The Cherenkov Telescope Array and its Key Science Projects

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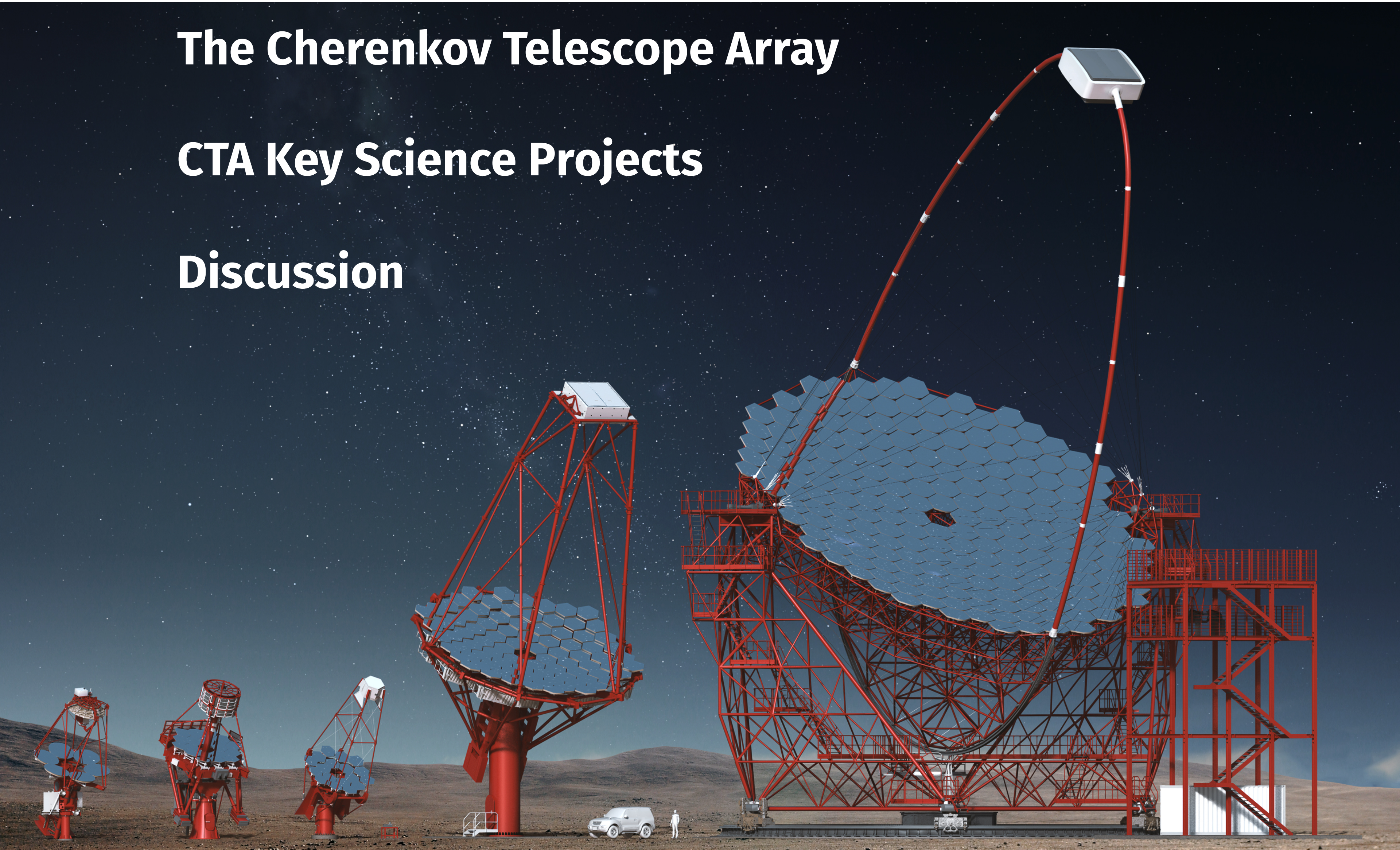
Outline

The Cherenkov Telescope Array

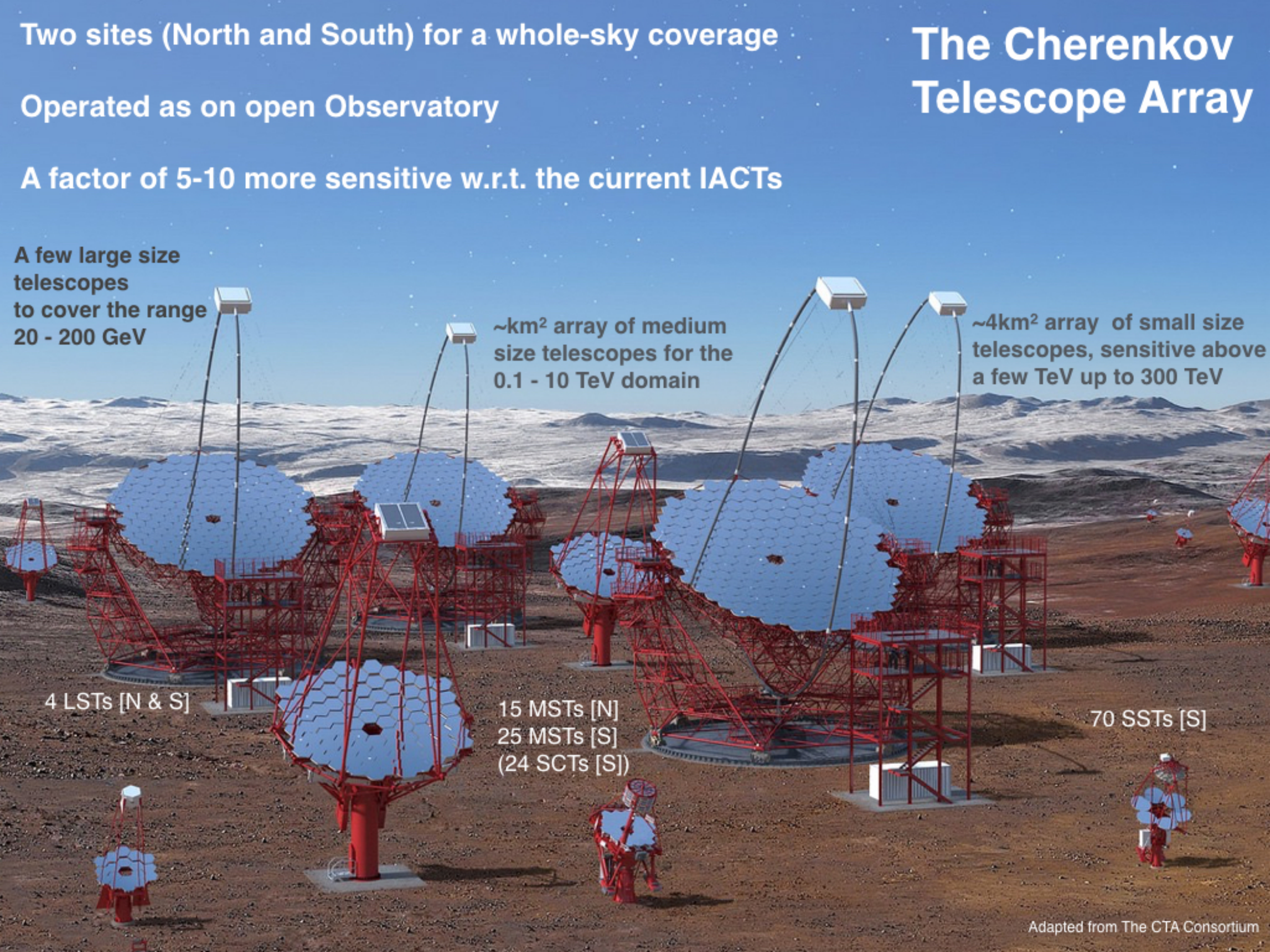
CTA Key Science Projects

Discussion



CTA Project


Zeuthen
DESY
Spain
La Palma
Bologna
INAF
northern hemisphere
southern hemisphere
1,350 members
from 210 institutes
in 32 countries
Chile
Paranal
La Palma Map: ©2015 Google, Inst. Geogr. Nacional
Paranal Map: ©2015 Google
Array Sites
Headquarters
Science Data Management Centre

