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cherenkov
telescope
array

Gamma Ray Astrophysics with CTA: Introduction

Stefano Vercellone (INAF – OA Brera)

stefano.vercellone@brera.inaf.it



Outline

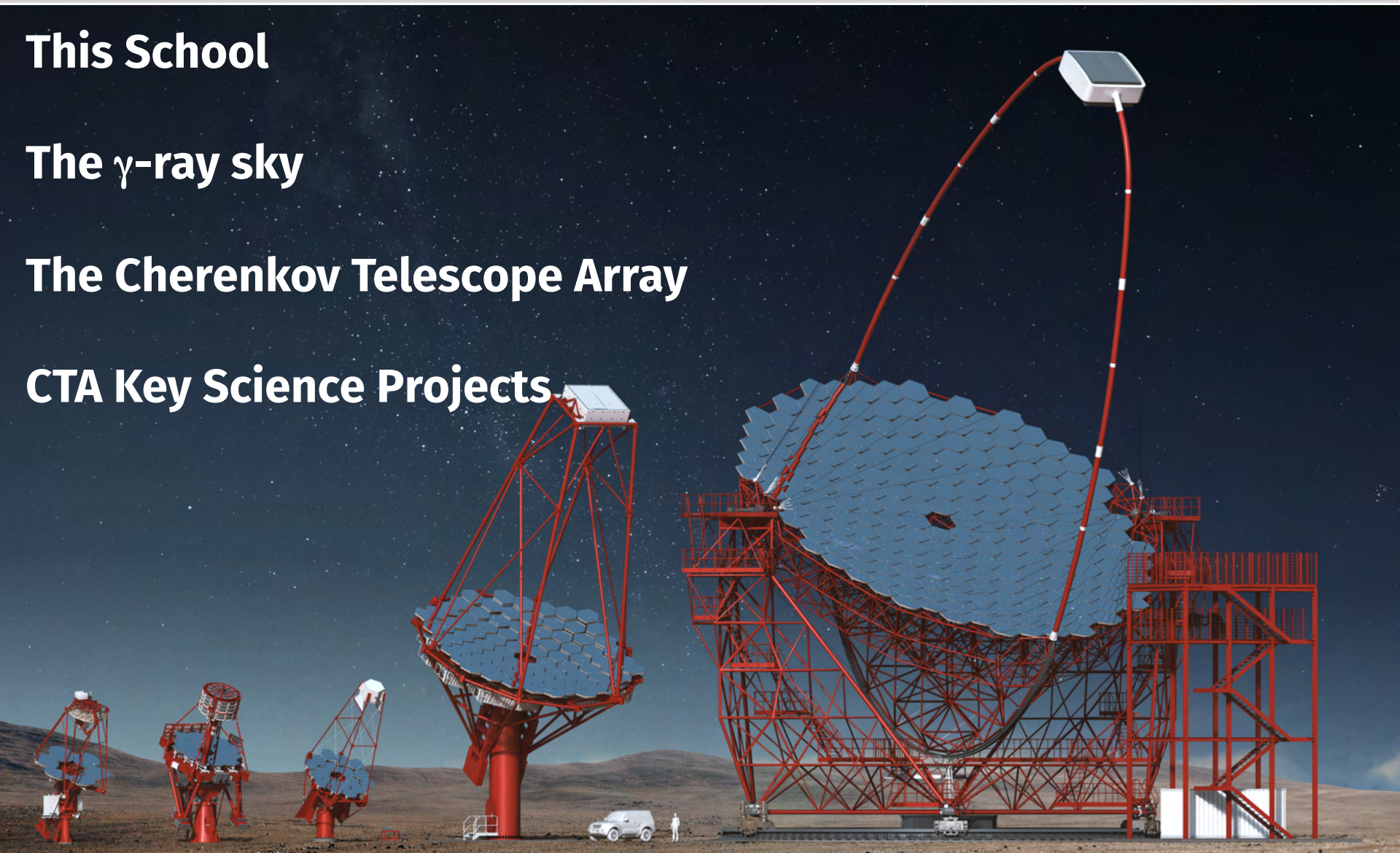


This School

The γ -ray sky

The Cherenkov Telescope Array

CTA Key Science Projects



Outline

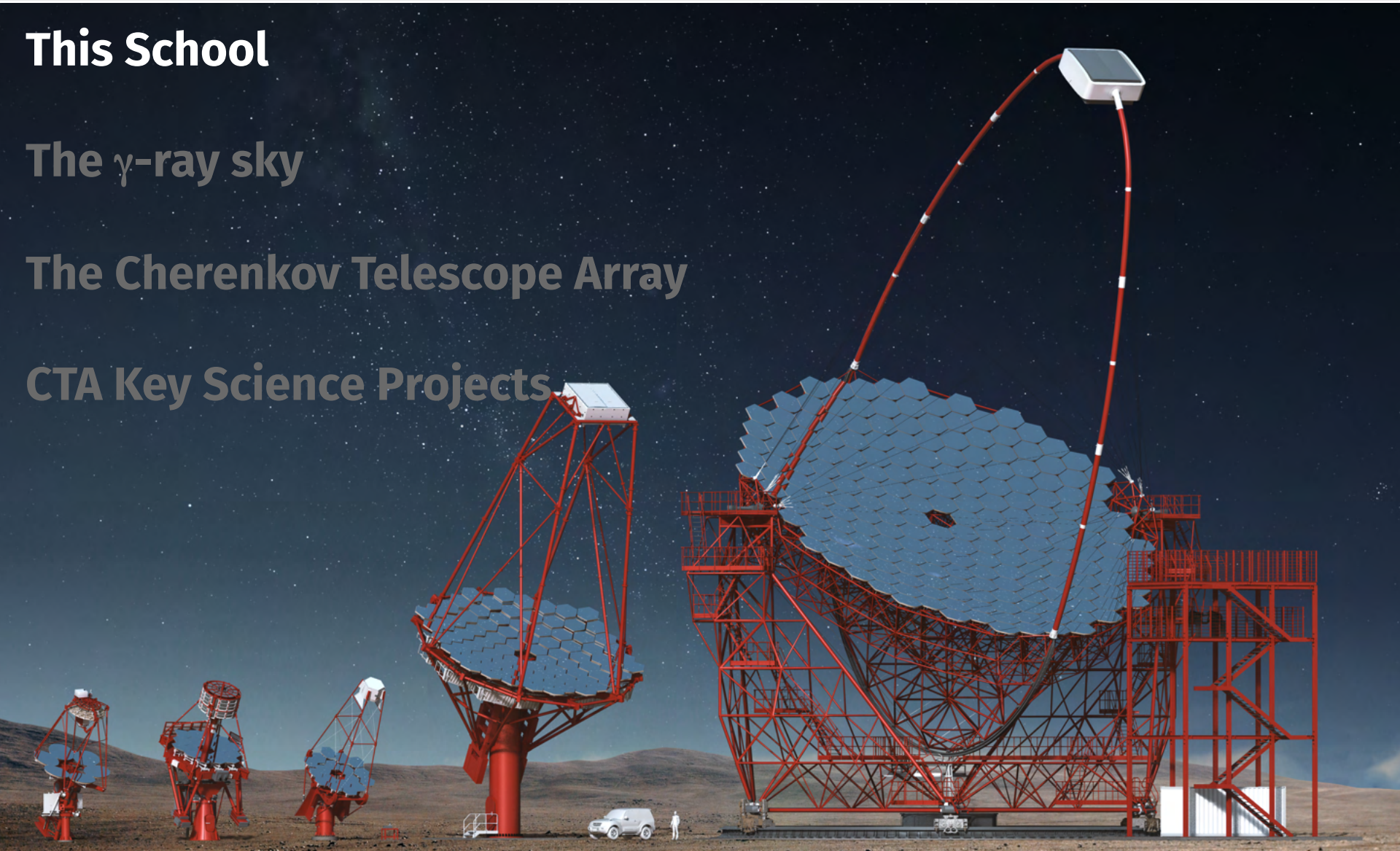


This School

The γ -ray sky

The Cherenkov Telescope Array

CTA Key Science Projects



The School format



- **Morning**

- Lectures on all the CTA scientific areas both in the galactic and in the extragalactic domains as well as in the fundamental physics one.
- A multi-wavelength and multi-messenger approach will also be discussed.
- A dedicated session will present also future gamma-ray missions concepts and their relation to CTA.



Details in the blue boxes

The School format



- **Lunch**

- Free! Enjoy the Dolomites which are a UNESCO World Heritage Site!

