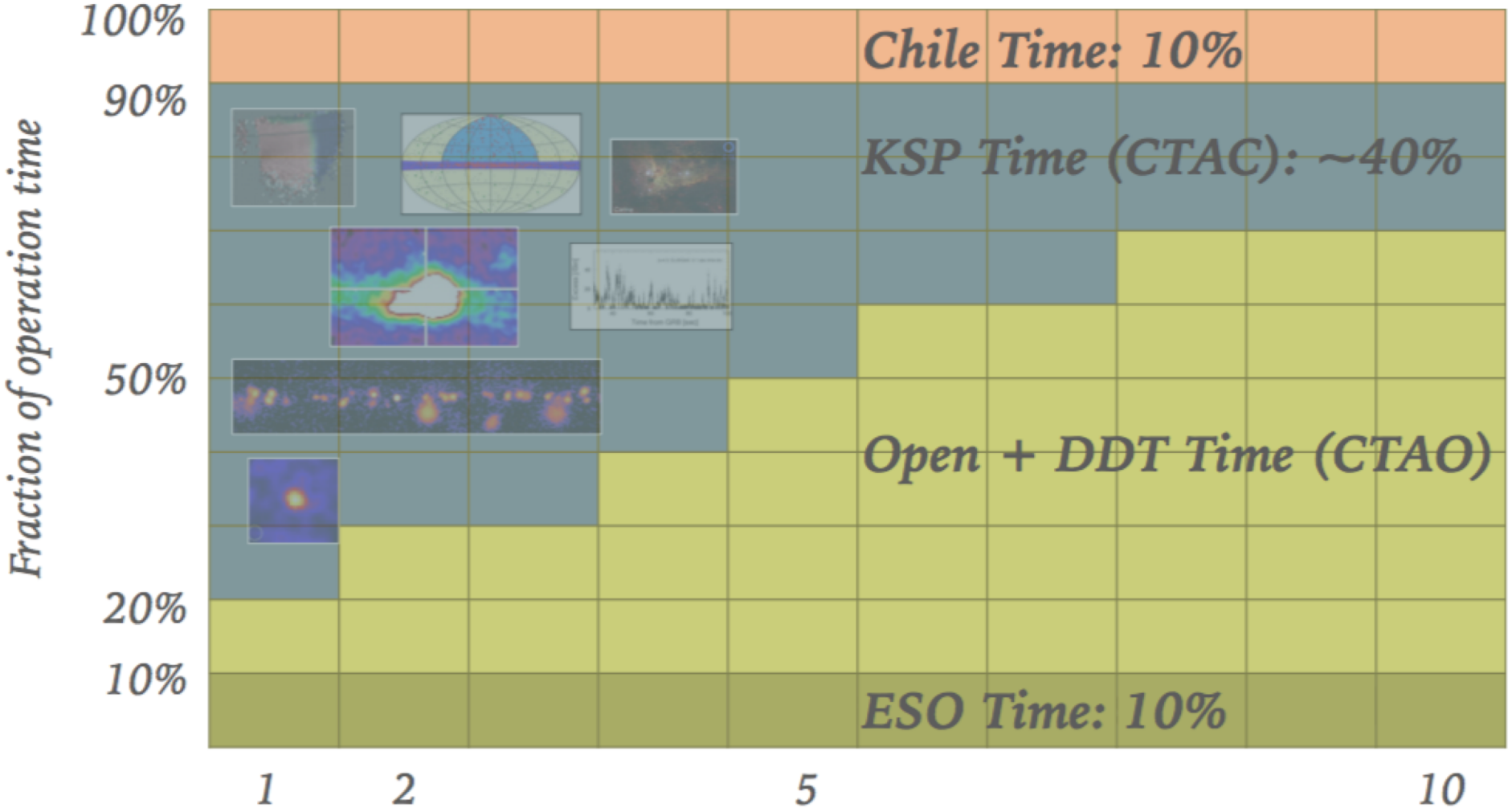


These are just a few of the future major multi-wavelength facilities available during the CTA era at lower energies.

We should add **LIGO** + **VIRGO** + **LISA*** (gravitational waves), **IceCube** + **KM3NeT*** (neutrinos) for the multi-messenger astrophysics.

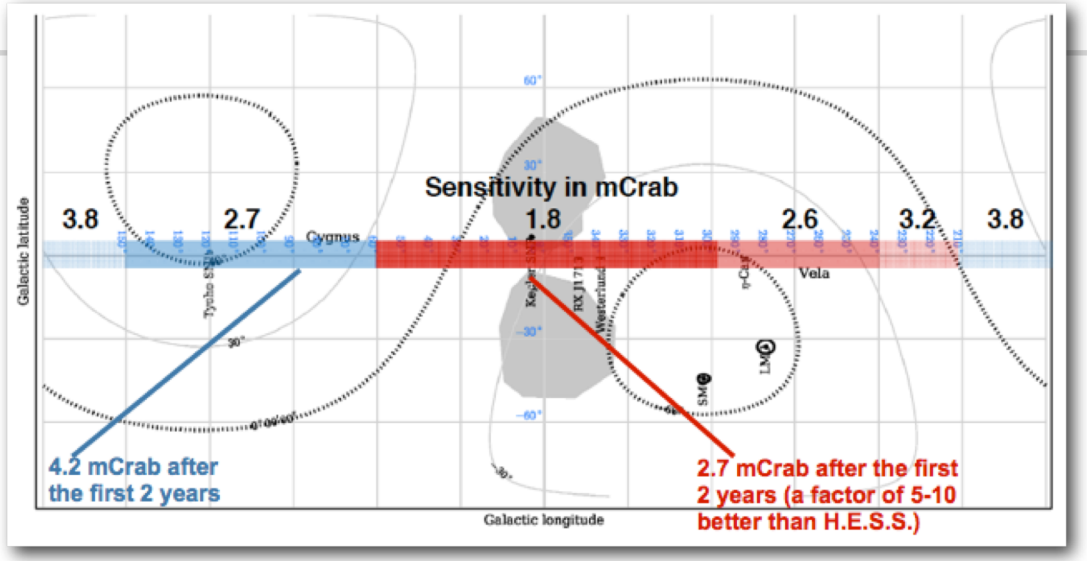
* Proposed and/or planned

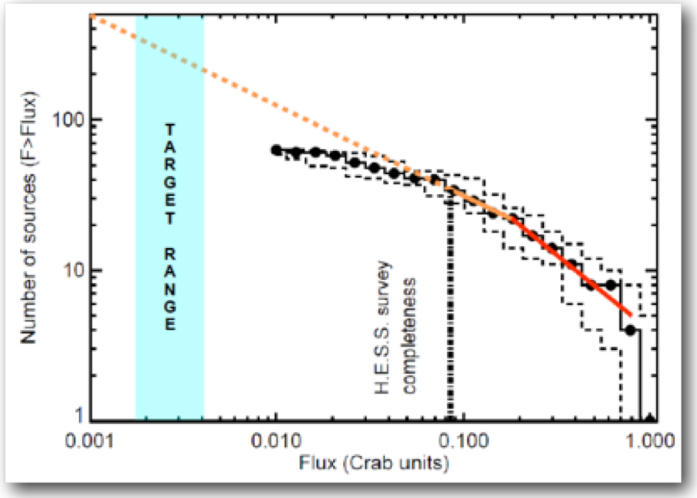
Illustration of possible KSPs vs. GO time-budget



About 1350 hours/yr (South)