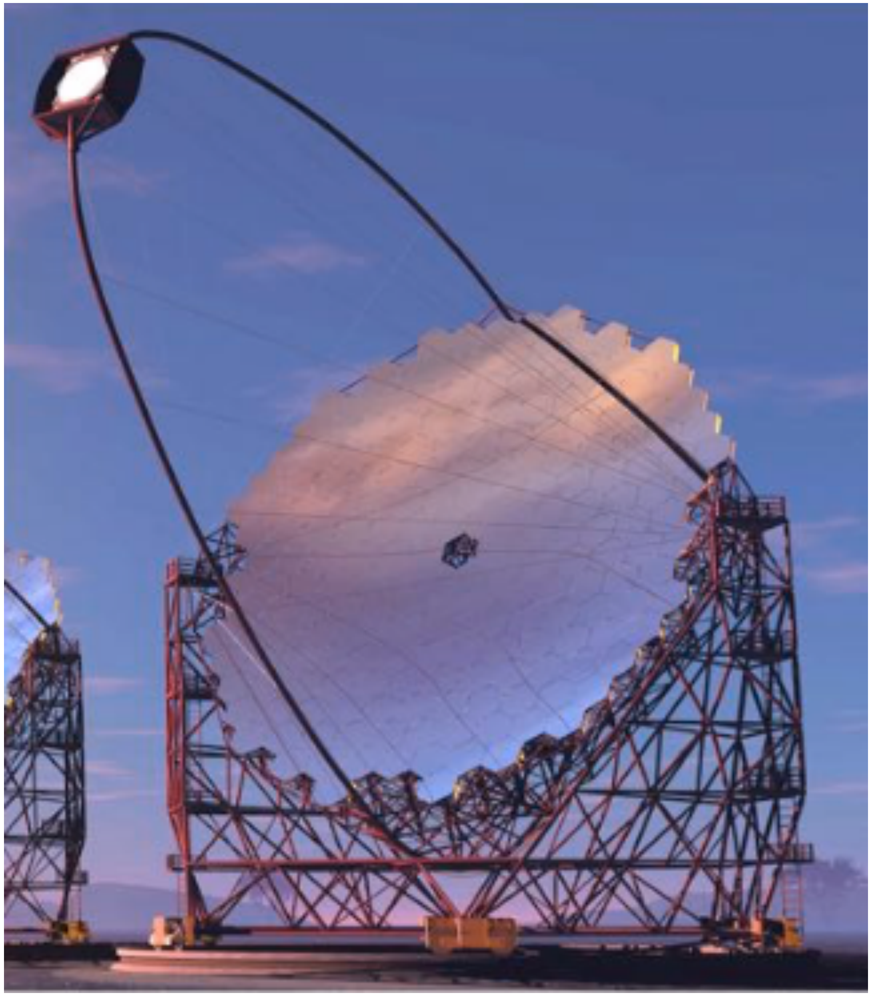

The Cherenkov Telescope Array
Two sites (North and South) for a whole-sky coverage
Operated as on open Observatory
A factor of 5-10 more sensitive w.r.t. the current IACTs
A few large size telescopes to cover the range 20 - 200 GeV
~km² array of medium size telescopes for the 0.1 - 10 TeV domain
~4km² array of small size telescopes, sensitive above a few 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

CTA Telescopes

Telescope	Large	Medium		Small		
	LST	MST	SCT	SST-1M	ASTRI SST-2M	GCT SST-2M
Number North array	4	15	TBD	0		
Number South array	4	25	TBD	70		
Optics						
Optics layout	Parabolic mirror	Davies-Cotton	Schwarzschild-Couder	Davies-Cotton	Schwarzschild-Couder	Schwarzschild-Couder
Primary mirror diameter (m)	23	13.8	9.7	4	4.3	4
Secondary mirror diameter (m)	–	–	5.4	–	1.8	2
Eff. mirror area after shadowing (m^2)	368	88	40	7.4	6	6
Focal length (m)	28	16	5.6	5.6	2.15	2.28
Focal plane instrumentation						
Photo sensor	PMT	PMT	silicon	silicon	silicon	silicon
Pixel size (degr.), shape	0.10, hex.	0.18, hex.	0.07, square	0.24, hex.	0.17, square	0.15-0.2, square
Field of view (degr.)	4.5	7.7/8.0	8.0	9.1	9.6	8.5 - 9.2
Number of pixels	1855	1764/1855	11328	1296	1984	2048
Signal sampling rate	GHz	250 MHz / GHz	GHz	250 MHz	S&H	GHz
Structure						
Mount	alz-az, on circular rail	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner
Structural material	CFRP / steel	steel	steel	steel	steel	steel
Weight (full telescope, tons)	100	85	~85	9	15	8
Max. time for repositioning (s)	20	90	90	60	80	60

Credits: The CTA Consortium

Large Size Telescope

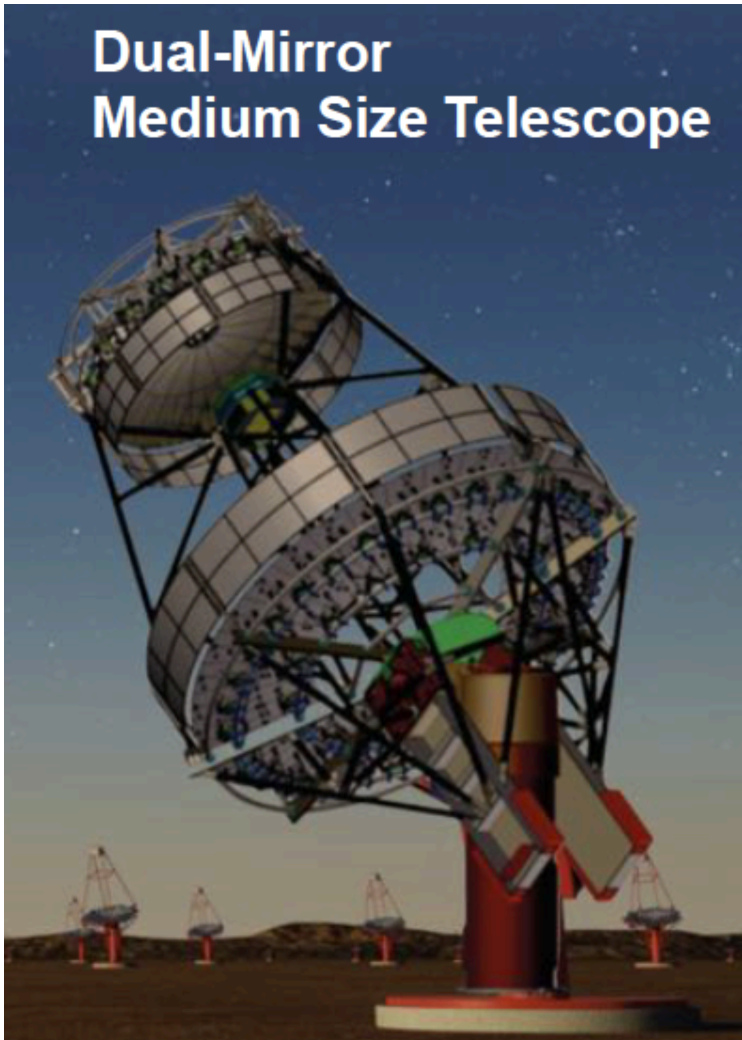


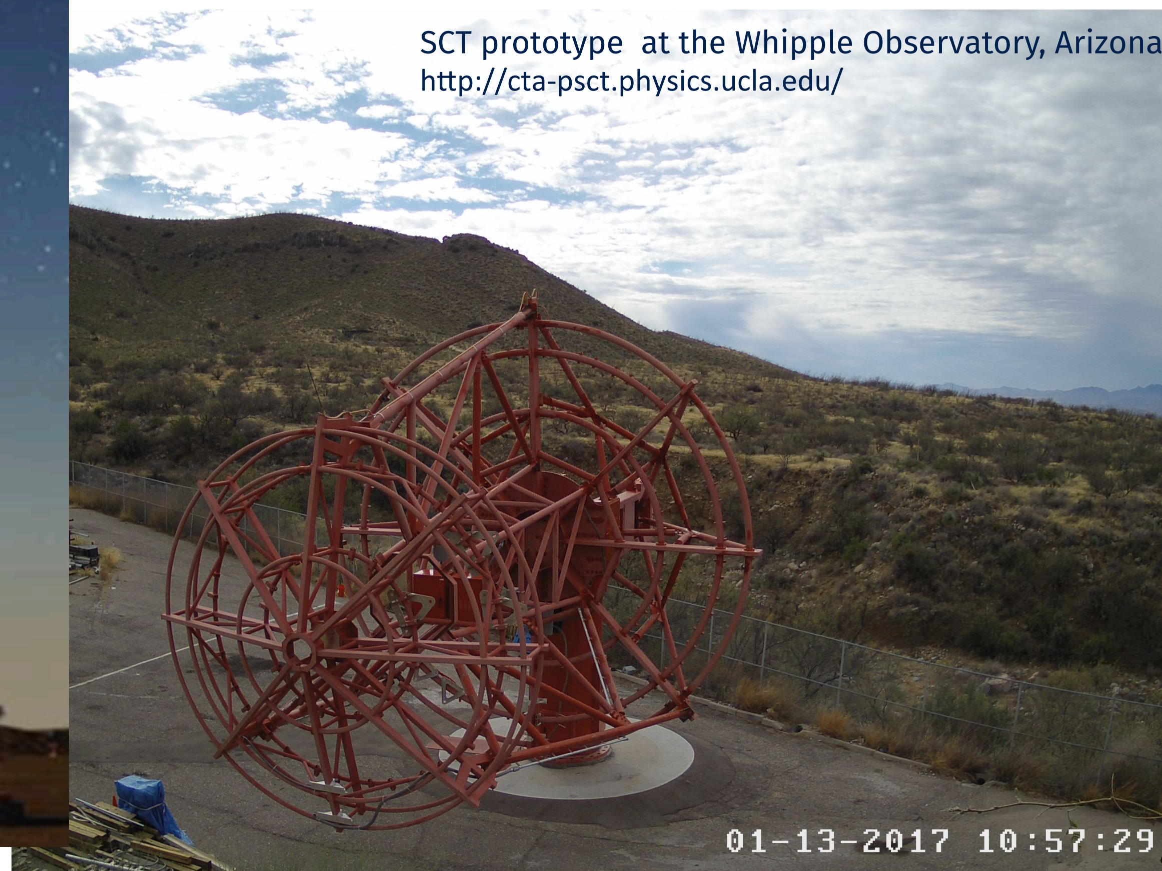
- La Palma prototype operational by end of 2017.
- http://webcam.lst1.iac.es/stream2view.htm

