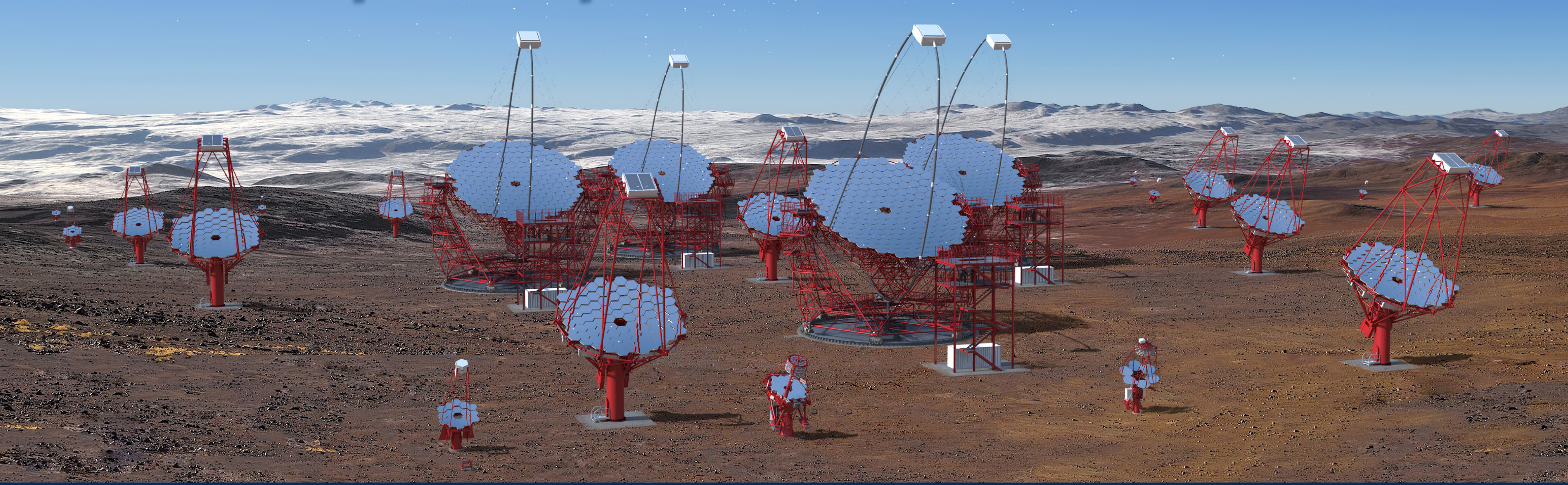
cta cherenkov telescope array

Key science projects, scienza di osservatorio con CTA e partecipazione INAF



Stefano Vercellone (INAF – OA Brera)

stefano.vercellone@brera.inaf.it

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

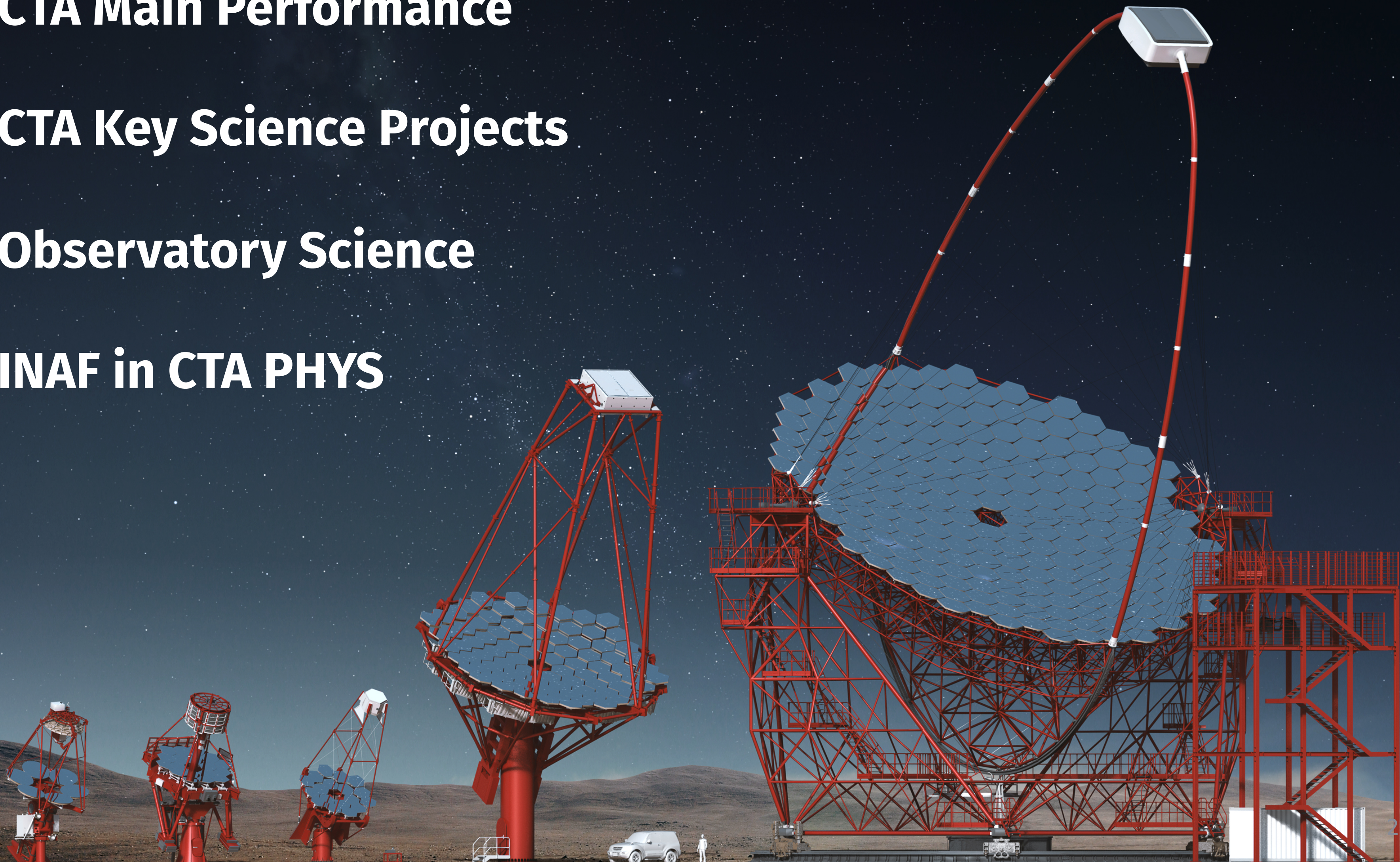
Outline

CTA Main Performance

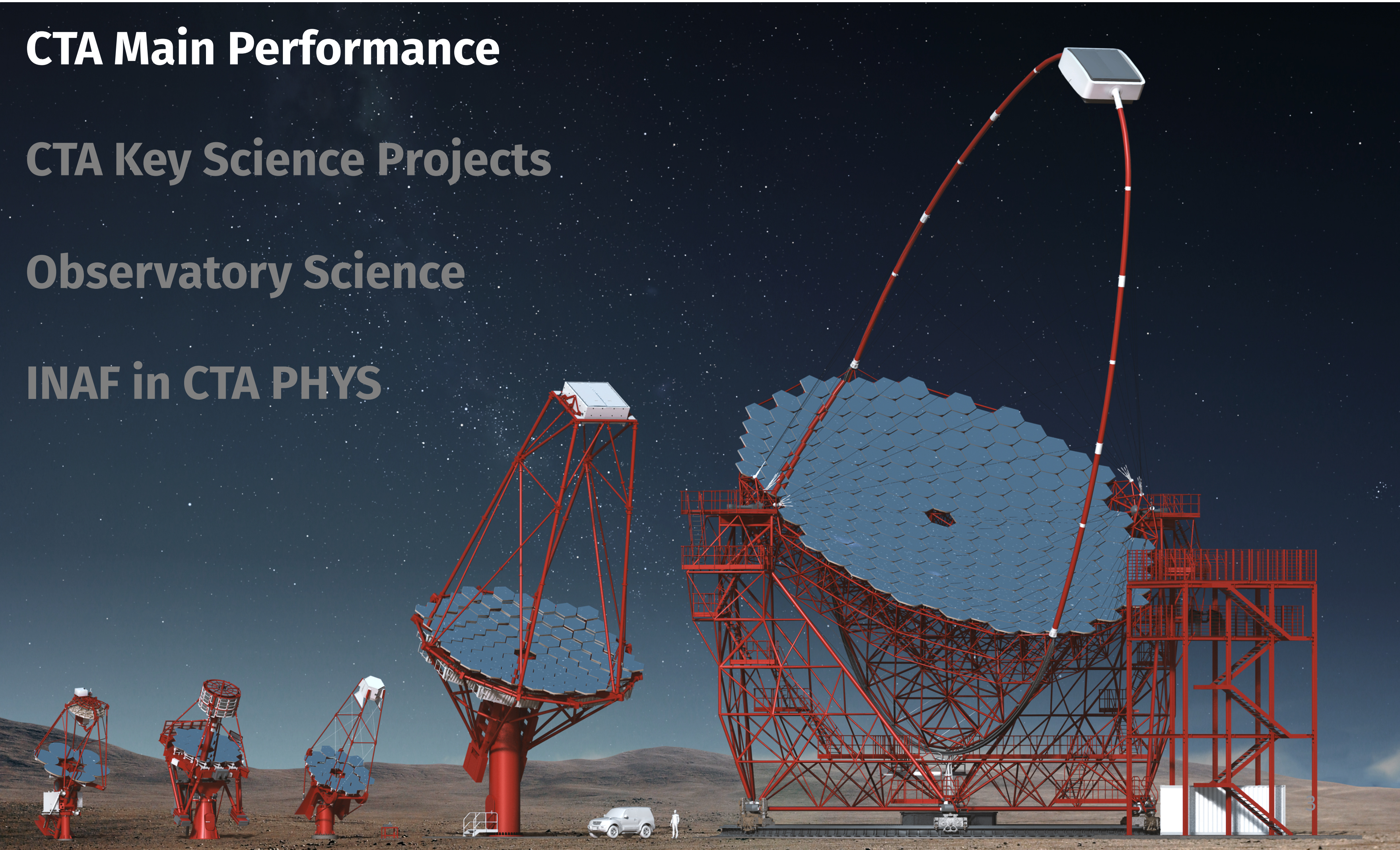
CTA Key Science Projects

Observatory Science

INAF in CTA PHYS



Outline



CTA Main Performance

CTA Key Science Projects

Observatory Science

INAF in CTA PHYS

The Cherenkov Telescope Array
(South Site)

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(South Site)

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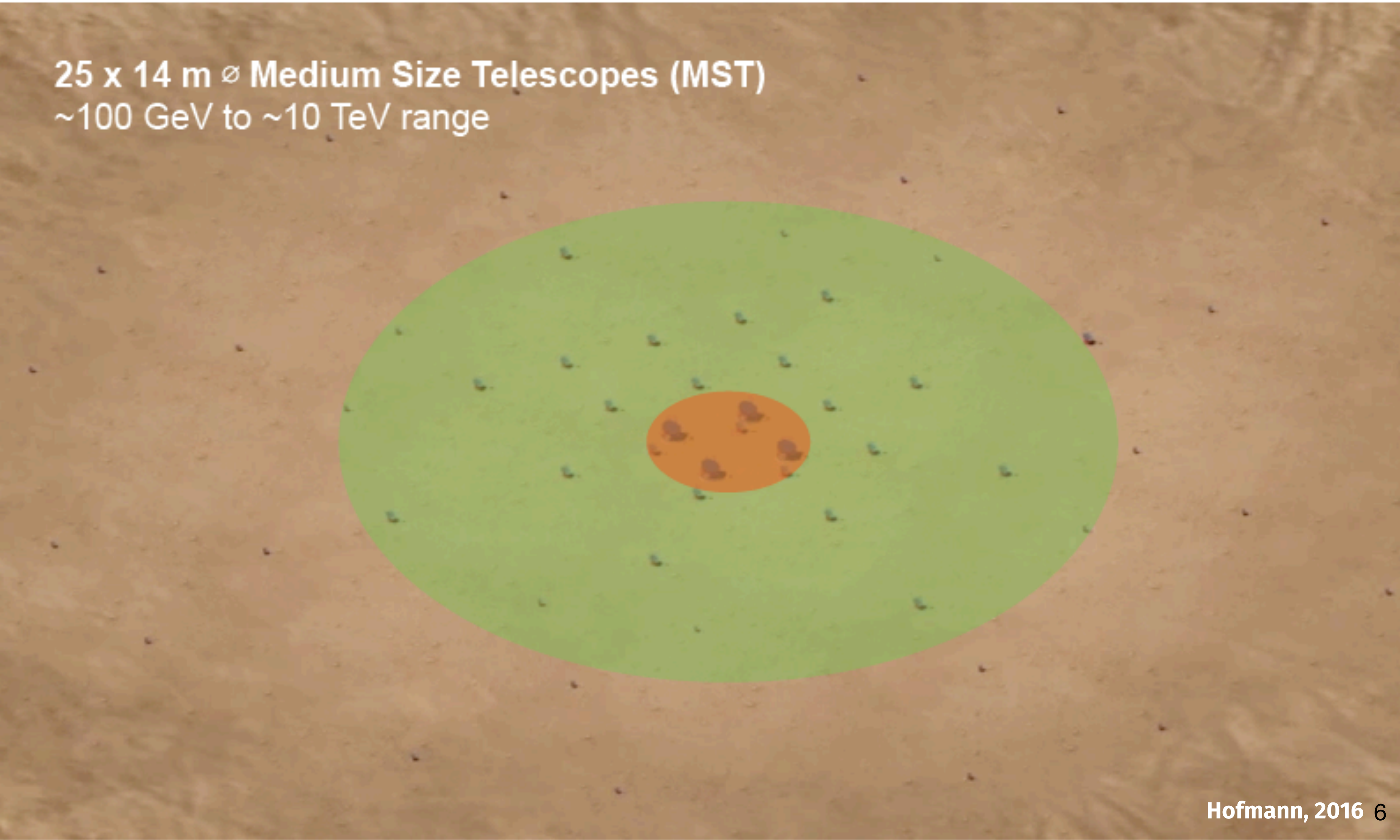
(South Site)