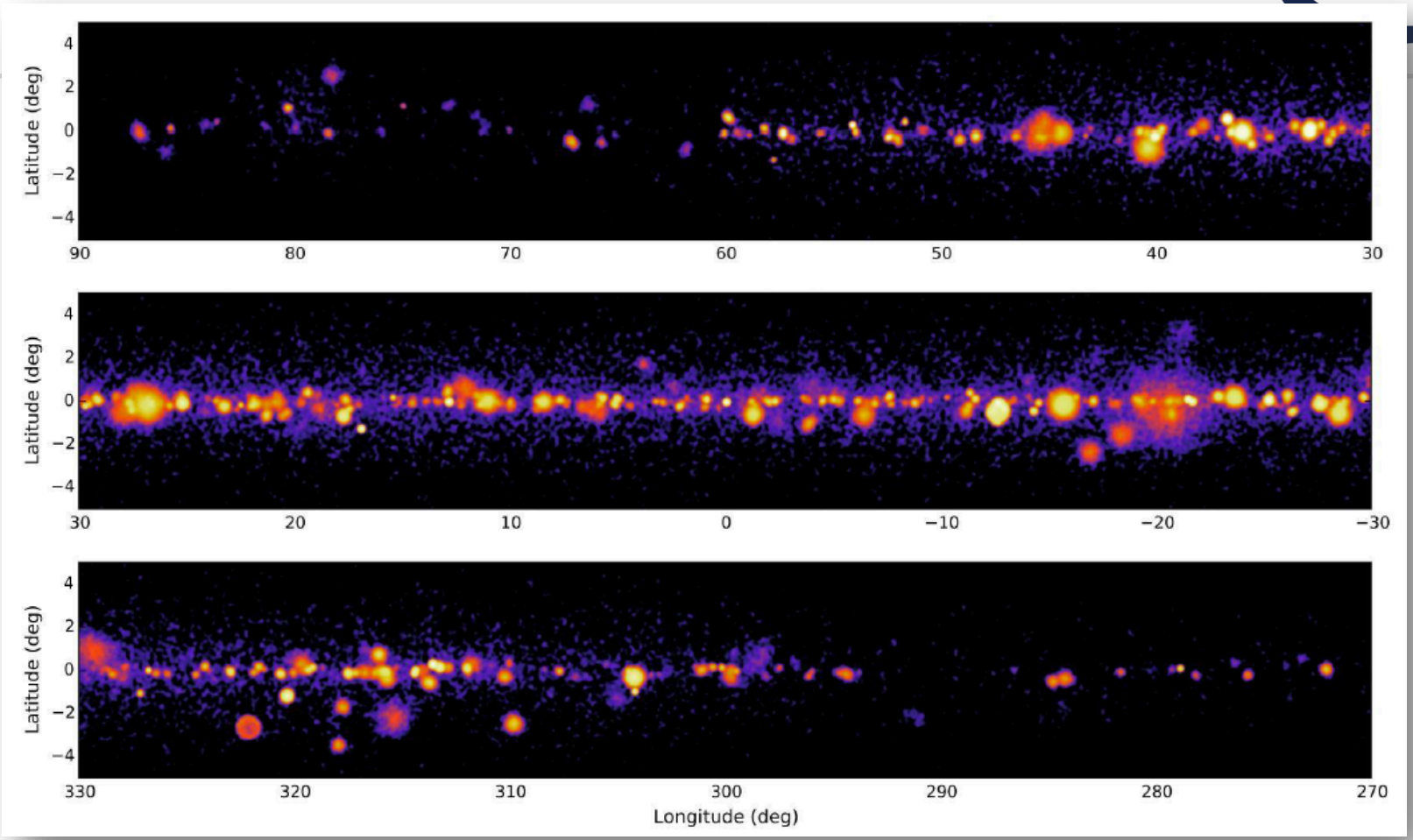
Galactic Plane Survey





- Discovery of PeVatron candidates ➡ origin of cosmic rays
- Detection of many new VHE sources O(300 – 500), particularly PWNe and SNRs
- Discovery of new VHE gamma-ray binaries
- Production of a multi-purpose legacy data set
- **Radio/mm and X-ray facilities** →PSR ephemerides, **PWNe/SNRs morphology**/SEDs, MWL **phase-resolved studies in binaries**, **cross-correlation of catalogs** and identification of new VHE sources, …
- Non-thermal X-ray emission → a natural tracer of locations of extreme particle acceleration.

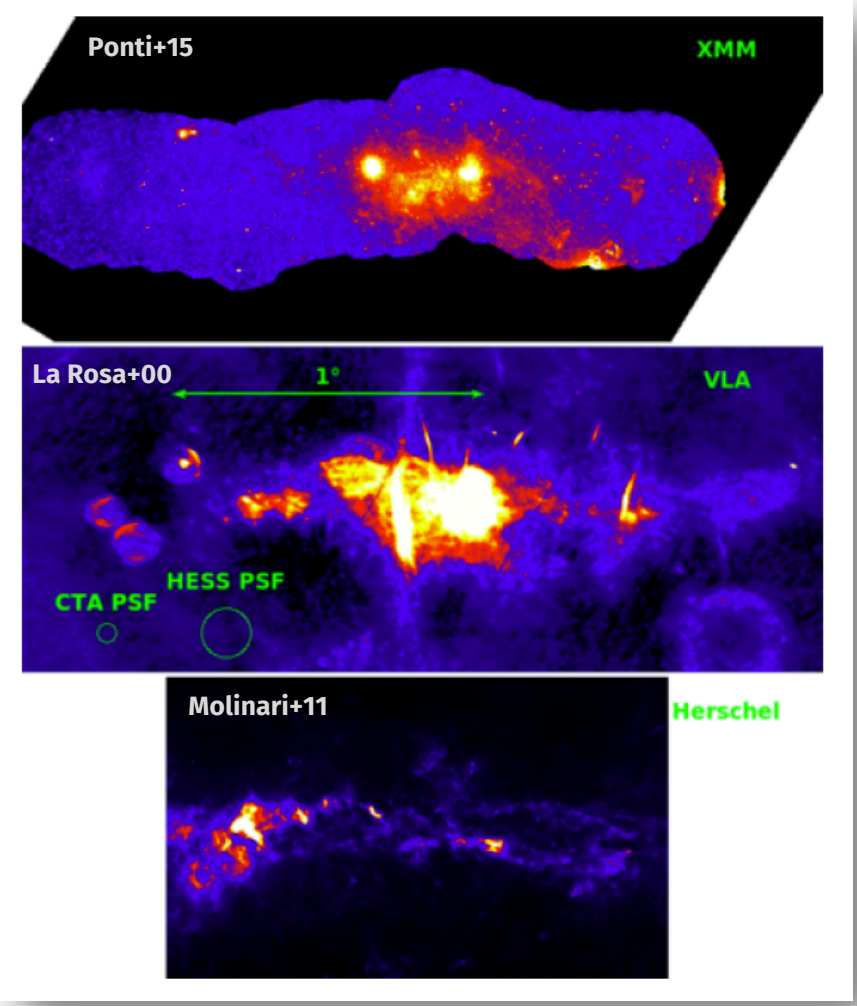
Galactic Plane Survey



Simulated CTA image of the Galactic plane for the inner region 90º < l < 90º, adopting the actual proposed GPS observation strategy, a source model incorporating both **supernova remnant and pulsar wind nebula populations and diffuse emission.**

SKA and its precursors can provide extremely useful information to be used as inputs.