Credits: The CTA Consortium

Medium Size Telescope Prototype

Dual-mirror MST prototype





Credits: The CTA Consortium

Small size telescope prototypes

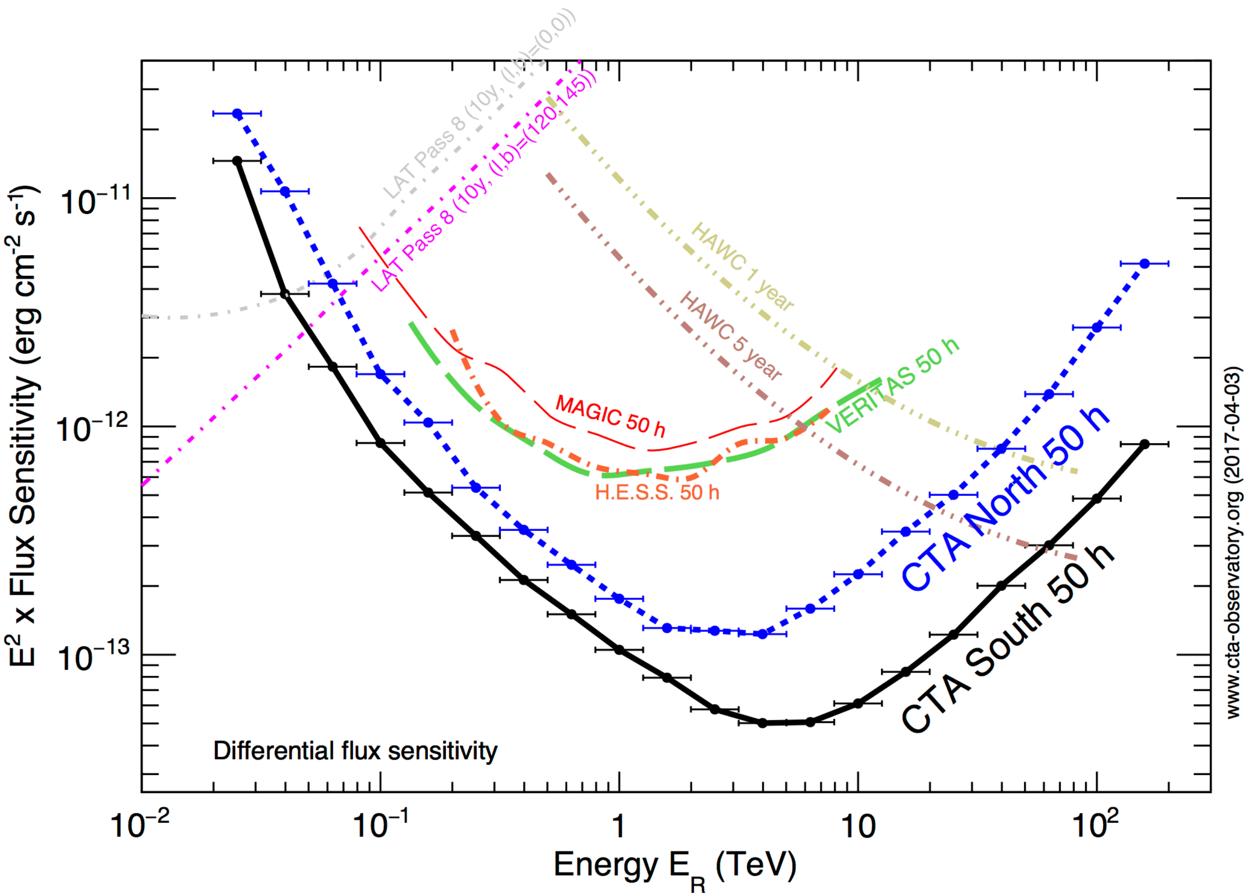
SST-2M GCT prototype in Paris

SST-1M prototype in Krakow

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

CTA Performance

Differential Sensitivity



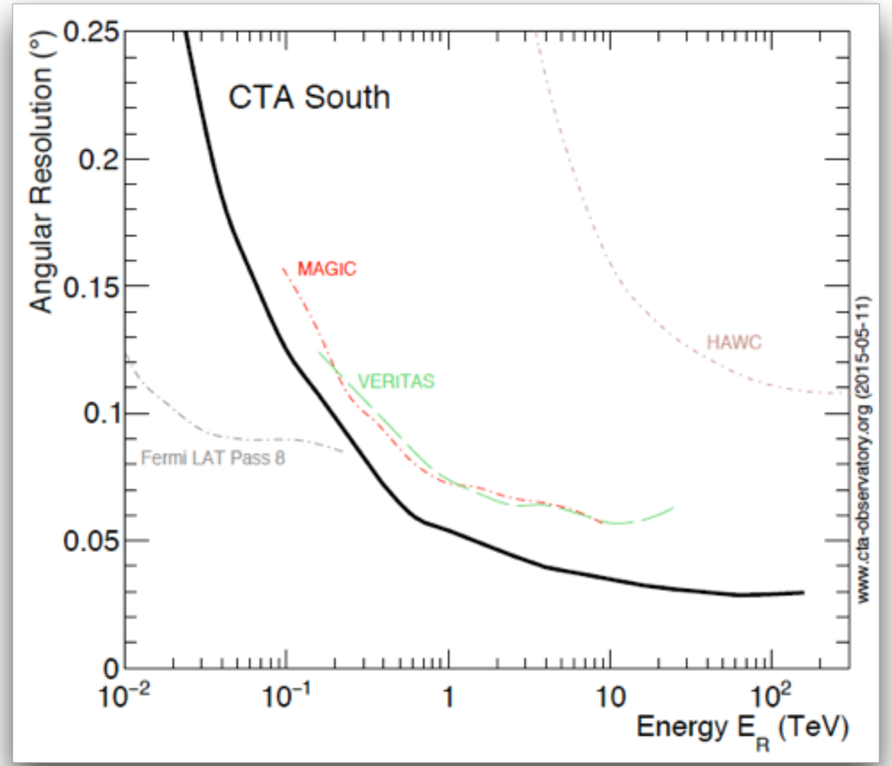
A factor of **5-10 improvement** in sensitivity in the domain of **about 100 GeV to some 10 TeV.**