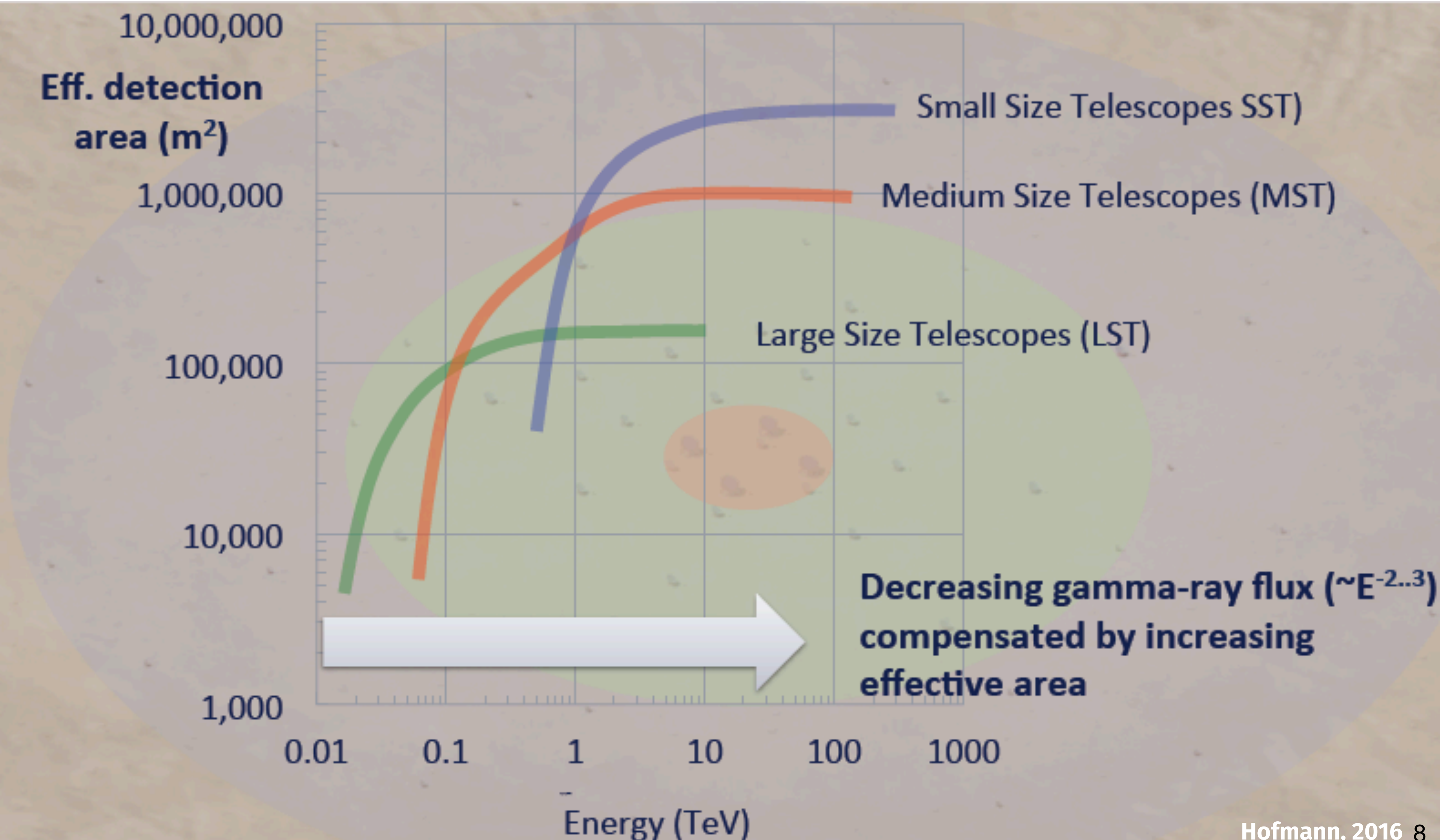


Hofmann, 2016

The Cherenkov Telescope Array
(South Site)

Hofmann, 2016

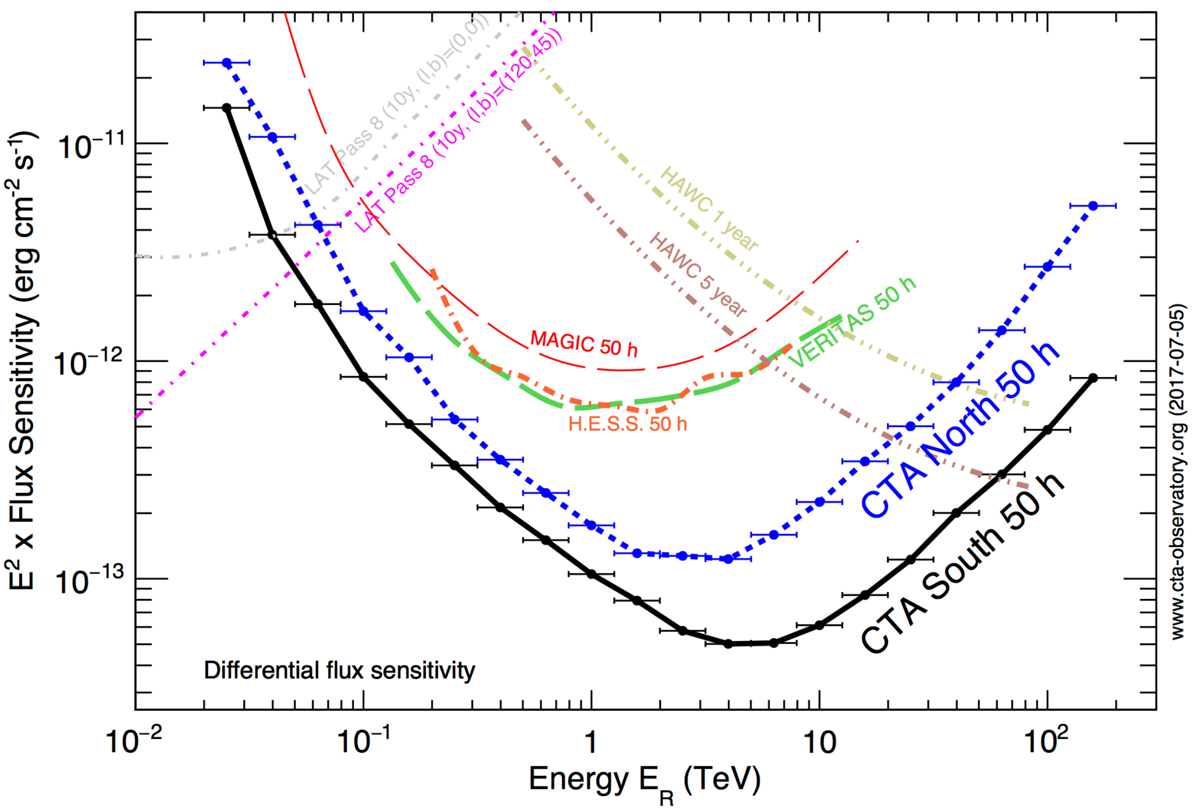
EFFECTIVE AREA FOR GAMMA-RAY DETECTION



Hofmann, 2016

CTA Performance

Differential Sensitivity

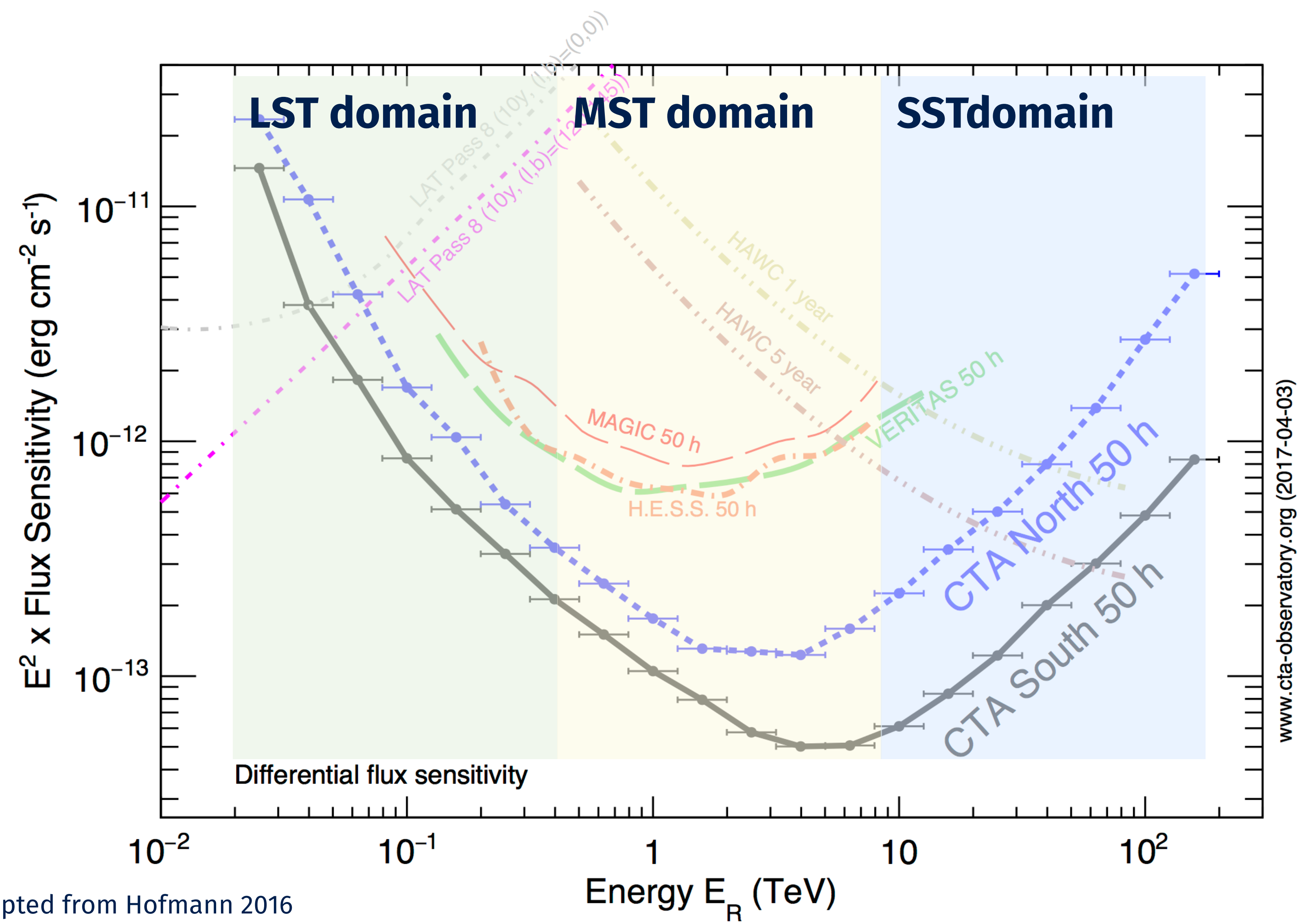


A factor of **5-10 improvement** in sensitivity in the domain of **about 100 GeV to some 10 TeV.**