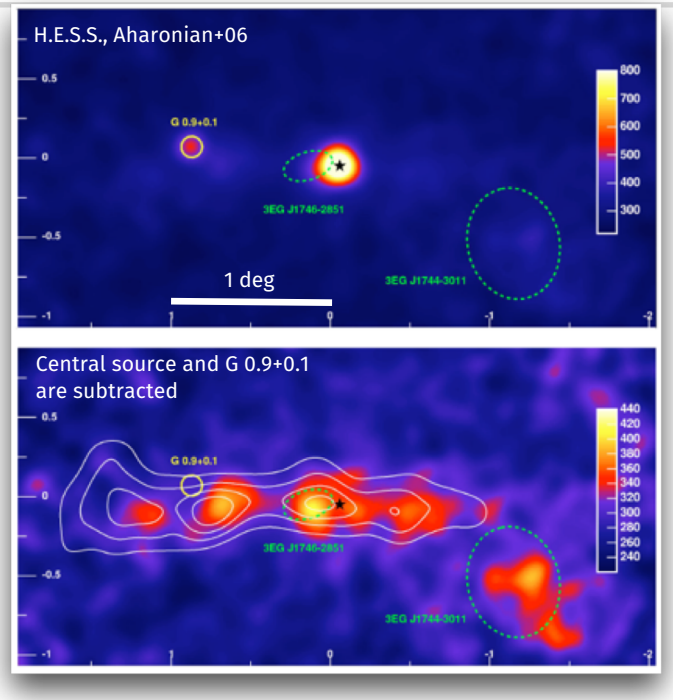
Galactic Centre Survey

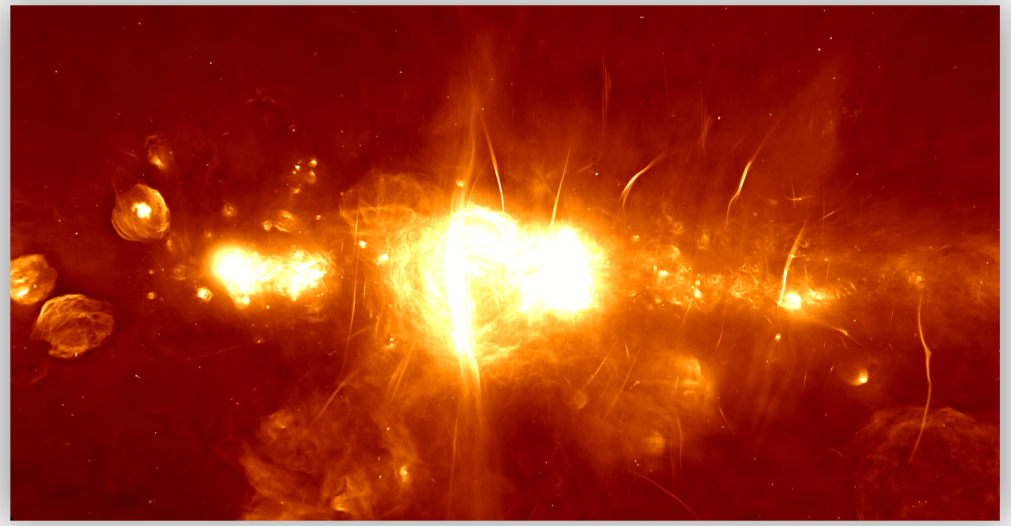


Multi-wavelength view of the **inner Galactic Centre region**, showing the **wide variety of diffuse emission.**

The **CTA point spread function** is shown in comparison with that of the currently operating H.E.S.S. telescope to illustrate the **possibility of resolving structures with CTA that are point-like with existing instruments**.

Galactic Centre Survey





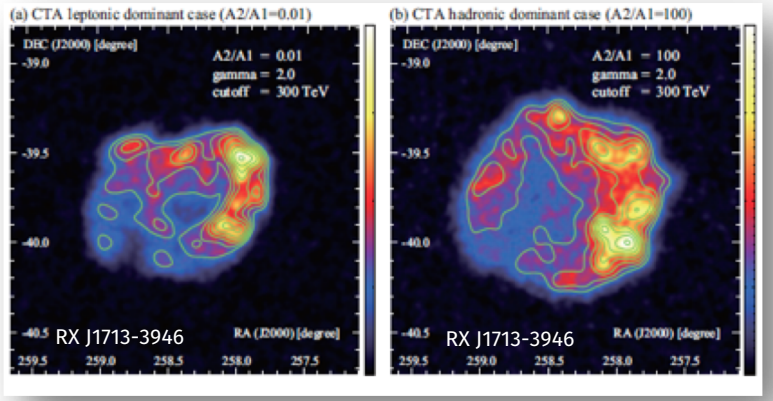
MeerKAT image of the central regions of our Galaxy with a wealth of never before seen features, as well as a clearer view of previously known supernova remnants, star-forming regions, and radio filaments.
(Credit: SARAO)

- Determination of the **nature of the central source**
- A detailed view of the **VHE diffuse emission**
- Search for **variability** in the VHE source near **Sgr A***
- Studying the **interaction of the central source with neighboring clouds**
- Global **VLBI array at mm/sub-mm frequencies**, → direct **imaging of the jet-launching regions** of key sources such as Sgr A*.

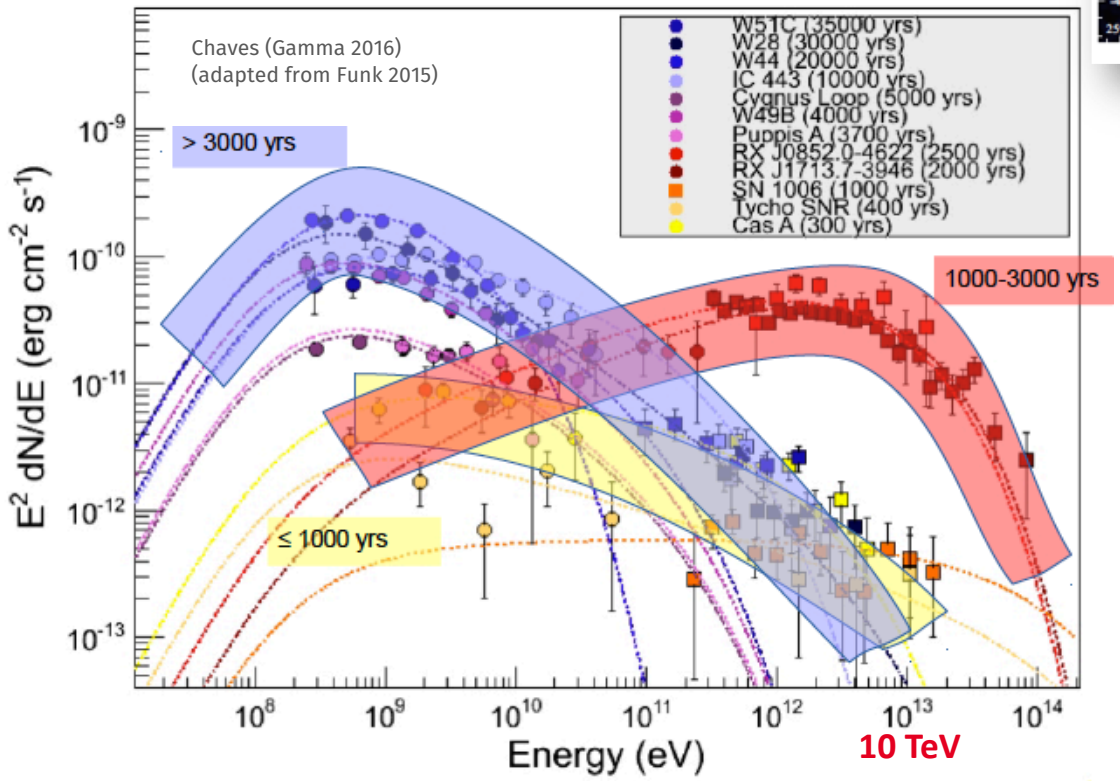
Cosmic-ray PeVatrons

What sources may accelerate hadrons to the knee?