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

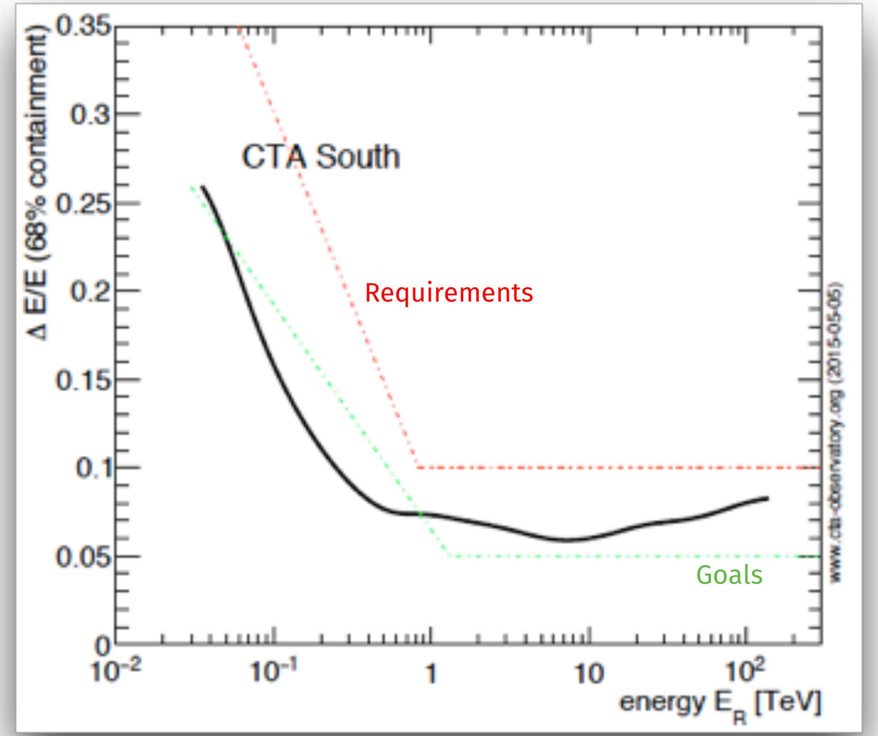
Credits: The CTA Consortium

CTA Performance

Angular Resolution



Energy Resolution

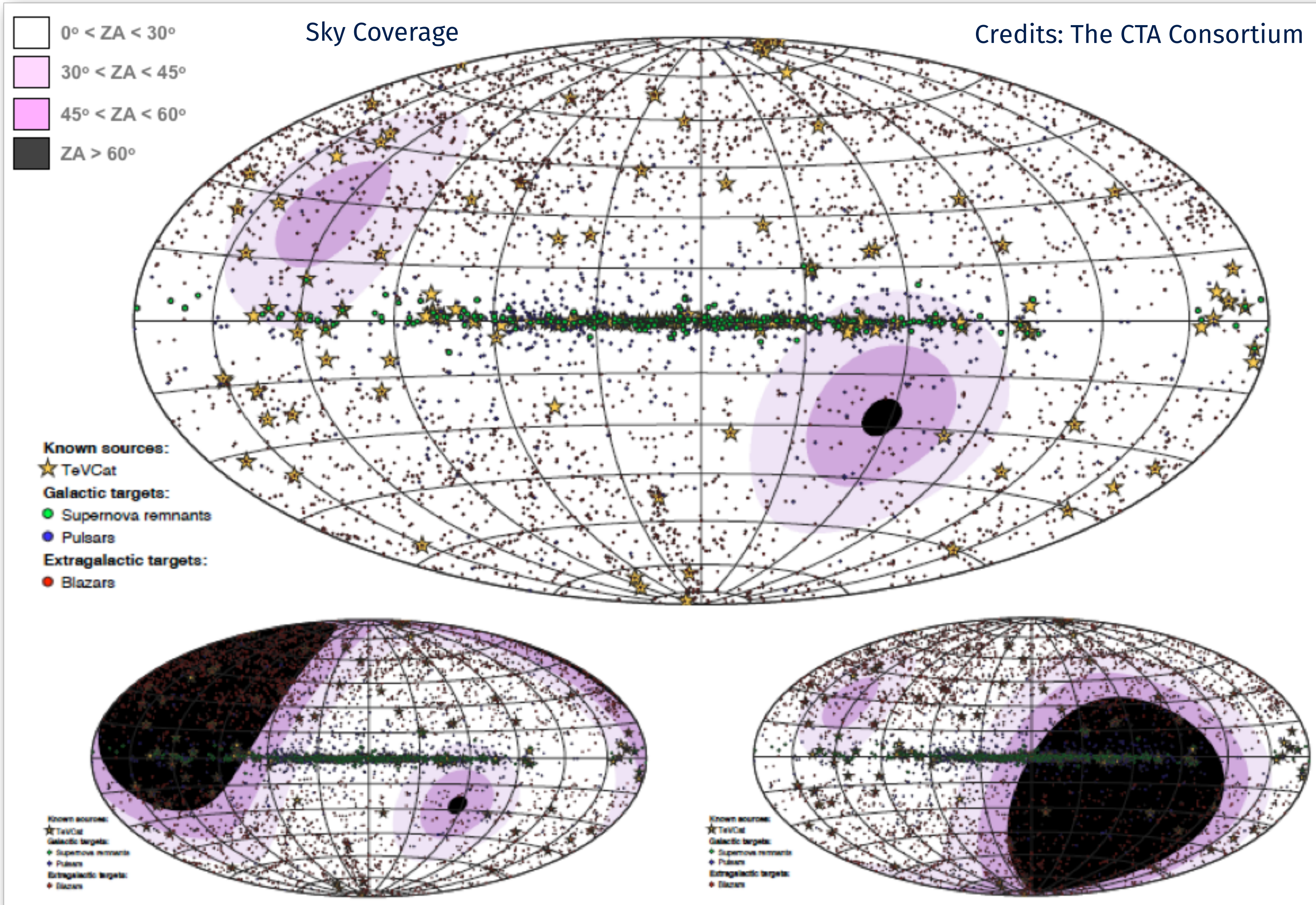


Further improvements of shower reconstruction algorithms and optimization of event selection can improve the IRFs.

You can download the Instrument response functions at the following URL:
https://www.cta-observatory.org/science/cta-performance/

Credits: The CTA Consortium

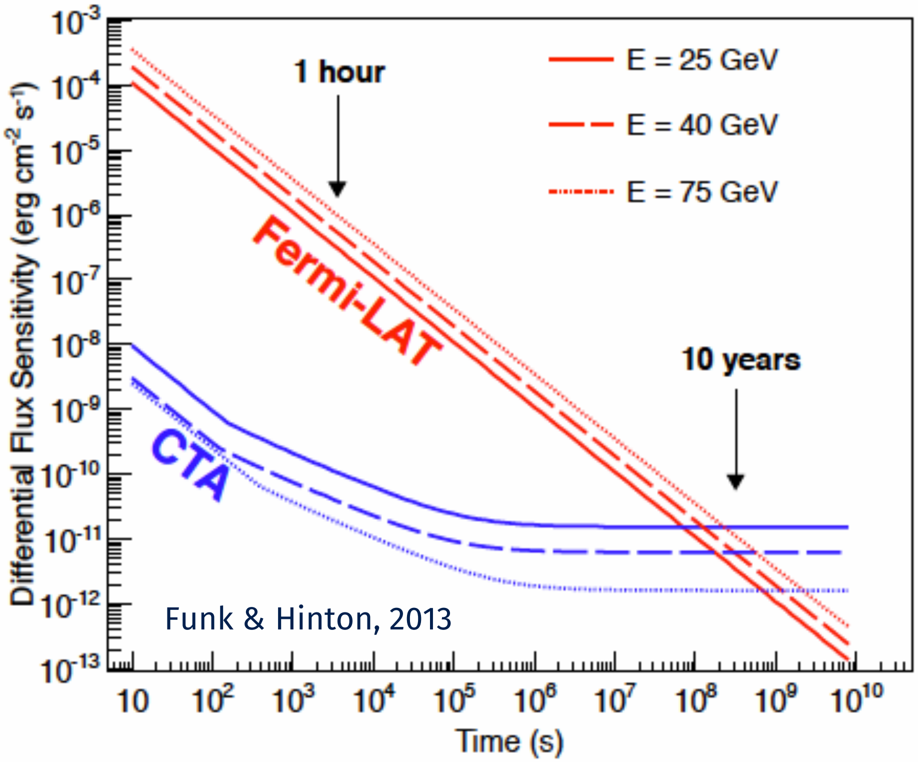
CTA as an *all-sky* Observatory



CTA as a *transient factory*

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

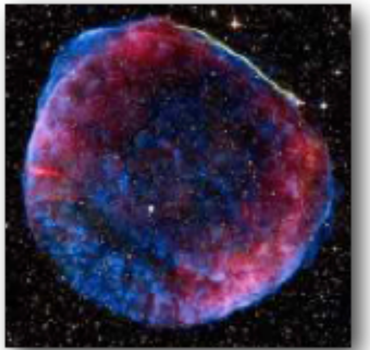
- **Disadvantage over Fermi**
  - Limited FoV (compared to Fermi)
  - Prompt reaction to external trigger is critical



CTA Main Scientific Themes

Cosmic Particle Acceleration

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



Probing Extreme Environments

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

Physics frontiers – beyond the Standard Model

- 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?

Adapted from J. Knödlseder.
More information on Astroparticle Physics, Vol. 43, 1-356 (2013) & CTA Contributions to the 2015 ICRC Conference [arXiv:1508.05894]

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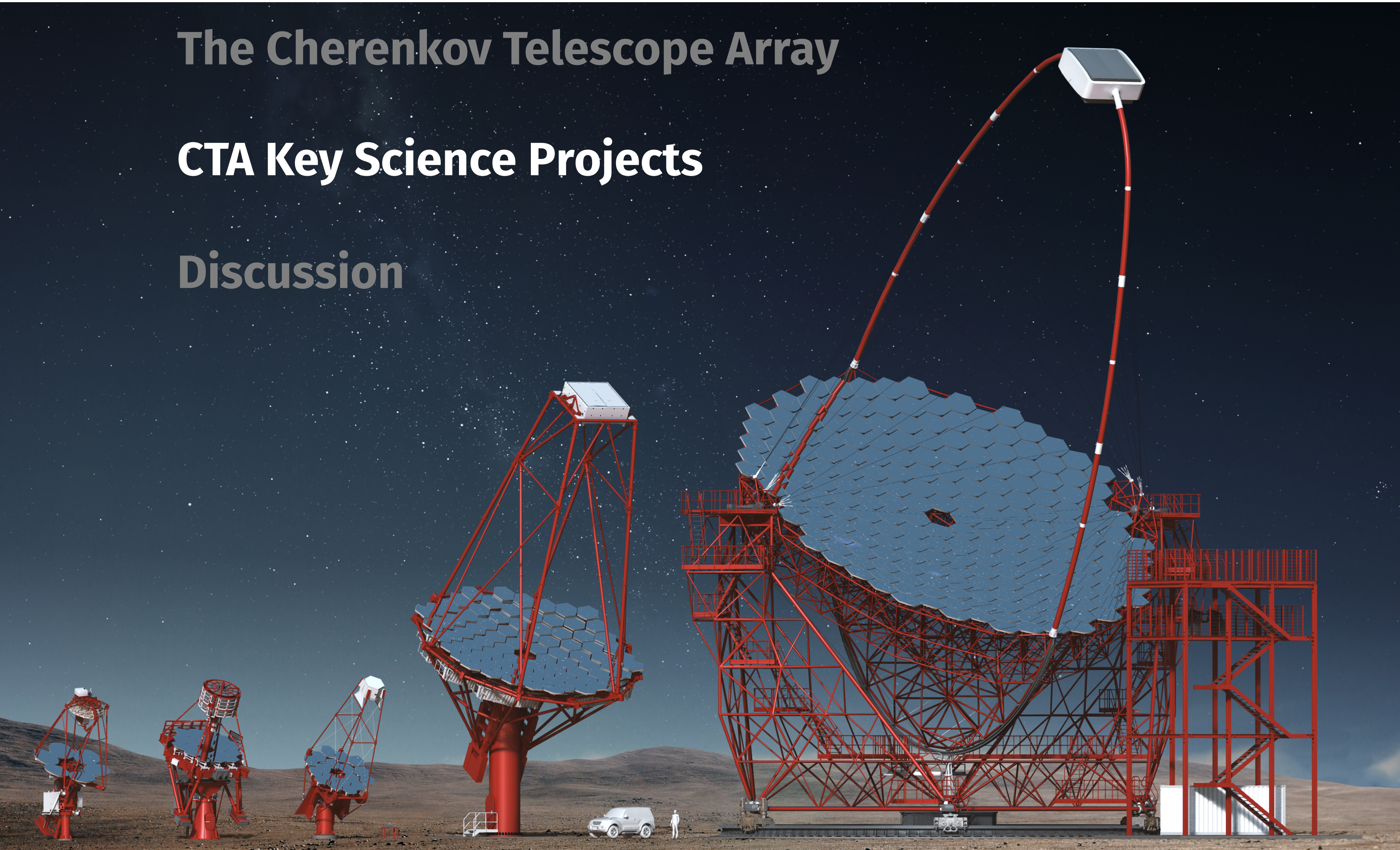


CTA Key Science Projects

The criteria used for selection of the baseline KSPs

1. **Excellent scientific case and clear advance** beyond the state of the art;

2. **Production of legacy data-sets** of high value to a wider community;

3. **Clear added value of doing this as a KSP** rather than as part of the Guest Observer Programme:
    1. the **scale of the project** in terms of observing hours - very large projects will be difficult to accommodate in the open time early in the lifetime of the observatory;
    2. the need of a **coherent approach** across multiple targets or pointings;
    3. the **technical difficulty** of performing the required analysis and hence reliance on consortium expertise.

