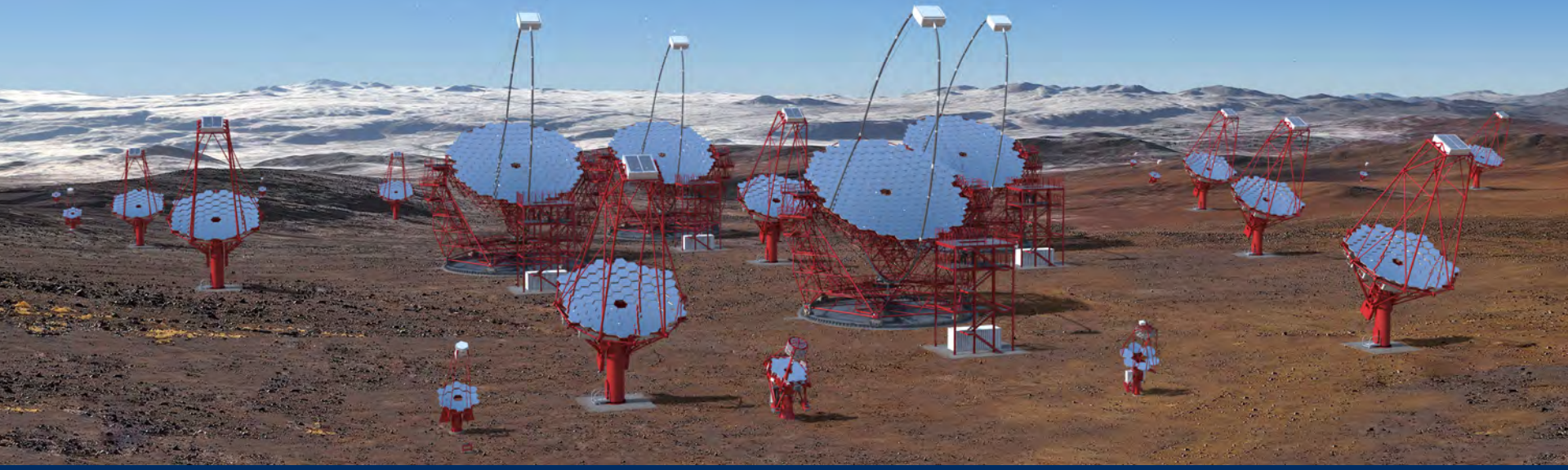
cherenkov telescope array

The Cherenkov Telescope Array: key science projects and multi-wavelength synergies



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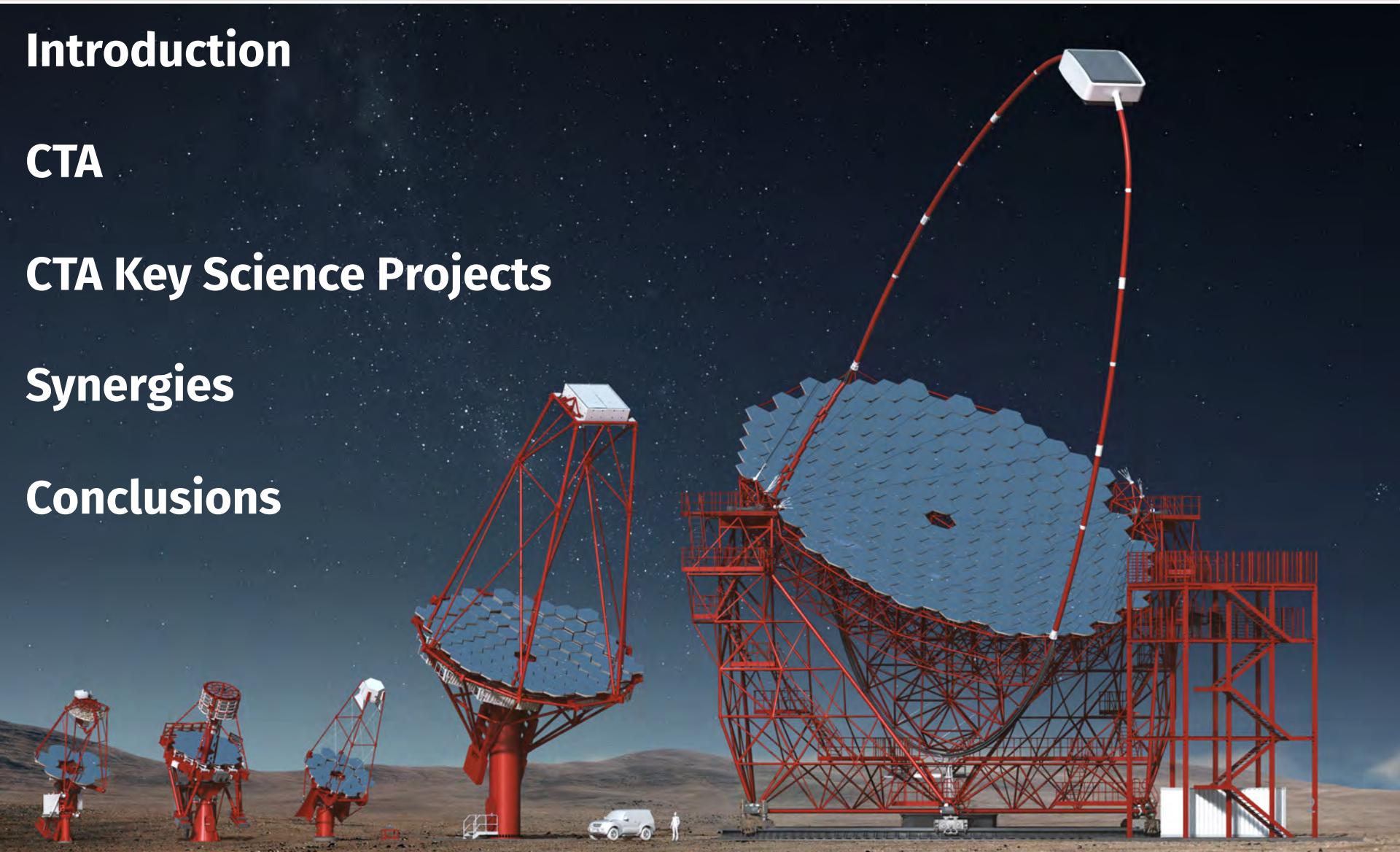
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Outline



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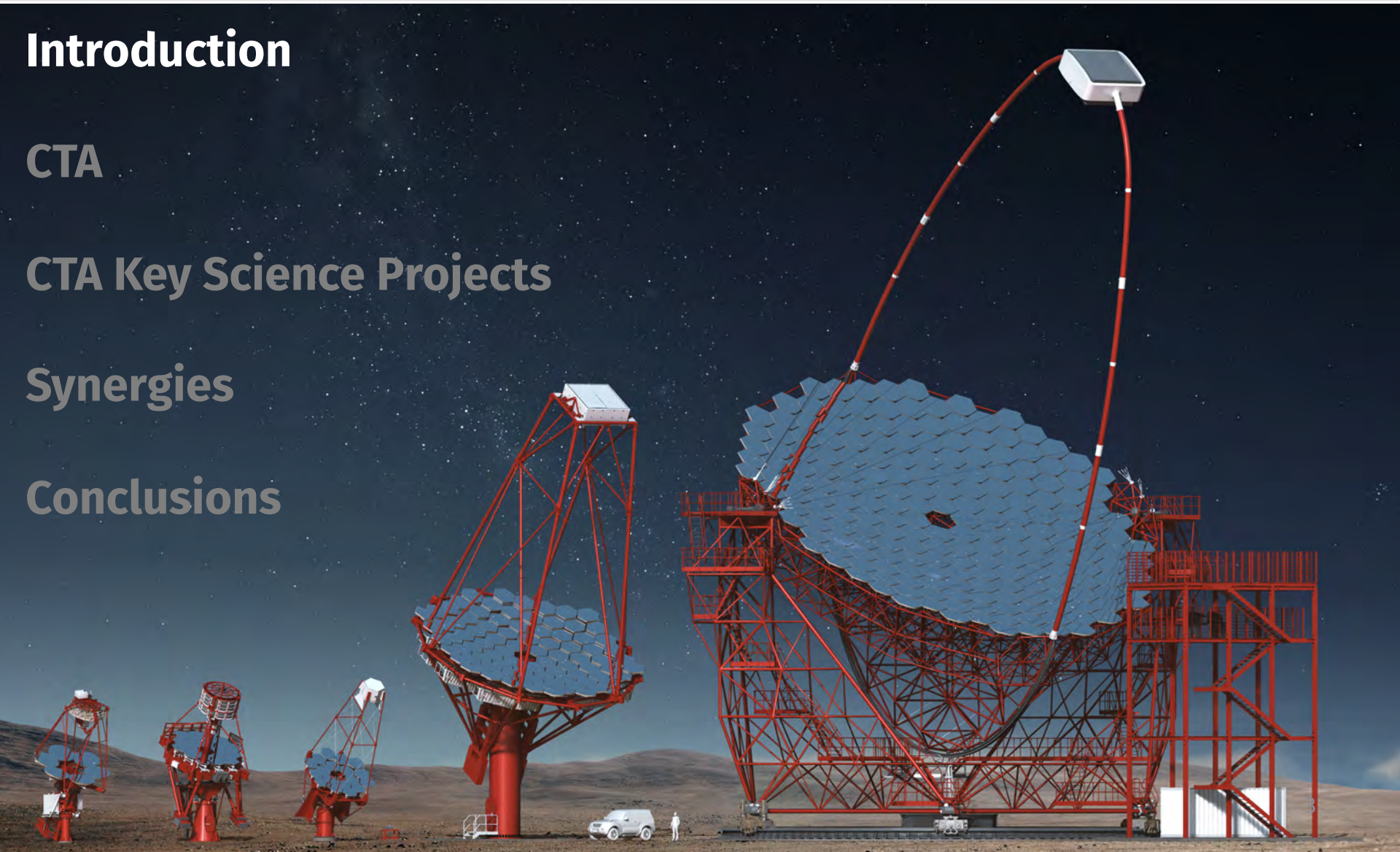