- **Afternoon**

- Hands-on activities
- Contributed talks
- Social activities



See talk by

F. Longo – *Hands-on session introduction*

Outline

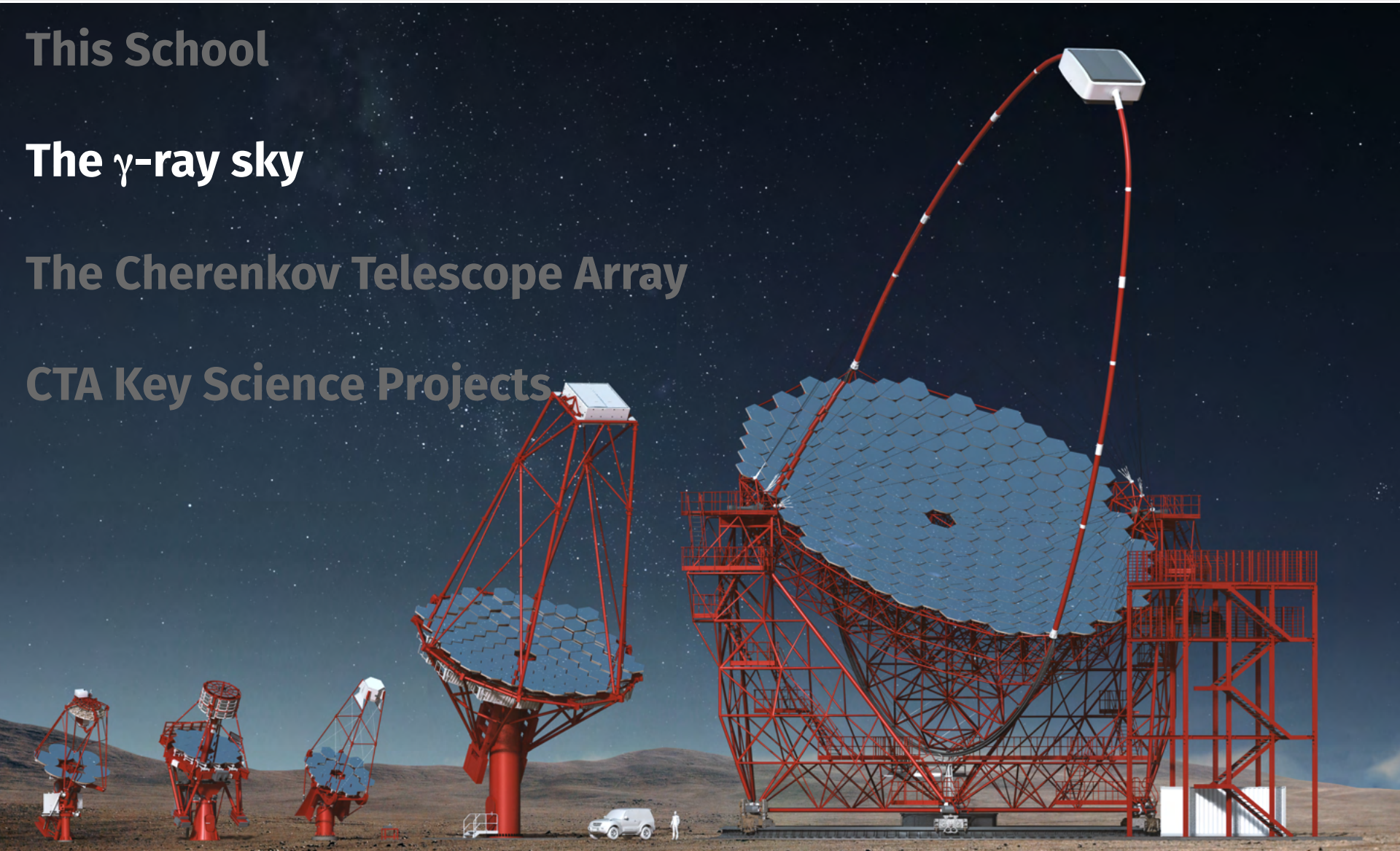


This School

The γ -ray sky

The Cherenkov Telescope Array

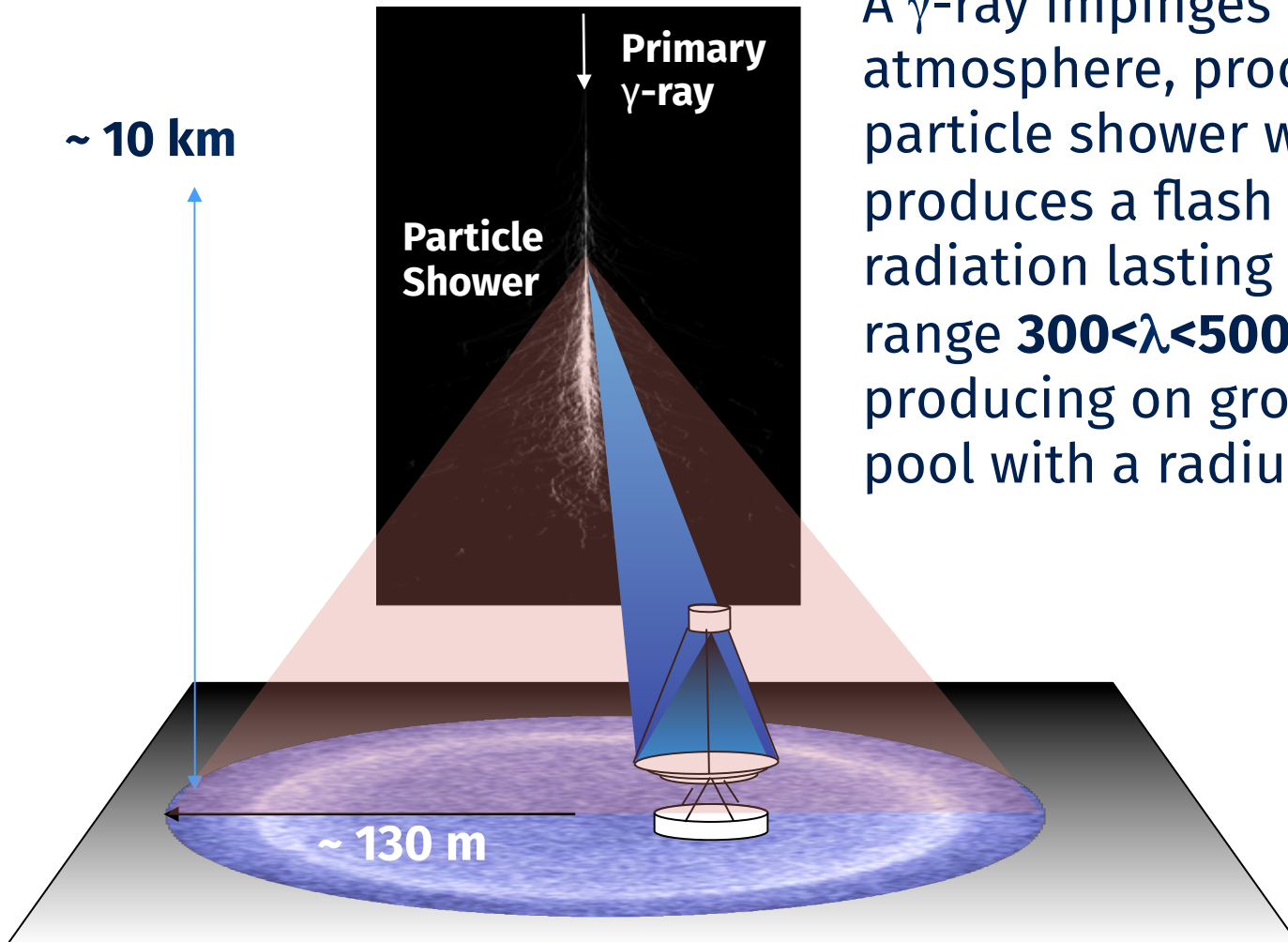
CTA Key Science Projects



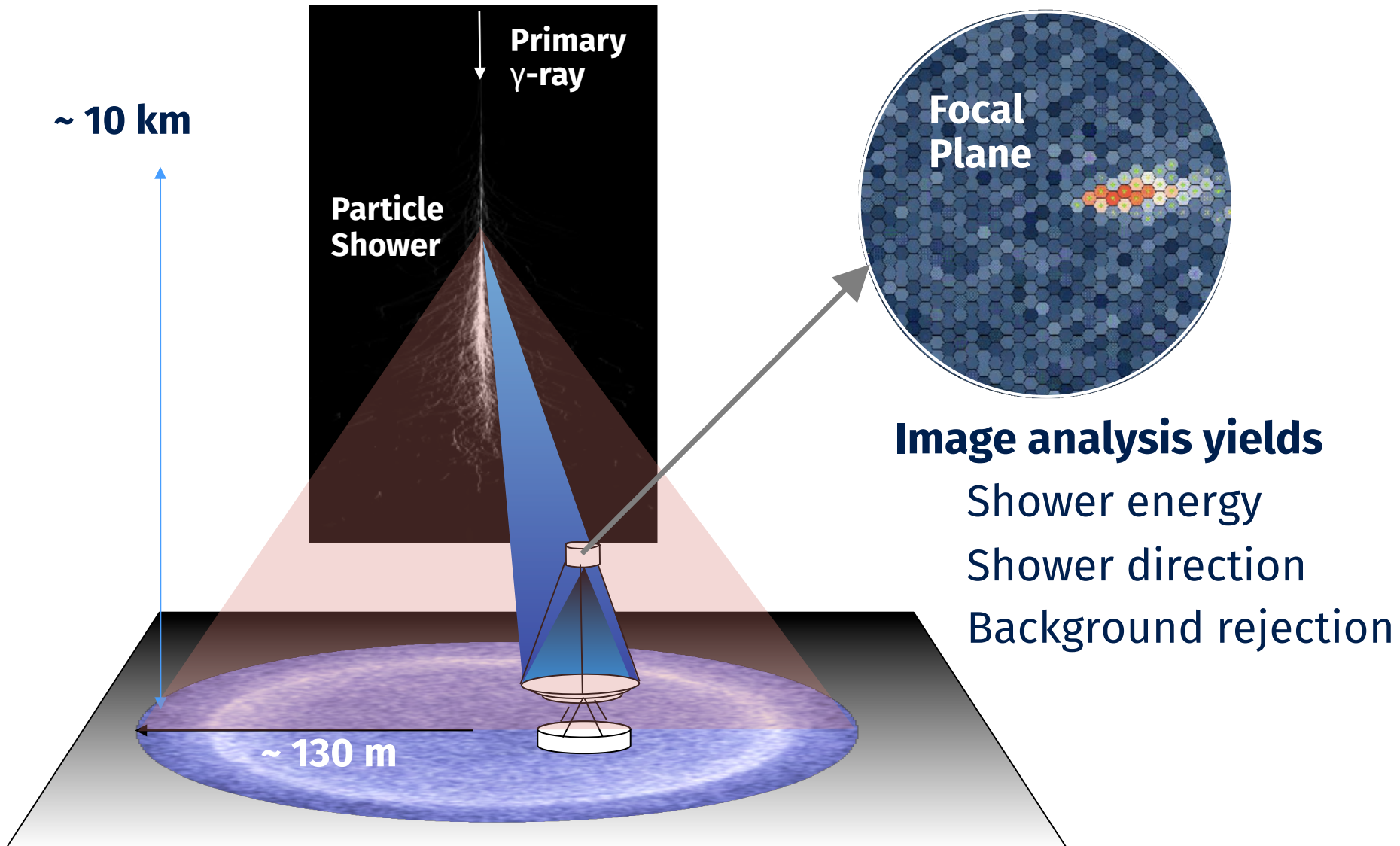
The Cherenkov Telescopes



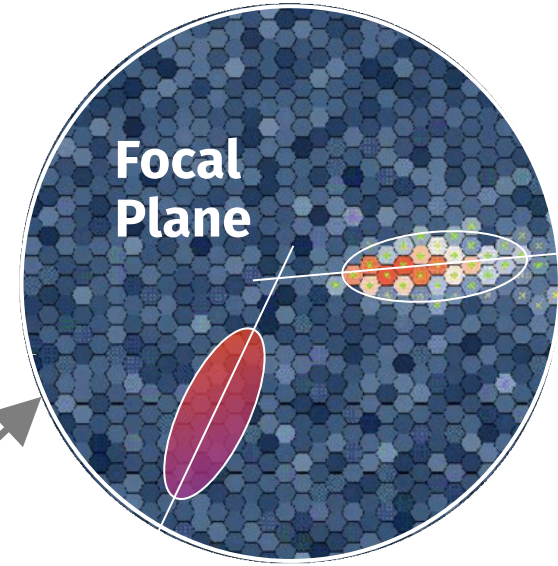
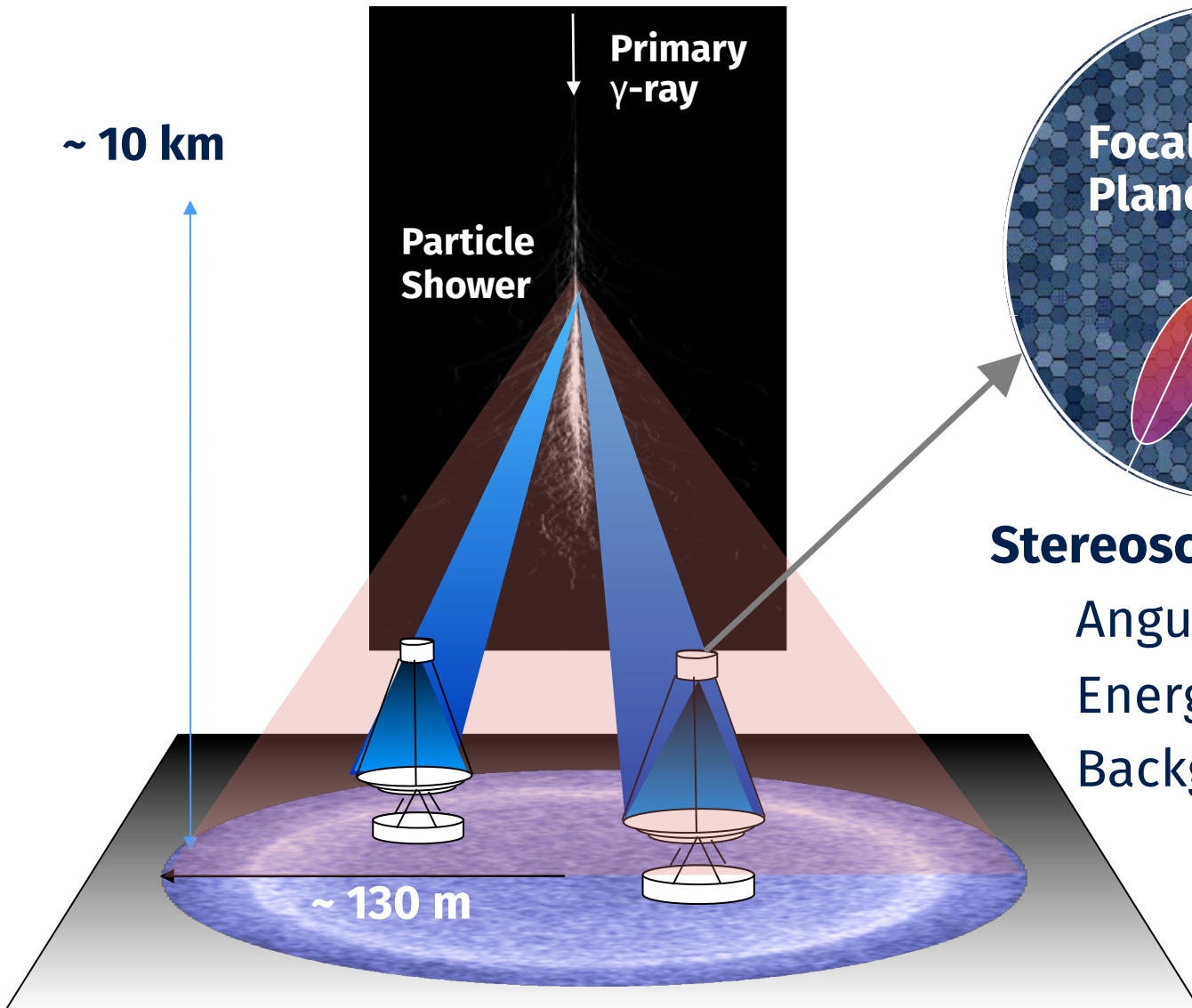
A γ -ray impinges the atmosphere, producing a particle shower which, in turns, produces a flash of Cherenkov radiation lasting **5-20 ns** in the range **$300 < \lambda < 500 \text{ nm}$** and producing on ground a light pool with a radius of **~130m**.