CTA Key Science Projects

1. Dark Matter Programme
2. Galactic Centre Survey
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Non-Gamma-ray Science

I will mainly discuss these KSPs, a detailed review of all the CTA Key Science Projects can be found in "The CTA Science", to be uploaded on *arXiv* shortly.

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

The Dark Matter Programme

Galaxy cluster Abell 1689
Credits: The CTA Consortium

The existence of dark matter as the dominant gravitational mass in the Universe **is by now well established** but the detailed **nature of dark matter is at present still unknown.**

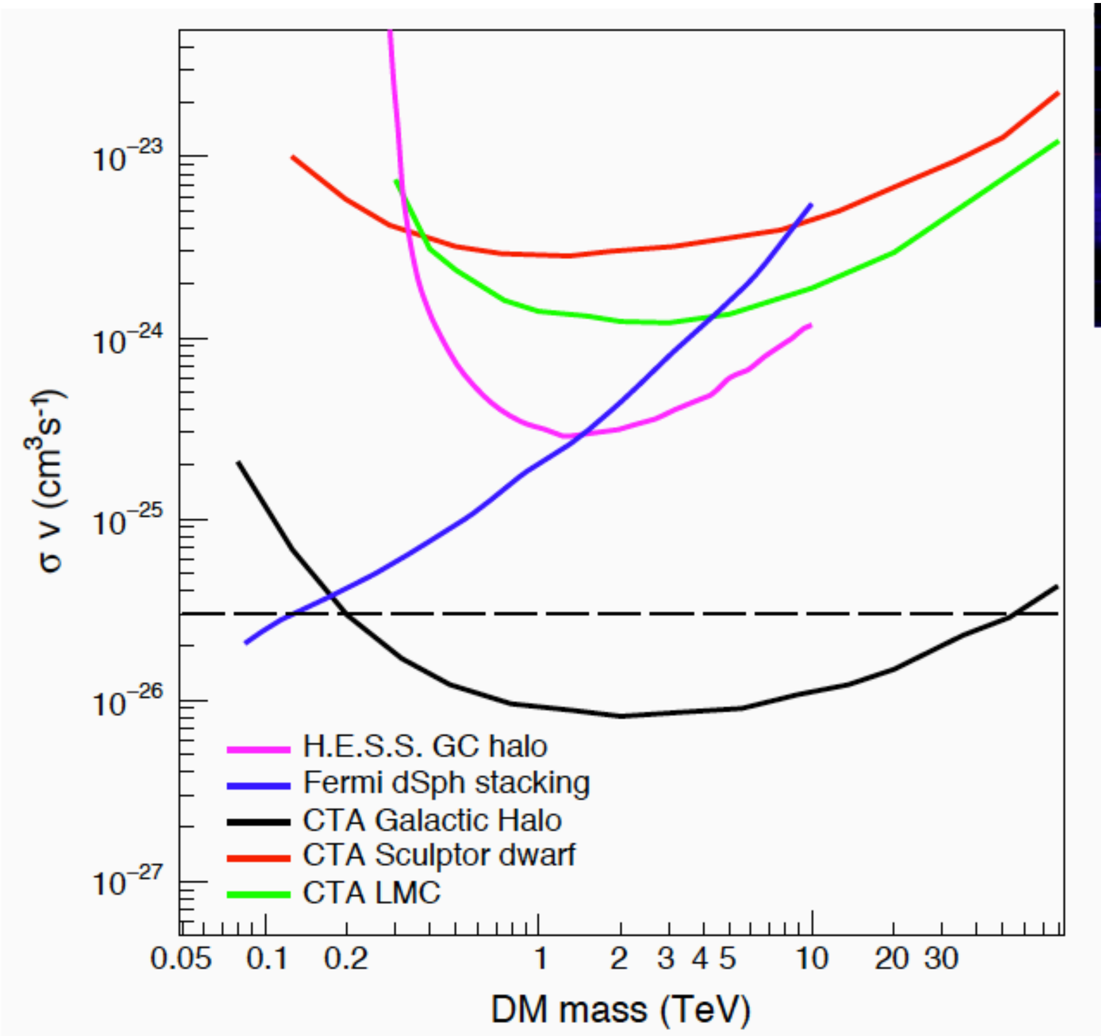
The priority for the CTA dark matter program is to **discover the nature of dark matter** with a positive observation.

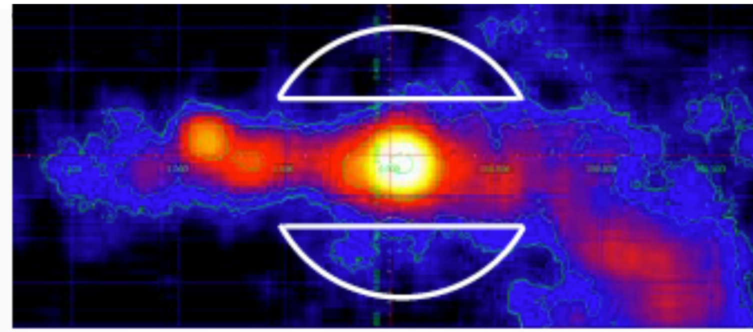
The principal target for dark matter observations in CTA **is the Galactic halo**.

Observations will be taken within several degrees from the Galactic Centre.

500 hours in this region provide sensitivities below the thermal cross-section and give a significant chance of discovery in some of the most popular models for **WIMPs**.

The Dark Matter Programme





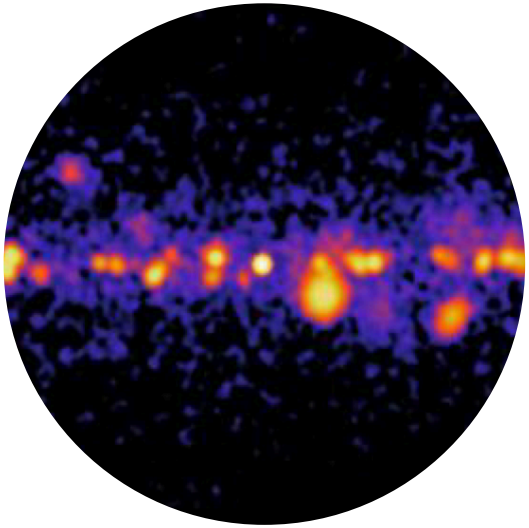
The plan is to **avoid the inner Galactic region** because of its

- multitude of sources
- uncertain DM profile

Deep 500 hr exposure

The CTA sensitivity curves use the same method and W^+W^- annihilation modes for each target and the NFW dark matter profile.

The Galactic Plane Survey



Credits: The CTA Consortium

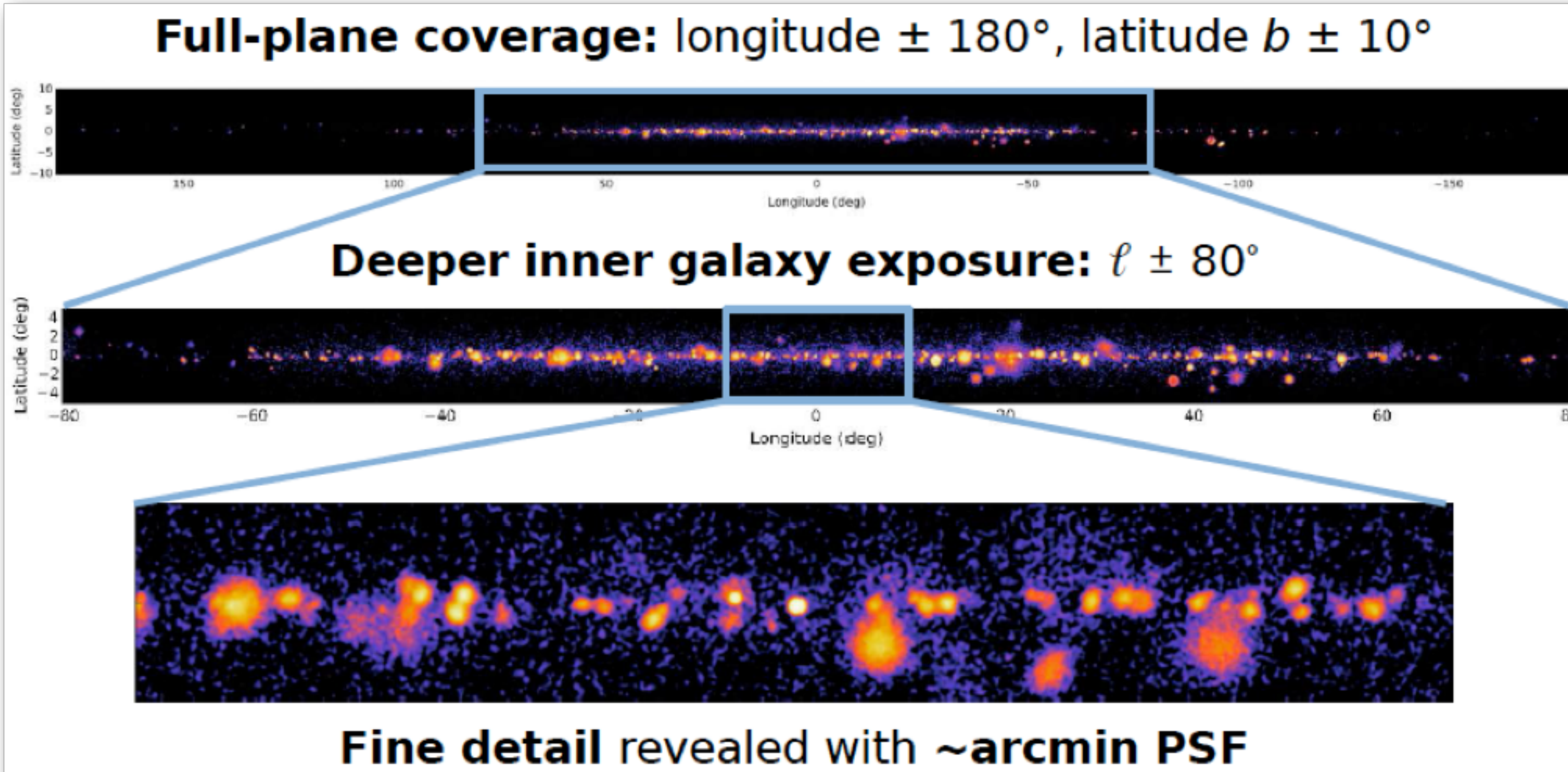
CTA will carry out a **survey of the full Galactic** plane using both the southern and northern CTA observatories.