SNRs are standard paradigm, but only a handful provide strong evidence for hadron acceleration so far, and only up to ~ 10 TeV



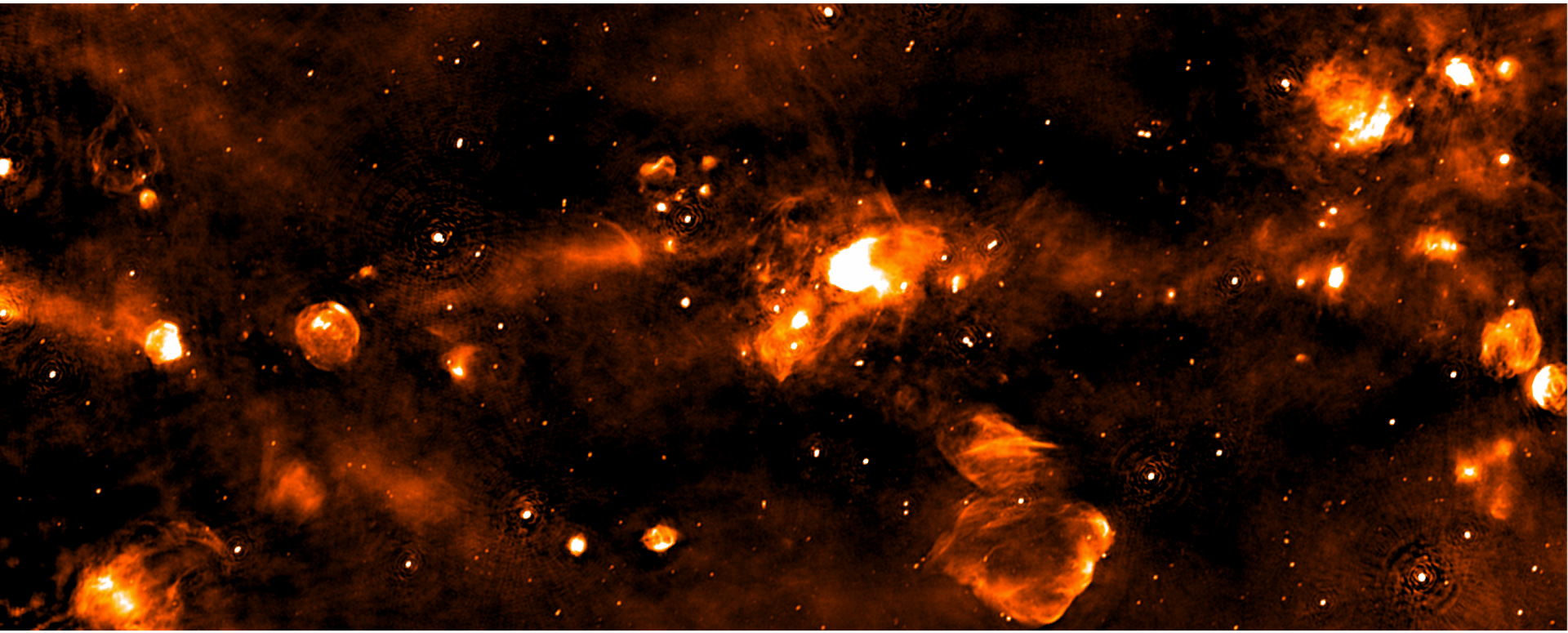
Nakamori et al., 2015 50 hr CTA simulation



Use **GPS as finder** and **follow-up 5 brightest sources with no cut-off.**

MWL information critical for identification → SKA

ASKAP Observations



Credits: G. Umana et al., in preparation (see also F. Bufano's talk)

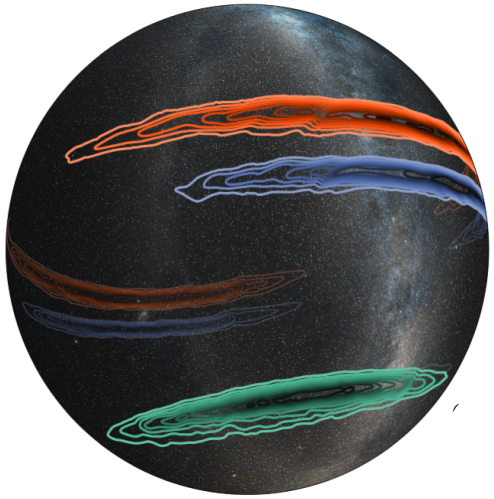
The **SCORPIO Project** found several **SNRs** which could be used as a **reference for CTA simulations and future observations.**

Multi-messenger Astrophysics window is open !

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

Potential 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.**

Transient Factories & SKA will generate an **overwhelming number of triggers, → 20 new FRBs discovered by ASKAP** (Shannon et al, 2018)**.**

The **definition of appropriate response criteria** is the key to understand the potential for VHE follow-up.