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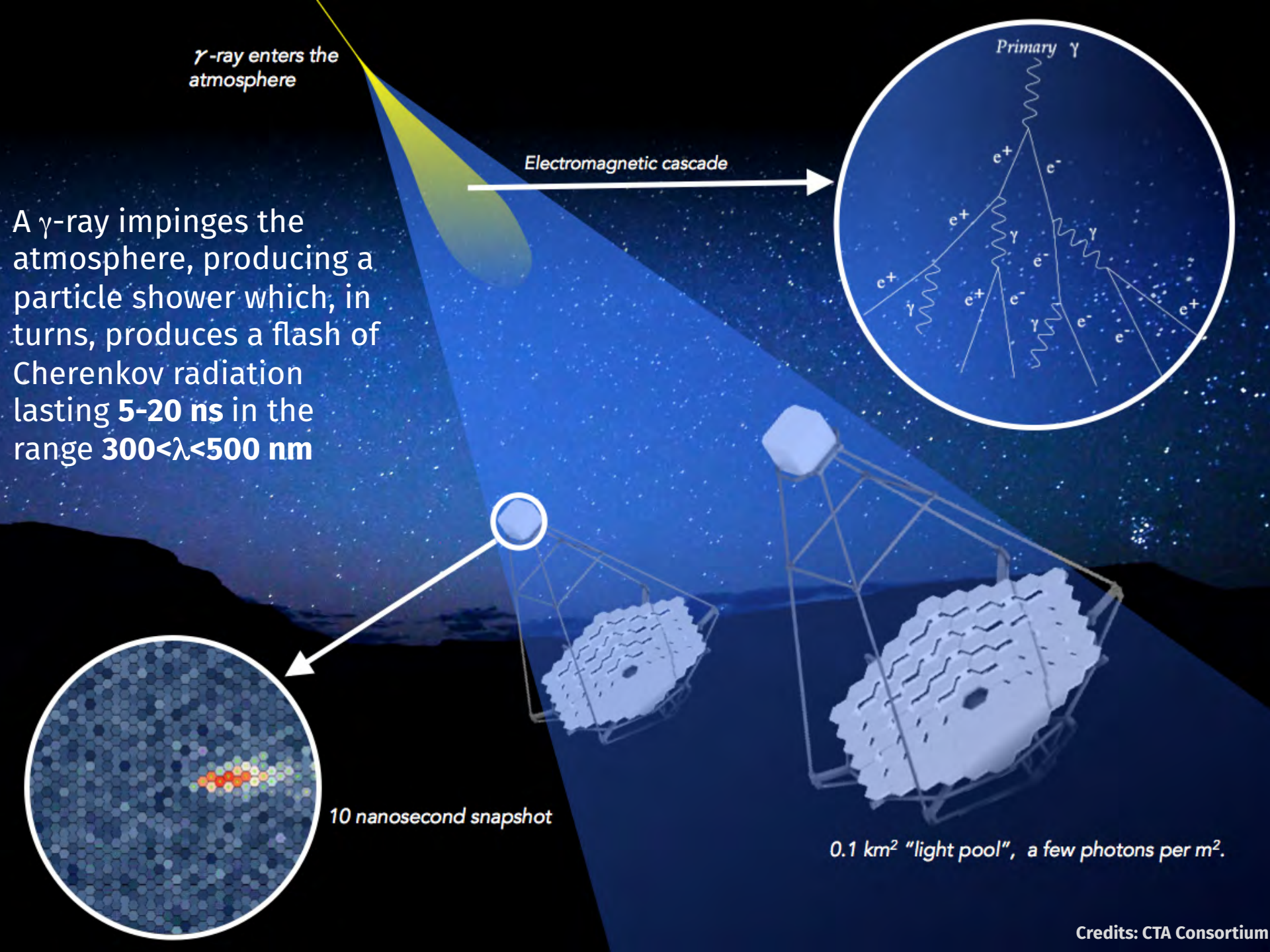
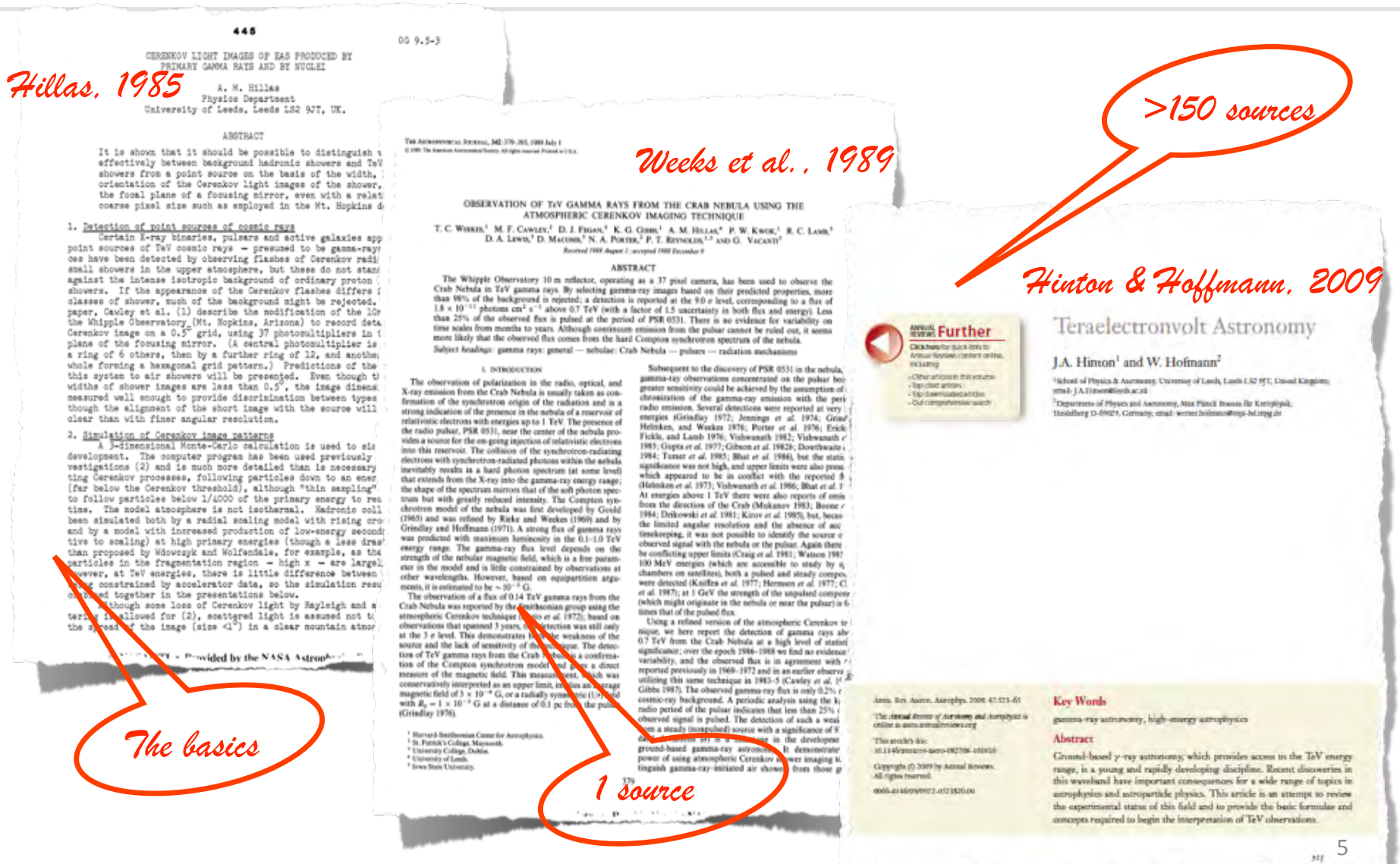
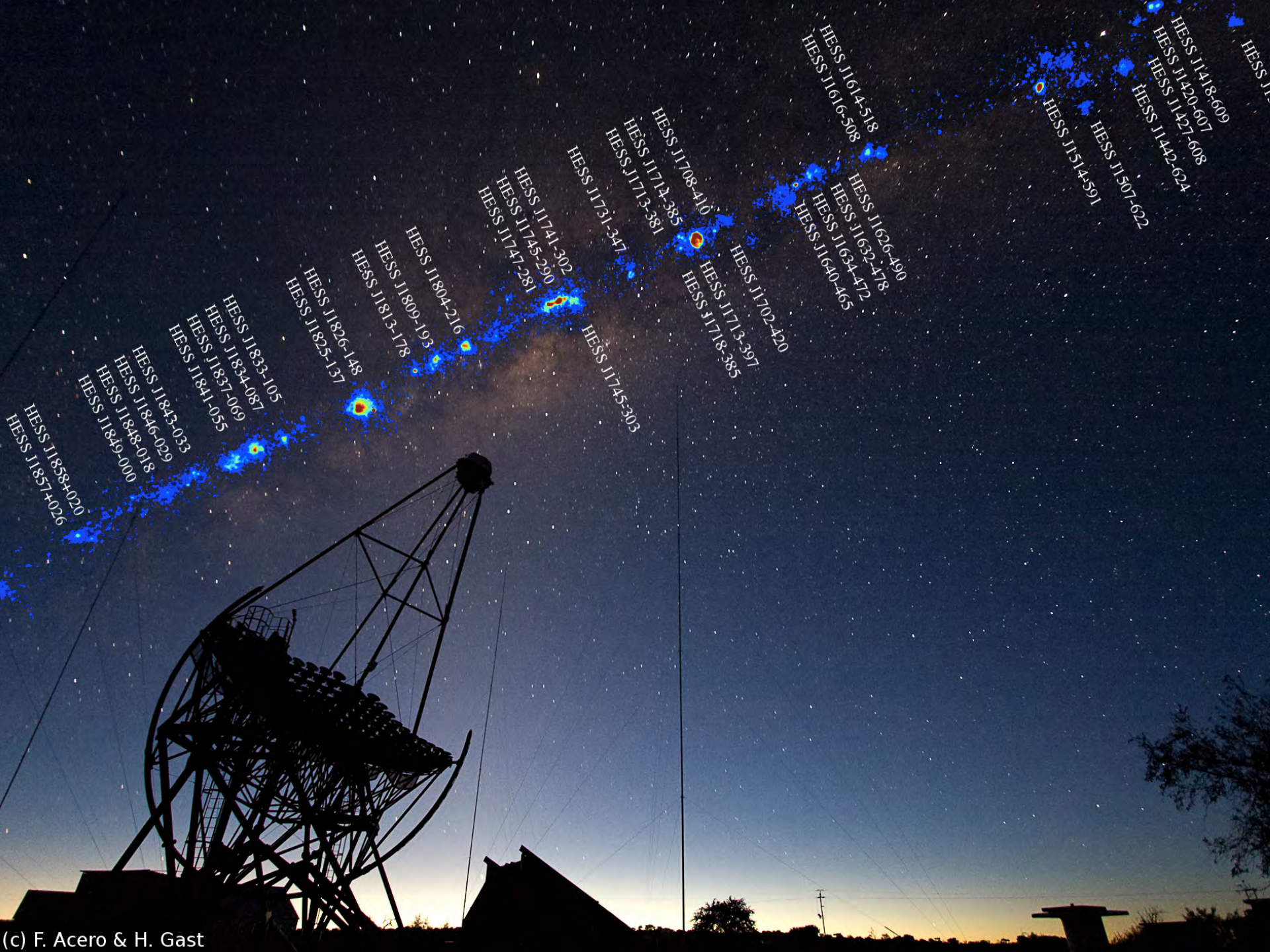


A γ-ray impinges the atmosphere, producing a particle shower which, in turns, produces a flash of Cherenkov radiation lasting **5-20 ns** in the range **300<λ<500 nm**

Credits: CTA Consortium

VHE high-level timeline




HESS J1858+020
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HESS J1849-000
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HESS J1834-087
HESS J1837-069
HESS J1841-055
HESS J1826-148
HESS J1825-137
HESS J1804-216
HESS J1809-193
HESS J1813-178
HESS J1741-302
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HESS J1745-303
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HESS J1616-508
HESS J1514-591
HESS J1507-622
HESS J1442-624
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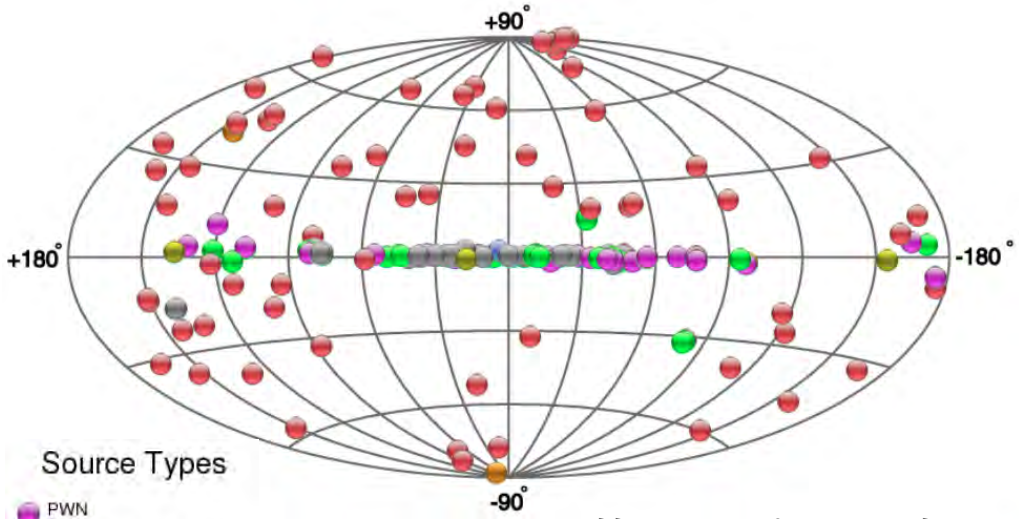
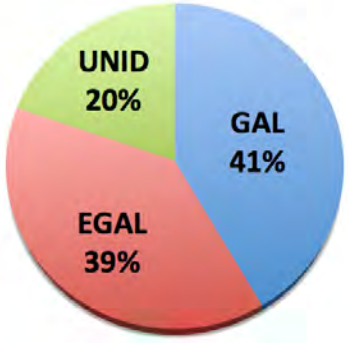
HESS J1420-607
HESS J1418-609
(c) F. Acero & H. Gast

The sky above 50 GeV



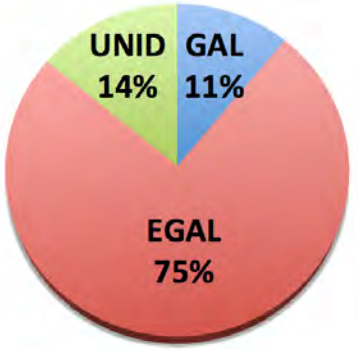
Wakely & Horan http://tevcat.uchicago.edu/