The Cherenkov Telescopes

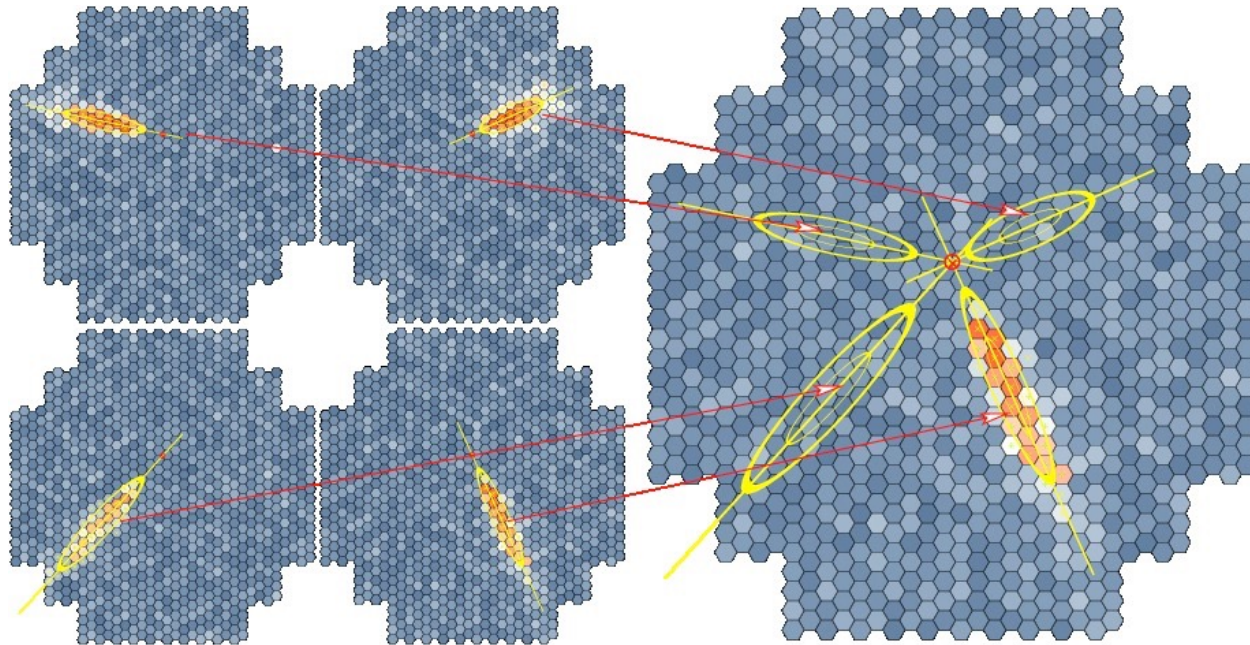


The Cherenkov Telescopes



Stereoscopic view improves
Angular resolution
Energy resolution
Background rejection

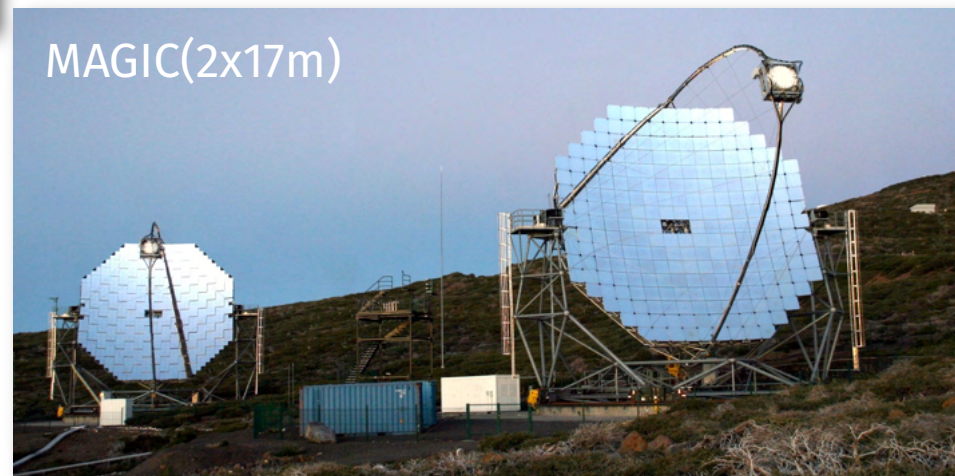
The Cherenkov Telescopes



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

**More on the Cherenkov technique, sources and physics in:
Hinton & Hofmann, 2009, ARAA, 47, 523**

The current IACT status



Telescopes not to scale

VHE high-level timeline



445

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

Hillas, 1985

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

ABSTRACT

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

1. Detection of point sources of cosmic rays

Certain X-ray binaries, pulsars and active galaxies appear to be gamma-ray sources - presumed to be gamma-ray sources have been detected by observing flashes of Cerenkov light in the upper atmosphere, but these do not stand against the intense isotropic background of ordinary proton showers. If the appearance of the Cerenkov flashes differs from that of showers, such of the background might be rejected. paper, Cawley et al. (1) describe the modification of the Whipple Observatory (Mt. Hopkins, Arizona) to record data Cerenkov image on a 0.5° grid, using 37 photomultipliers in the plane of the focusing mirror. (A central photomultiplier is a ring of 6 others, then by a further ring of 12, and another whole forming a hexagonal grid pattern.) Predictions of the this system to air showers will be presented. Even though the width of shower images are less than 0.5° , the image diameter measured well enough to provide discrimination between types though the alignment of the short image with the source will clear than with finer angular resolution.

2. Simulation of Cerenkov image patterns

A 3-dimensional Monte-Carlo calculation is used to simulate development. The computer program has been used previously investigations (2) and is much more detailed than is necessary ting Cerenkov processes, following particles down to an energy (far below the Cerenkov threshold), although "thin sampling" to follow particles below $1/4000$ of the primary energy to resolution. The model atmosphere is not isothermal. Hadronic collisions are simulated both by a radial scaling model with rising cross-section and by a model with increased production of low-energy secondary particles to scaling) at high primary energies (though a case drawn from proposed by Młoczyński and Wolfendale, for example, as the particles in the fragmentation region - high x - are larger, however, at TeV energies, there is little difference between models constrained by accelerator data, so the simulation results are put together in the presentations below.

though some loss of Cerenkov light by Rayleigh and a tail of light allowed for (2), scattered light is assumed not to be spread of the image (size $< 1^\circ$) in a clear mountain atmosphere.

provided by the NASA Astronaut

The basics

00 9.5-3

The Astrophysical Journal, 342:379-385, 1989 July 1
© 1989 The American Astronomical Society. All rights reserved. Printed in the U.S.A.

Weeks et al., 1989

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

T. C. WEEKS¹, M. F. CAWLEY¹, D. J. FRIDAY¹, K. G. GIBBS¹, A. M. HILLAS¹, P. W. KWON², R. C. LAAR², D. A. LEWIS², D. MACOMBS², N. A. PORTER¹, P. J. RAYMOND^{1,2}, AND G. VAUGHAN²

Received 1989 August 7; accepted 1989 December 9

ABSTRACT

The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detection is reported at the 9.0σ level, corresponding to a flux of 1.8×10^{-11} photons $\text{cm}^{-2} \text{s}^{-1}$ above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0551. There is no evidence for variability on time scales from months to years. Although continuous emission from the pulsar cannot be ruled out, it seems most likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula. Subject headings: gamma rays: general — nebulae: Crab Nebula — pulsars — radiation mechanisms

1. INTRODUCTION

The observation of polarization in the radio, optical, and X-ray emission from the Crab Nebula is usually taken as confirmation of the synchrotron origin of the radiation and is a strong indication of the presence in the nebula of a reservoir of relativistic electrons with energies up to 1 TeV. The presence of the radio pulsar, PSR 0551, near the center of the nebula provides a source for the on-going injection of relativistic electrons into this reservoir. The collision of the synchrotron-radiating electrons with synchrotron-radiated photons within the nebula inevitably results in a hard photon spectrum (at some level) that extends from the X-ray into the gamma-ray energy range; the shape of the spectrum mirrors that of the soft photon spectrum but with greatly reduced intensity. The Compton synchrotron model of the nebula was first developed by Gould (1965) and was refined by Butler and Weekes (1969) and by Grindlay and Hoffmann (1971). A strong flux of gamma rays was predicted with maximum luminosity in the 0.1–1.0 TeV energy range. The gamma-ray flux level depends on the strength of the nebular magnetic field, which is a free parameter in the model and is little constrained by observations at other wavelengths. However, based on equipartition arguments, it is estimated to be $\sim 10^{-5}$ G.

The observation of a flux of 0.14 TeV gamma rays from the Crab Nebula was reported by the Wisconsin group using the atmospheric Cerenkov technique (Weekes et al. 1972), based on observations that spanned 3 years. A detection was still only at the 3σ level. This demonstrates the extreme weakness of the source and the lack of sensitivity of the technique. The detection of TeV gamma rays from the Crab Nebula is a confirmation of the Compton synchrotron model (Gould et al. 1972), based on measurements of the magnetic field. This measurement, which was conservatively interpreted as an upper limit, implies an average magnetic field of 3×10^{-6} G, or a radially symmetric (1.0) field with $B_p = 1 \times 10^{-7}$ G at a distance of 0.1 pc from the pulsar (Grindlay 1978).

¹ Harvard-Smithsonian Center for Astrophysics,
St. Francis College, Massachusetts,
² University College, Dublin,
³ University of Leeds,
⁴ Iowa State University.

1 source

>150 sources

Hinton & Hoffmann, 2009

Teraelectronvolt Astronomy

J.A. Hinton¹ and W. Hofmann²

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Heidelberg D-69189, Germany; email: werner.hofmann@mpi-kernphysik.de

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0068-4146/09/070523-02\$12.00