		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

Outline

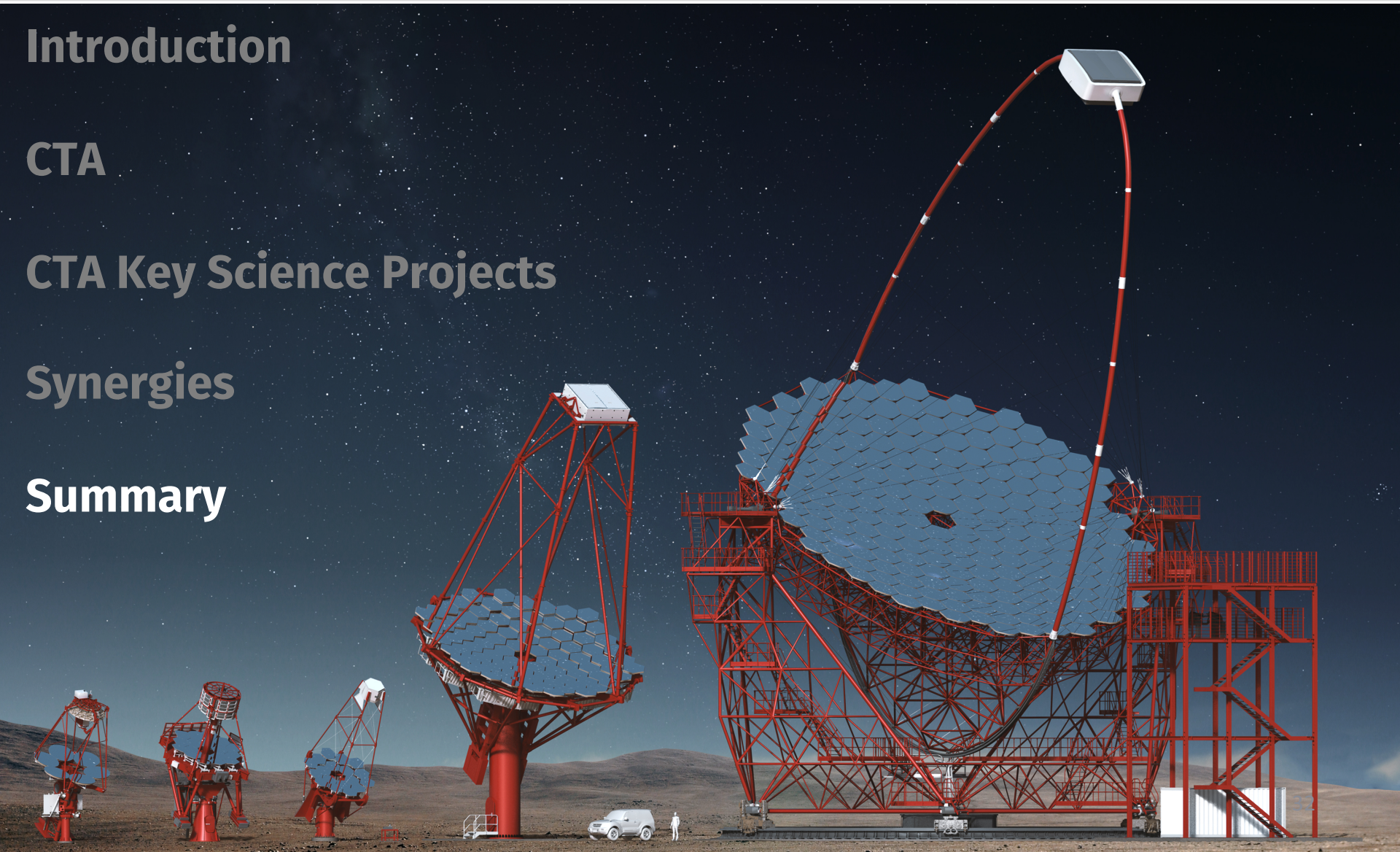
Introduction

CTA

CTA Key Science Projects

Synergies

Summary



1st CTA Science Symposium

Pre-registration

#ctasymposium2019

WHEN /

6-9 MAY 2019

WHERE /

Teatro Duse

Via Cartoleria 42, Bologna

Regular registration opening soon !

https://indico.cta-observatory.org/event/1946/overview

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.

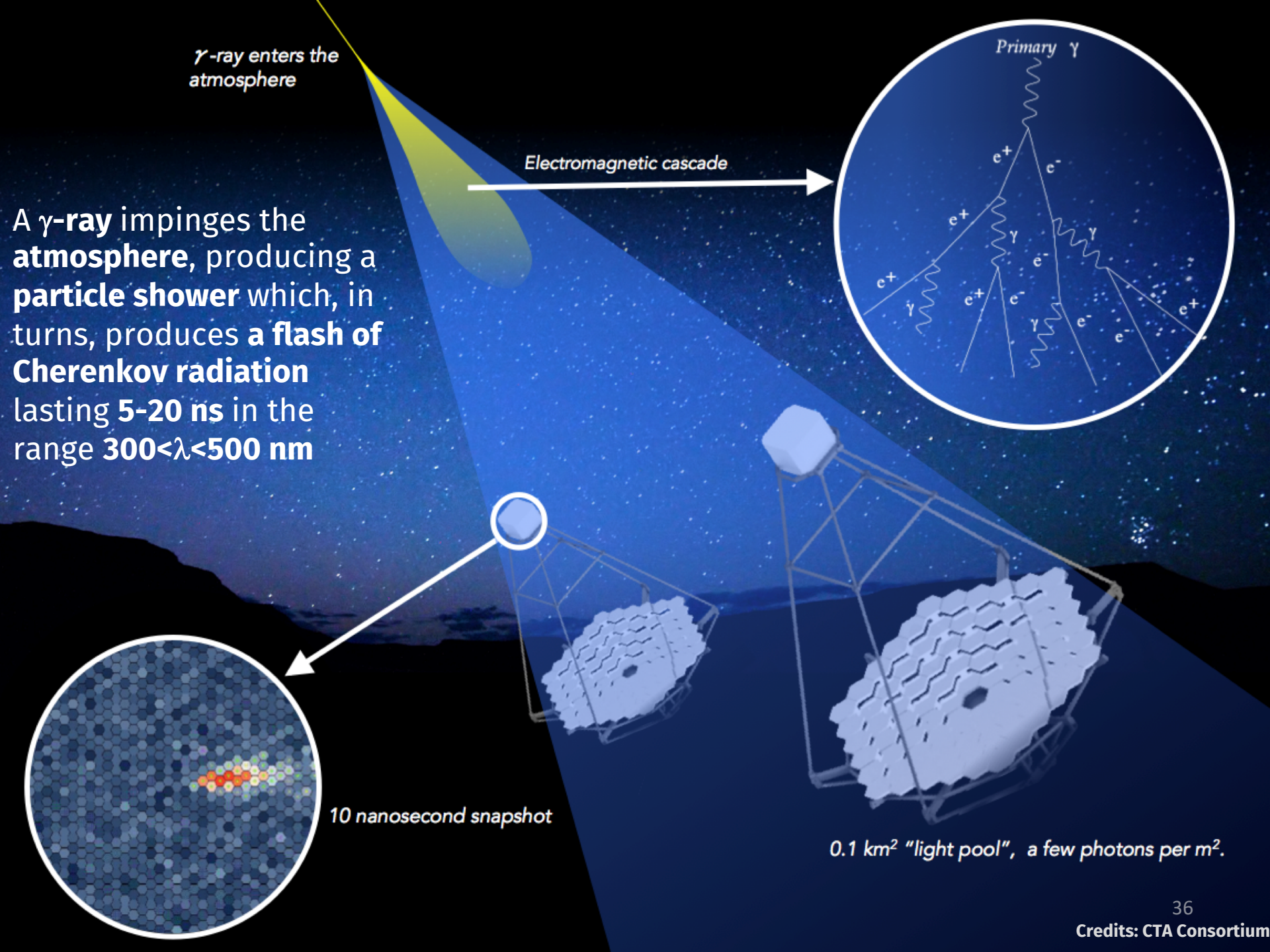
Proprietary time (significant fraction in the first years) will be articulated in **Key Science Projects.**

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

CTA will have important **synergies** with both **SKA** and other astronomical and astro-particle facilities.

We gratefully acknowledge financial support from the agencies and organizations listed here:
http://www.cta-observatory.org/consortium_acknowledgments