The Survey will provide a **complete and systematic view of the Galaxy** to facilitate our understanding of Galactic source populations and diffuse emission, and **a comprehensive data-set and catalogue**.

The CTA GPS will be a factor of 5 – 20 more sensitive than surveys carried out by earlier or existing atmospheric Cherenkov telescopes.

In the Northern Hemisphere, the CTA will complement/extend observations made by HAWC. **CTA will go deeper by a factor of 5 – 10 compared to HAWC**, at much lower energy and with substantially better angular resolution.

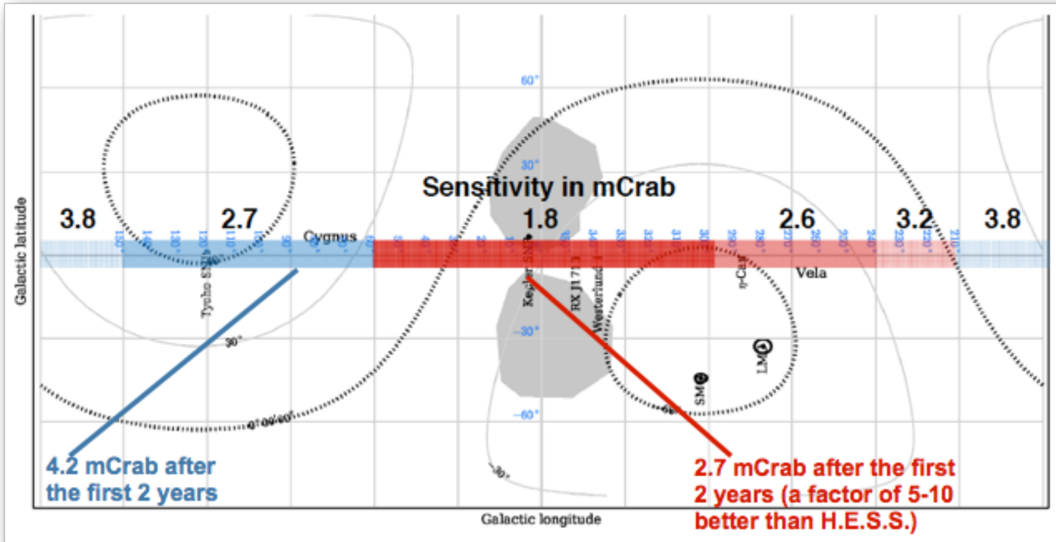
Galactic Plane Survey

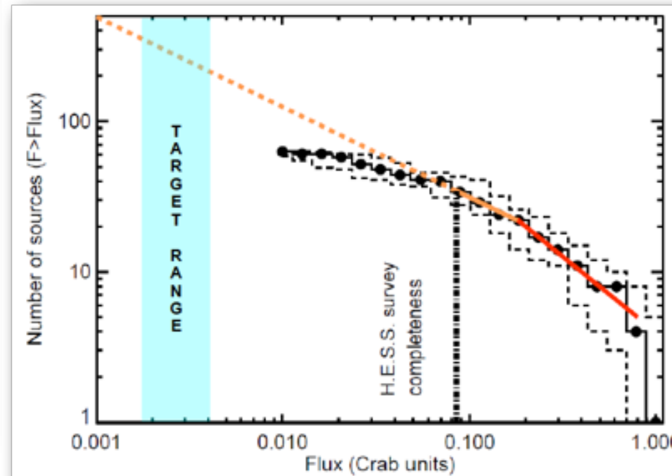


J. Knödlseder and CTA Consortium

Galactic Plane Survey

The CTA Consortium

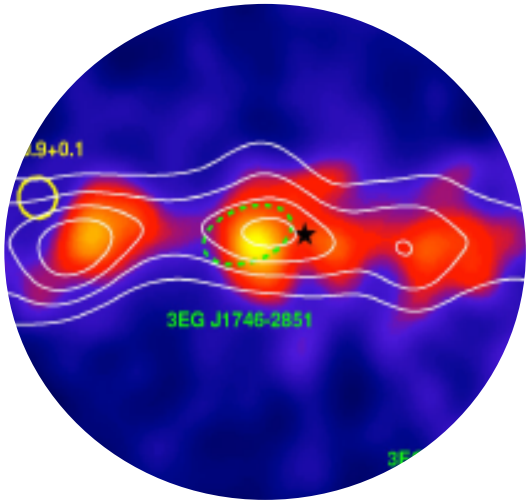




Expected results

- 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

The Galactic Centre Survey



Credits: The H.E.S.S. Collaboration

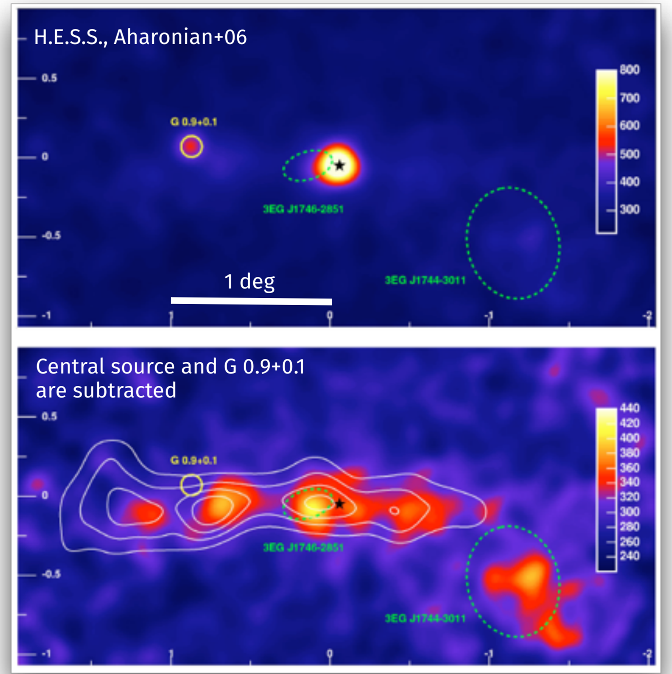
The region within a few degrees from the **Galactic Centre** is full of a **wide variety of high-energy emitters.**

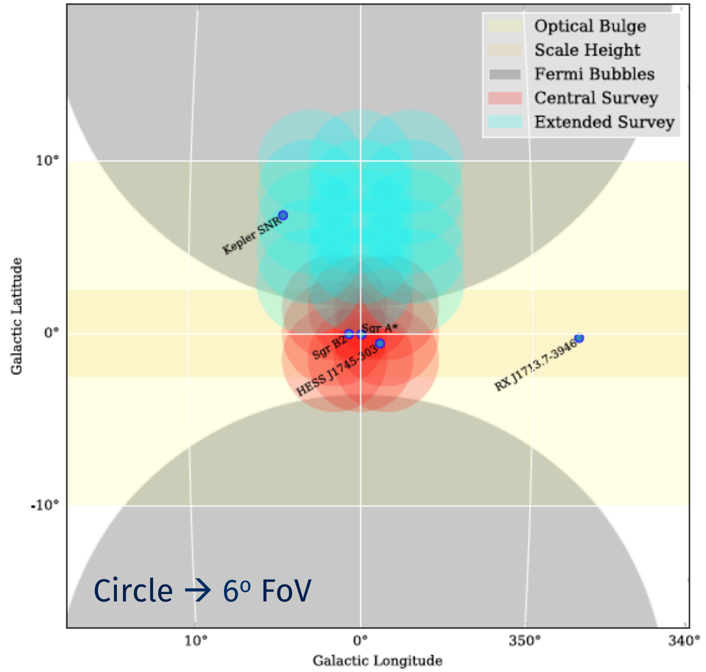
The central VHE source has been well studied with H.E.S.S., VERITAS, and MAGIC, but **still remains unidentified due to source confusion and limited sensitivity to variability and small-scale morphology.**

Deep observations of this object with CTA will provide

- **an optimal angular resolution** to image the arc-minute scale VHE source
- the possibility to search for **variability** of the central source
- sufficient **spectral sensitivity and energy coverage** to determine the maximum energy reached by accelerated cosmic rays in this region.