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

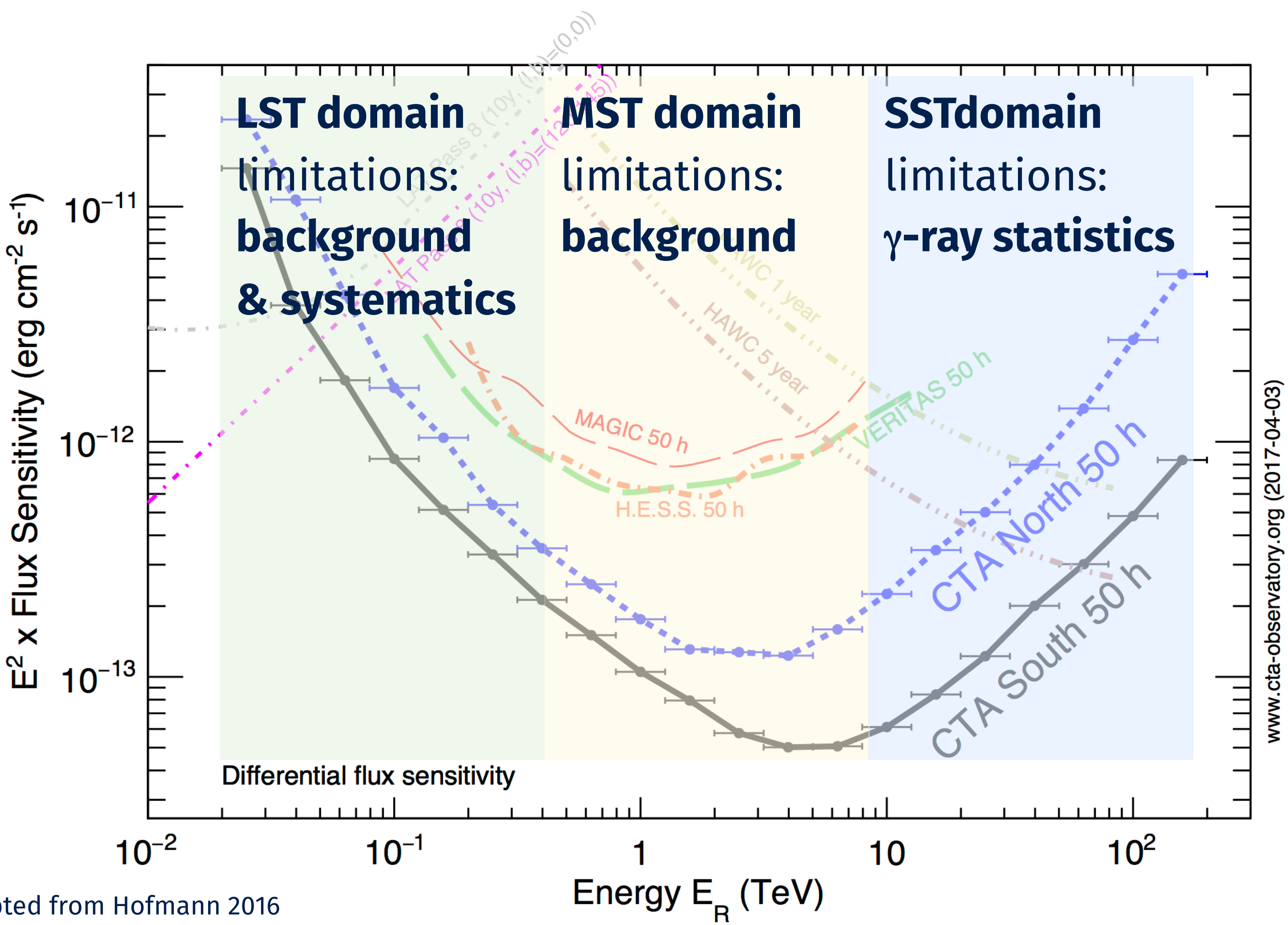
Credits: The CTA Consortium

CTA Performance



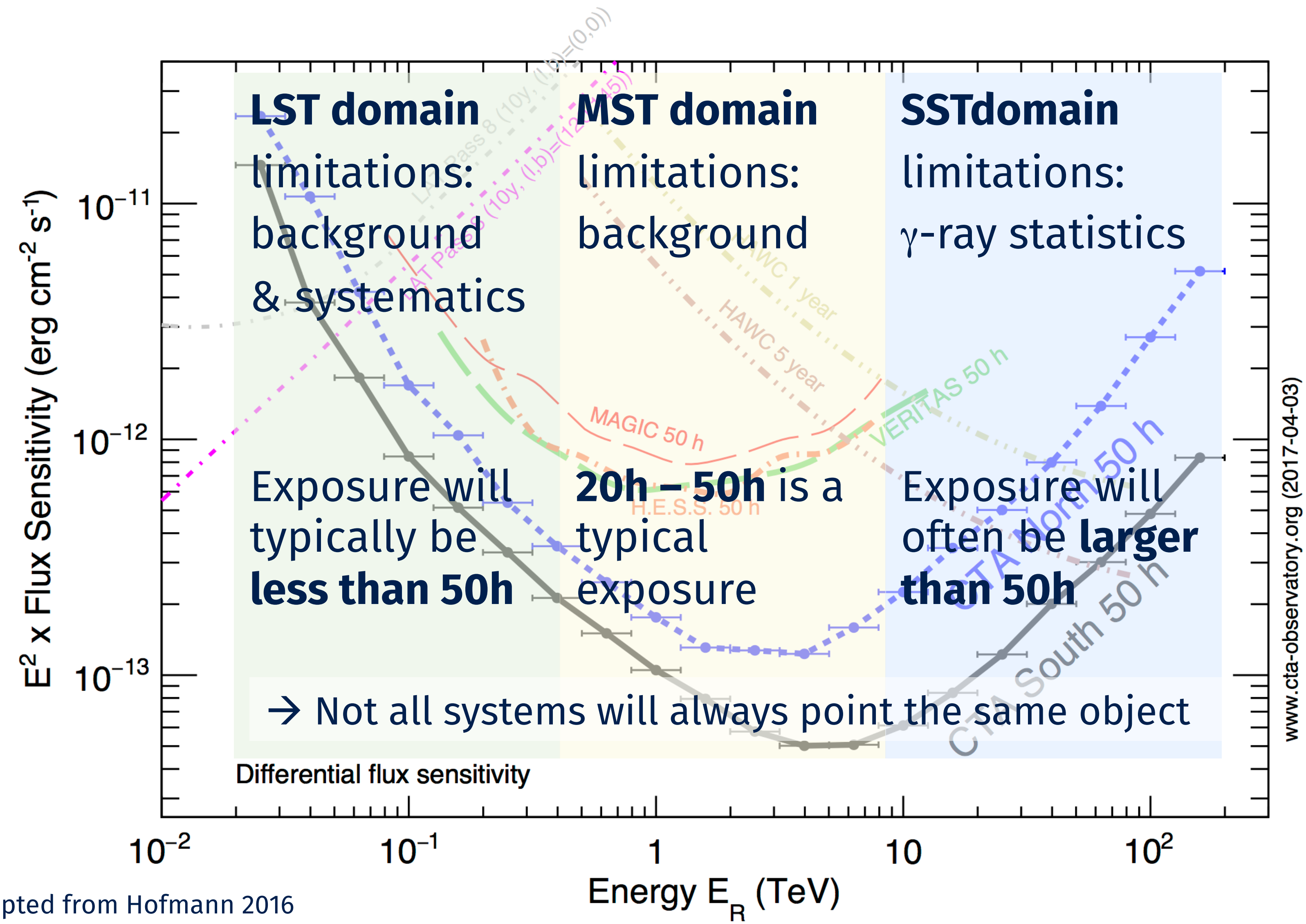
Adapted from Hofmann 2016

CTA Performance



Adapted from Hofmann 2016

CTA Performance



LST domain
limitations:
background
& systematics

Exposure will typically be **less than 50h**

MST domain
limitations:
background

20h – 50h is a typical exposure

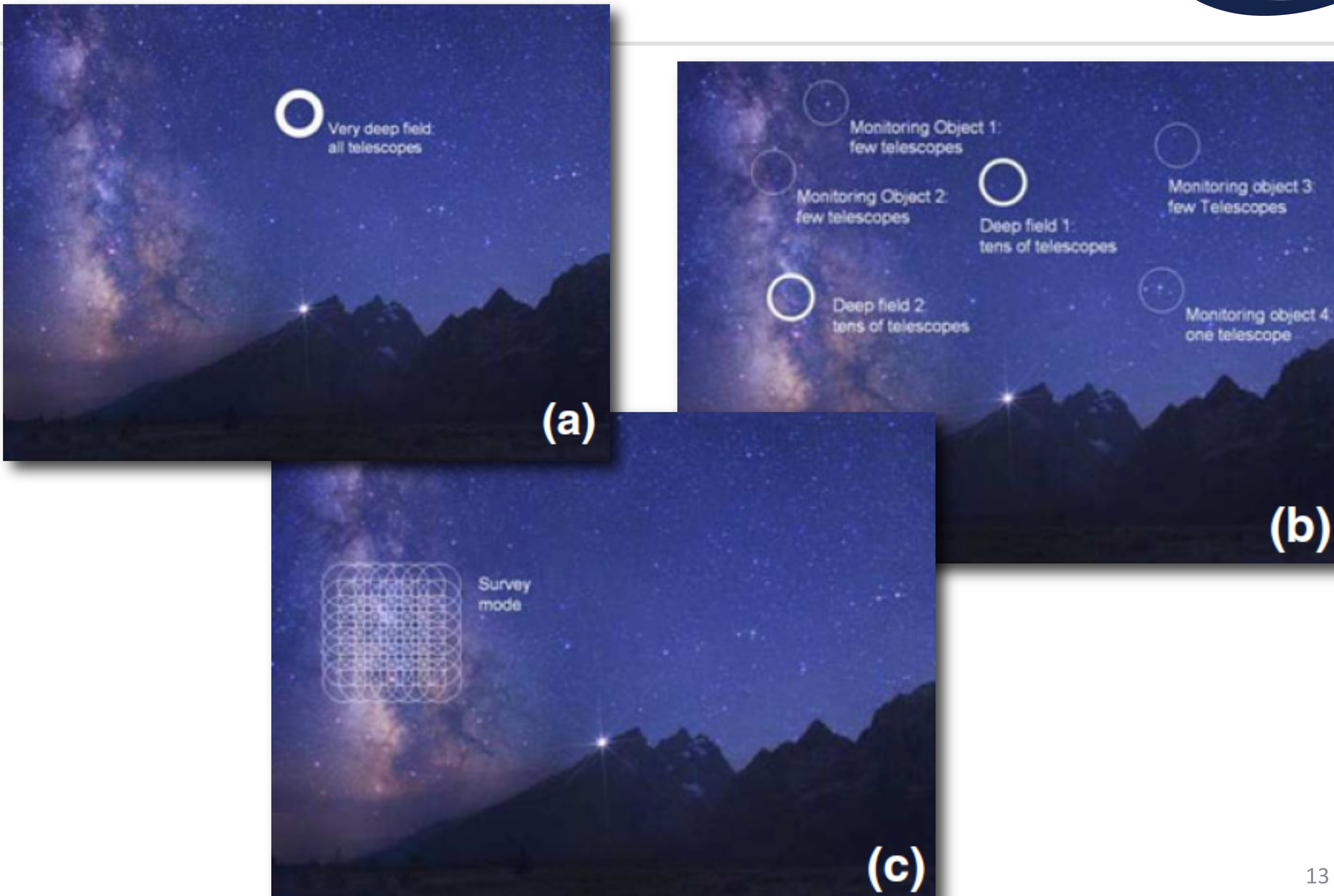
SSTdomain
limitations:
γ-ray statistics

Exposure will often be **larger than 50h**

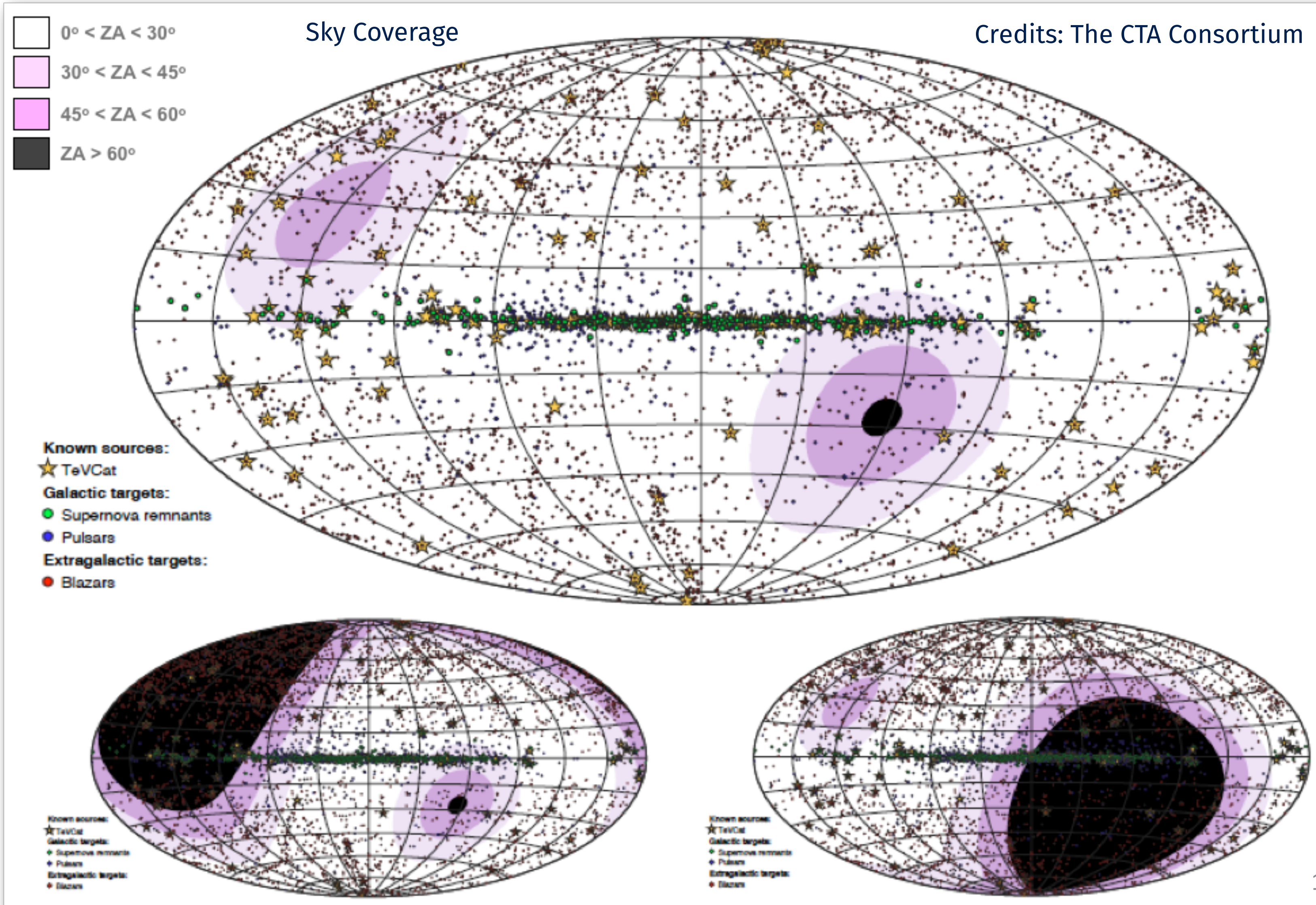
→ Not all systems will always point the same object