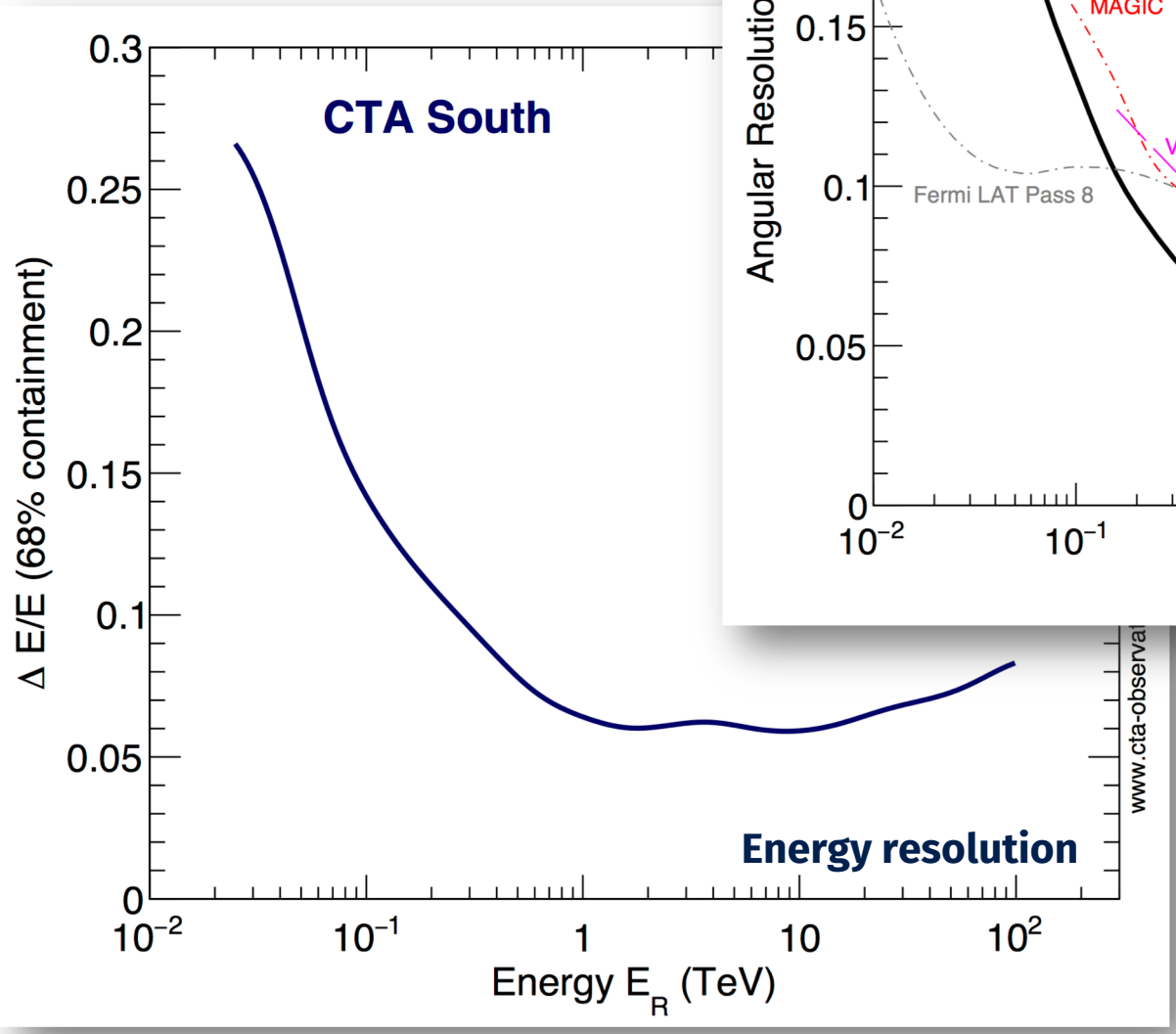
BACKUP SLIDES

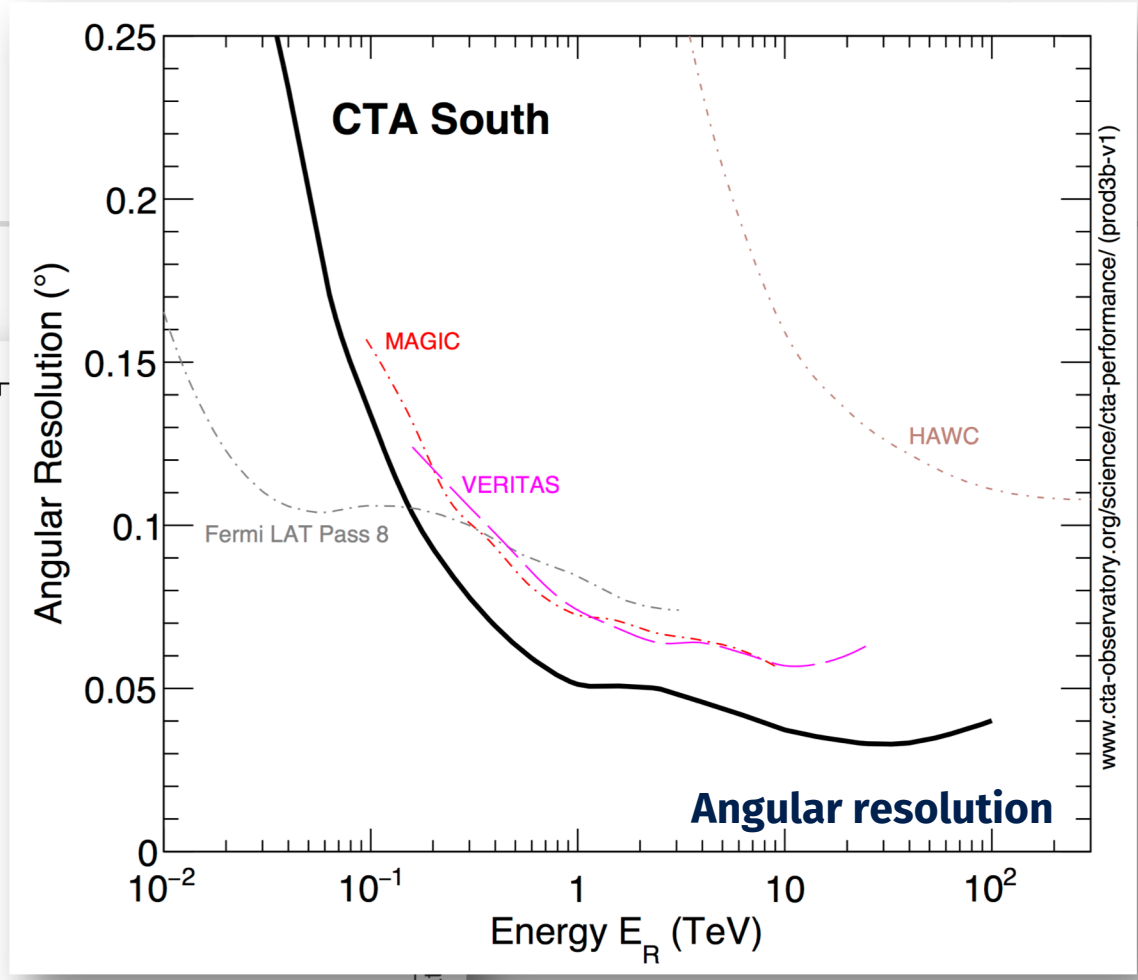


A **γ-ray** impinges the **atmosphere**, producing a **particle shower** which, in turns, produces **a flash of Cherenkov radiation** lasting **5-20 ns** in the range **300<λ<500 nm**

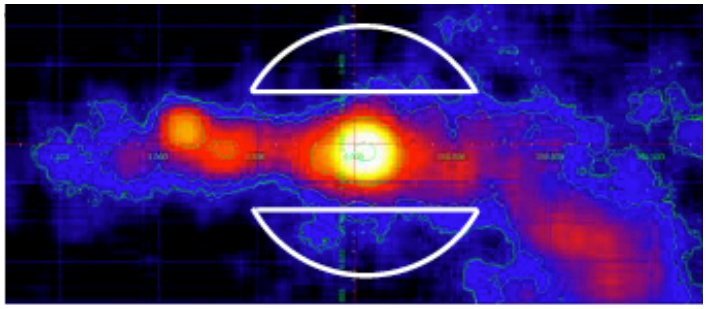
Credits: CTA Consortium

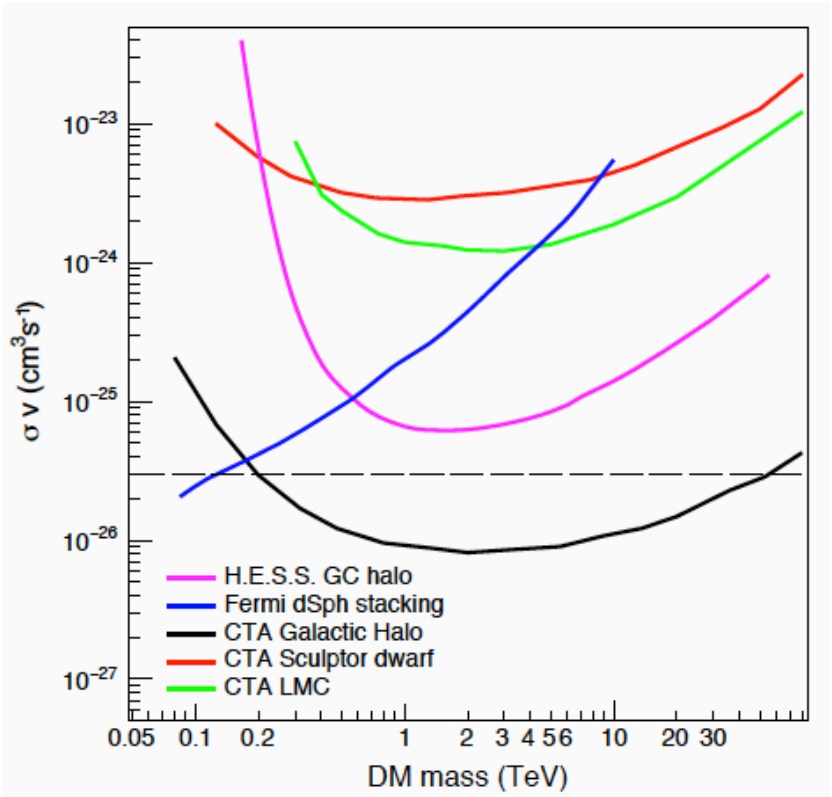
CTA Performance





The Dark Matter Programme





- **Key target: Galactic Centre halo**
  - Deep observation O(525 h) to reach canonical thermal cross-section for wide WIMP mass range
- **Complementary observations**
  - Dwarf Sph. Galaxies O(100 h)
  - LMC O(340 h)
  - Perseus Gal. Cluster O(300 h)
  - Expect strategy to evolve with new information