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

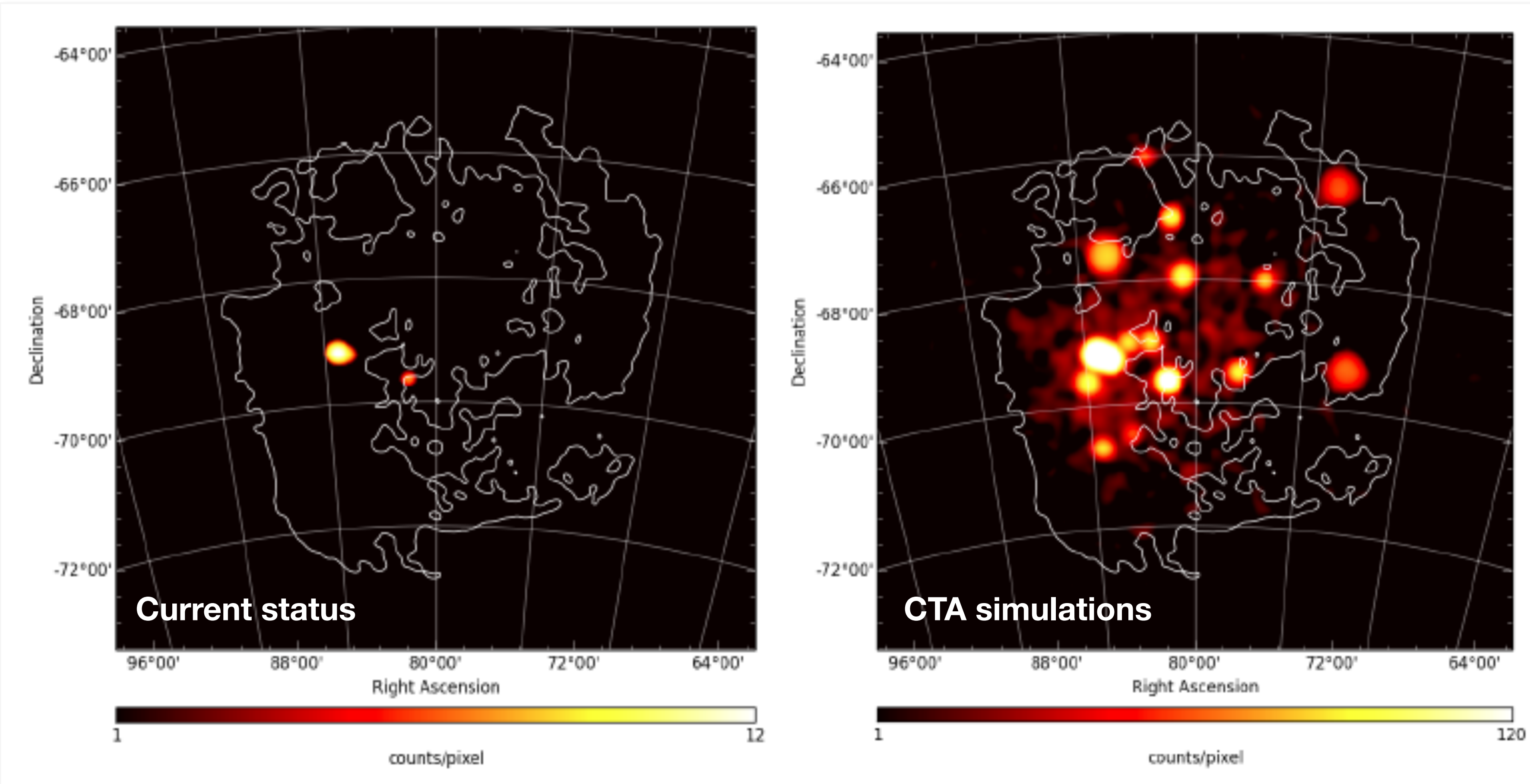
Credits: Schaefer 2015

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.

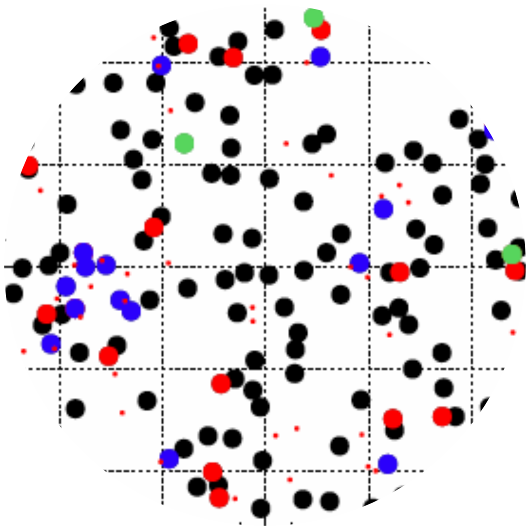
LMC Survey



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



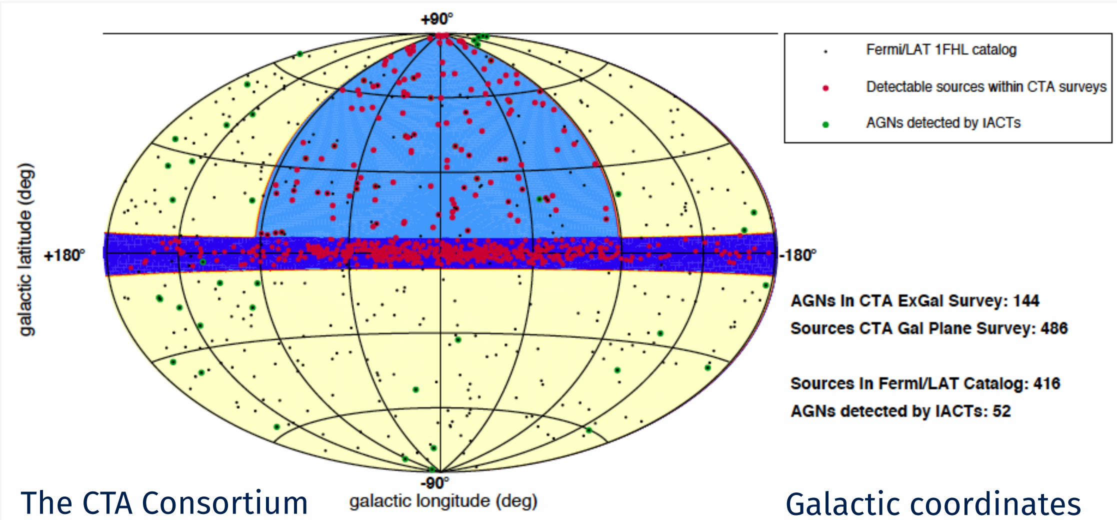
Credits: The CTA Consortium

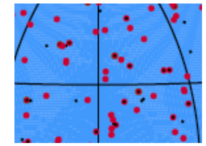
The aim is to perform a blind survey of 25% of the sky, and to construct an unbiased VHE extragalactic source catalogue with an integral sensitivity limit of ~5 mCrab.

CTA will combine the **deep MSTs sensitivity** for E > 100 GeV and the **wide SSTs field of view** (>9º).

We expect the **discovery of extreme BL Lac objects** peaking in the 0.1 – 1 TeV region, thanks to the good spectral coverage provided by MSTs and SSTs in the 0.1 – 10 TeV energy range.

Extra-galactic Survey





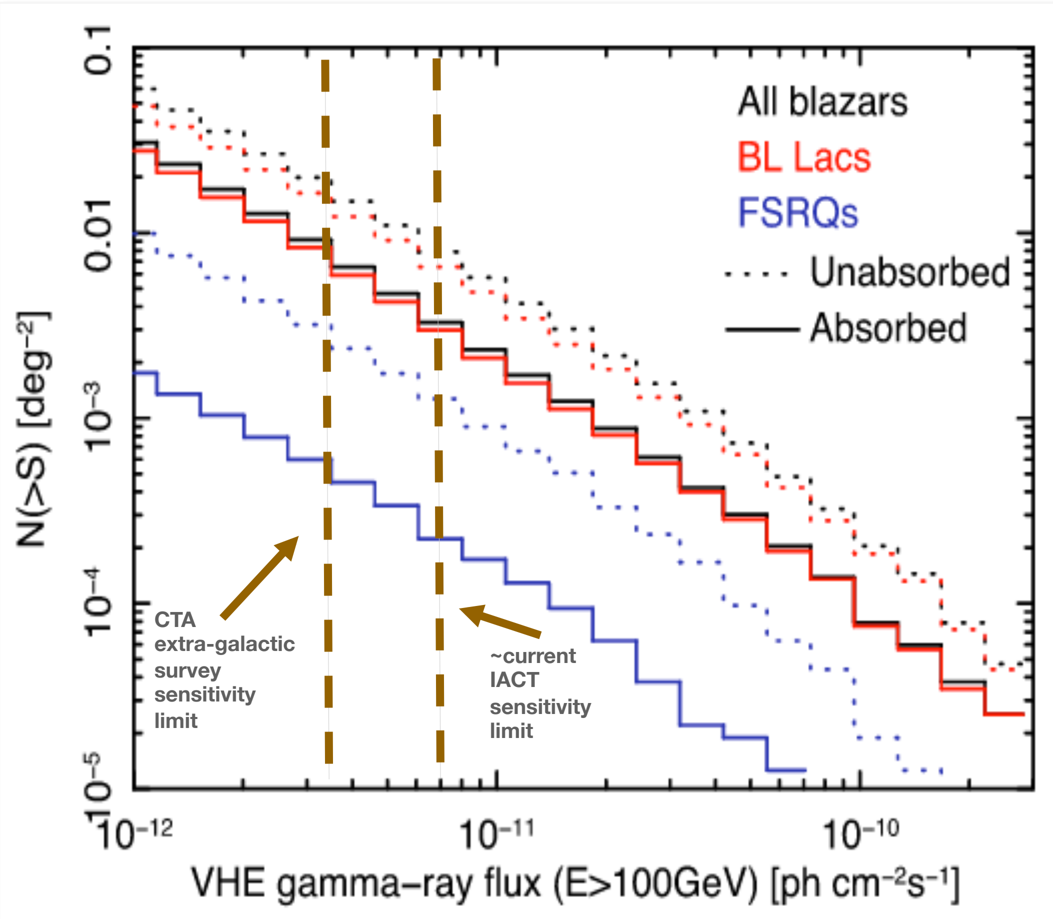
1/4 of the sky (~10^4 deg^2)
Limiting flux ~ 5 mCrab