Adapted from Hofmann 2016

CTA Possible Observing Strategy



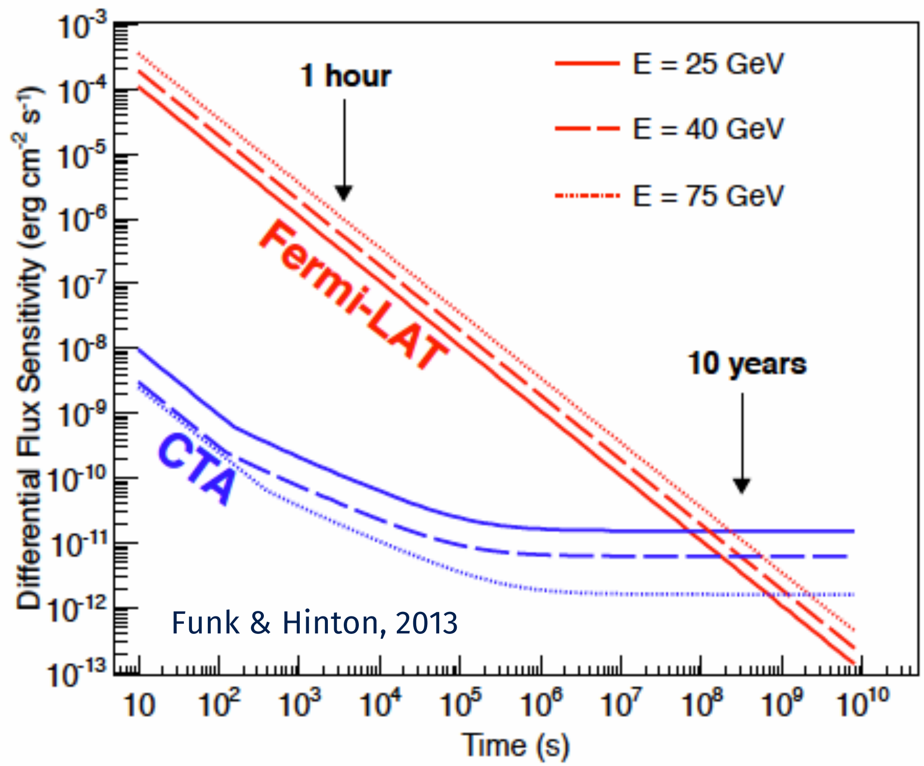
CTA as an *all-sky* Observatory



CTA as a *transient factory*

- **Huge advantage over Fermi** in energy range of overlap for ~minute to ~week 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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CTA Key Science Projects

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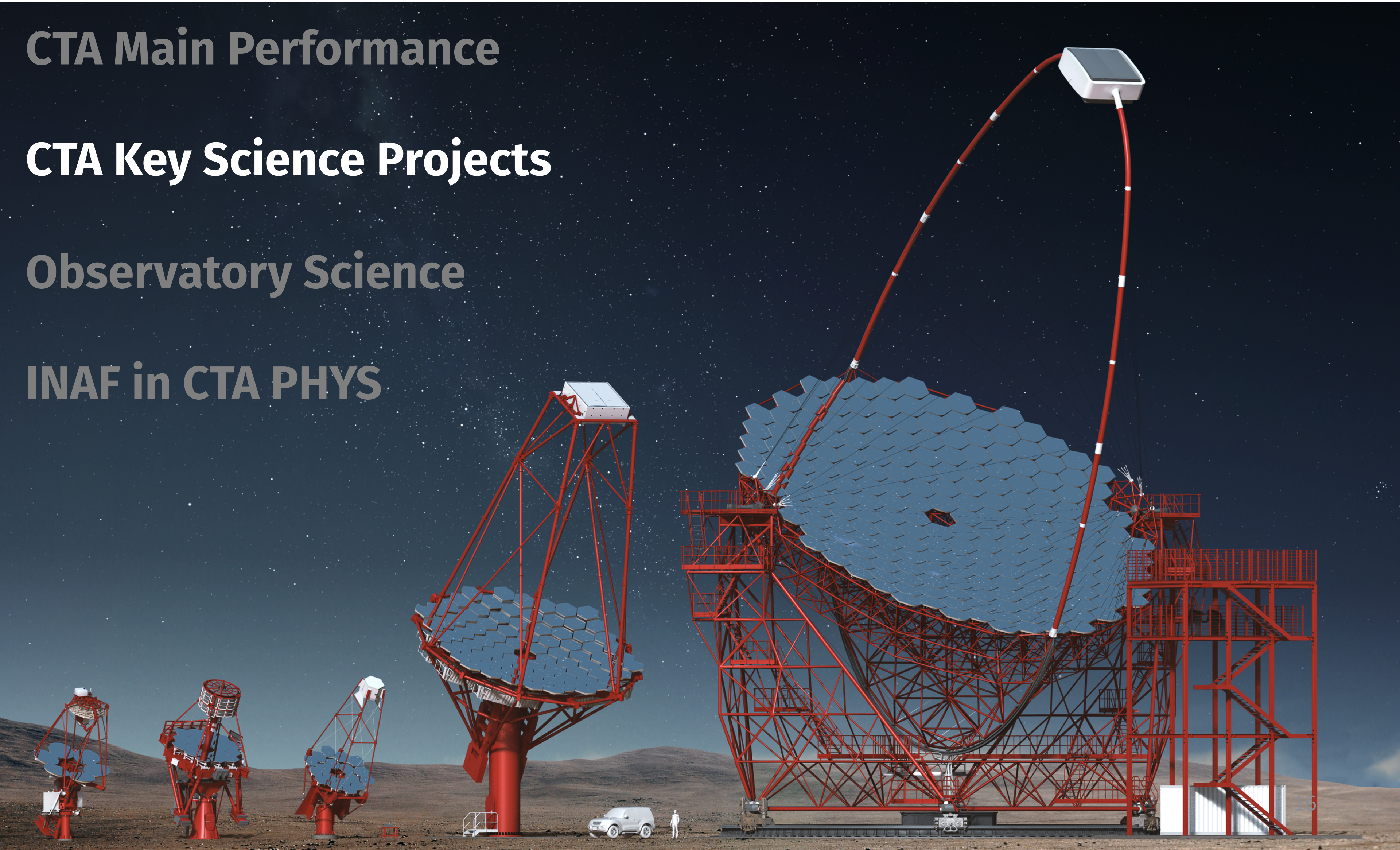
INAF in CTA PHYS



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

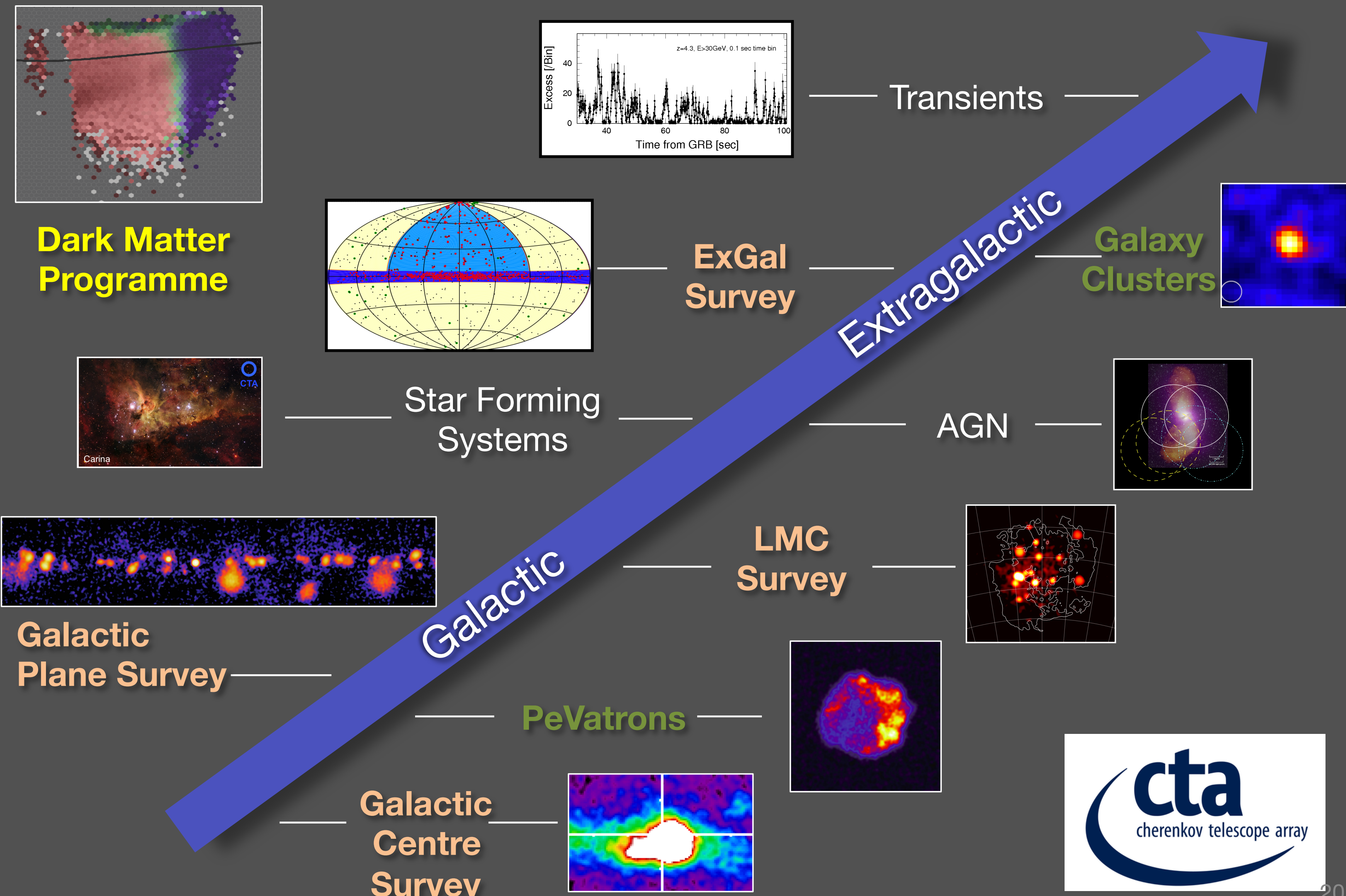
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

Cta Observing Programme (1)

- Baseline plan for first ten years (see Business Plan)
  - **40%** Core Programme, organized by Consortium
  - **60%** Open time, DDT, and host country time
  - **Preparatory studies for KSP observations prior to start of CTA user operations**, if time left during Array Commissioning and Science Verification (ACSV)

Cta Observing Programme (2)

- 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
  - Summarized in document "**Science with CTA**" – newly released to arXiv archive
  - Large potential for **guest observer proposals** – building on results from the KSP surveys
  - We expect that **the KSPs will be reviewed** (and adjusted accordingly) on a regular basis before, and during, the operational phase.



Excess [/Bin]
z=4.3, E>30GeV, 0.1 sec time bin
Time from GRB [sec]
Transients
Dark Matter Programme
ExGal Survey
Galaxy Clusters
Extragalactic
CTA
Carina
Star Forming Systems
AGN
LMC Survey
Galactic
Galactic Plane 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 →

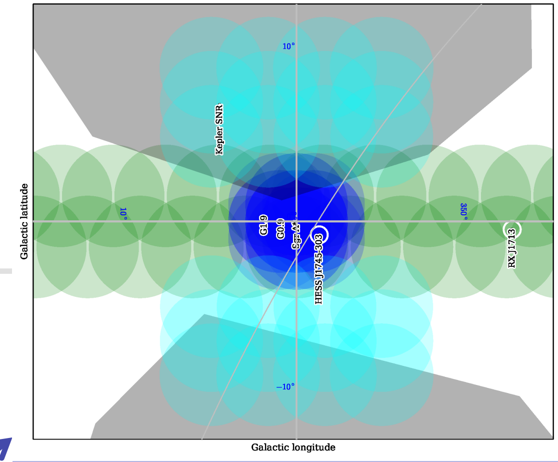
- **KSPs are sets of observations** addressing multiple science questions within CTA themes.
- **Check-marks** → impact of each KSP on a particular science question.
- **The DM Programme** has a transversal nature (GC, LMC, Galaxy Clusters).

Science with CTA

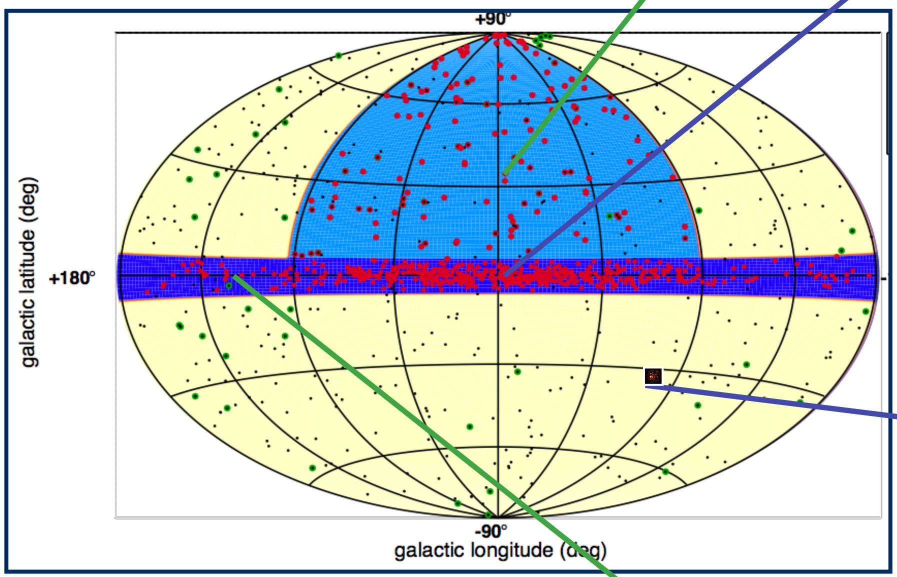
[arXiv:1709.07997](https://arxiv.org/abs/1709.07997)