Galactic Plane Survey

Telescope	Hemisphere	Galactic Plane Coverage	Energy (GeV)	Sensitivity (mCrab)
Fermi-LAT 2FHL	(space)	full plane	> 50	$\sim$30 – 40
H.E.S.S.-I	S	$-95° < l < 60°$, $\lvert b\rvert \lesssim 2°$	$\gtrsim 300$	4 – 20
VERITAS	N	$67° < l < 83°$, $-1° < b < 4°$	$\gtrsim 300$	20 – 30
ARGO-YBJ	N	northern sky	> 300	240 – 1000
HEGRA	N	$-2° < l < 85°$, $\lvert b\rvert < 1°$	> 600	150 – 250
Milagro	N	northern sky	$> 10,000$	300 – 500

Current GPS surveys

CTA GPS survey

	STP (Years 1 – 2)		LTP (Years 3 – 10)	Total (Years 1 – 10)	
Galactic Longitude	**Hours**	**Sensitivity**	**Hours**	**Hours**	**Sensitivity**
SOUTH					
300° – 60° , Inner region	300	**2.7 mCrab**	480	780	**1.8 mCrab**
240° – 300° , Vela, Carina			180	180	**2.6 mCrab**
210° – 240°			60	60	**3.1 mCrab**
				1020	
NORTH					
60° – 150° , Cygnus, Perseus	180	**4.2 mCrab**	270	450	**2.7 mCrab**
150° – 210° , anti-Centre, etc.			150	150	**3.8 mCrab**
				600	

Observatory	Hemisphere	Energy Thresh.	Ang. Resolution	Pt. Source Sensitivity
CTA	N, S	125 GeV	$\sim 0.07°$ at 1 TeV	2 – 4 mCrab
HAWC	N	2 TeV	$0.30°$	20 mCrab

CTA/HAWC survey performance

Galactic Centre Survey

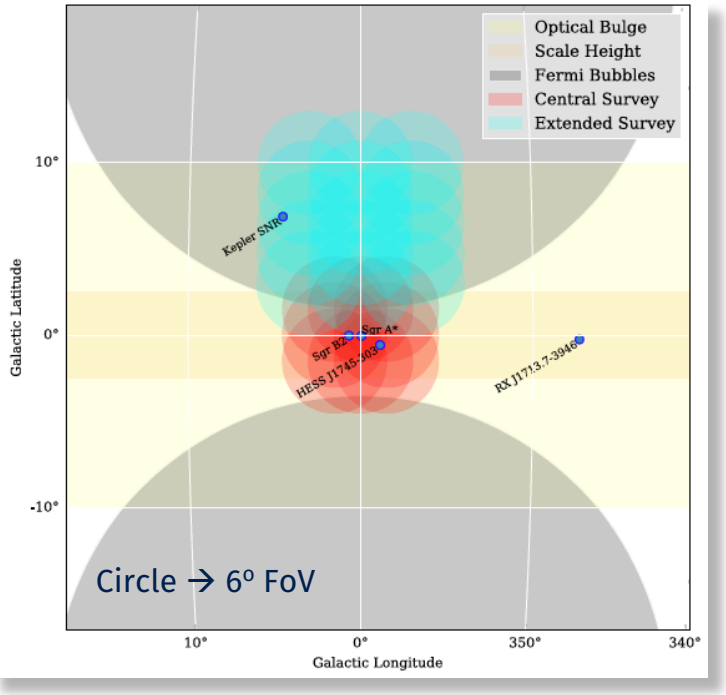
	Deep Exposure	Extended Survey
Time requested	525 h	300 h
Priority	1	3
Strategy	survey	survey
Site	S	S
Sub-array	Full	Full
Zenith Range	$< 40°$	$< 50°$
Atmosphere Quality	high	high
Targets Covered	multiple	multiple

Central survey region: a deep exposure of 525 h, centered on Sgr A*(l = ±1.0º, 0º and b = ±1.0º, 0º).

- **1st year** → updated analysis of the central source.
- **3rd year** → detailed study of the extended/diffuse emission will be possible + data for DM search.

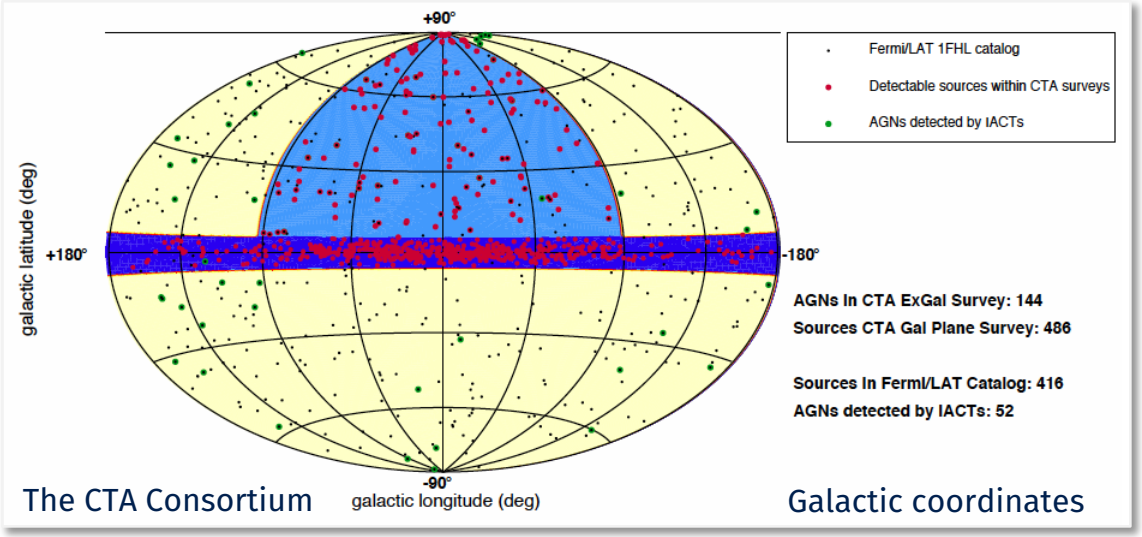
Extended survey region: 300 h of exposure covering a large region to the south or north of the GPS region out to 10º in latitude.

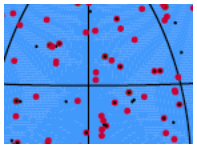
These observations can be taken after the deep exposure, i.e. after the third year of operation.