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.
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 deg^2.**

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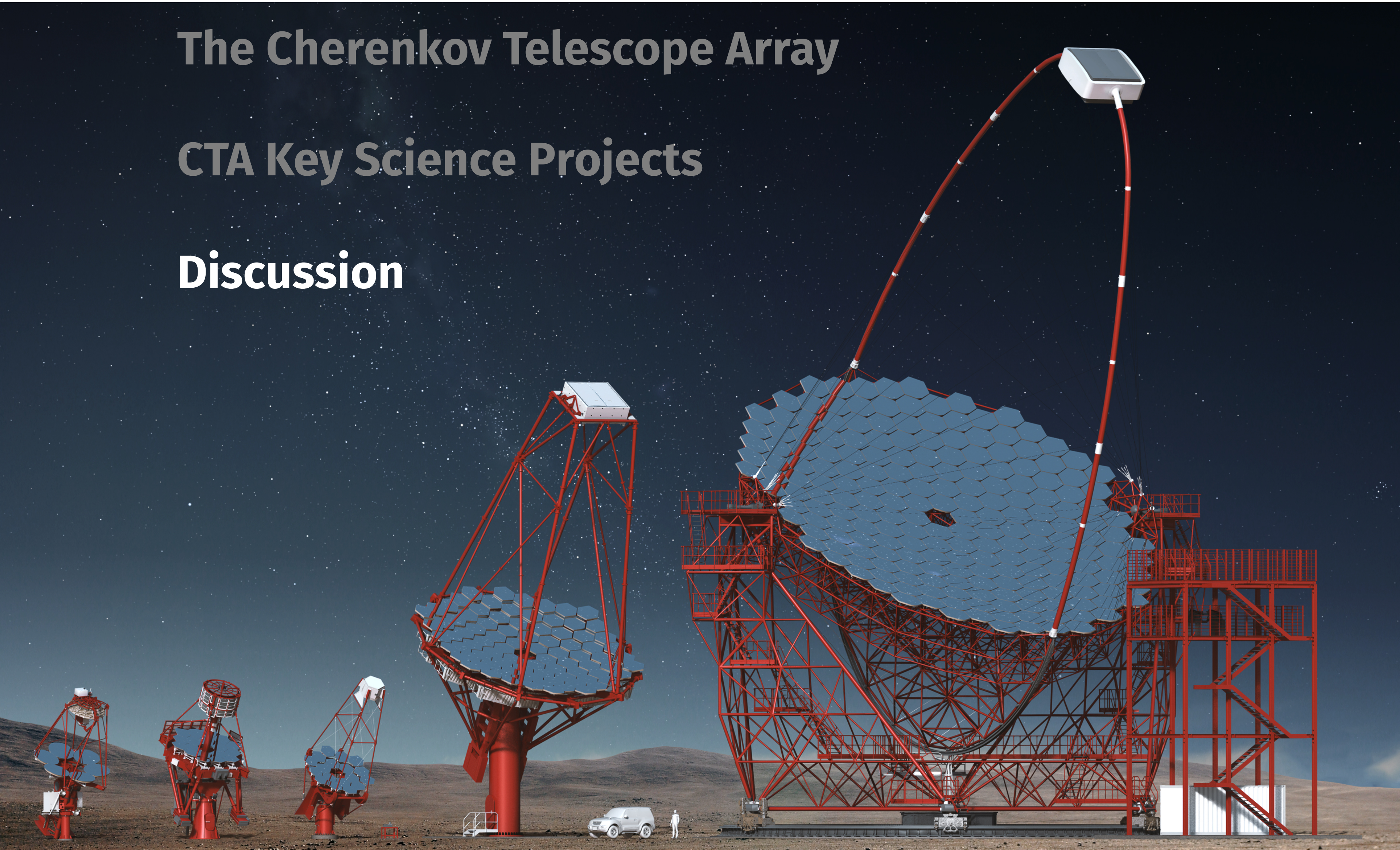
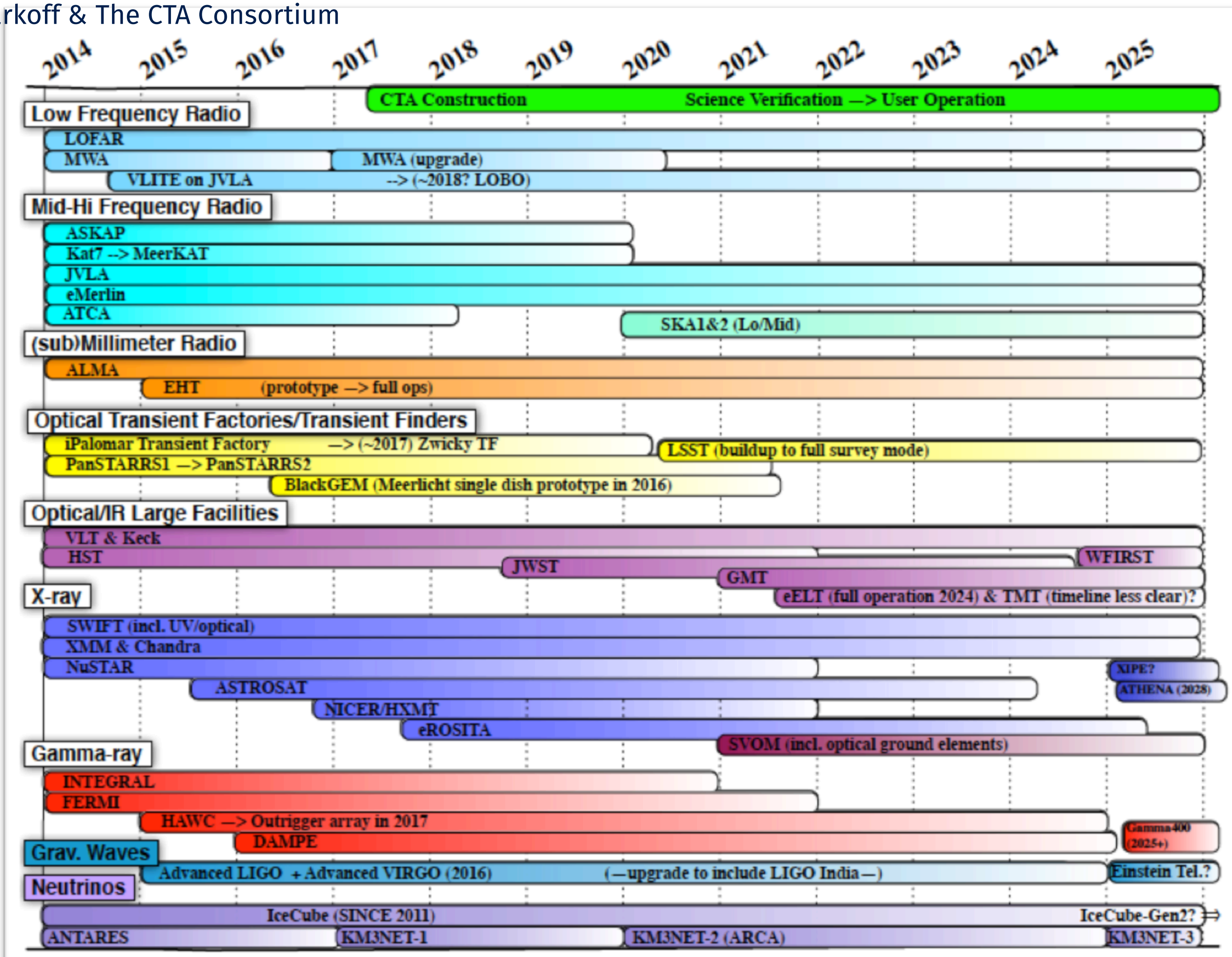


Synergies during CTA operation

Credits: S. Markoff & The CTA Consortium



CTA PHYS Working Group

The **PHYS WG is composed of ~340 members**, while SWGs are composed as follows (note that one can register for more than one SWG and numbers are rounded)

Registrations are always open for CTA Consortium members!

https://portal.cta-observatory.org/_layouts/people.aspx?MembershipGroupId=989

Galactic	~160
Cosmic Rays	~130
Extra-galactic	~150
Transients	~150
Dark matter and exotic physics	~100
Intensity Interferometry	~ 25
MWL Transverse WG	~ 70

Collaborations/Contributions

Among others, collaborations and contributions may be on

- **Science activities**
  - We have established the new PHYS Science Working Groups and several activities are ongoing
    - Computation of the KSPs performance metrics
    - Data Challenge
    - Simulations and theoretical activities for the science Consortium papers
    - Multi-wavelength transverse group studies
- **Software development**
  - CTA low-level pipelines (e.g., Monte Carlo, and reconstruction/analysis pipelines)
  - Specific analysis tools are being developed by the Consortium (e.g., Ctools, GammaPy…).
    - Might be important to familiarize with the CTA analysis tools

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 Programs.
- Synergies with current and planned MWL facilities will allow us to investigate source properties across several decades in energy.
- Contributions on the PHYS working group activities and on more technical activities (e.g., SW pipelines, Monte-Carlo,...) are welcome!