Key Words

gamma-ray astronomy, high-energy astrophysics

Abstract

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

HE & VHE view and future perspectives



See talks by

P. Caraveo – *High-energy γ -ray astrophysics*

G. Ambrosi – *Future c-rays experiments in the CTA era*

M. Tavani – *Future γ -ray experiments in the CTA era*

S. Funk – *VHE science after 10 years of CTA*

100 GeV – 50 TeV sky

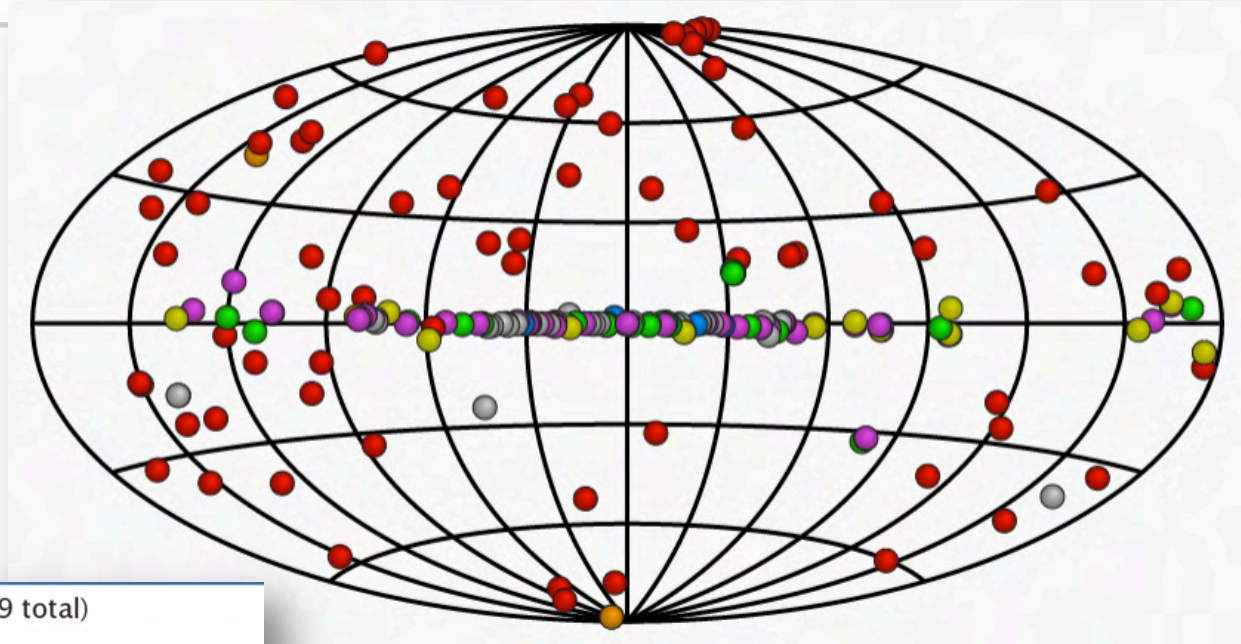


TeVCat 2

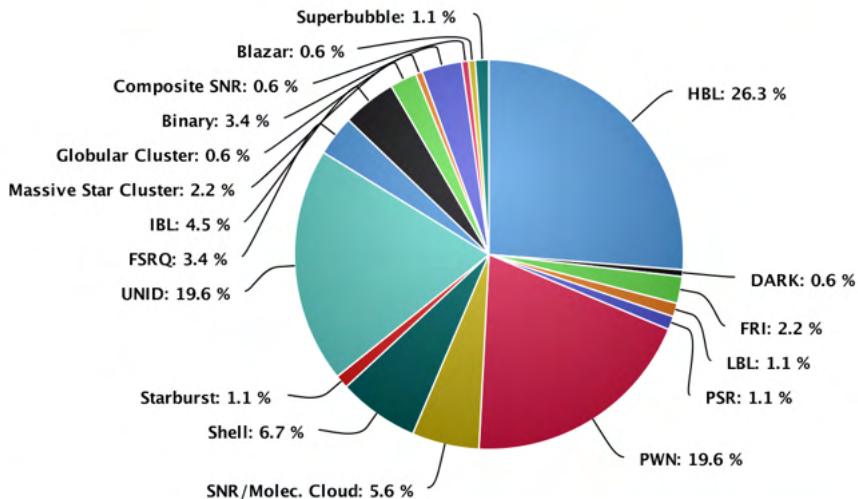
H.E.S.S., MAGIC, VERITAS

~180 sources

E>100 GeV

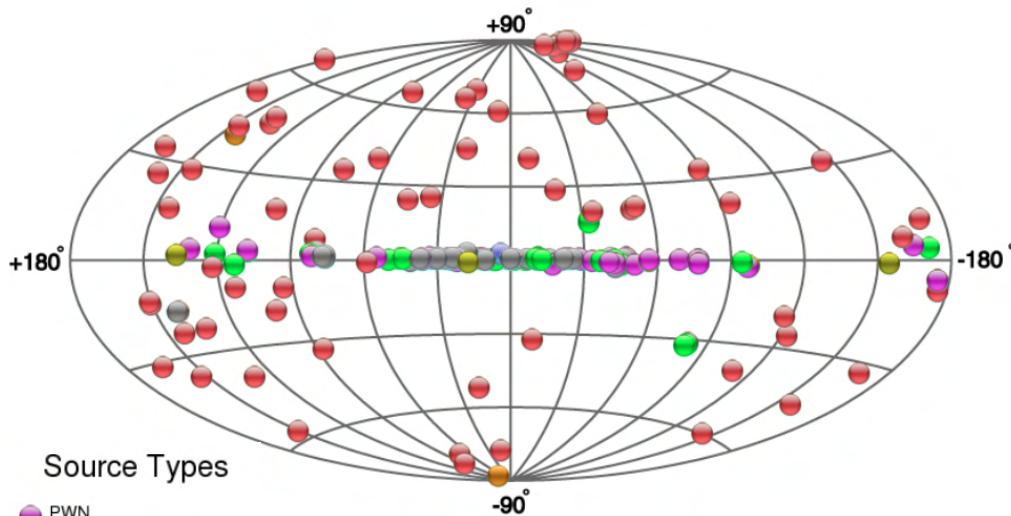


TeVCat Source Types (179 total)



Wakely & Horan+16

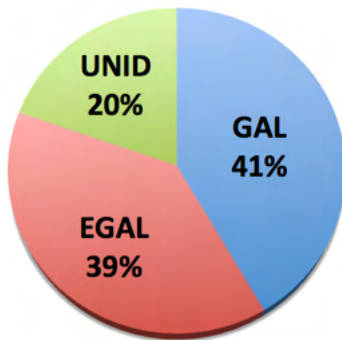
The Fermi sky above 50 GeV



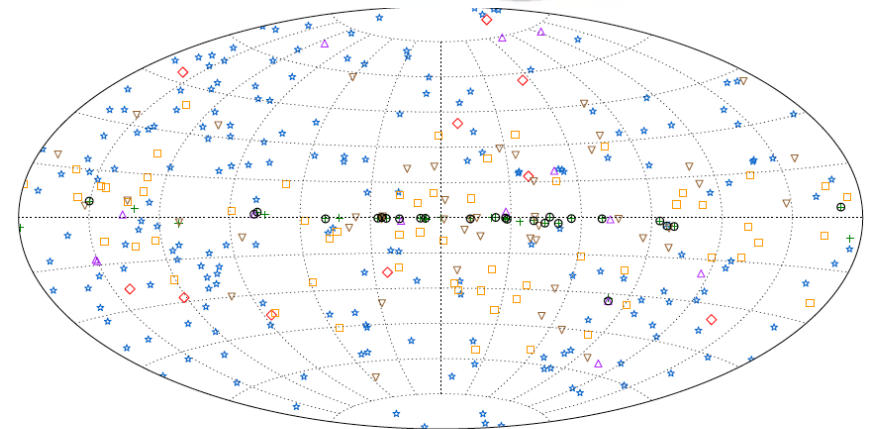
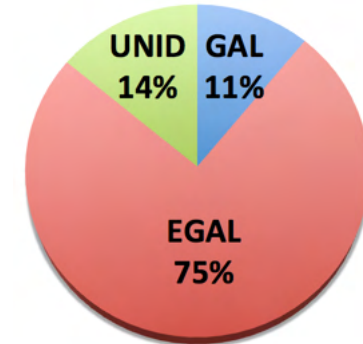
- Source Types**
- PWN
 - Binary XRB PSR Gamma BIN
 - HBL IBL FRI FSRQ Blazar LBL AGN (unknown type)
 - Shell SNR/Molec. Cloud Composite SNR Superbubble
 - Starburst
 - DARK UNID Other
 - uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR

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

~180 TeVcat sources



360 Fermi-LAT sources E>50 GeV



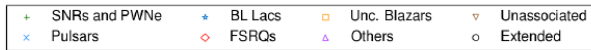
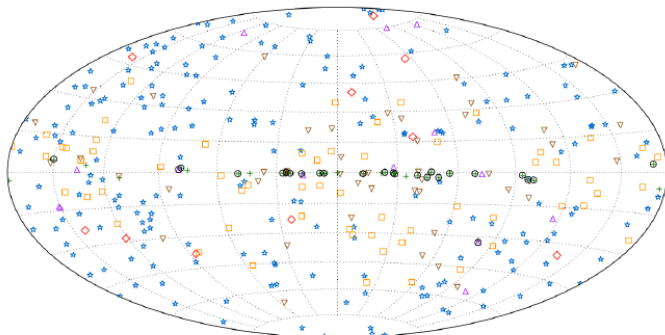
- | | | | | | | | |
|---|---------------|---|---------|---|--------------|---|--------------|
| + | SNRs and PWNe | * | BL Lacs | □ | Unc. Blazars | ▽ | Unassociated |
| × | Pulsars | ◇ | FSRQs | △ | Others | ○ | Extended |

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.**

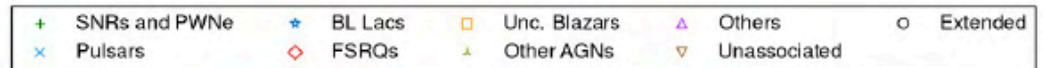
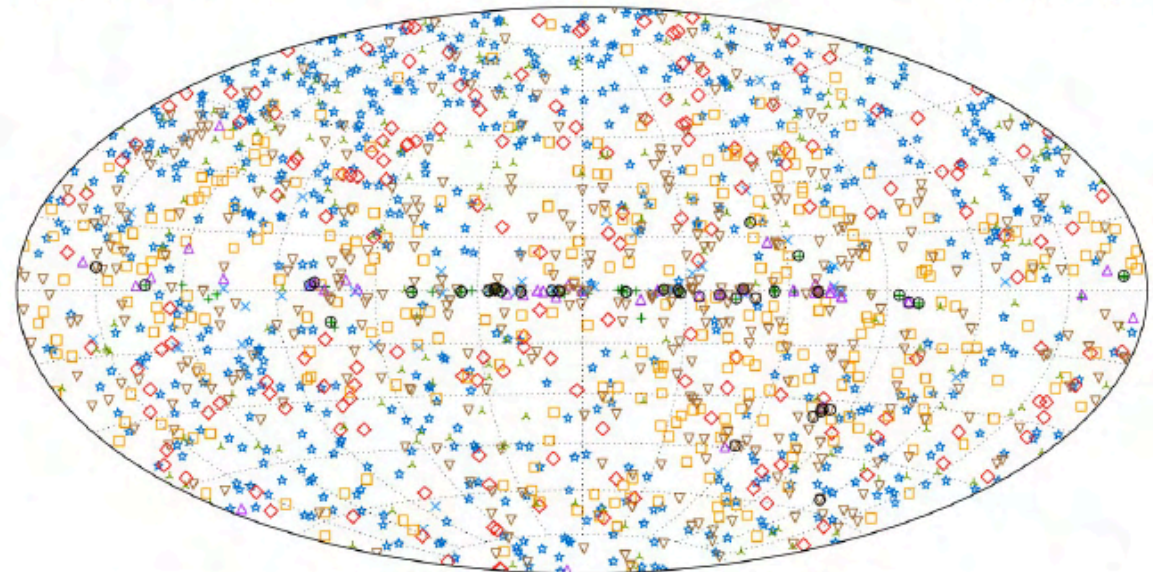
Beyond 2FHL → 3FHL

2FHL, E>50 GeV

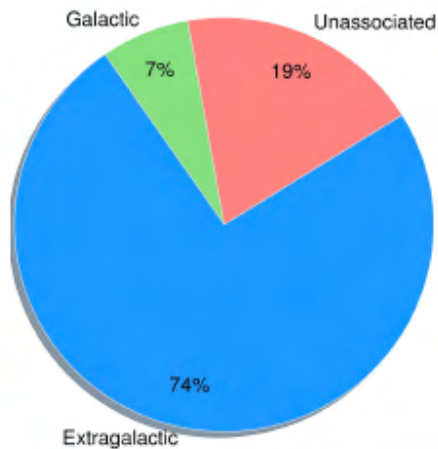


3FHL, E>10 GeV

Preliminary



3FHL, arXiv:1702.00664



10 GeV – 2 TeV

7 years of data

1556 sources

214 brand new (not in 1FHL/2FHL/3FGL)