Submitted to
International Journal of Modern Physics D

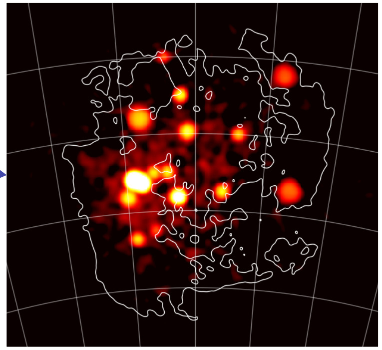
The Survey KSPs



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

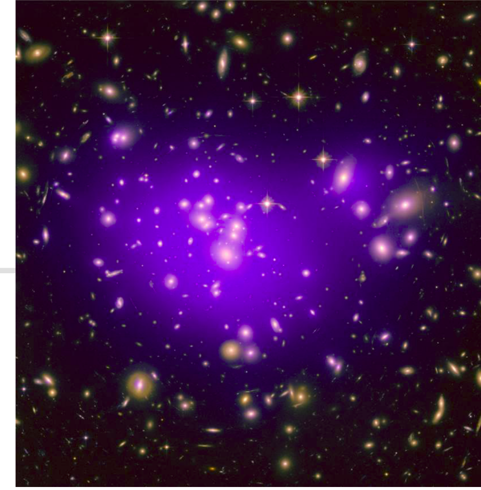


SSTs involved In all of them

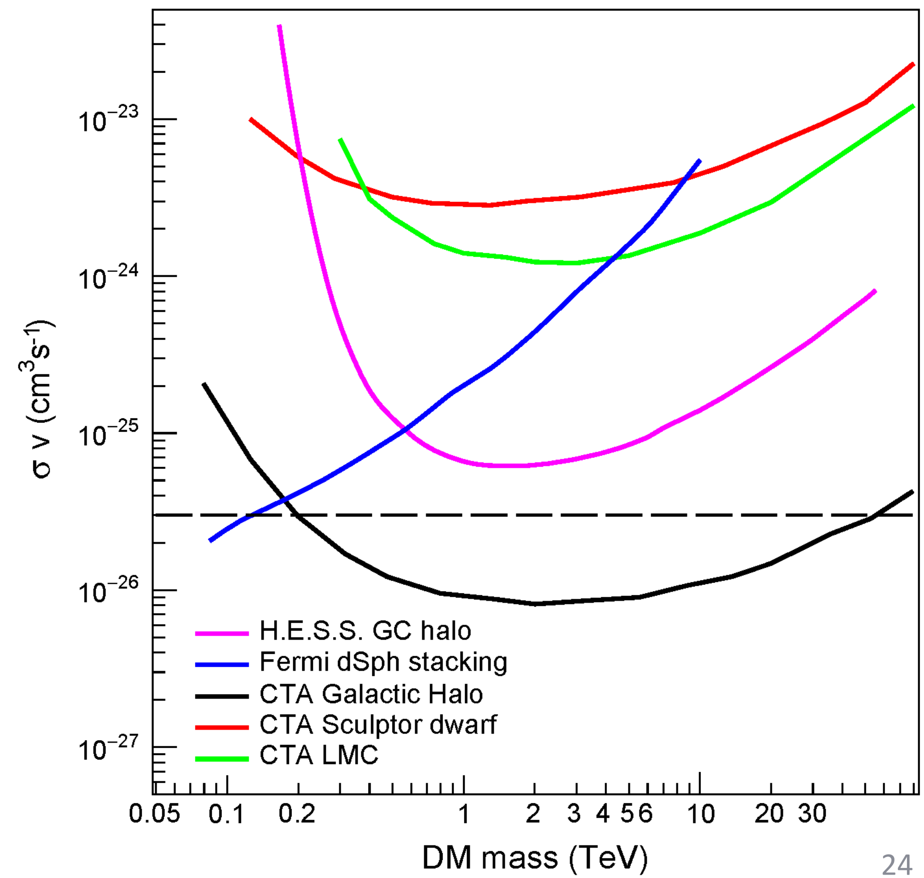
Galactic Plane Survey:
Survey of entire plane to ~2 mCrab
Galactic source population: SNRs, PWNe, etc.
PeVatron candidates, early view of GC, 1620 h

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

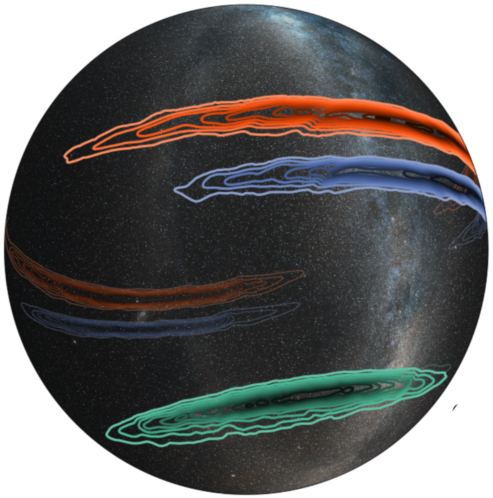
Dark Matter Programme



- **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



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

Neutrinos Astrophysics

```
TITLE:    GCN CIRCULAR
NUMBER:   21916
SUBJECT:  IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE:     17/0
FROM:     Erik                                              umd.edu>
```

✔

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

✔

ATel #10817; *Razm*

Credential Certification: I

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

✔

Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel
SA/MSFC) on behalf of the Fermi-LAT collaboration
on 28 Sep 2017; 10:10 UT
cation: David J. Thompson (David.J.Thompson@nasa.gov)

AGILE confirmation of gamma-ray activity from the IceCube-170922A error region

✔

ATel #10801; *F. Lucarelli (SSDC/ASI and INAF/OAR), G. Piano (INAF/IAPS), C. Pittori, F.*
Verrecchia (SSDC/ASI and INAF
A. Bulgarelli (INAF/IASF-Bo
Vercellone (INAF/OA-Brera), I
Striani (CIFS and INAF/IAPS), I
Trifoglio (INAF/IASF-Bo), A. C
A. Chen (Wits University), A.
Lazzarotto, I. Lapshov, L. Paccia
M. Rapisarda (ENEA-Frascati)
(INAF/IASF-Bo), A. Pellizzo
Vallazza (INFN Trieste), F. Lo
(INFN and Univ. Roma Tor Verg
and Univ. Roma Sapienza), I

[Previous | Next]

✖

H.E.S.S. follow-up of IceCube-170922A

ATel #10787; *Mathieu de Naurois for the H.E.S.S. collaboration*

Credential Cert

Subjects: VHE, Neutrinos

VERITAS follow-up observations of IceCube neutrino event 170922A

✖

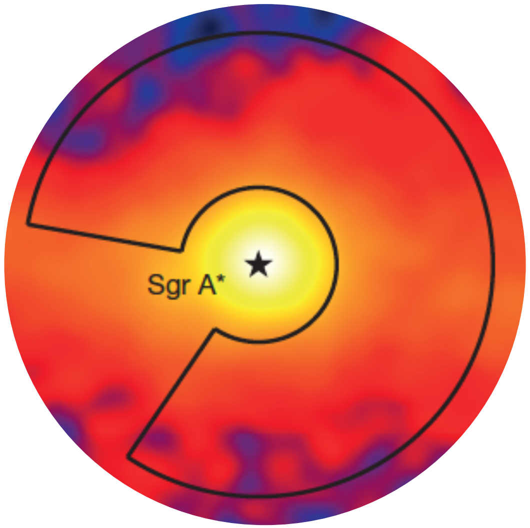
ATel #10833; *Reshmi Mukherjee*
on 9 Oct 2017; 22:32 UT
Certification: Reshmi Mukherjee (muk@astro.columbia.edu)

HAWC gamma ray data prior to IceCube-170922A

✖

ATel #10802; *Israel Martinez, Ignacio Taboada, Michelle Hui and Robert Lauer for the HAWC collaboration*
on 30 Sep 2017; 02:10 UT
Credential Certification: Ignacio Taboada (itaboada@gatech.edu)

Cosmic-ray PeVatrons

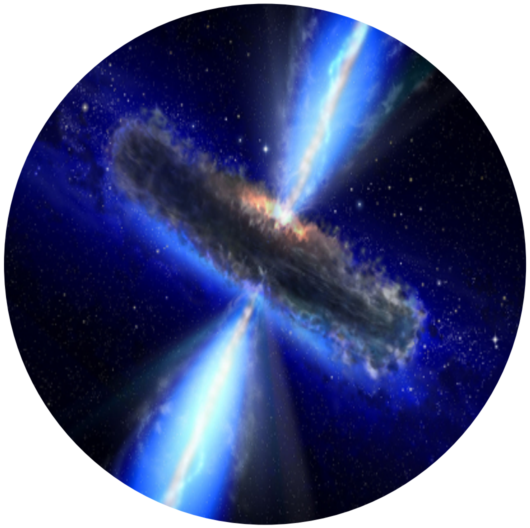


Credits: The H.E.S.S. Collaboration

Supernova remnants might be able to satisfy the cosmic-ray energy requirement if they can somehow convert ~10% of the supernova kinetic energy into accelerated particles.

CTA will perform **deep observations of known sources with particularly hard spectra**. Moreover, it will search for **diffuse gamma-ray emission from the vicinity of prominent gamma-ray bright SNRs.**

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**.

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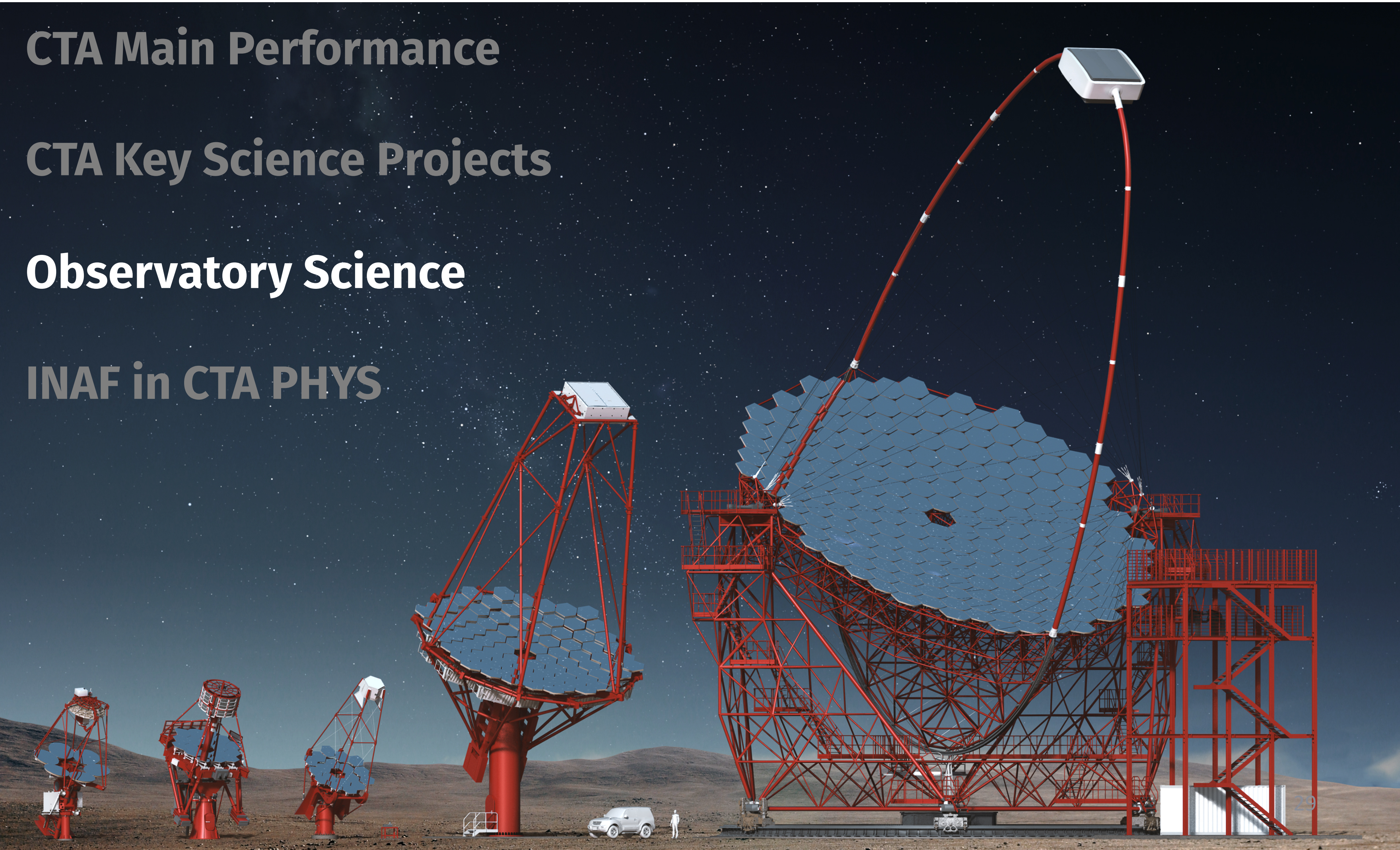
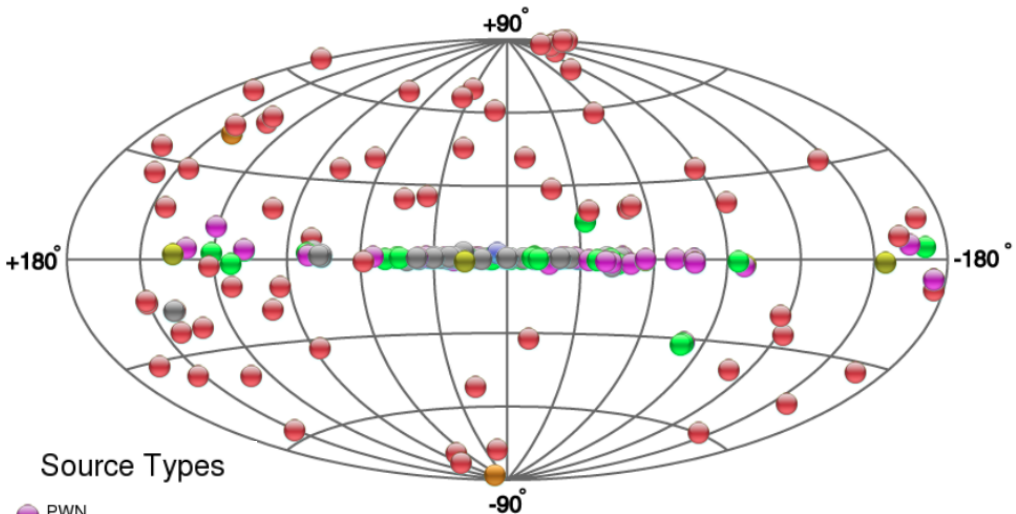
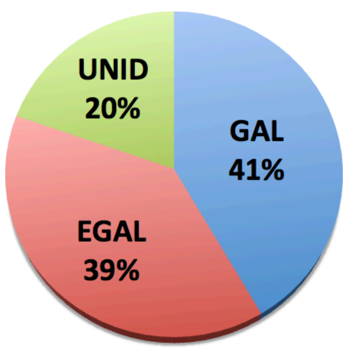