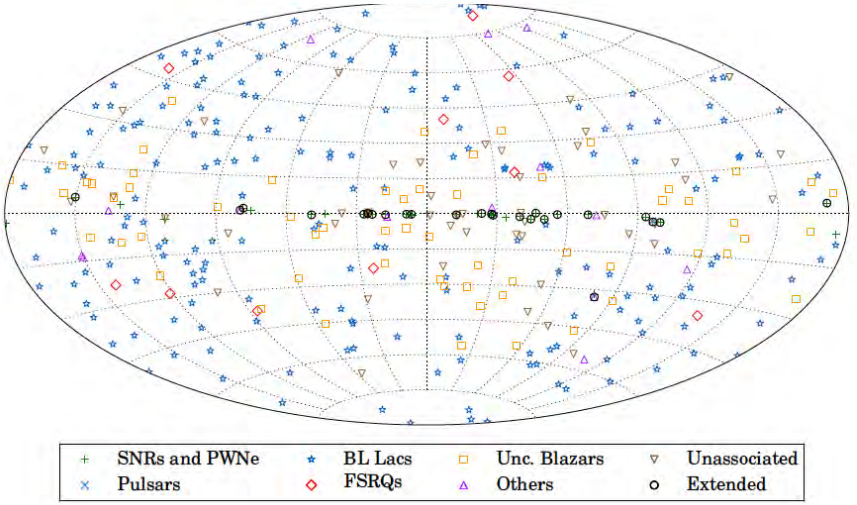
~180 TeVCat sources



H.E.S.S.
MAGIC
VERITAS

360 *Fermi*-LAT sources E>50 GeV

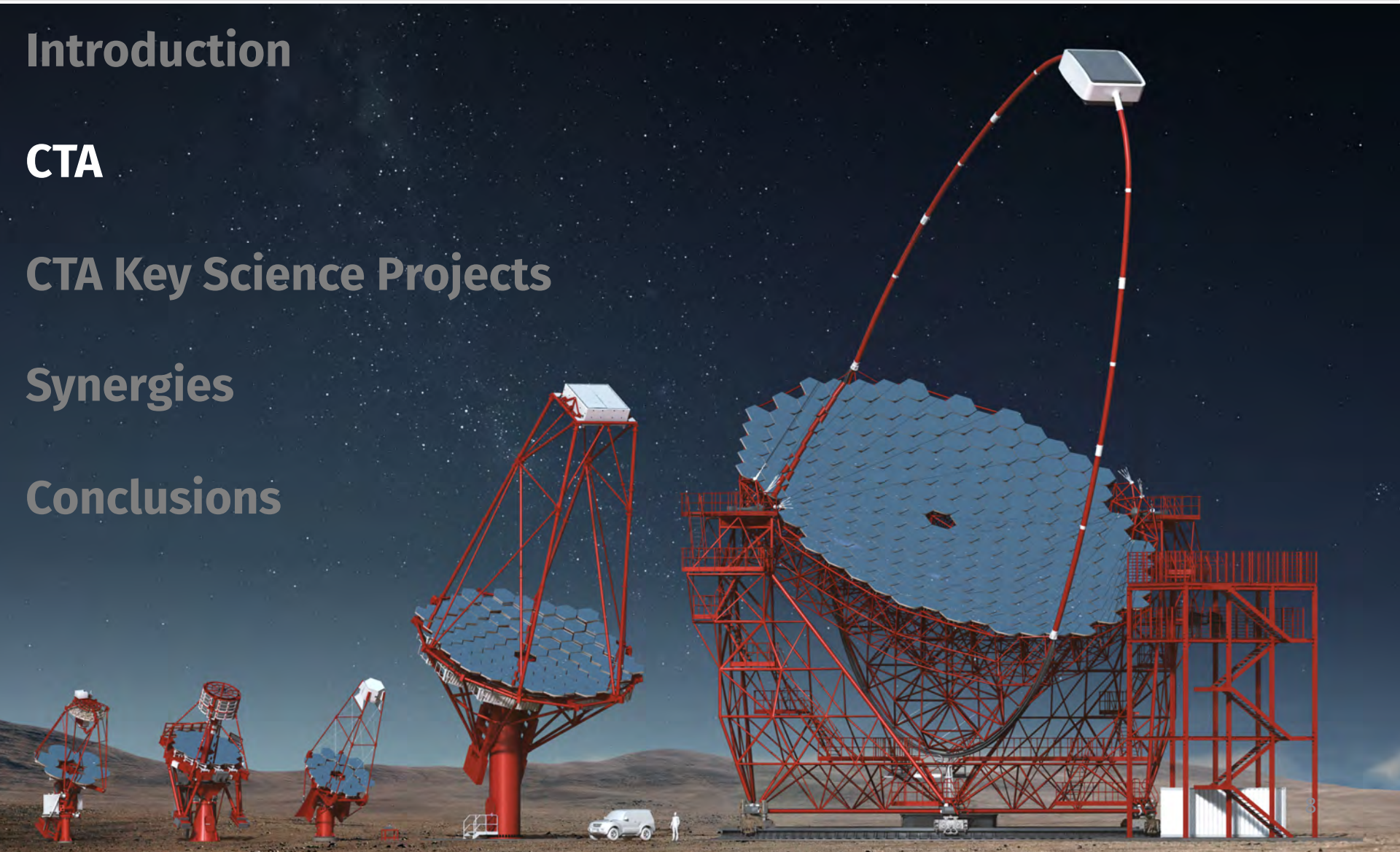




2FHL Ackermann+16

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.

Outline



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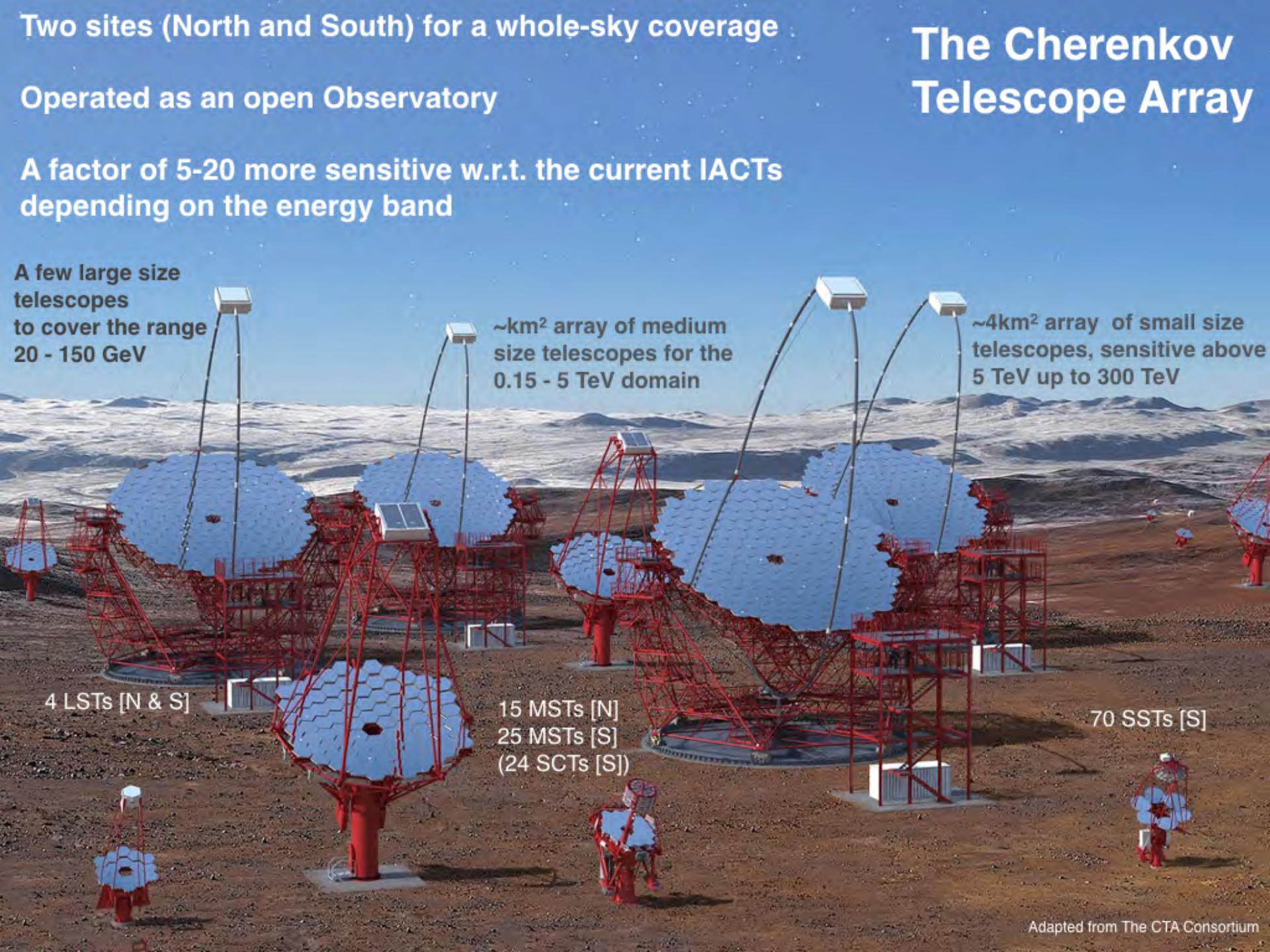
The Cherenkov Telescope Array