0.1 – 100 TeV sky

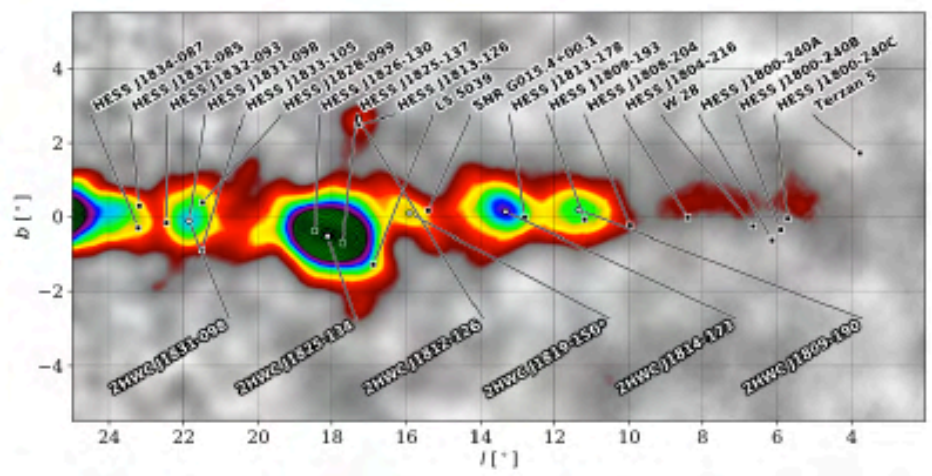
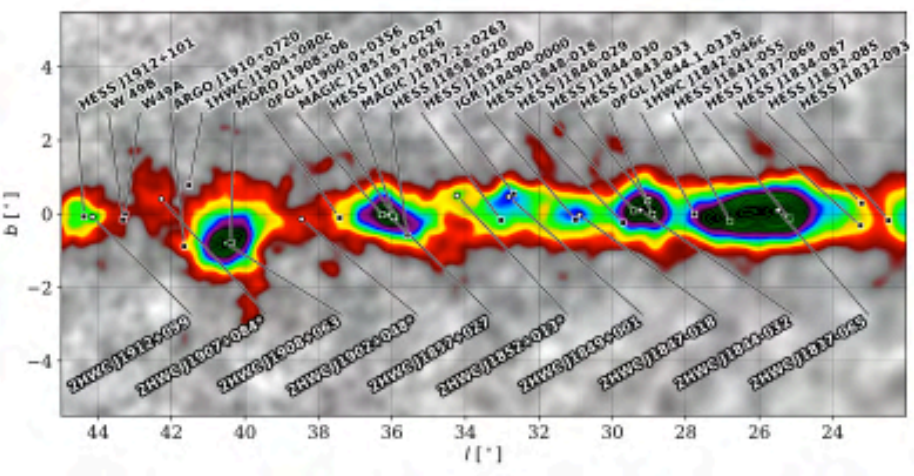
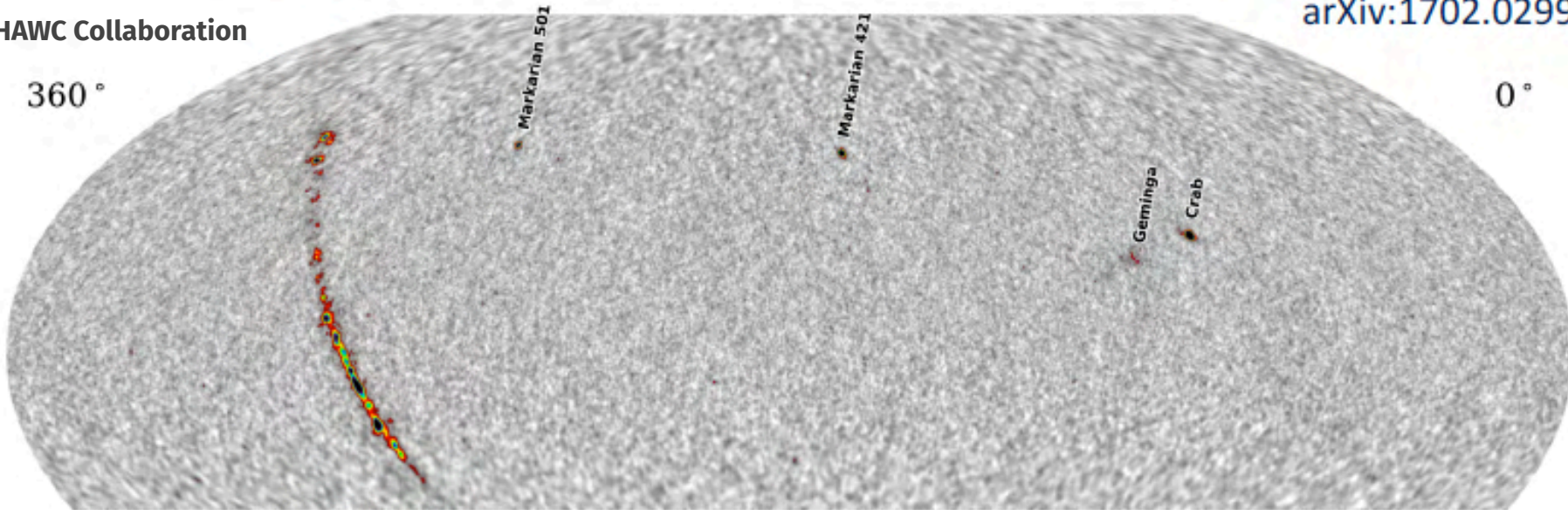


HAWC Collaboration

arXiv:1702.02992

360°

0°



See talks by

G. Barbiellini – *10 years of AGILE*

L. Latronico – *The HE view of the γ -ray sky with Fermi*

S. Casanova – *Recent results from HAWC*

Outline

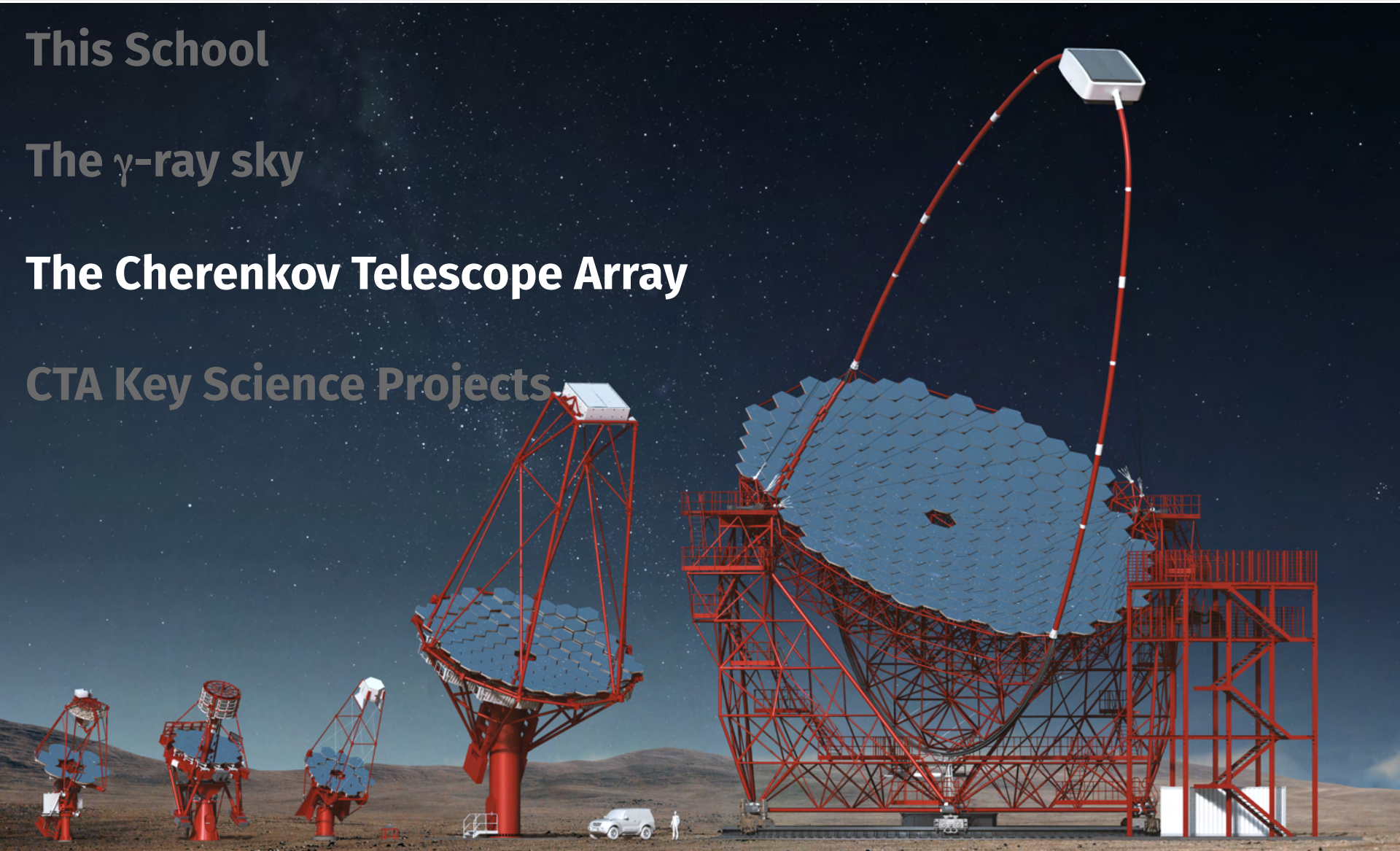


This School

The γ -ray sky

The Cherenkov Telescope Array

CTA Key Science Projects



How to improve w.r.t. current IACTs ?



How to improve w.r.t. current IACTs ?

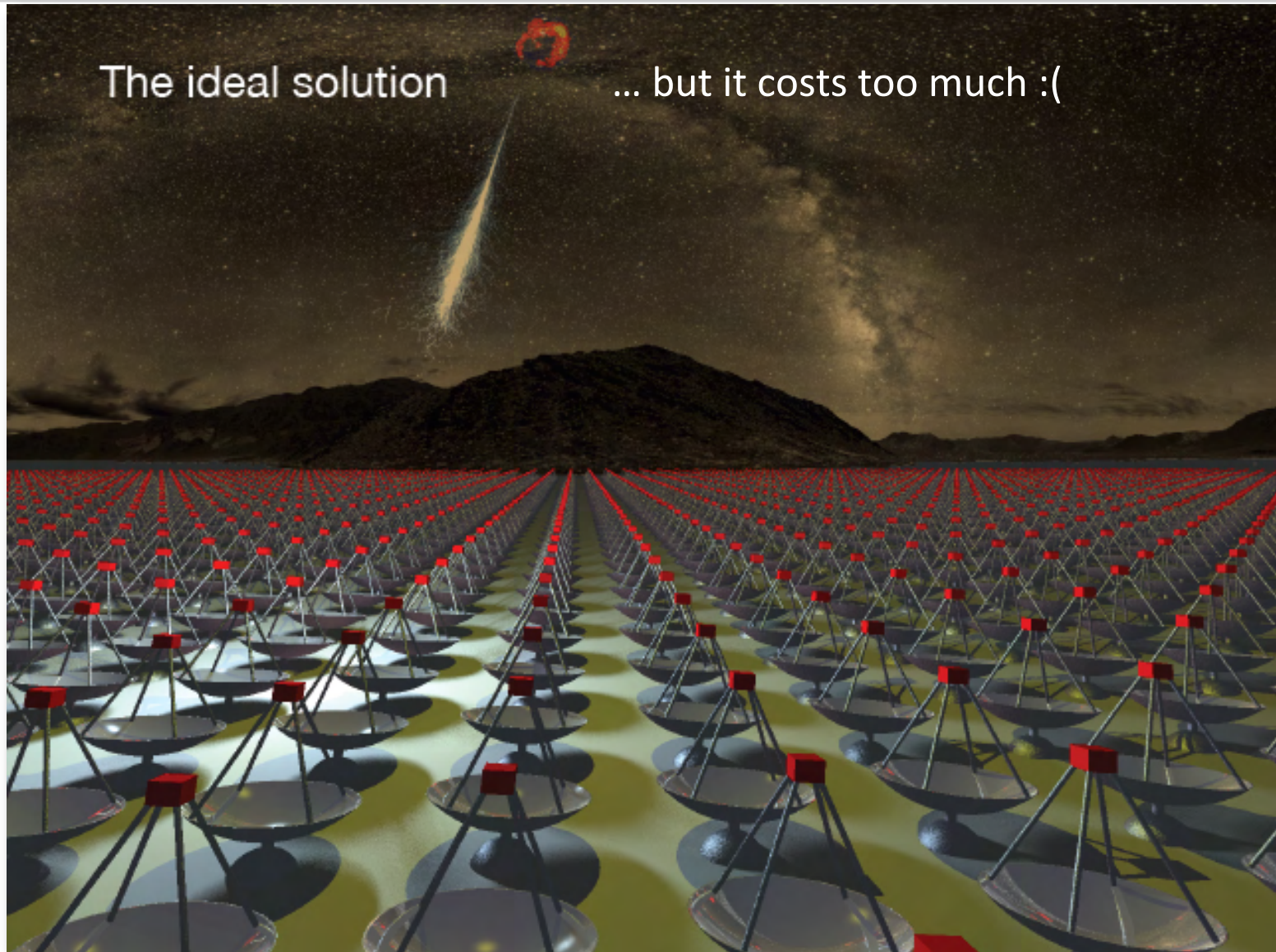


A long time ago in a galaxy far,
far away....

How to improve w.r.t. current IACTs ?



How to improve w.r.t. current IACTs ?