The sky above 50 GeV

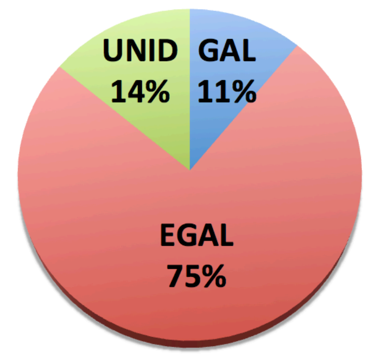


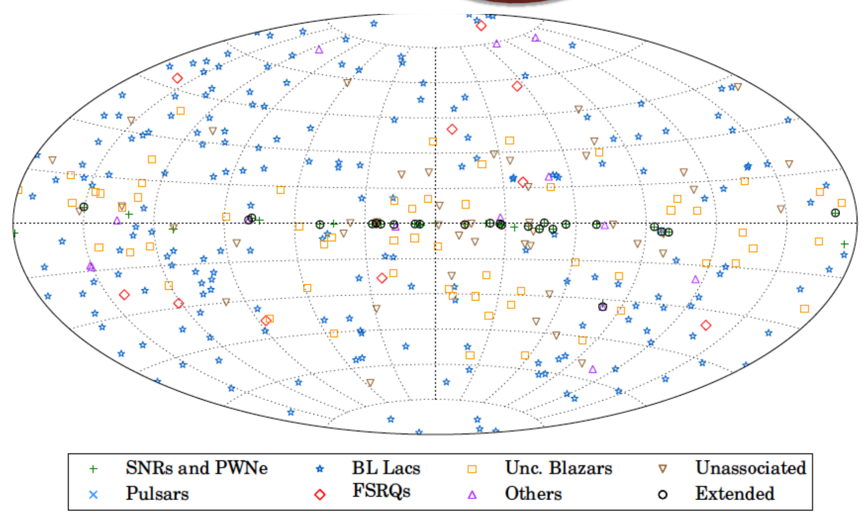
Wakely & Horan http://tevcat.uchicago.edu/

~180 TeVCat sources



360 *Fermi*-LAT sources E>50 GeV





2FHL Ackermann+16

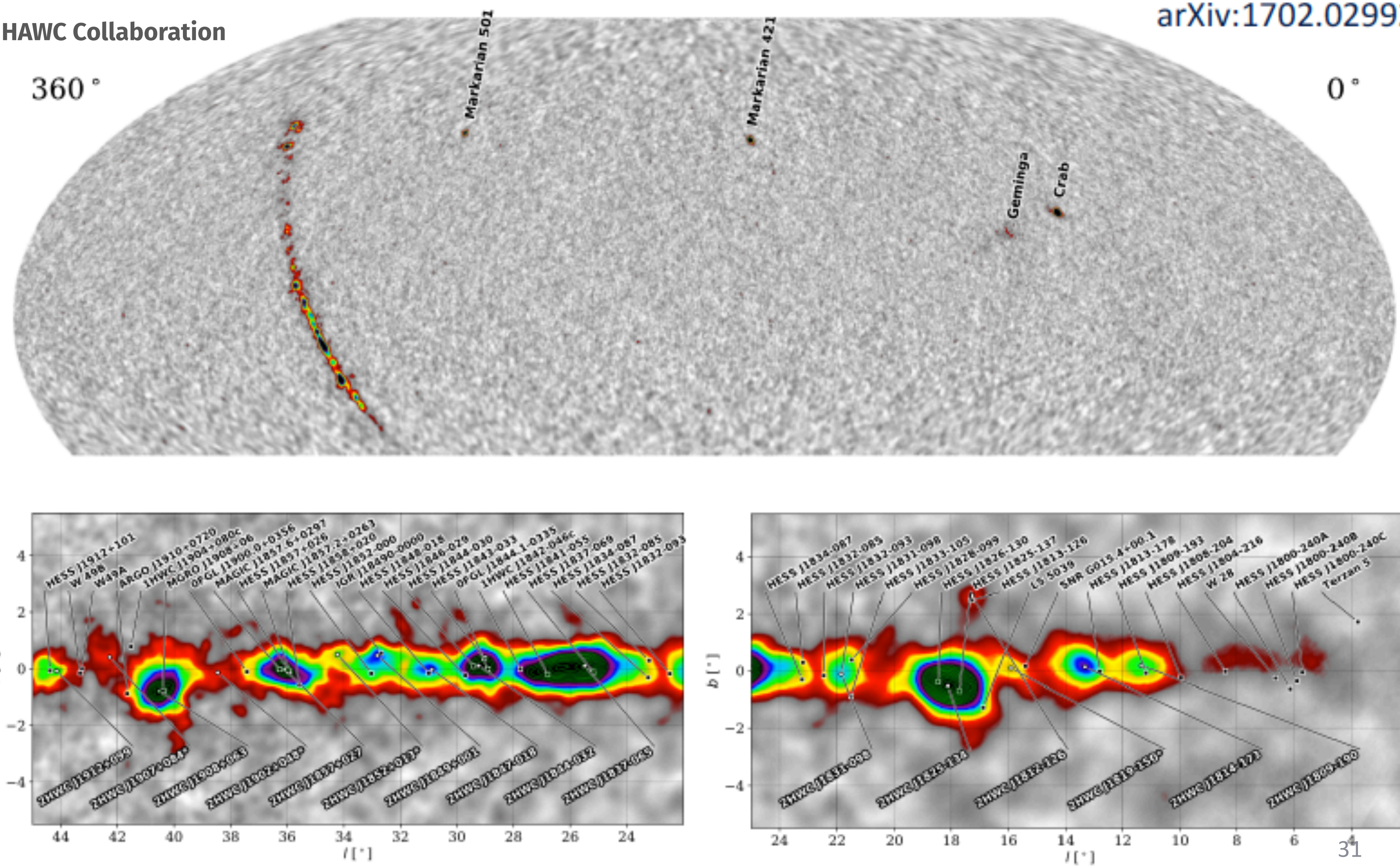
Only ~25% of the 2FHL sources have been previously detected by Cherenkov telescopes.

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
- ...

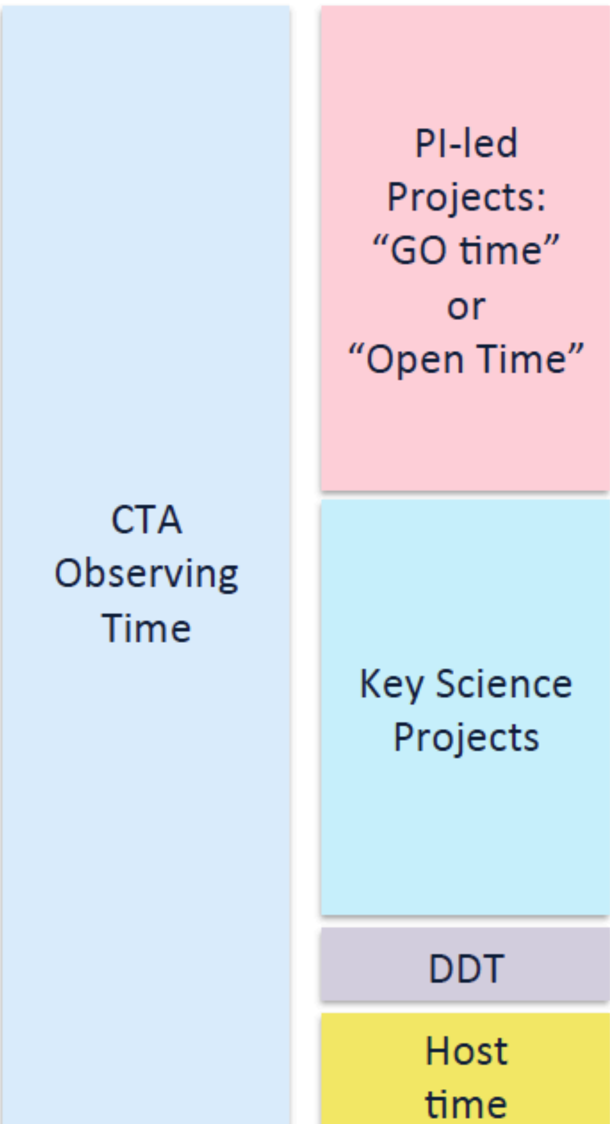
Proposal-Driven User Programme

Credits: Hofmann, Gamma 2016

CTA as an Open Observatory

- Regular (likely annual) AOs
- Proposals evaluated by TAC, resulting in a long-term schedule
- Short-term scheduling on site, taking into account telescope availability, sky and environmental conditions
- Queue-mode operation by Observatory night operators
- Presence on site of observers not required / not foreseen
- Observers will receive photon lists in FITS format, IRFs, and science tools (*ctapipe*, currently under tests with H.E.S.S., MAGIC, and VERITAS data)
- Data publicly available after a proprietary period

CTA as an Open Observatory



Open Time Pool: Proposals by scientists from CTA member states (some fraction of time open to non-members); reviewed by TAC

Details tbd

Key Science Projects carried out by the CTA Consortium

Director's Discretionary Time

Time provided to **host countries / host organisations** under hosting agreement

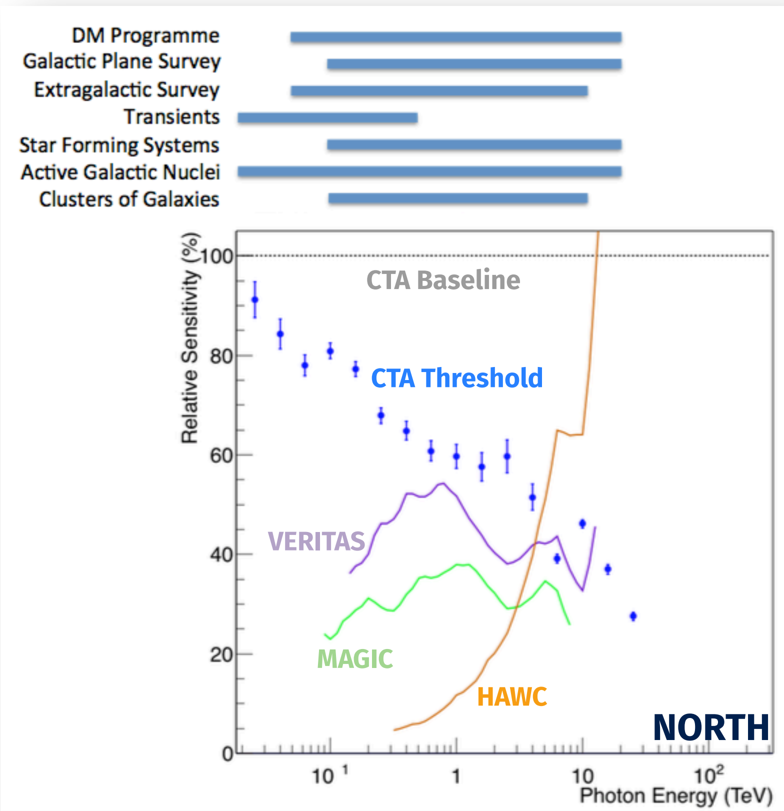
CTA Threshold

Approved by the CTAO Council

		CTA Baseline (€400M)	CTA Implementation Threshold (€250M)
Northern Array	Number of LSTs	4	4
	Number of MSTs	15	5
Southern Array	Number of LSTs	4	0
	Number of MSTs	25	15
	Number of SSTS	70	50

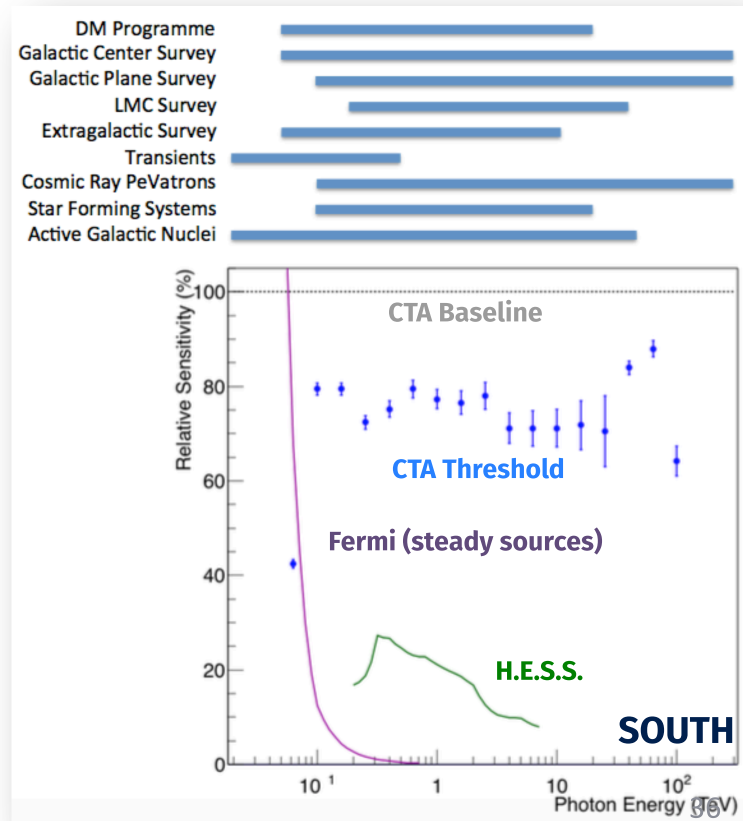
CTA Performance (Threshold)

Qualitative metrics results allowed a first determination of **CTA threshold performance** for the KSPs in different energy ranges.