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

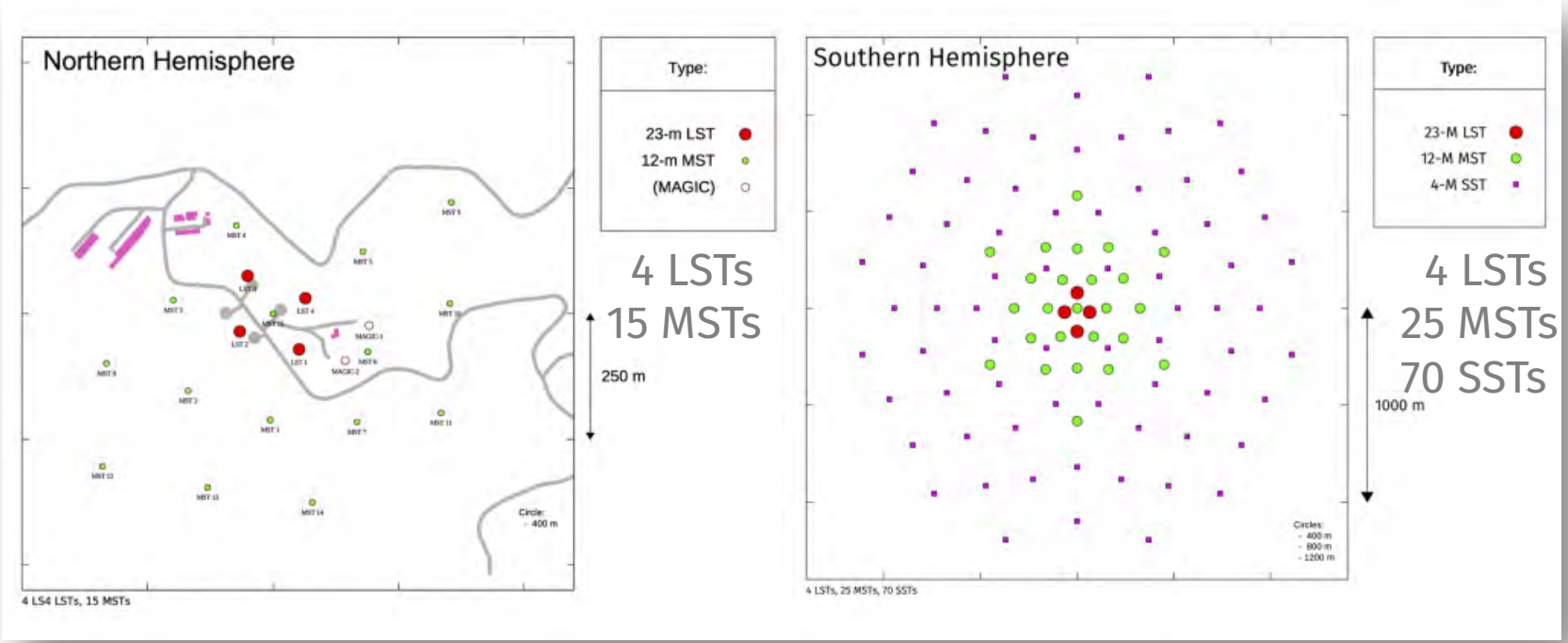
Where to find us

High-level timeline and proposed layout

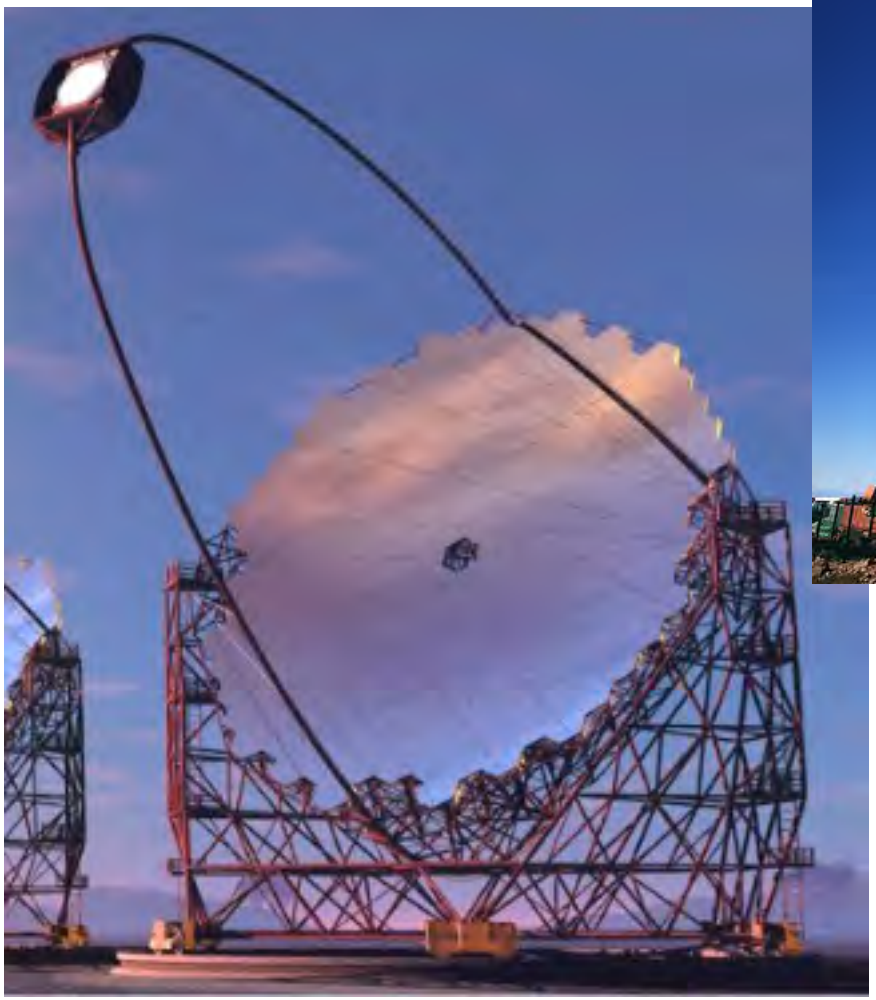
Project Phases

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

https://www-zeuthen.desy.de/cta_cam/photogallery/content/index.html

Credits: The CTA Consortium

Small size telescope prototypes

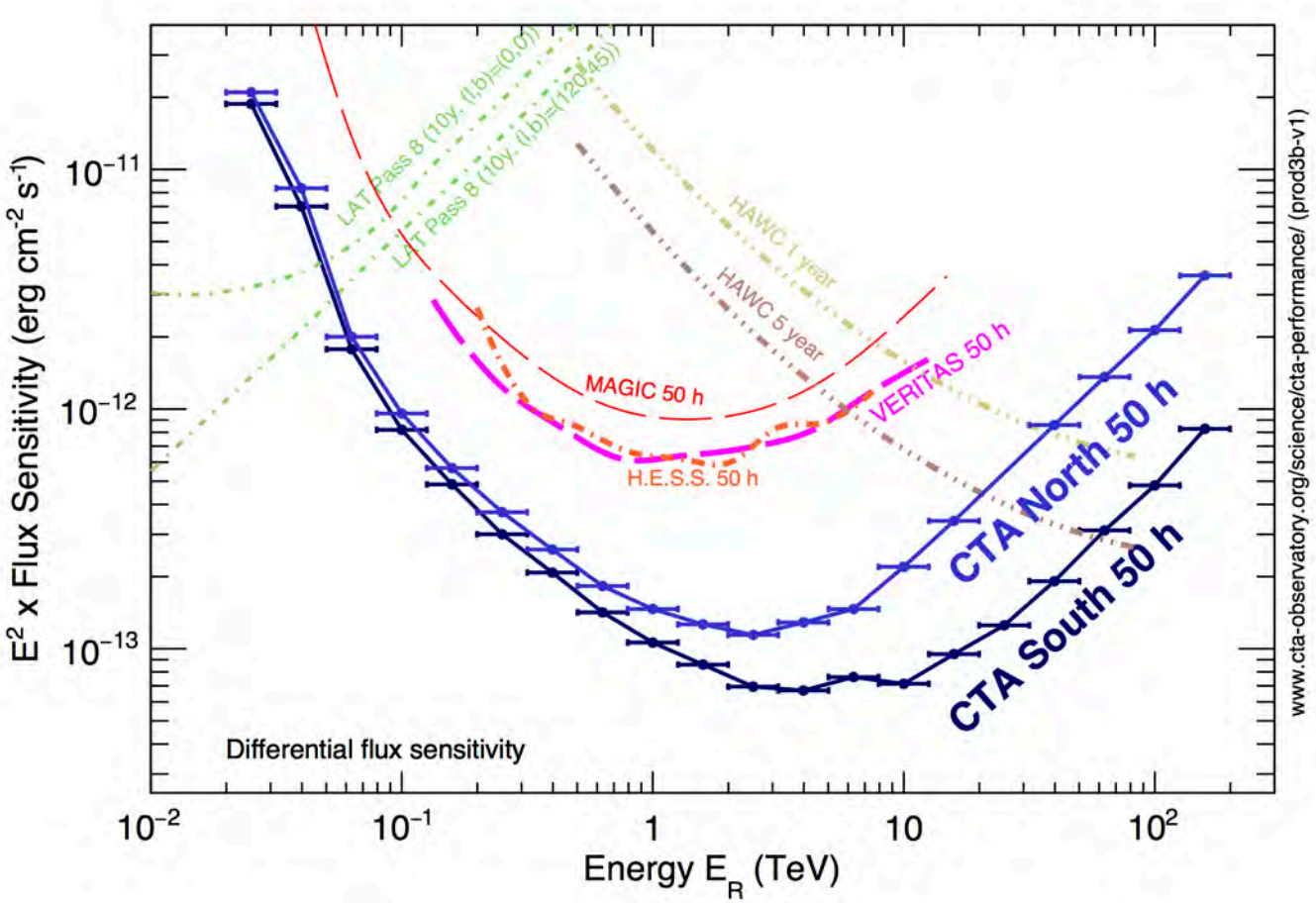
SST-2M GCT prototype in Paris

SST-1M prototype in Krakow

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

CTA Performance

Differential Sensitivity

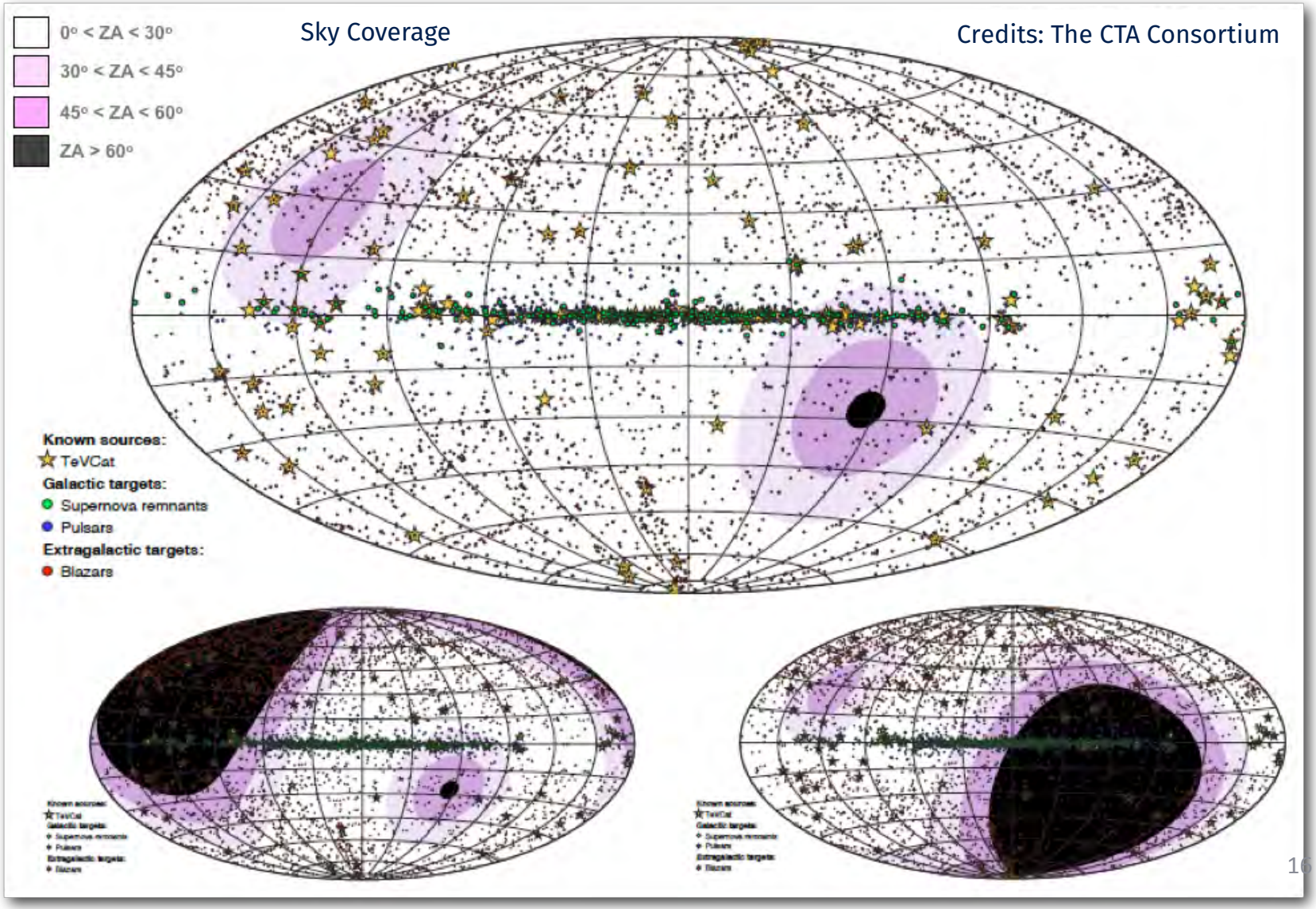


A factor of **5-20 improvement** in sensitivity depending on energy, relative to current IACTs.

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

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

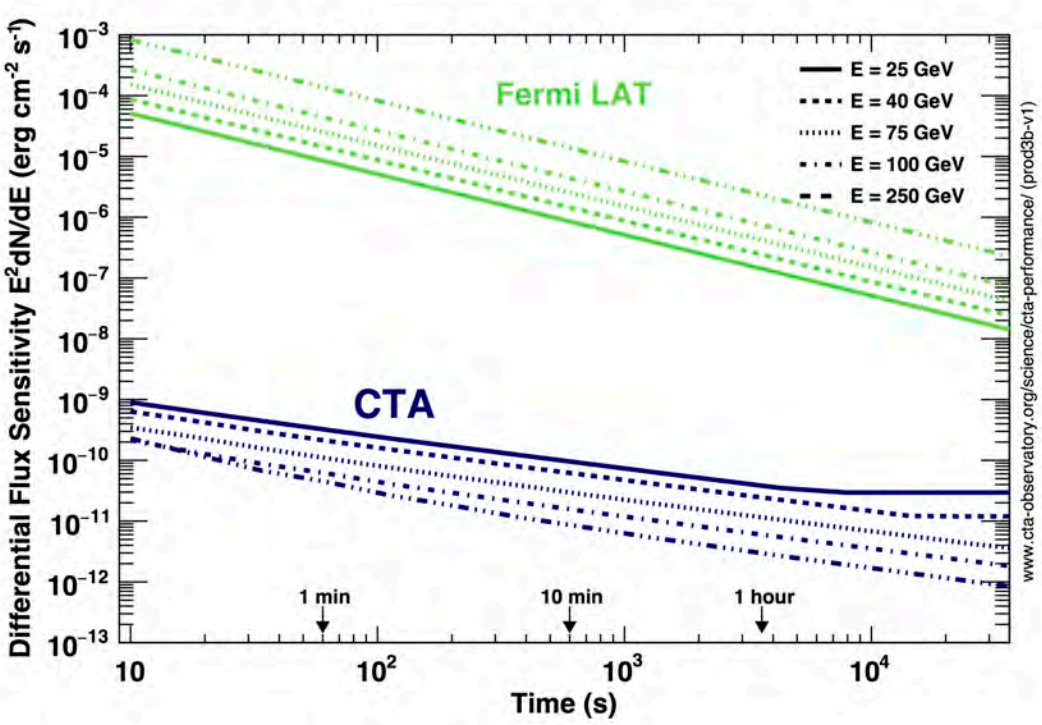
CTA as an *all-sky* Observatory



CTA as a *transient factory*

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

- **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

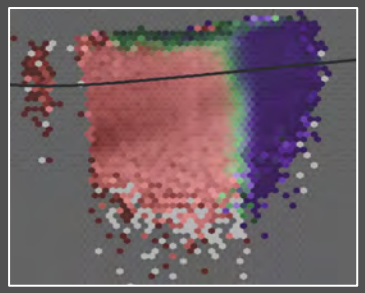
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

CTA Observing Programme

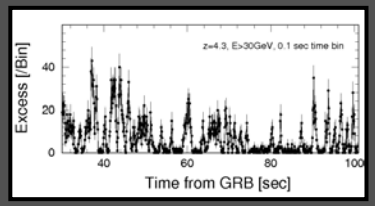
- **9 Key Science Projects** (KSPs) and **1 DM Programme**
  - **KSPs are a sets of observations addressing multiple science questions within CTA themes**