The ideal solution

... but it costs too much :(

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

Operated as an open Observatory

A factor of 5-10 more sensitive w.r.t. the current IACTs

The Cherenkov Telescope Array

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

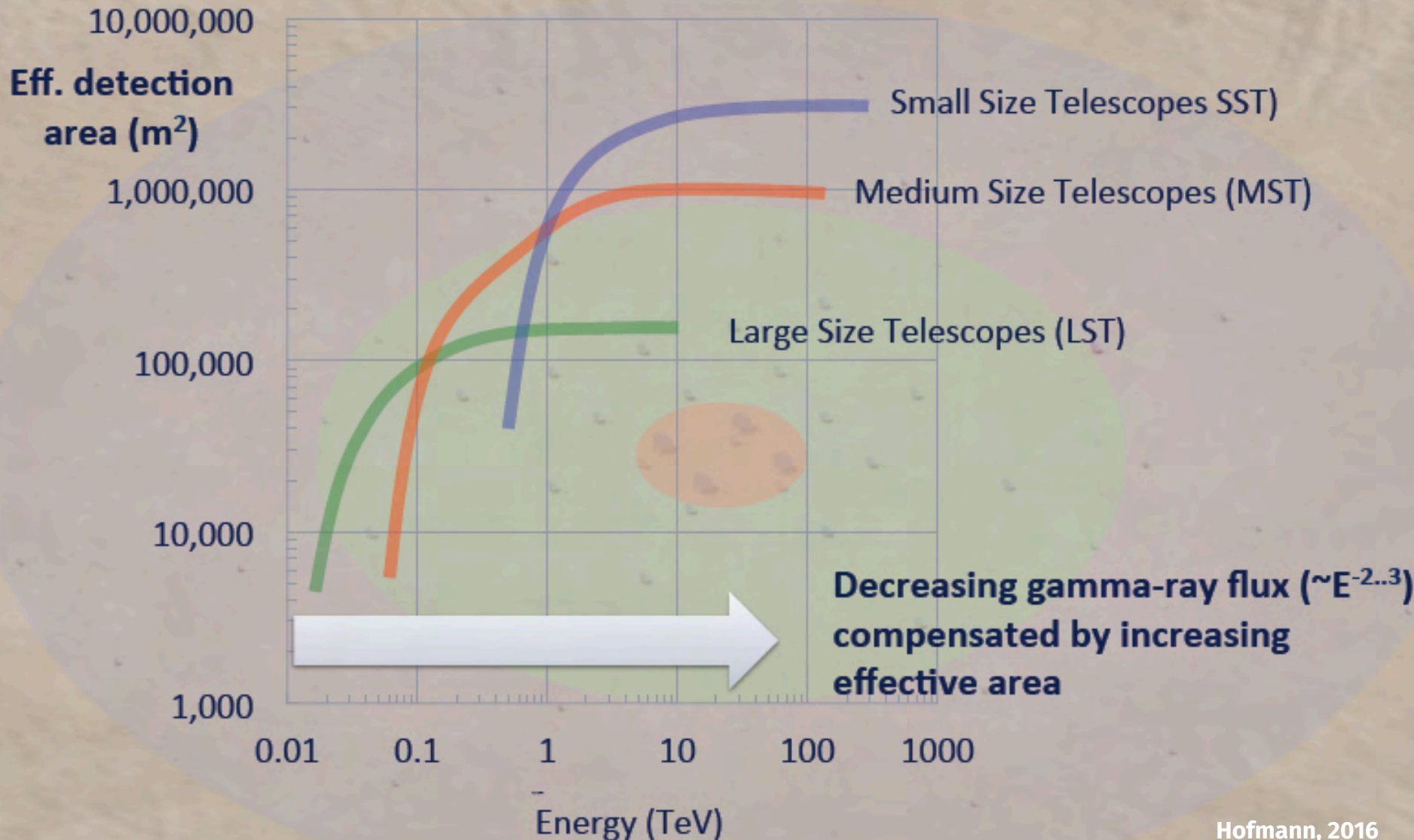
~4km² array of small size telescopes, sensitive above a few TeV up to 300 TeV

4 LSTs [N & S]

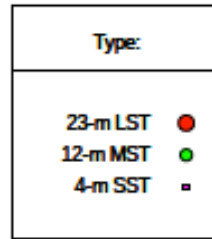
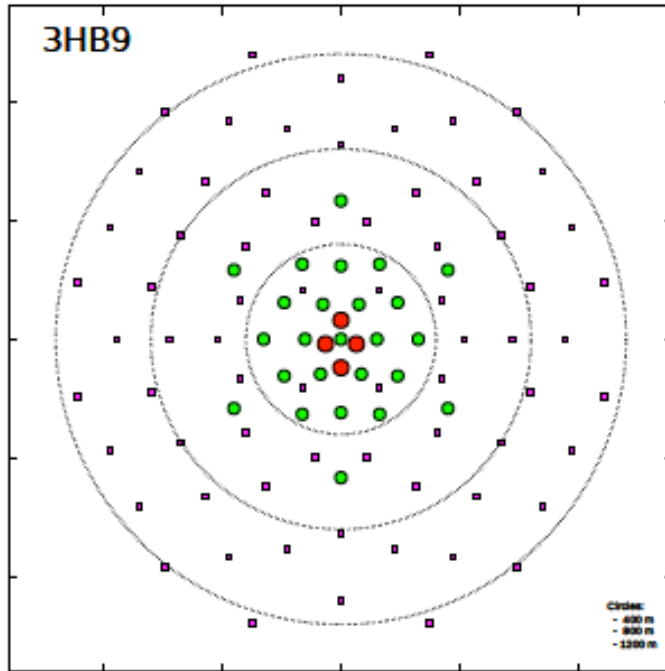
15 MSTs [N]
25 MSTs [S]
(24 SCTs [S])

70 SSTs [S]

Effective area for gamma-ray detection



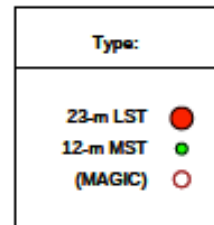
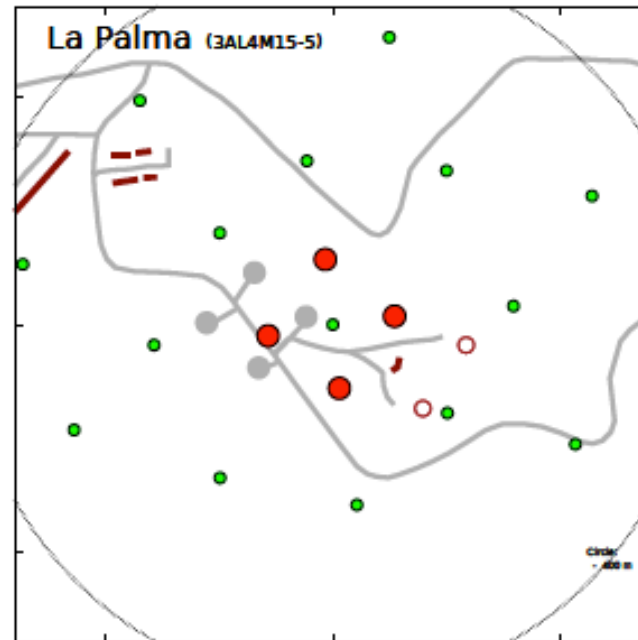
CTA Telescope layout