KSPs energy ranges

The higher, the better



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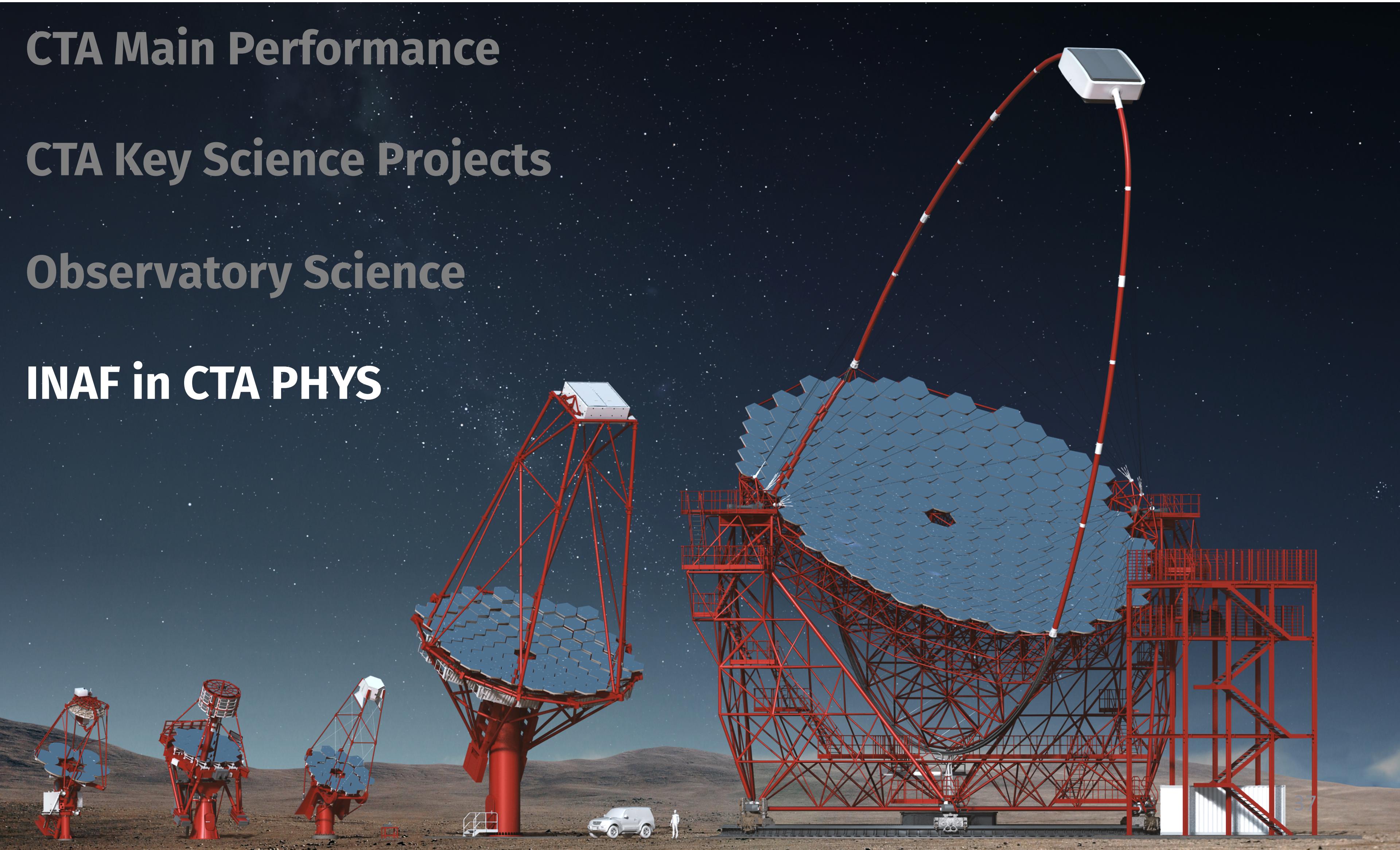
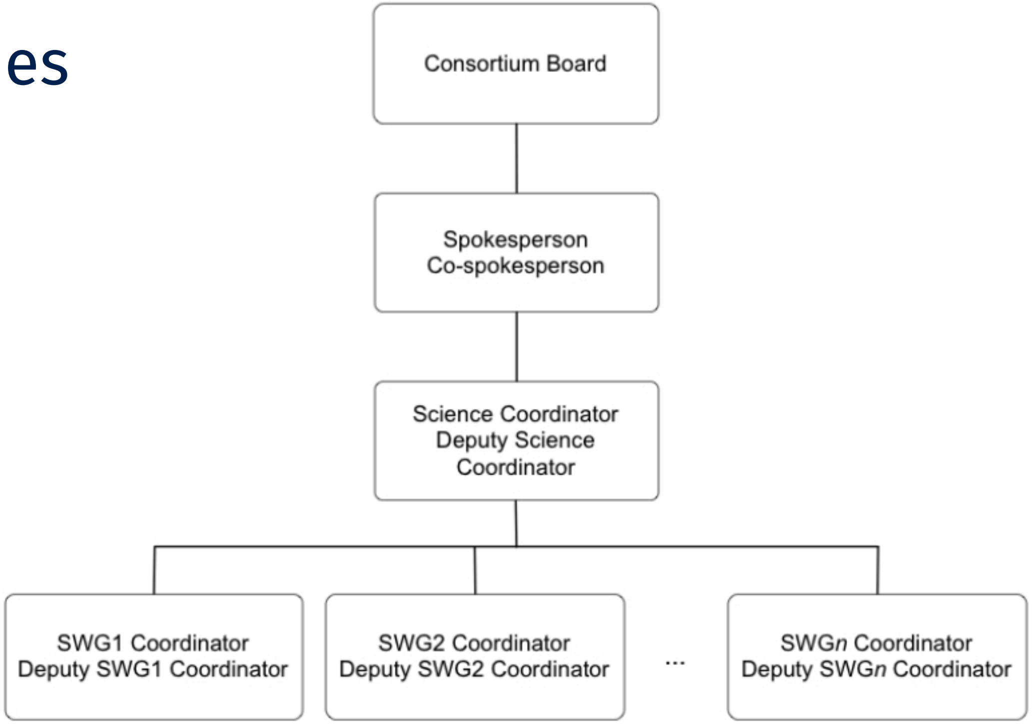


PHYS WG Organization

The PHYS WG has been re-organized following a structured scheme, matching the different science topics.

Coordinators and Deputies rotate following a year-based scheme.

Deputy becomes Coordinator, for a total term of duty of 2 years.



Current PHYS WG Management

CTAC Science Coordinator: Stefano Vercellone (INAF)

CTAC Deputy Science Coordinator: Stefan Funk (FAU)

1. **Galactic**
    1. Jamie Holder (Coordinator, U. Delaware)
    2. Roberta Zanin (Deputy, MPI-K)
2. **Cosmic-rays**
    1. Stefan Ohm (Coordinator, DESY)
    2. Sabrina Casanova (Deputy, IFJ-PAN)
3. **Extra-galactic**
    1. Elina Lindfors (Coordinator, U. Turku)
    2. **Fabrizio Tavecchio (Deputy, INAF)**
4. **Transients**
    1. Catherine Boisson (Coordinator, Obs. Paris)
    2. Daniela Hadasch (Deputy, ICRR)
5. **Dark matter and exotic physics**
    1. Fabio Zandanel (Coordinator, Grappa Inst.)
    2. Aldo Morselli (Deputy, INFN)
6. **Intensity interferometry**
    1. Dainis Dravins (Coordinator, Lund Obs.)
    2. Michael Daniel (Deputy, CfA)

Multi-wavelength and synergies

1. Sera Markoff (Coordinator, U. Amsterdam)
2. Emma de Oña Wilhelmi (Deputy, IEEC-CSIC)

INAF in PHYS

63 [/432 (~15%)] members of the PHYS WG are INAF scientists.

People can apply to one or more SWGs.

SWG	INAF Scientists	Total	INAF %
Galactic	29	207	~14
Cosmic Rays	11	148	~7
Extra-galactic	21	191	~11
Transients	32	186	~17
Dark matter & exotic physics	7	129	~5
Intensity Interferometry	4	25	~16

The INAF participation in the CTA SWGs roughly reflects the topics of the CTA/SKA successful grants.

Intensity Interferometry is not a current Key Science Project.

How to get involved in PHYS Tasks?

- **Computation of Quantitative KSPs *performance metrics***, to provide the tools to quickly and efficiently adapt KSPs to external conditions (such as Observatory performance for different implementations of CTA).

- **Refine key CTA science cases** and analysis procedures and document them in Consortium publications.

- **1st CTA Data Challenge**, to probe simulation and analysis tools and to engage more people in data analysis.

- **Multi-wavelength and synergies activities**, to evaluate and plan access to relevant facilities.

How to get involved in PHYS Tasks?

- **Computation of Quantitative KSPs *performance metrics***, to provide the tools to quickly and efficiently adapt KSPs to external conditions (such as Observatory performance for different implementations of CTA). **– Almost completed**

- **Refine key CTA science cases** and analysis procedures and document them in Consortium publications. **– To be revamped**

- **1st CTA Data Challenge**, to probe simulation and analysis tools and to engage more people in data analysis. **– Just started**

- **Multi-wavelength and synergies activities**, to evaluate and plan access to relevant facilities. **– Ongoing**

Consortium Papers

Refine key CTA science cases and analysis procedures and document them in Consortium publications

Planned Consortium publications

KSP	PUBLICATION TOPIC	GAL	CR	EGAL	TRANS	DMEP	II
DM	CTA sensitivity to DM annihil. in the GC					X	
	CTA sensitivity to DM annihil. in dwarf galaxies					X	
GPS	Updated paper describing GPS in more complete detail than in A.Ph. article	X					
LMCS	Prospects for the detection and study of SN 1987A using CTA	X	X				
	Probing cosmic rays in the LMC using CTA	X	X				
	Dark matter in the LMC	X	X			X	
EGALS	Transient survey with divergent pointing			X	X		
TRANS	Science of Galactic transients	X			X		
AGN	Expected AGN population based on latest Fermi catalog and performance curves			X			
	Evaluate the number of expected flares of AGNs as a function of redshift and AGN class based on long- term light-curves from F-LAT			X			
	Studies of the EBL, IGMF (pair echo), ALPs, LIV (pair threshold modification)			X		X	
	Focus on spectral modifications due to line-of-sight effects			X		X	
GAL.CL	CTA Prospects for Studying Dark Matter and Cosmic Rays in Clusters of Galaxies		X	X		X	

1st CTA Data Challenge

1st CTA data challenge

Aim: to produce simulated high-level science data covering a set of physics cases related to the KSPs. The main goal is**:**

- involve larger group of people in realistic analyses of CTA-like data (take a first step to prepare for first light)

We simulated three years of data north and south with observation time that could match the original KSP-allocated time

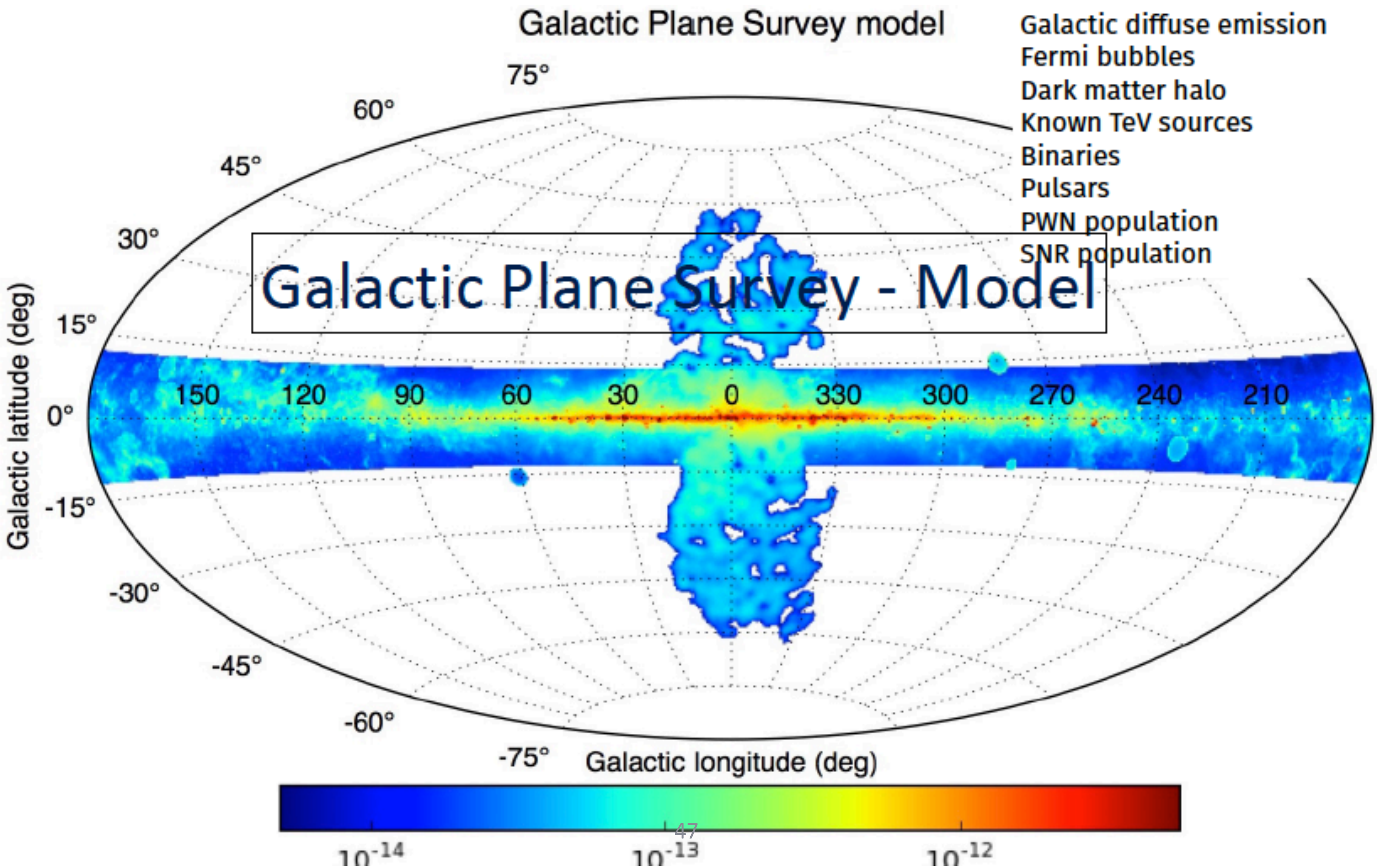
Focus on

- Galactic Plane Survey: total 1620 hours (1020 South, 600 North)
- Extragalactic Survey: total 500 hours (200 South, 300 North)
- Galactic Center Survey: total 825 hours (South)
- AGN Monitoring: 960 hours (North)