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

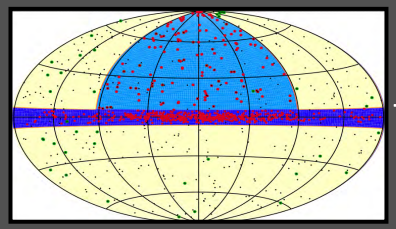
- Large potential for **guest observer proposals**
  - building on results from the KSP surveys



Dark Matter Programme



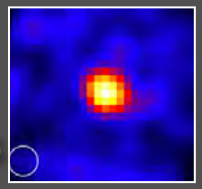
Transients



ExGal Survey

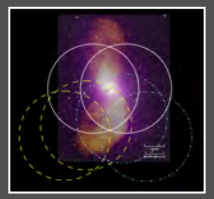
Extragalactic

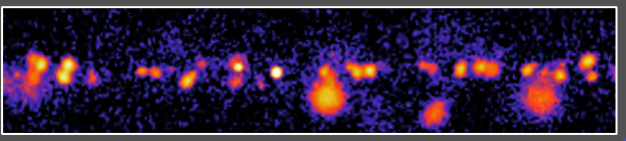
Galaxy Clusters



Star Forming Systems

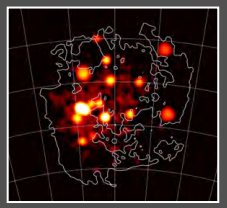
AGN



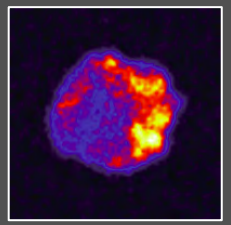


Galactic

LMC Survey

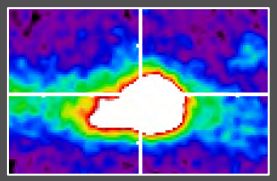


Galactic Plane Survey



PeVatrons

Galactic Centre Survey



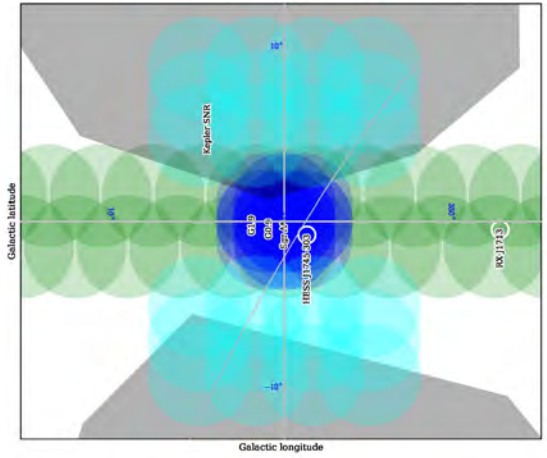
cta
cherenkov telescope array

Science with CTA

arXiv:1709.07997

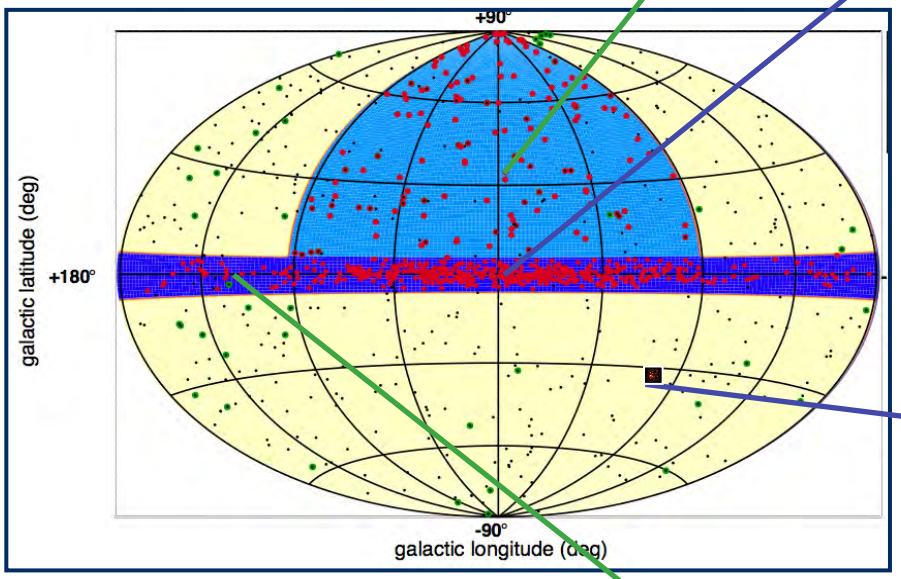
To be published as a book & open-access online version by World Scientific.

The Survey KSPs



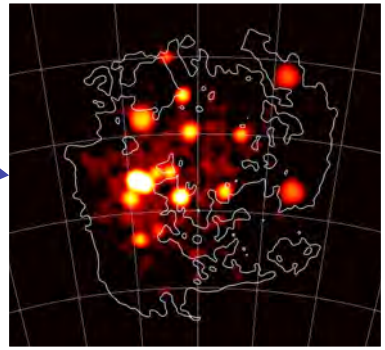
Extragalactic Survey:

Unbiased survey of ¼ sky to ~6 mCrab
VHE population study, duty cycle
New, unknown sources; 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



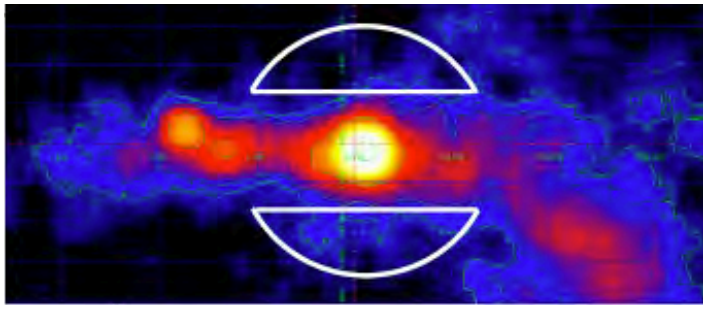
Galactic Plane Survey:

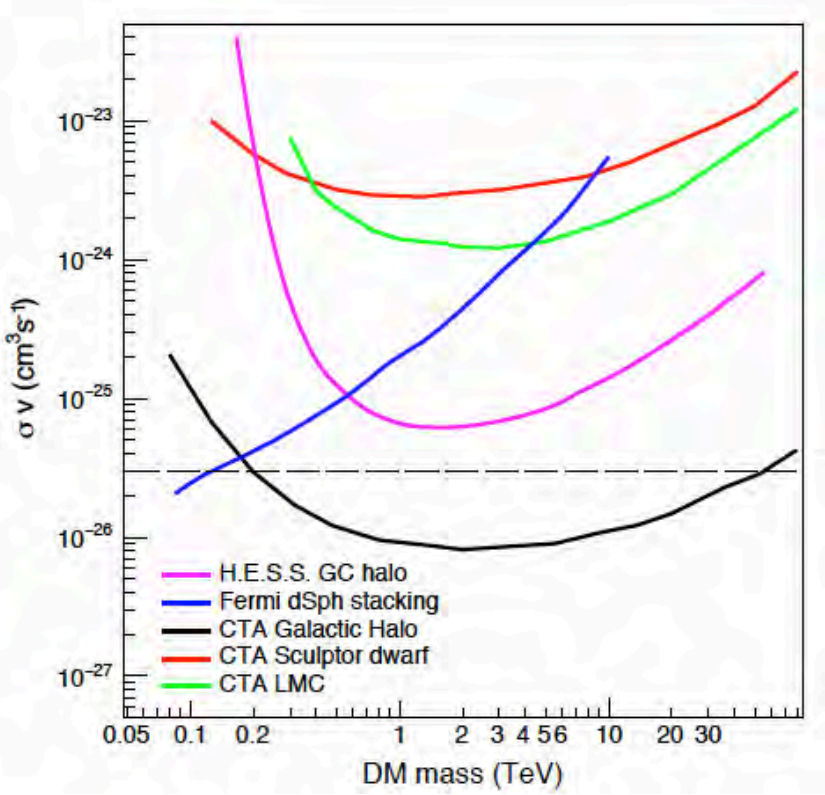
Survey of entire plane to ~2 mCrab
Galactic source population: SNRs, PWNe, etc.
PeVatron candidates, early view of GC, O(1620) h

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

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

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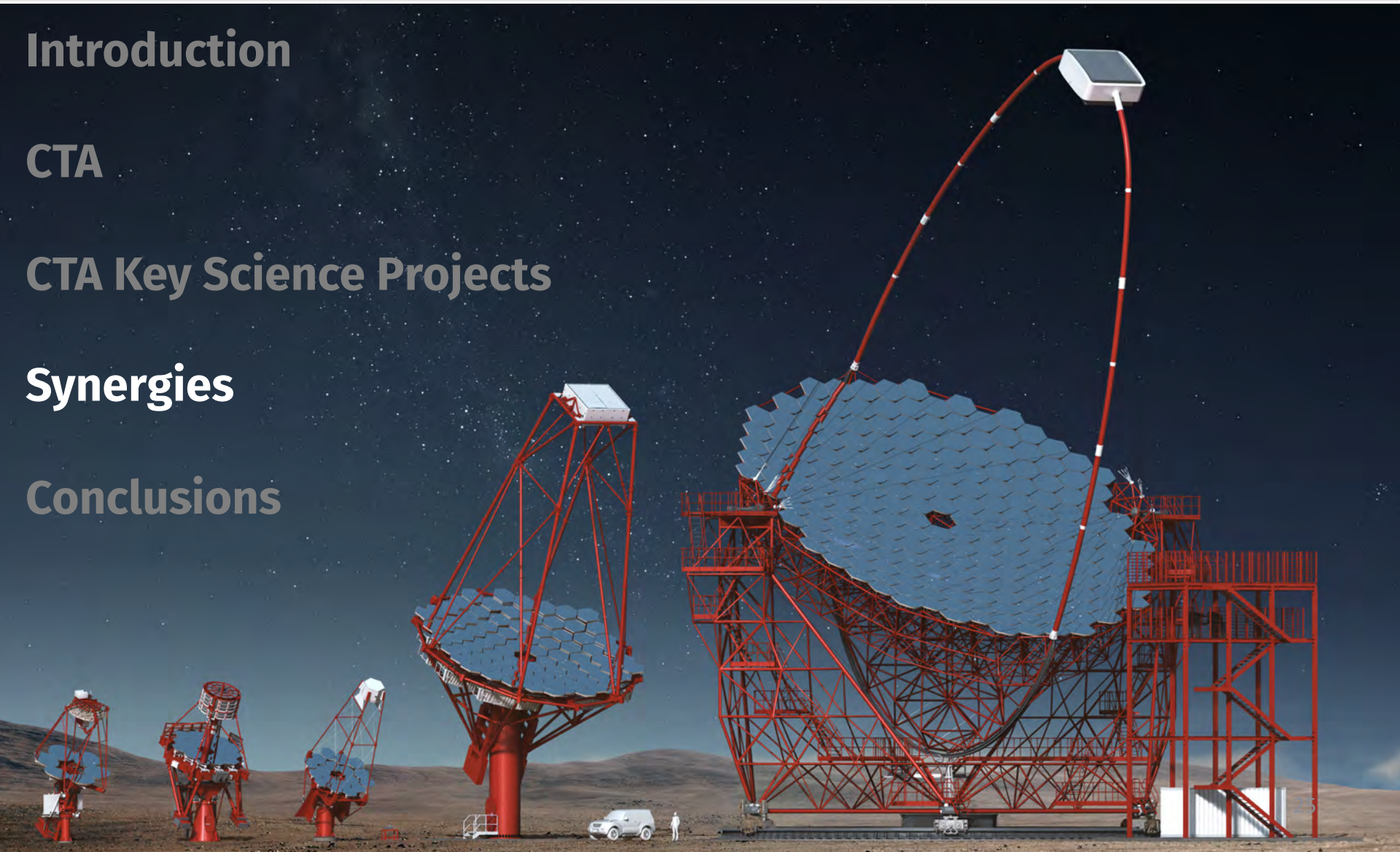
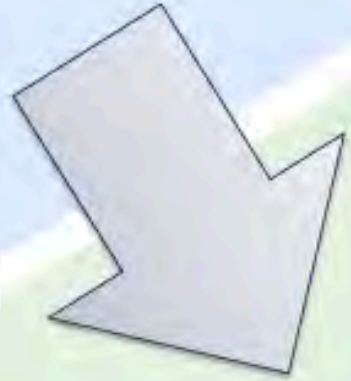