North:
4 LST
15 MST

4 LSTs, 25 MSTs, 70 SSTs

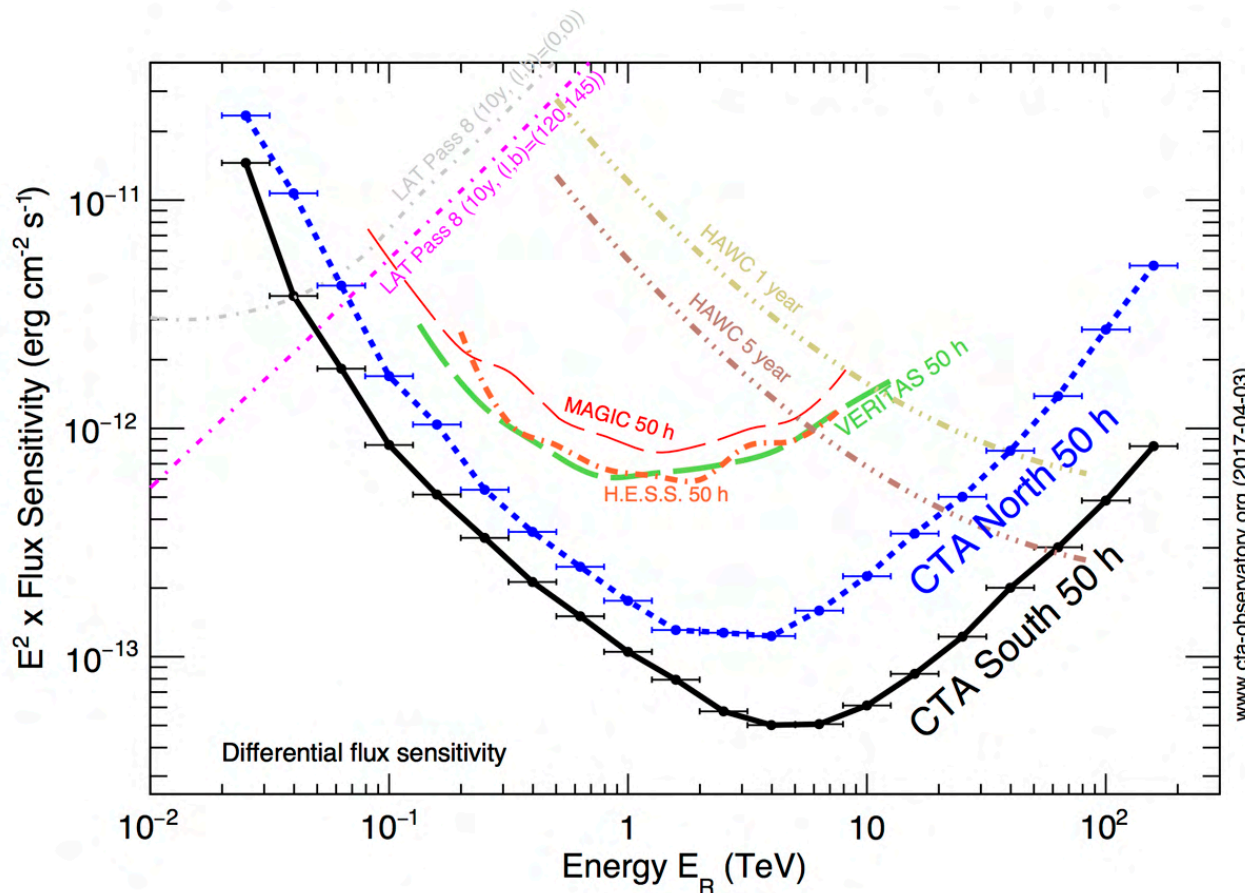
South:
4 LST
25 MST
70 SST



North (x) is up
West (y) is left

4 LSTs, 15 MSTs

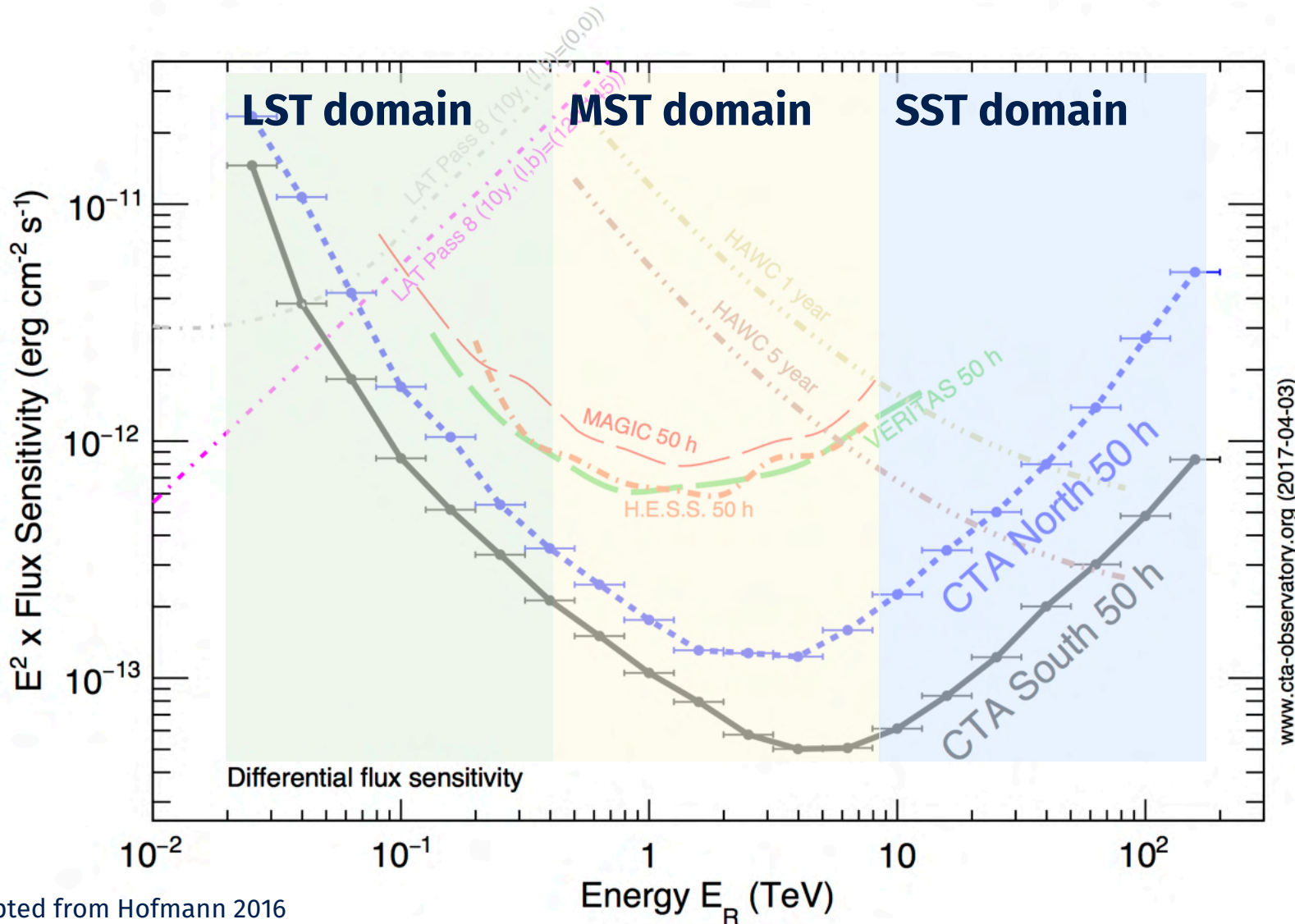
Differential Sensitivity



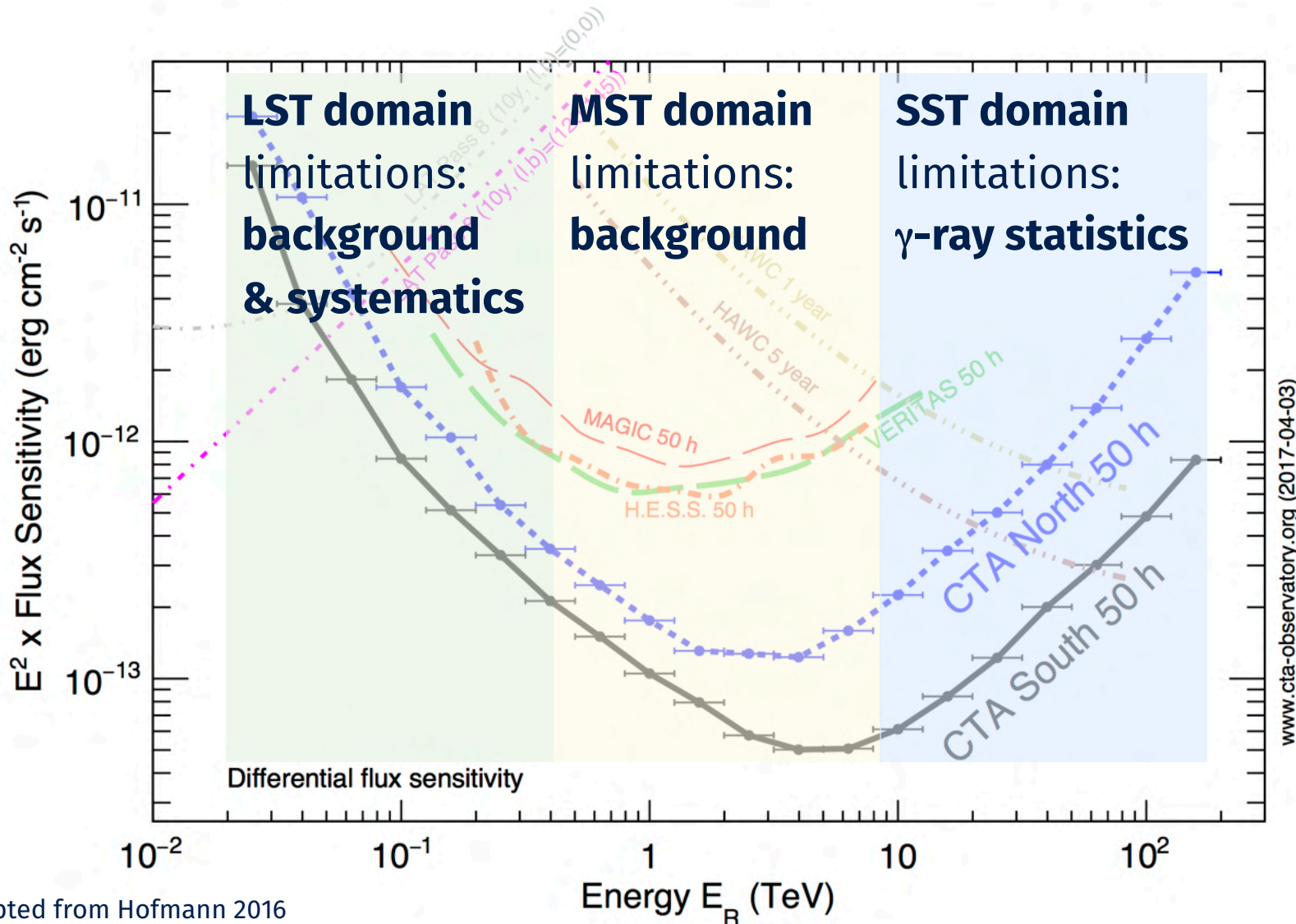
A factor of **5-10 improvement** in sensitivity in the domain of **about 100 GeV to some 10 TeV.**