The CTA Consortium

Extra-galactic Survey





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

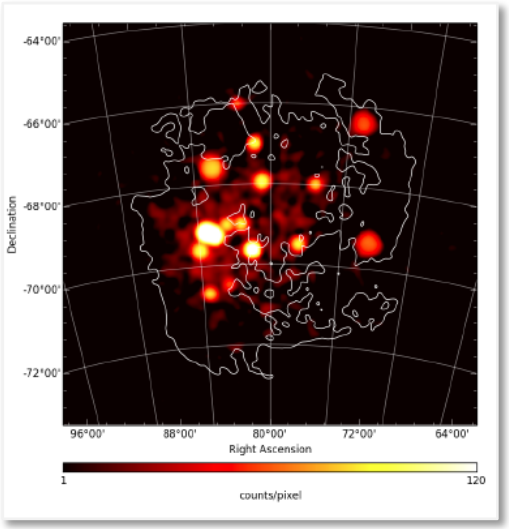
O(100) AGNs in 10^4 deg^2

The survey would connect with the Galactic Plane Survey ($|b| < 5^o$) over Galactic longitude $-90^o < l < 90^o$.

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.

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).

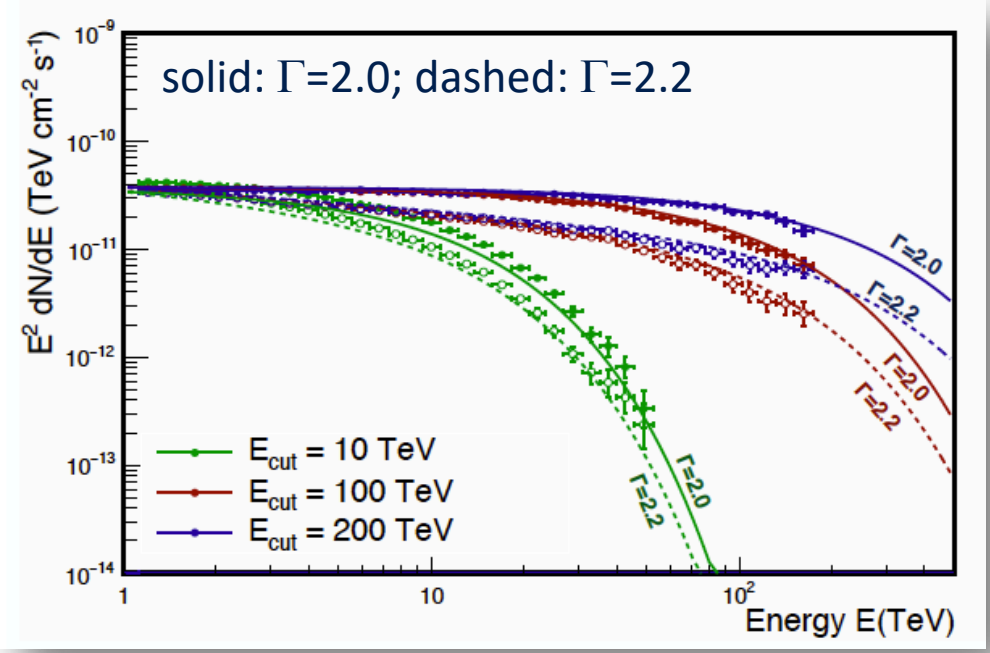
Its activity is attested by more than 60 supernova remnants, several HII regions, bubbles and shells observed at various wavelengths.

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

Mapping of the interstellar gas over wide areas is absolutely essential to enable **identification of sources** within large scale surveys such as that of the LMC.

(Sub)-millimeter wavelengths → detailed **understanding of the environment** into which shock waves propagate and through which accelerated particles are transported and interact.

Cosmic-ray PeVatrons



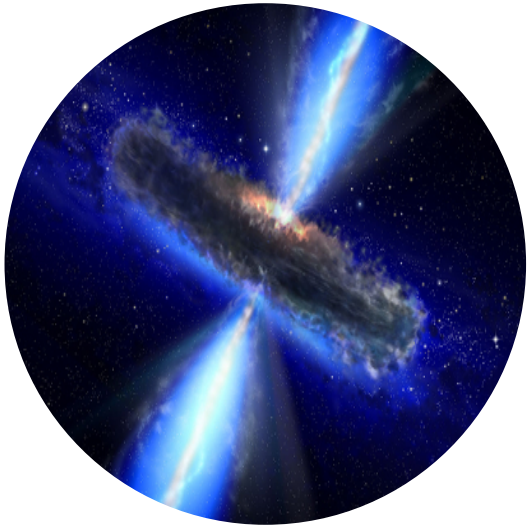
Simulated **reconstructed spectra for CTA for a PeVatron-like source** with a flux equal to the Crab nebula, using two photon indices.

Three different exponential energy cutoff values are used, as indicated by the colors.

Target	Type	Exposure (h)	Array	Year	Configuration
RX J1713.7–3946	SNR	50	S	$1-3$	Full array
PeVatrons	Unknown	5×50	S	>3	MSTs + SSTs

Use **GPS as finder** and **follow-up 5 brightest sources with no cut-off.**
MWL information critical for identification → SKA

Active Galactic Nuclei



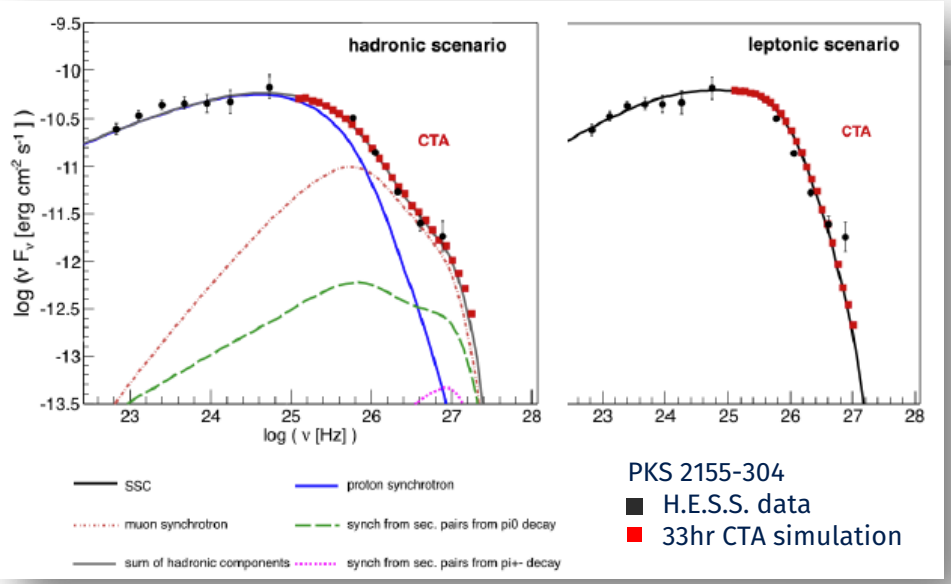
Credits: ESA/NASA

AGNs are known to emit **variable radiation** across the entire electromagnetic spectrum up to multi-TeV energies, with fluctuations **on time-scales** from **several years** down to **a few minutes.**

VHE observations of active galaxies harbouring super-massive black holes and ejecting relativistic outflows represent a unique tool to probe the **physics of extreme environments**, to obtain precise measurement of the **extragalactic background light** (EBL) and to constrain the strength of the **intergalactic magnetic field** (IGMF).

AGNs will be useful to investigate fundamental physics phenomena such as the **Lorentz invariance violation** and signatures of the existence of **axion-like particles**.

Active Galactic Nuclei



A set of **high-quality spectra** from different blazar types and different redshifts is needed to **unambiguously distinguish intrinsic spectral features**, such as shown here**, from external absorption**.

Such measurements put strong **constraints on the bulk Doppler factor**, as well as on particle acceleration and cooling processes.