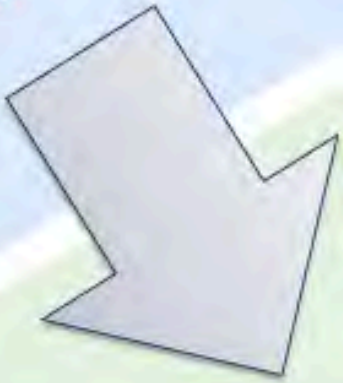
KSPs vs. proposal-driven programs

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

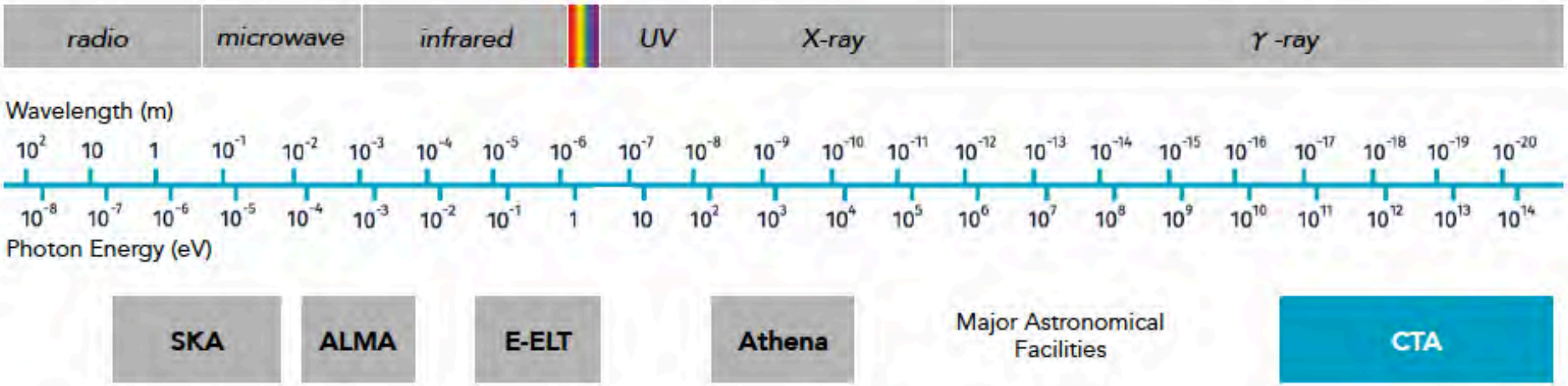


- Deep investigation of known sources
- Follow-up of KSP discovered sources
- Multiwavelength campaigns
- Follow-up of ToOs from other wavebands / messengers
- Search for new sources
- ...

Proposal-Driven User Programme

Credits: Hofmann, Gamma 2016

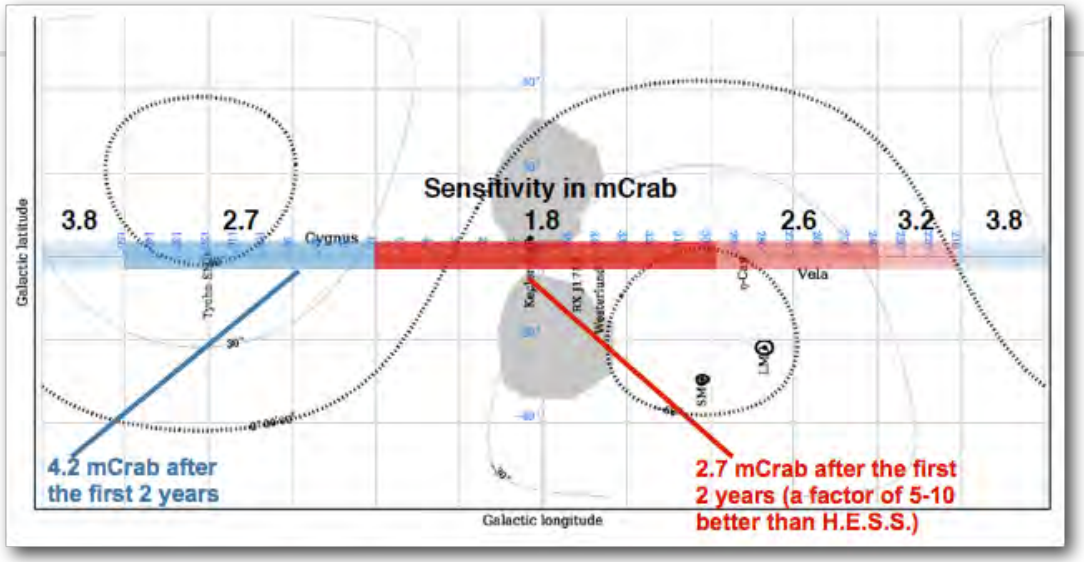
Synergies during CTA operation

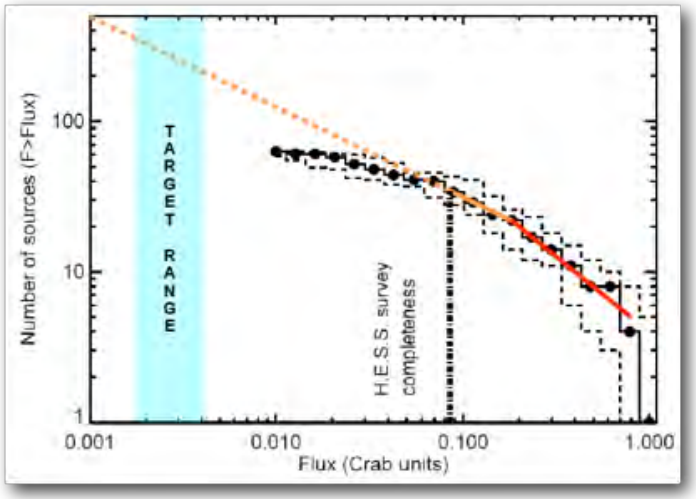


These are just a few of the future major multi-wavelength facilities available during the CTA era.

Galactic Plane Survey

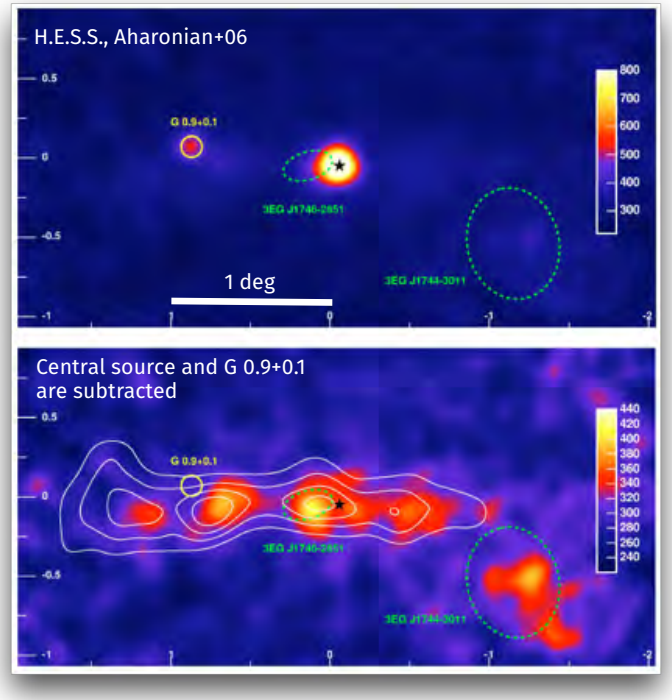
The CTA Consortium

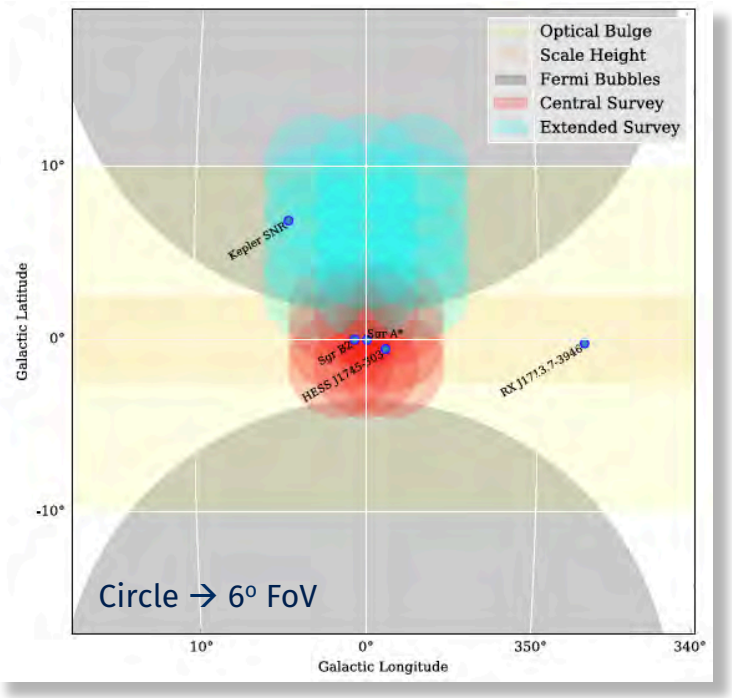




- Discovery of PeVatron candidates ➡ origin of cosmic rays
- Detection of many new VHE sources O(300 – 500), particularly PWNe and SNRs
- Discovery of new VHE gamma-ray binaries
- Production of a multi-purpose legacy data set
- **Radio/mm and X-ray facilities** →PSR ephemerides, **PWNe/SNRs morphology**/SEDs, 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 Centre Survey



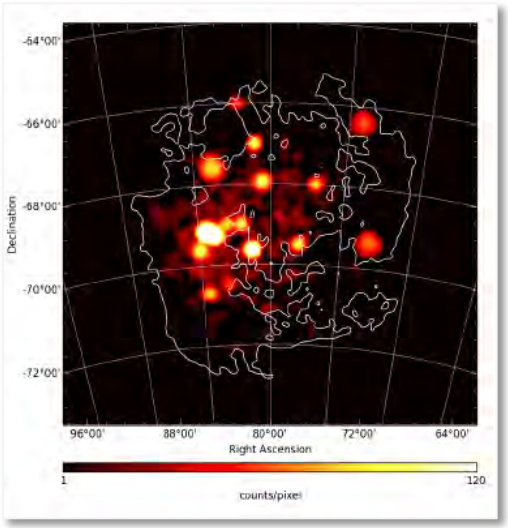


- Determination of the nature of the central source
- A detailed view of the VHE diffuse emission
- Search for variability in the VHE source near Sgr A*
- Studying the interaction of the central source with neighboring clouds
- Global **VLBI array at mm/sub-mm frequencies**, → direct **imaging of the jet-launching regions** of key sources such as Sgr A*
- AGNs **optical polarisation** studies of jets → derivation of **magnetic field parameters** that can be used to improve SED modeling and emission-region localisation

The CTA Consortium

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).

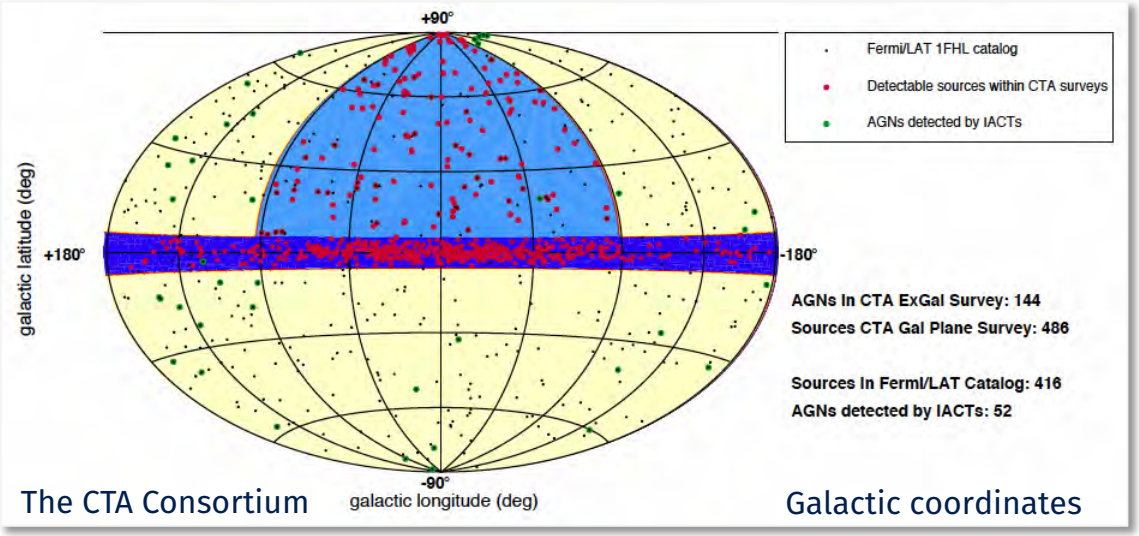
Its activity is attested by more than 60 supernova remnants, dozens to hundreds of HII regions, bubbles and shells observed at various wavelengths.

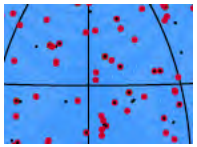
It is a unique place to obtain a resolved, global view of a star-forming galaxy at TeV energies.

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.

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.

eROSITA will be the first imaging **all-sky survey in the 2–10 keV** range → a primary reference for CTA source identification and **multi-wavelength correspondences**.