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

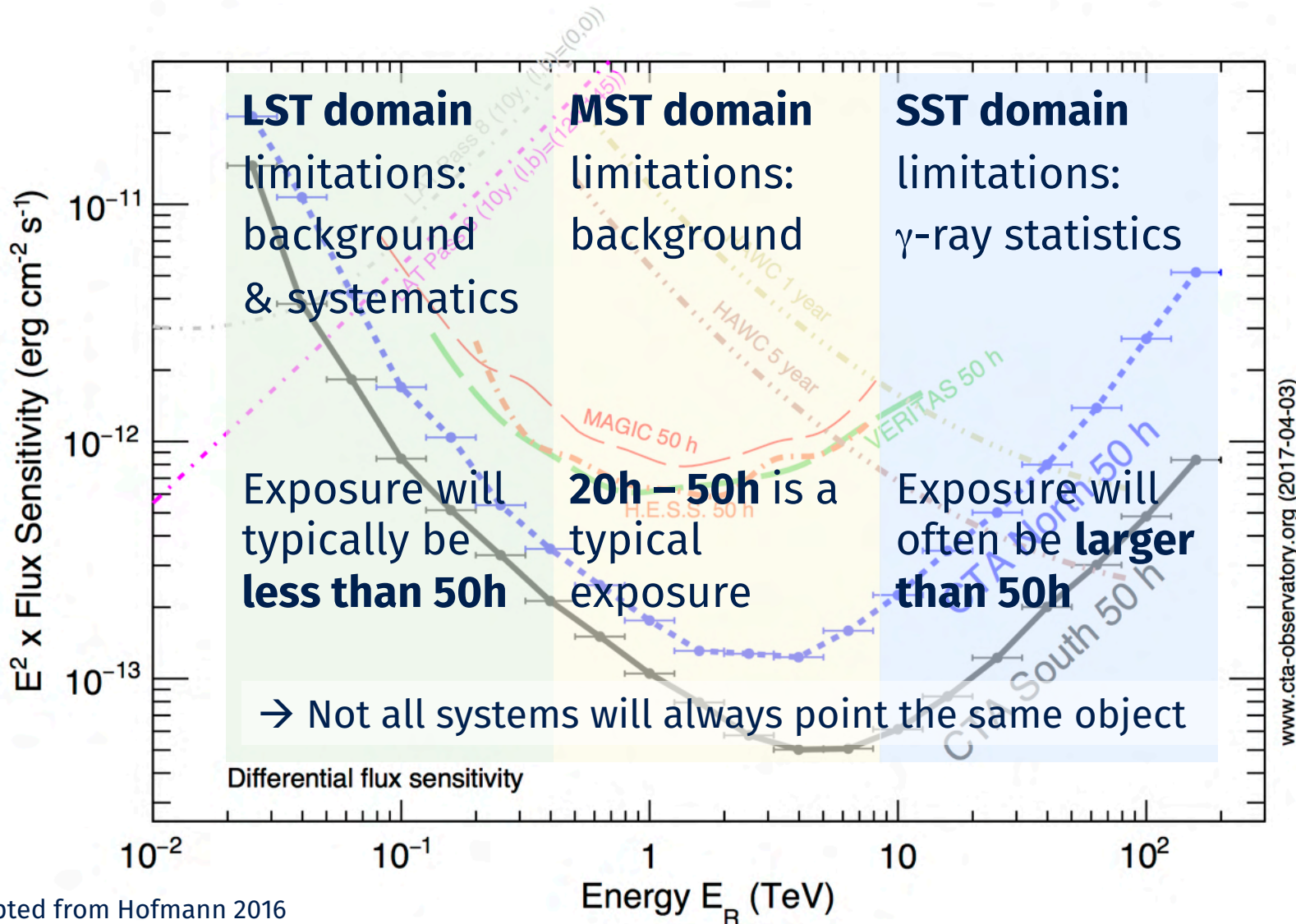
CTA Performance



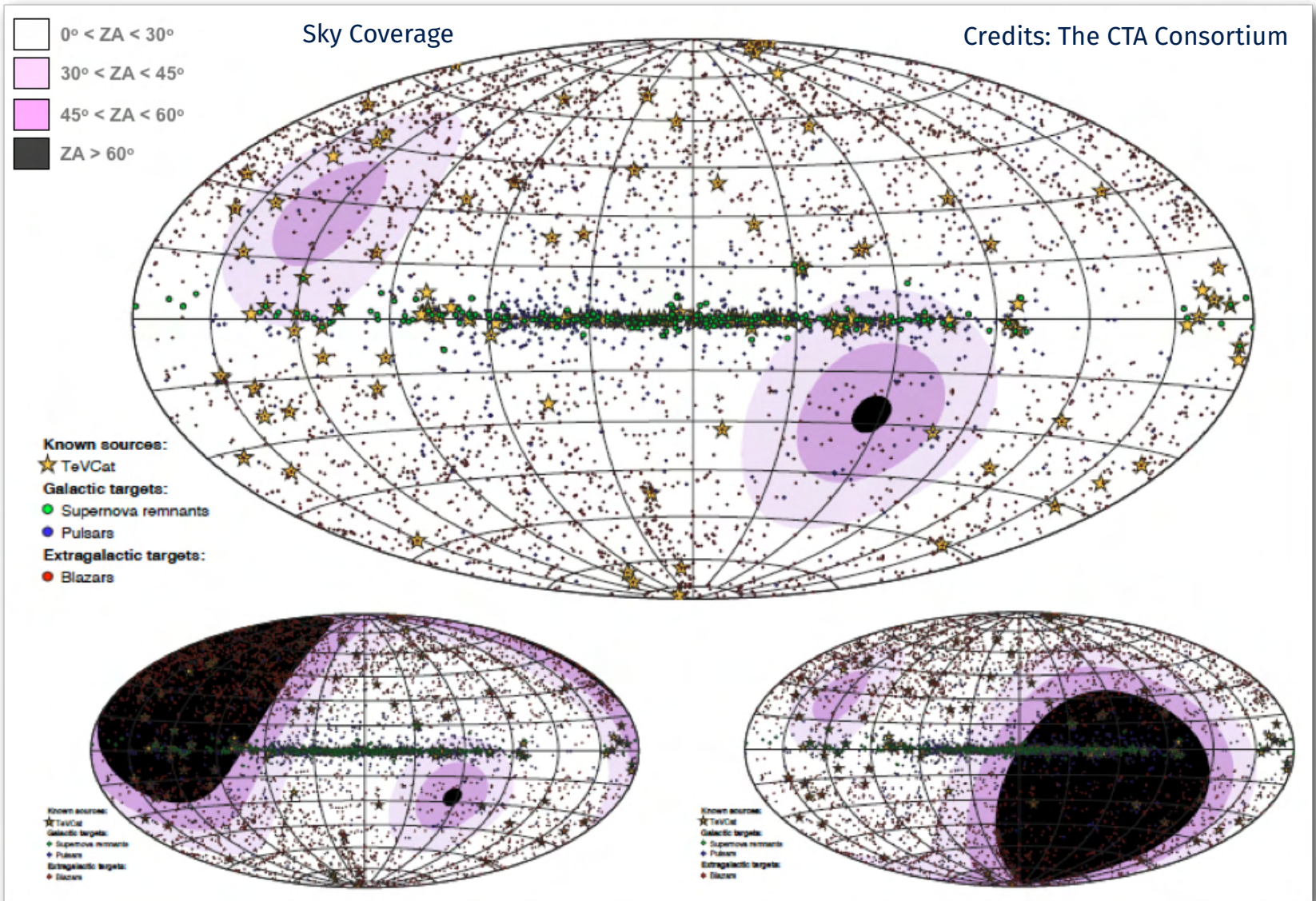
CTA Performance



CTA Performance



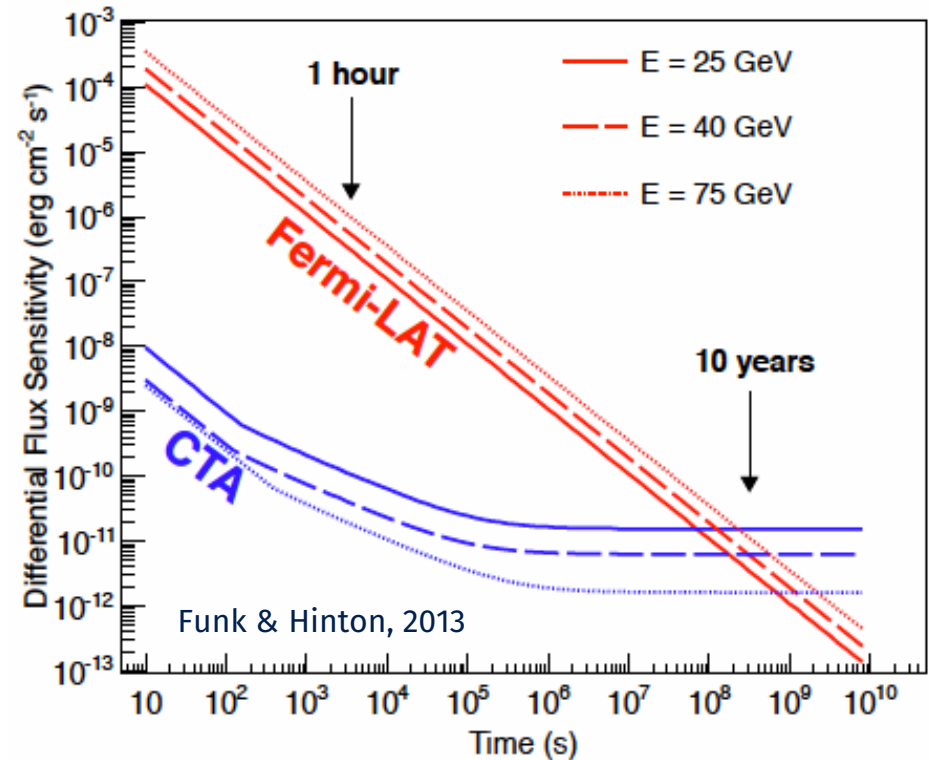
CTA as an *all-sky* Observatory



CTA as a *transient factory*



- **Huge advantage over Fermi** in energy range of overlap for ~minute to ~week timescale phenomena
 - Explosive transients
 - AGN flares
 - Binary systems
- **Disadvantage over Fermi**
 - Limited FoV (compared to Fermi)
 - Prompt reaction to external trigger is critical



See talks by

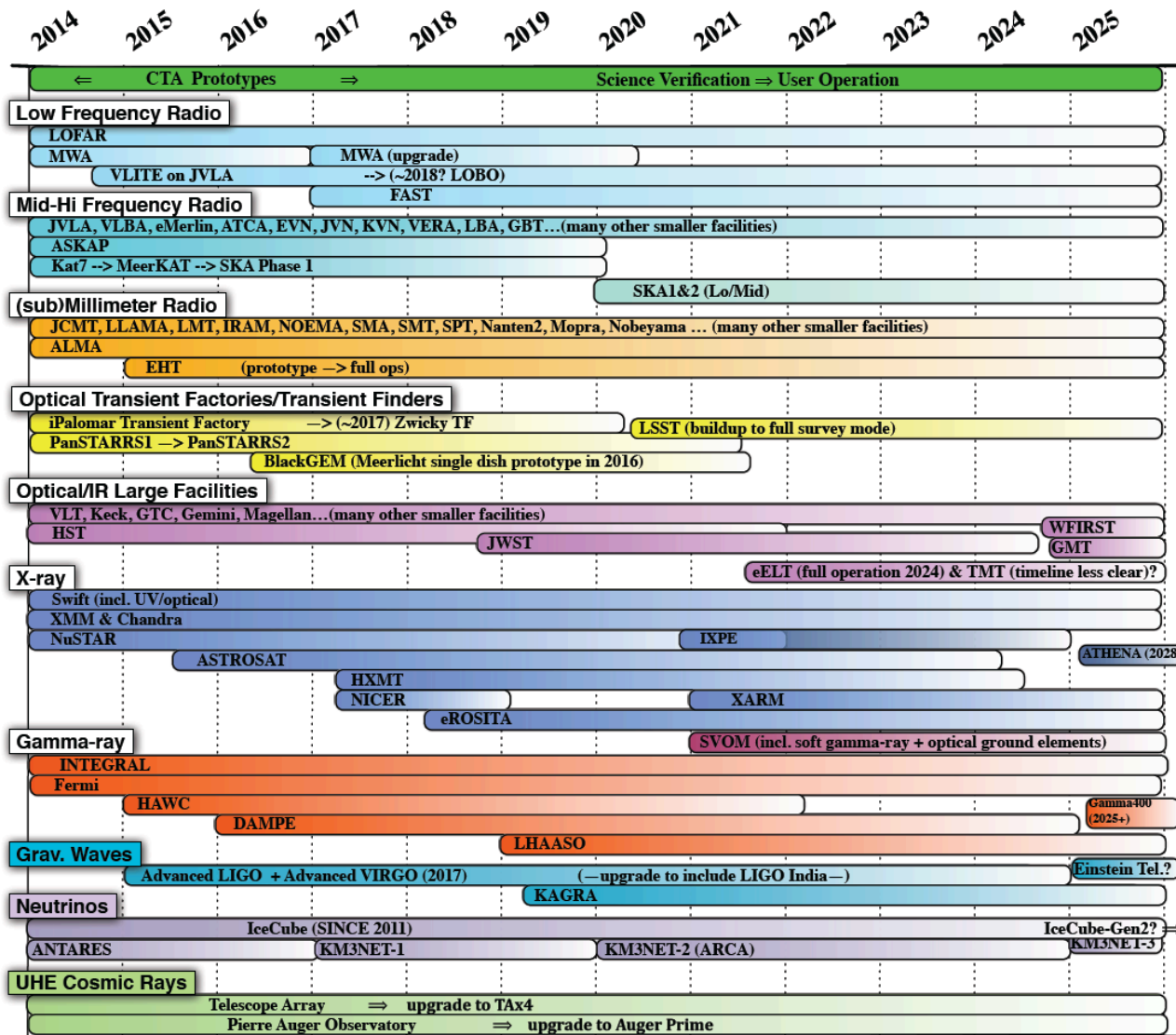
M. Martinez – *Overview of the CTA*

M. Teshima – *LST status*

S. Schlenstedt – *MST status*

G. Pareschi – *SST status*

Synergies during CTA operation



See talks by

F. De Palma – *The Galaxy as seen by Fermi*

G. Tagliaferri – *X-ray astrophysics and CTA*

F. D'Ammando – *Optical observations and CTA*

M. Giroletti – *CTA and SKA synergies*

K. Satalecka – *Neutrinos counterparts at VHE*

B. Bertucci – *Cosmic-ray studies in the CTA era*

Outline

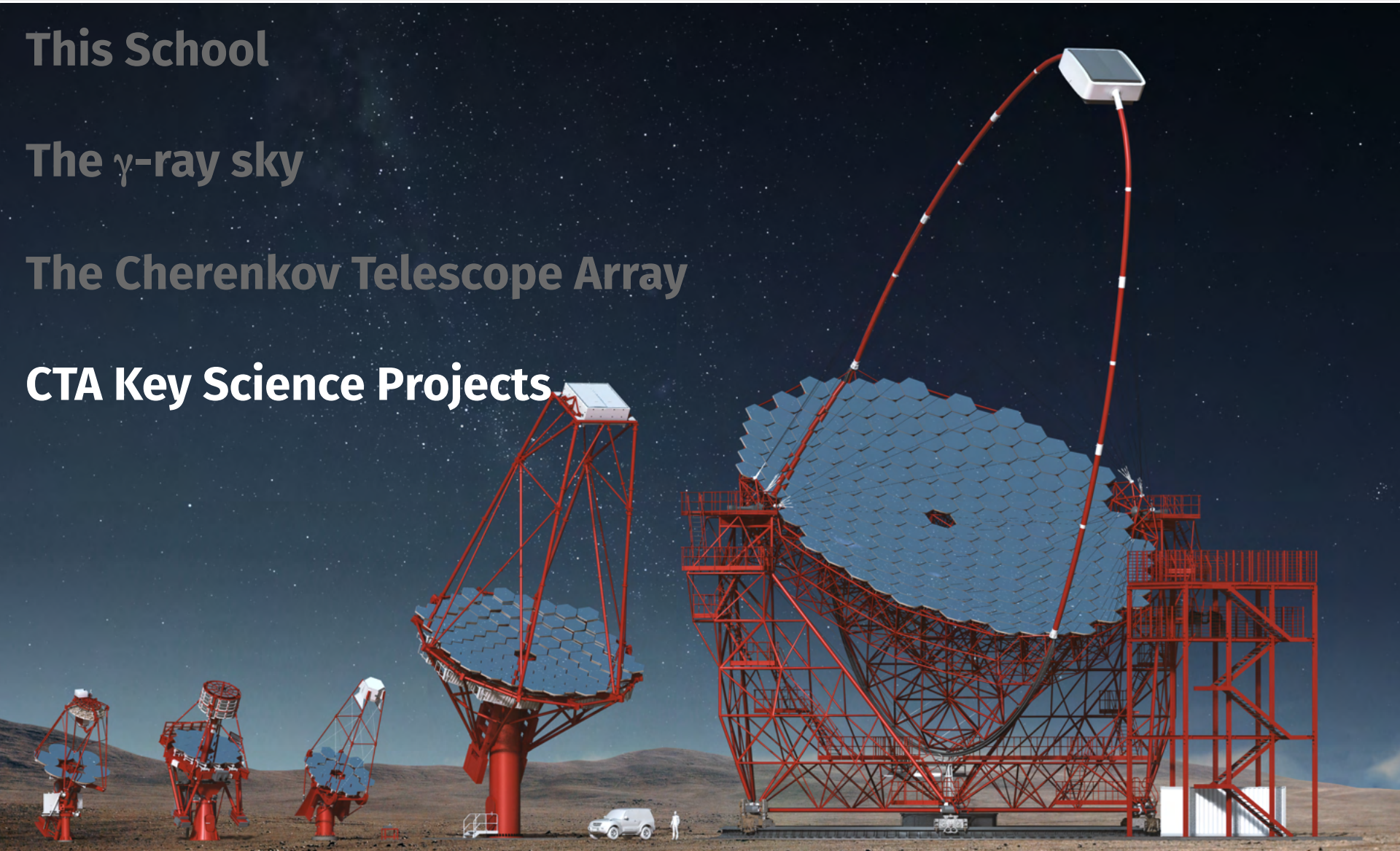


This School

The γ -ray sky

The Cherenkov Telescope Array

CTA Key Science Projects

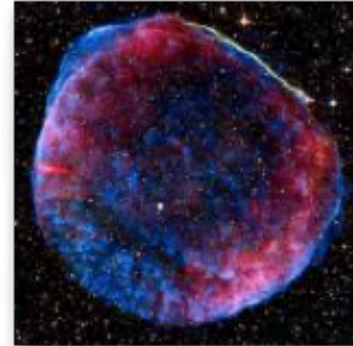


CTA Main Scientific Themes



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. Knödseder.

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

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.



Science with the Cherenkov Telescope Array



Science with CTA

Will become a regular
book / a special issue
journal.

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**

See talks by

G. Brunetti – *Galaxy clusters with CTA*

G. Van Eldik – *The Galactic survey at VHE*

A. Giuliani – *Galactic science with CTA*

D. Mazin – *Survey of the extra-galactic sky*

F. Tavecchio – *Extra-galactic sky with CTA*

E. Bissaldi – *GRB studies with CTA*

B. Patricelli – *Search for GW counterparts with CTA*

A. Morselli – *Dark matter studies with CTA*

M. Roncadelli – *Axion-like particles and CTA*

CTA PHYS Working Group



The **PHYS WG is composed of ~350 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

Next meeting



CTA PHYS WG Face-to-Face Meeting

Restricted Europe

18-20 September 2017

Max-Planck-Institut für Kernphysik

Europe/Berlin timezone

Overview

[Call for Abstracts](#)

[Timetable](#)

[Author List](#)

[Book of Abstracts](#)

[Registration](#)

[Conference Fee](#)

[Accommodation](#)

[Venue](#)

[Travel info](#)

[Conference dinner](#)

[Participant List](#)



Starts 18 Sep 2017 08:00

Ends 20 Sep 2017 19:00

Europe/Berlin



Max-Planck-Institut für Kernphysik

Otto-Hahn-Hörsaal, Library building

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69117 Heidelberg

Germany



Stefan Funk
Stefano Vercellone



Materials



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