Input example

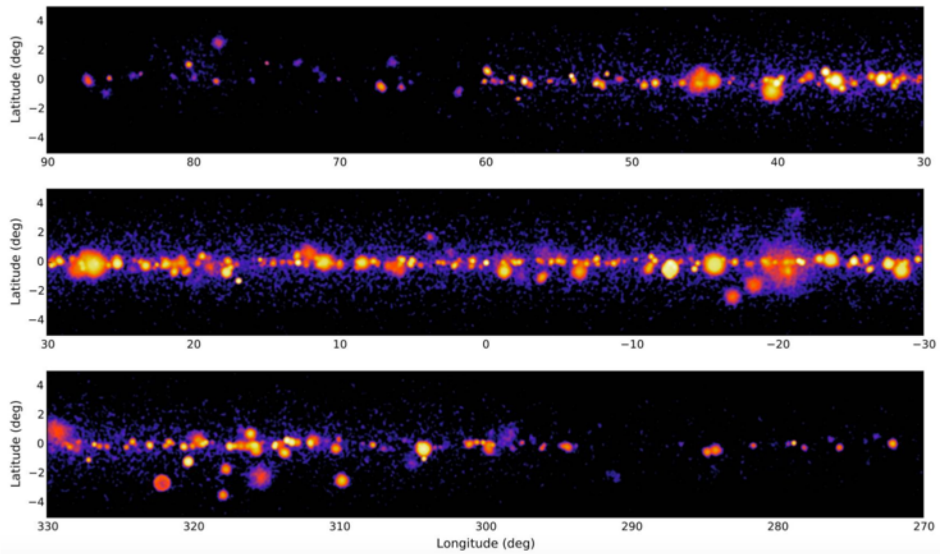
Galactic Plane Survey - Model

- Galactic diffuse emission
- Fermi bubbles
- Dark matter halo
- Known TeV sources
- Binaries
- Pulsars
- PWN population
- SNR population

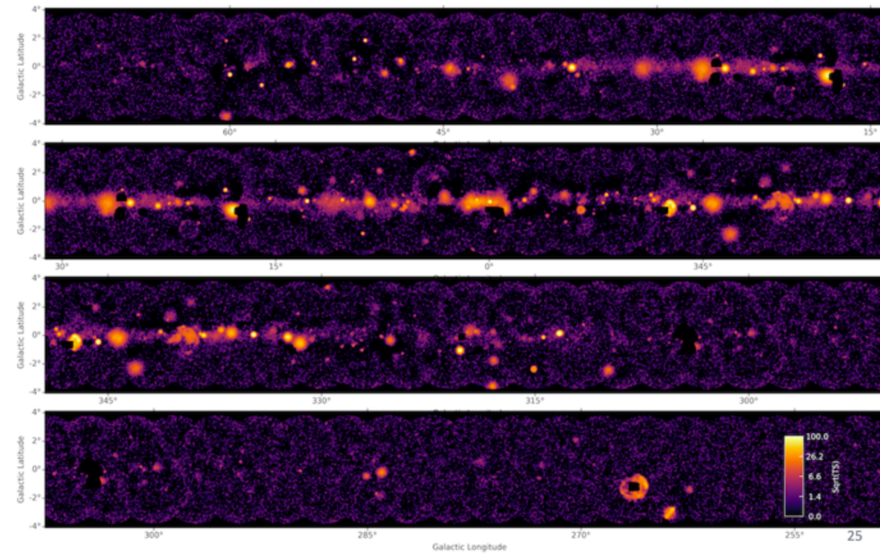


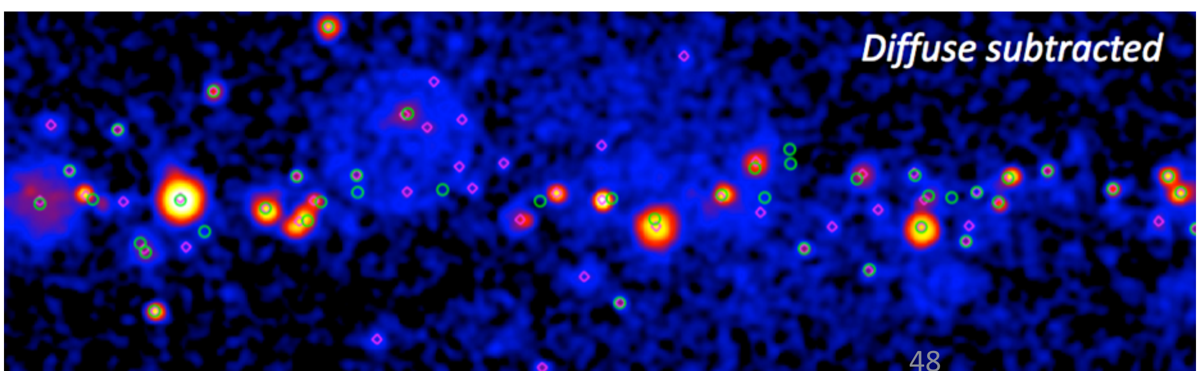
Preliminary results

CTOOLS



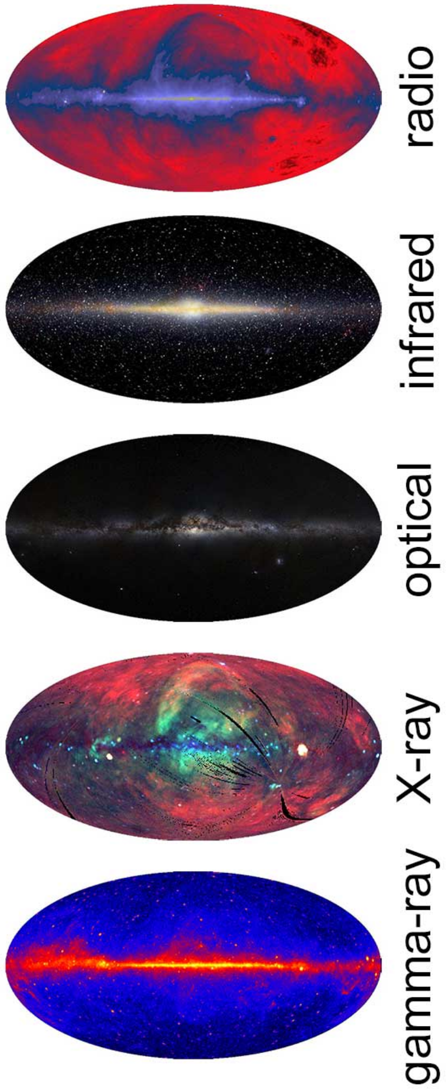
GammaPy



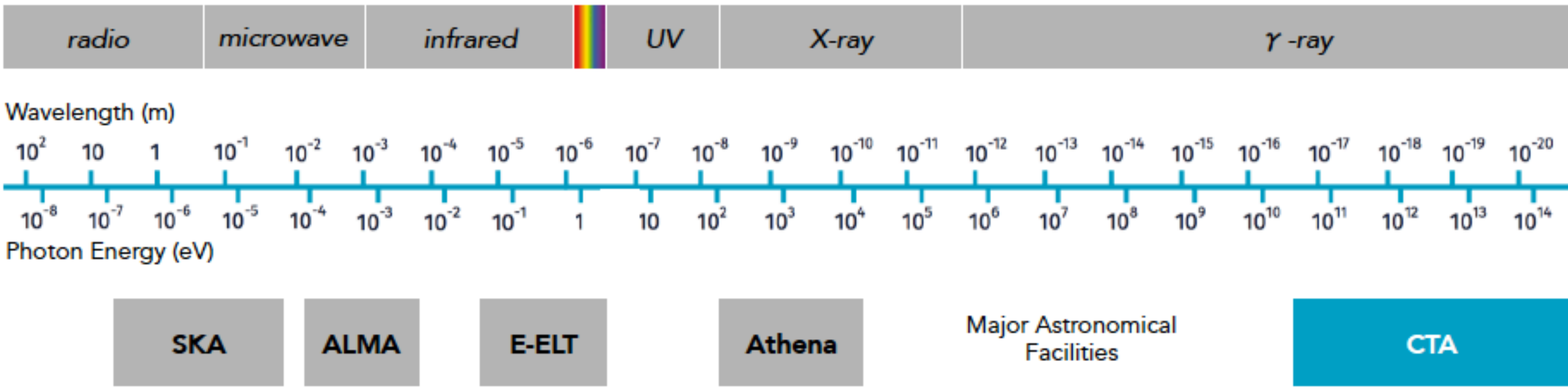


- Development of an automated catalog pipeline
- Optimizing source detection and studying source confusion

Multi-wavelength and synergies activities



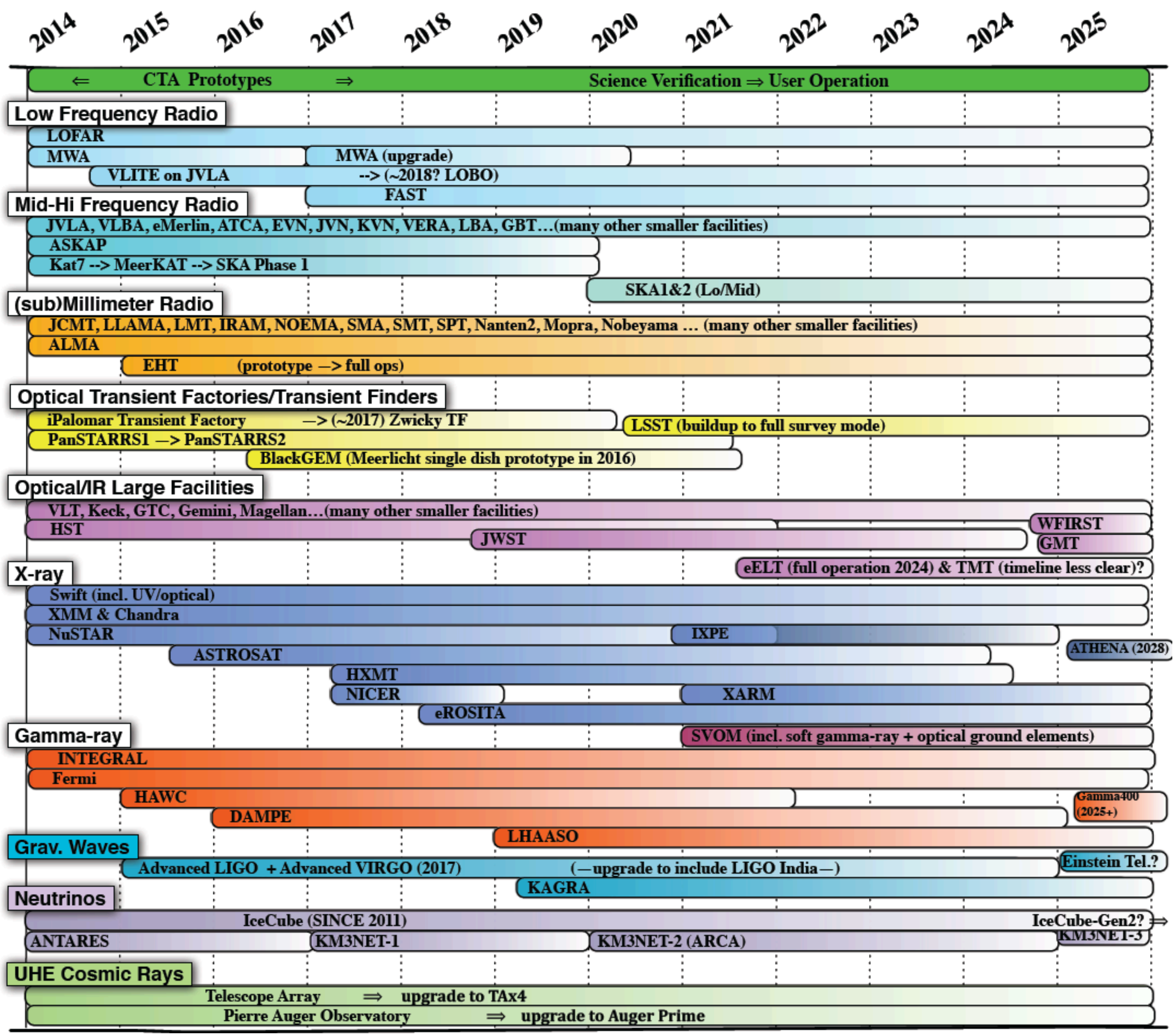
Synergies during CTA operation



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

Next slide shows…

Synergies during CTA operation



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 Programs.**
- Large potential for **guest observer proposals** – e.g., building on results from the KSP surveys.
- **Contributions** on:
  - PHYS working group activities
  - technical activities (e.g., analysis SW, Monte-Carlo,…)

Prospects

- **IRFs (Prod3b, internal distribution)**
  - North & South, baseline and threshold arrays, full and subsystems (LSTs, MSTs, SSTs, MSTs+SSTs), 20 and 40 deg ZA, 100s, 30m, 5h, 50h
- **From Prototypes to the Threshold**
  - We need to generate/obtain similar IRFs for a specific set of precursors.
- **Science cases**
  - Some KSPs can easily start well before the Threshold (e.g., AGN monitoring, Surveys, PeVatrons, Transients)
  - We have at least a couple of years where we have
    - ASTRI prototype data → an extraordinary opportunity!
    - Simulations and theoretical studies → to become leaders in a few main CTA topics
- **MAGIC:** tighten the link ?