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).

Transient Factories & SKA

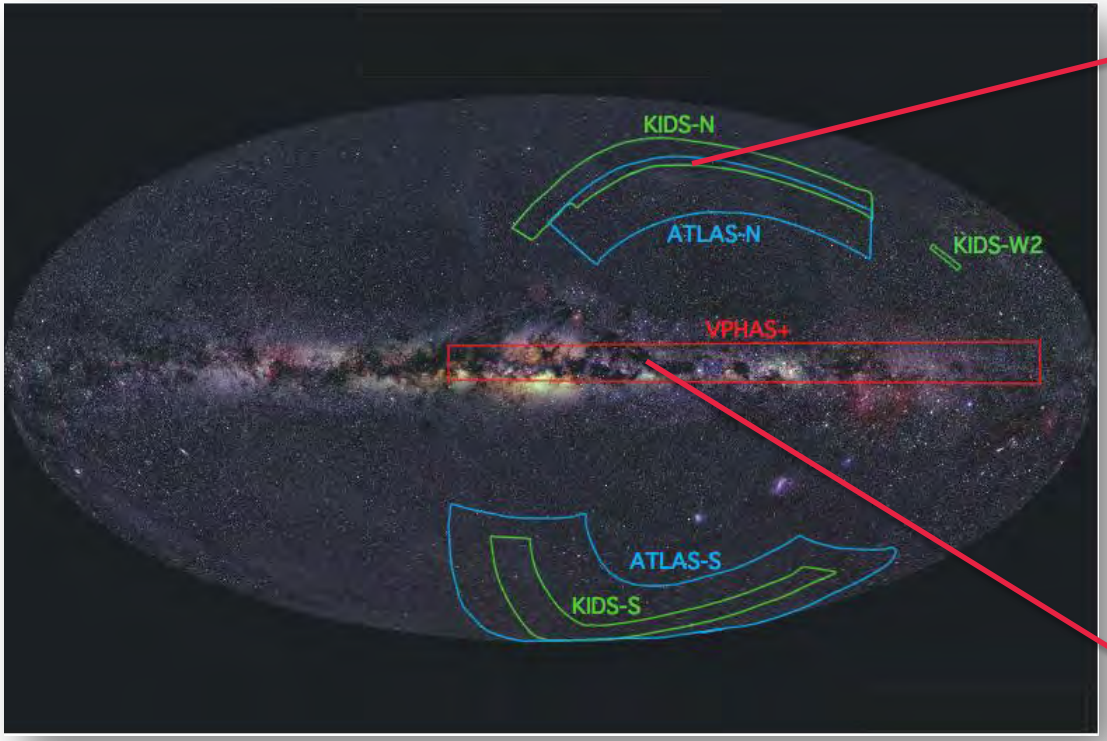
These facilities will generate **overwhelming number of triggers.**

It is key to understand the potential for VHE follow-up and **define appropriate response criteria.**

		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

VST Surveys



Credits: VST Scientific Collaboration

Synergies with the CTA **EGAL survey** KSP.

Synergies with the CTA **Galactic Plane survey** KSP and all KSPs investigating Galactic objects (**PeVatrons, Galactic Center**, ...)

Outline

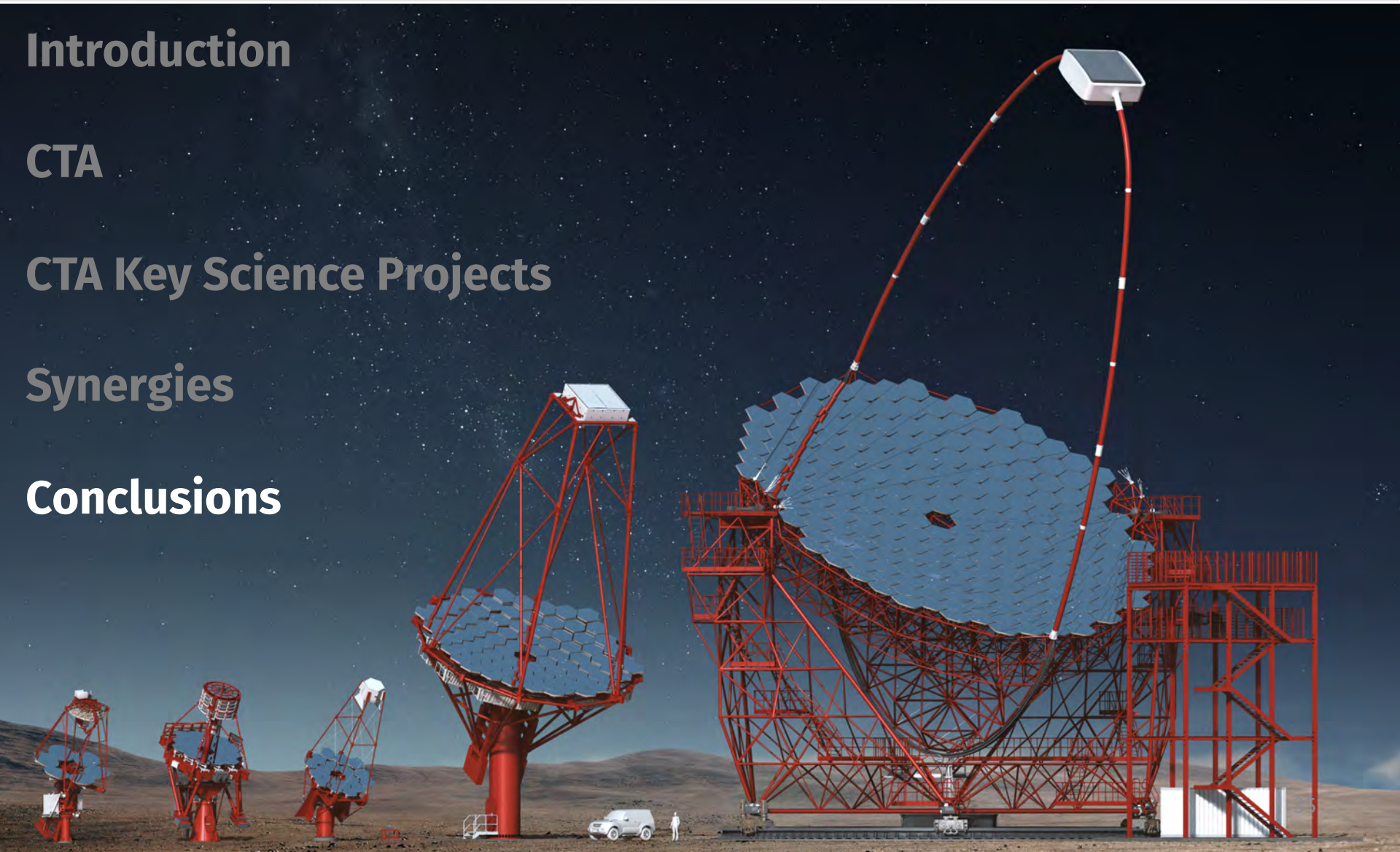
Introduction

CTA

CTA Key Science Projects

Synergies

Conclusions



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.

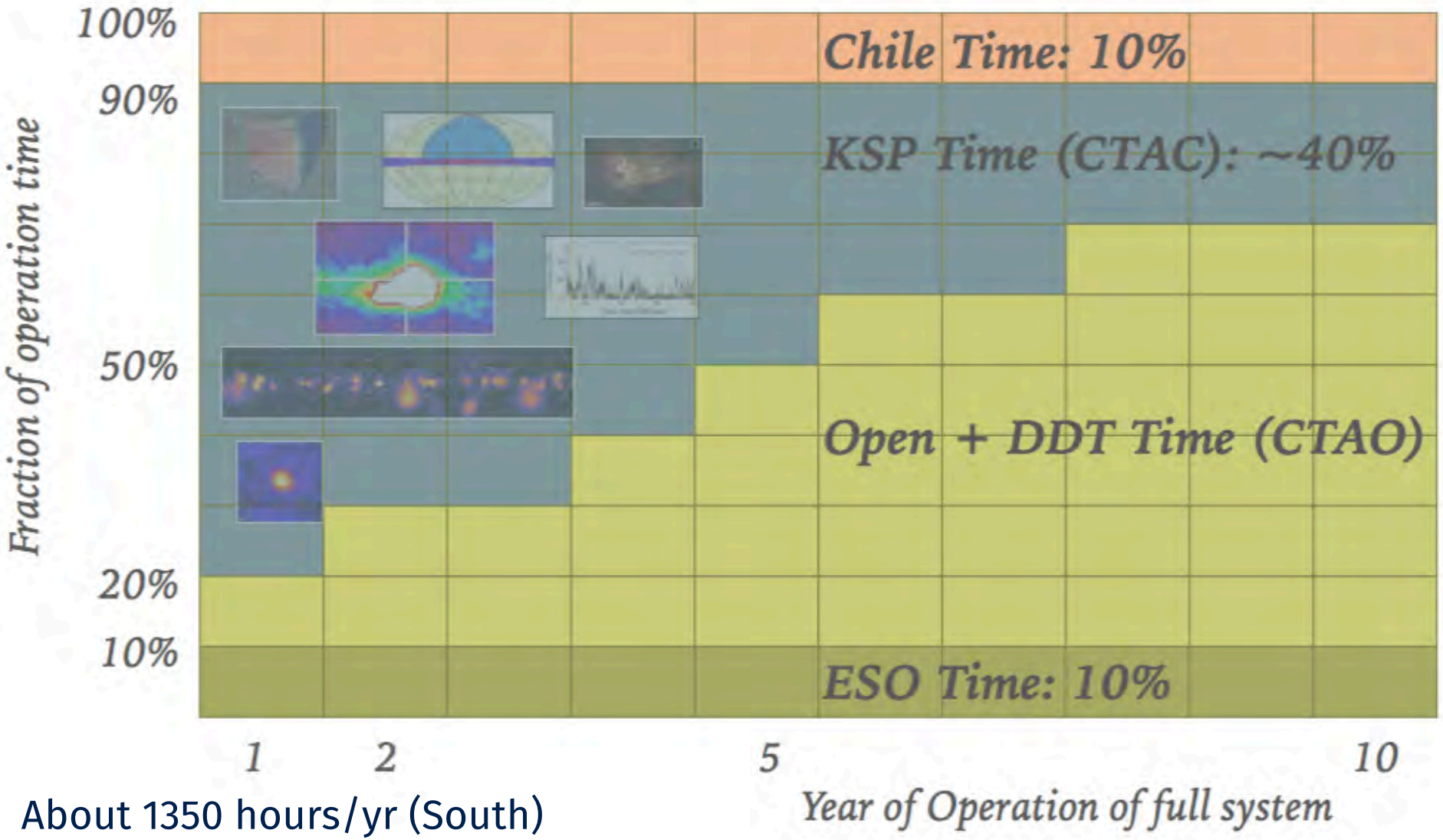
Proprietary time (significant fraction in the first years) will be articulated in **Key Science Projects.**

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

CTA will have important **synergies** with many astronomical and astro-particle facilities.

Backup

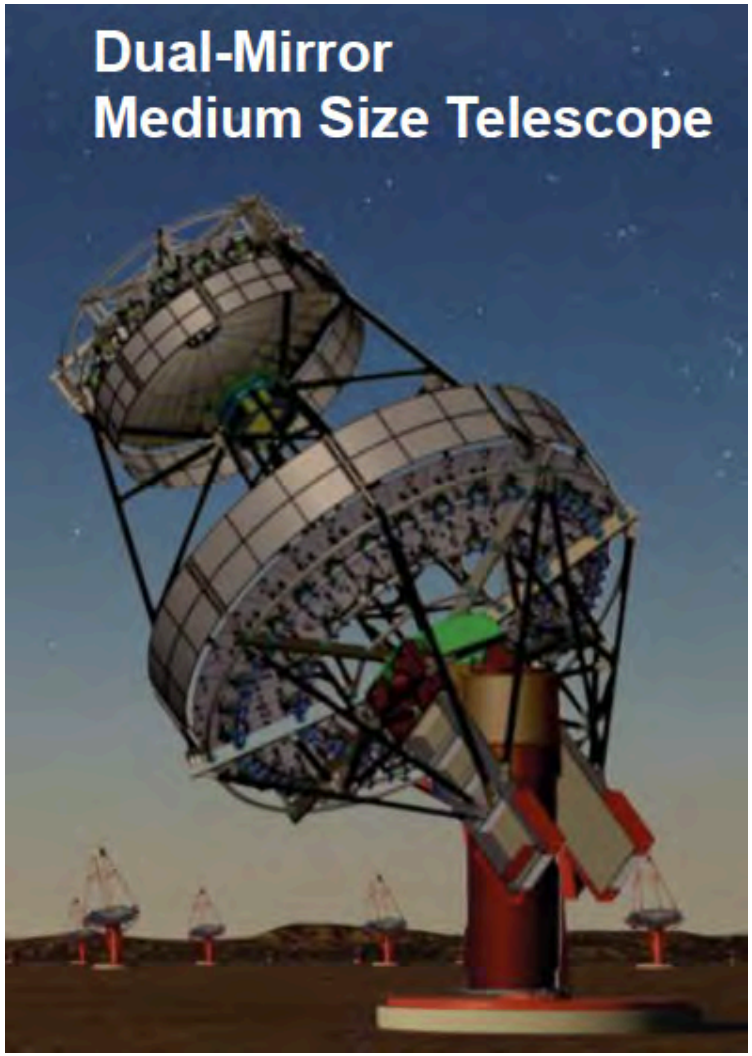
Possible KSP vs GO time budget



About 1350 hours/yr (South)

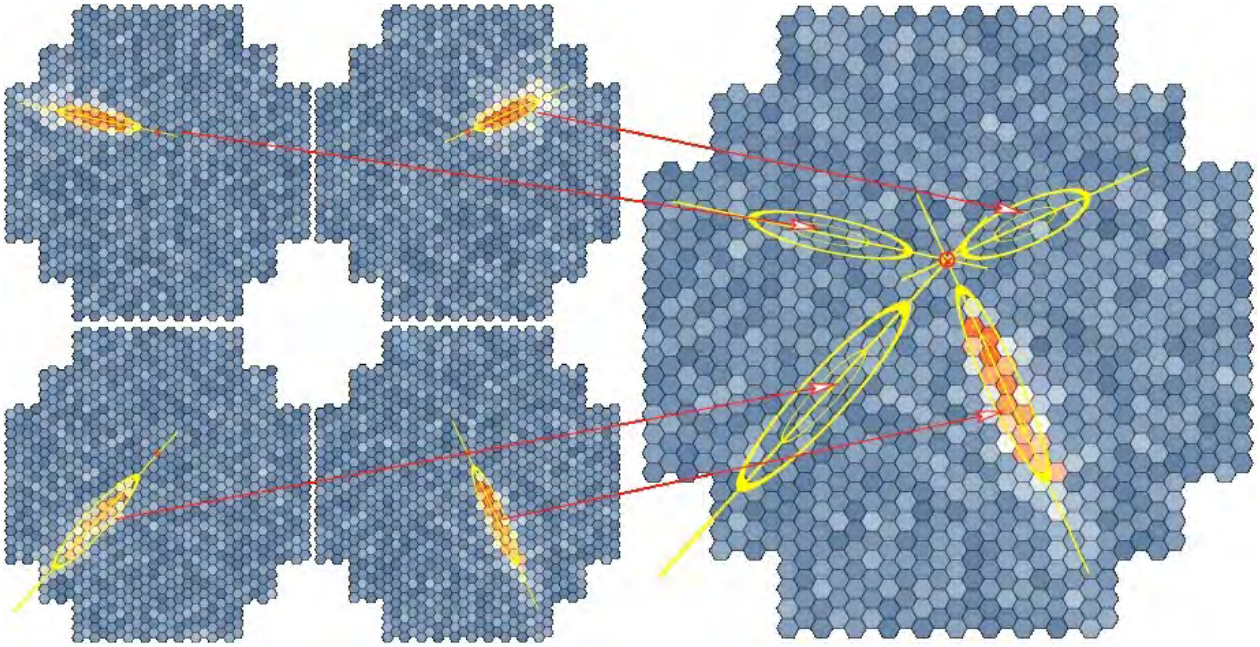
The current IACT status

Dual-mirror MST prototype



Credits: The CTA Consortium

The Cherenkov Telescopes

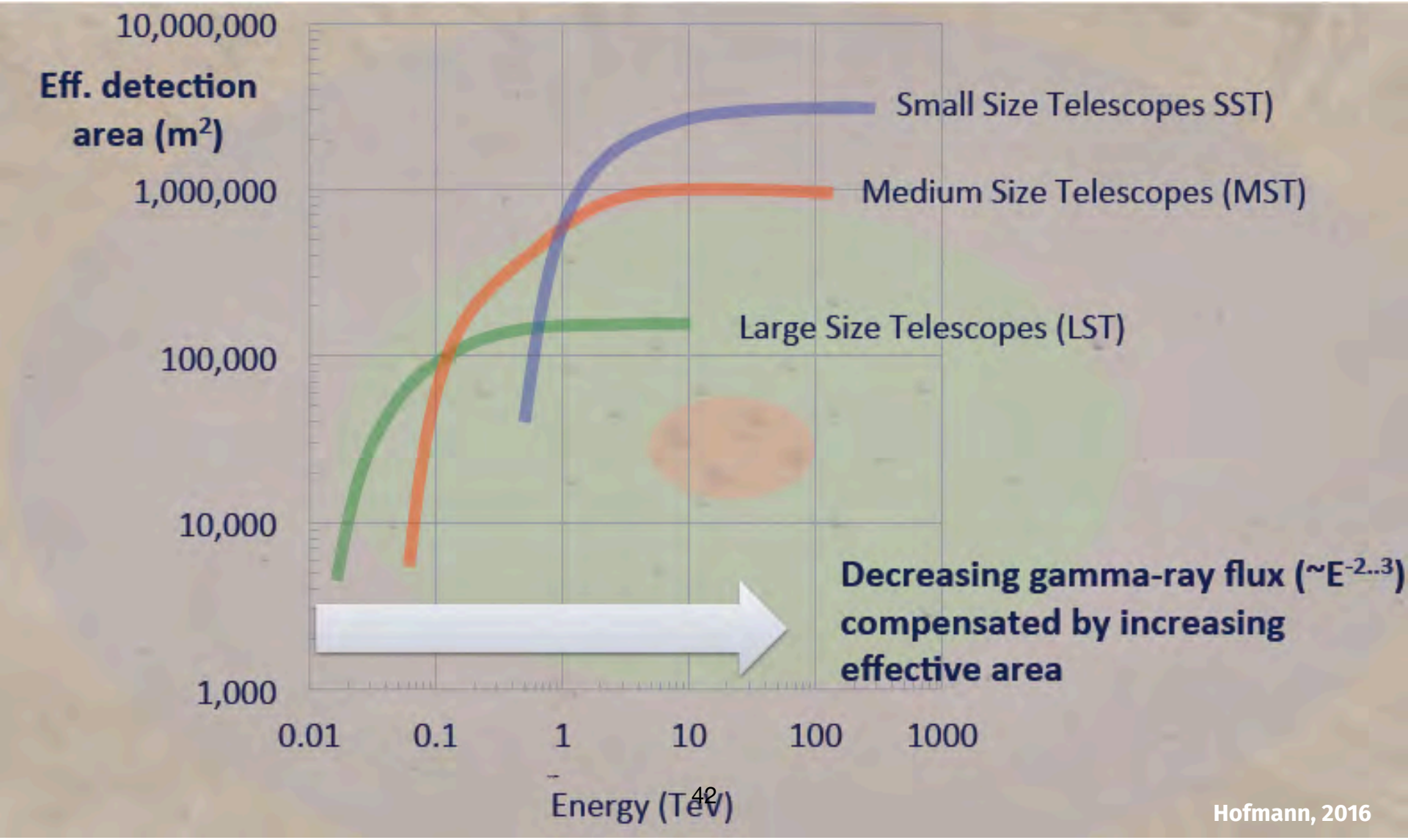


The intersection of major axes on the common FOV gives source position on the sky.

More on the Cherenkov technique, sources and physics in:

Hinton & Hofmann, 2009, ARAA, 47, 523

Effective area for gamma-ray detection

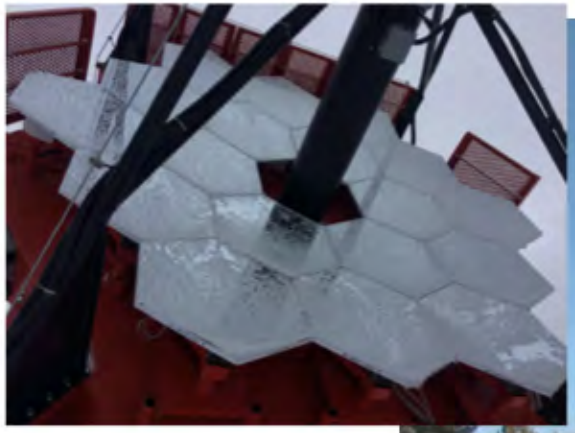


Hofmann, 2016

ASTRI: Etna is an astronomical site...

... in a peculiar environment...

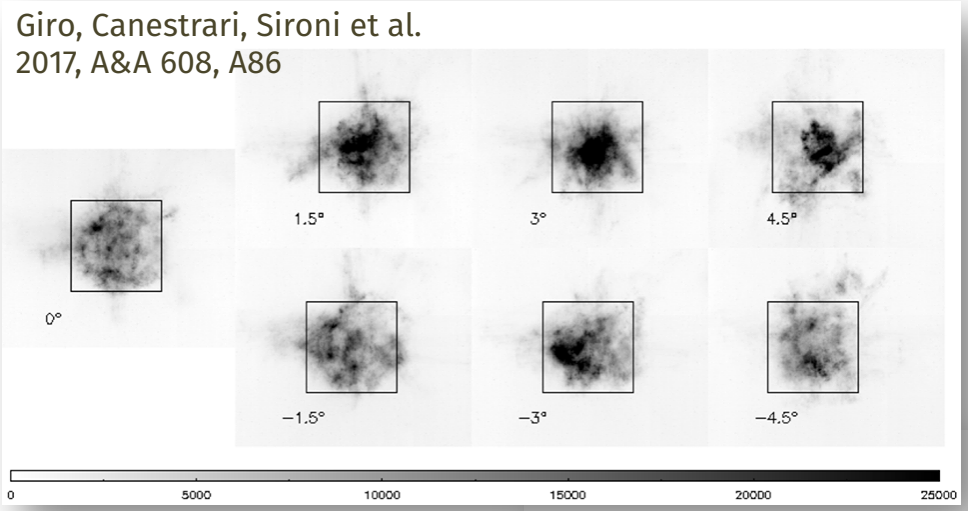
… where Winter may be severe…



Credits: G. Leto

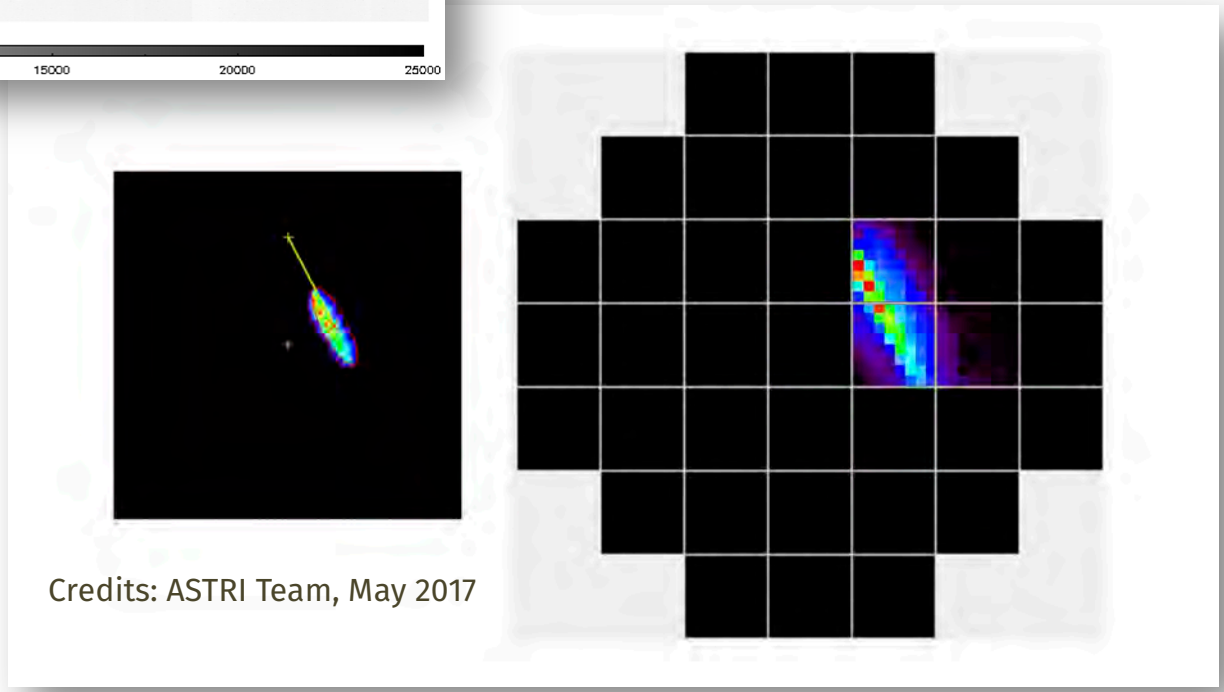
Winter 2014- 2015

… which we pass in full colours !



First ever optical characterization of a Schwarzschild-Couder telescope up to 4.5º 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