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cherenkov telescope array

Gamma Ray Astrophysics with CTA: Introduction

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NATIONAL INSTITUTE FOR ASTROPHYSICS

SEXTEN CENTER FOR ASTROPHYSICS

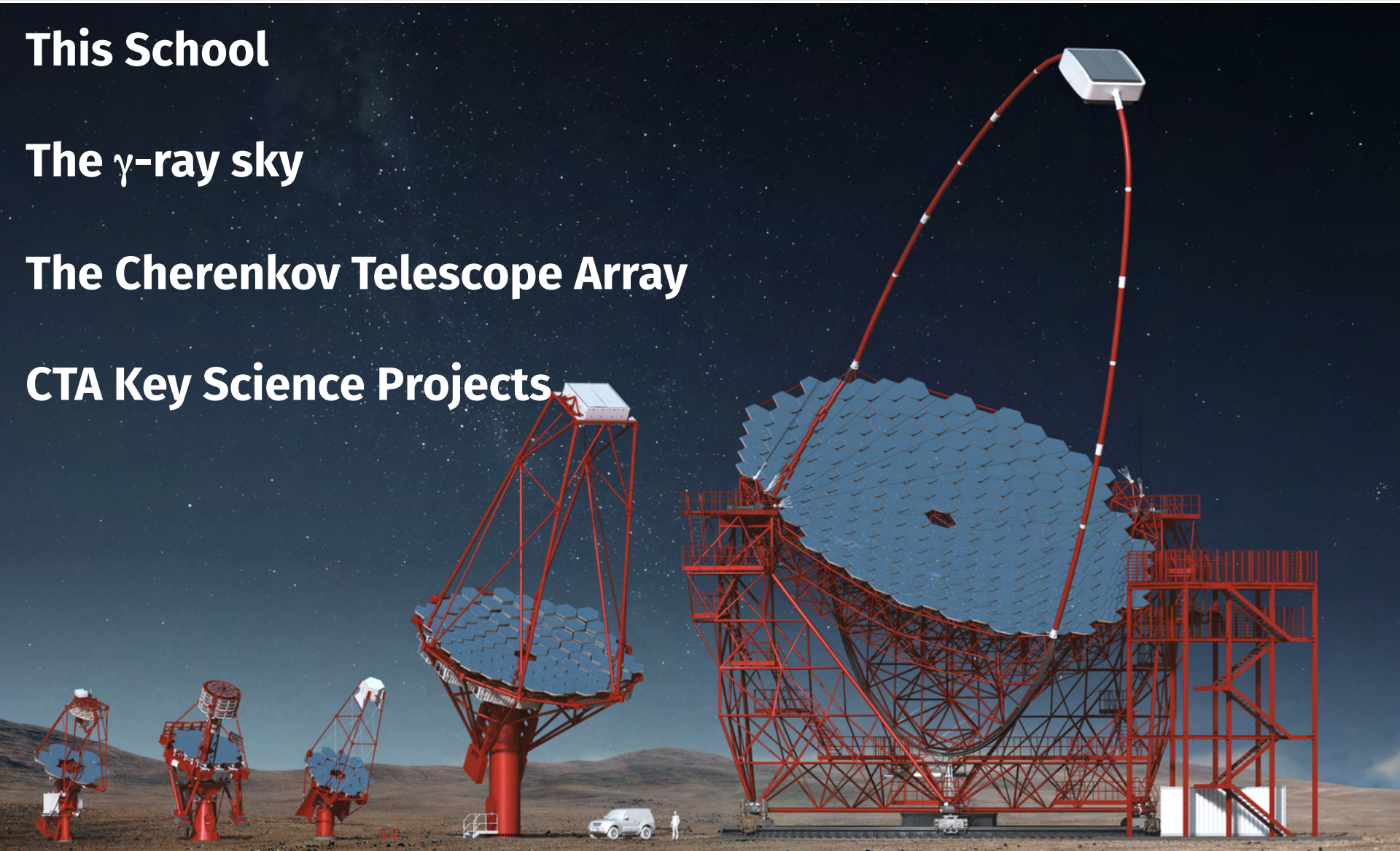
Outline

This School

The γ-ray sky

The Cherenkov Telescope Array

CTA Key Science Projects



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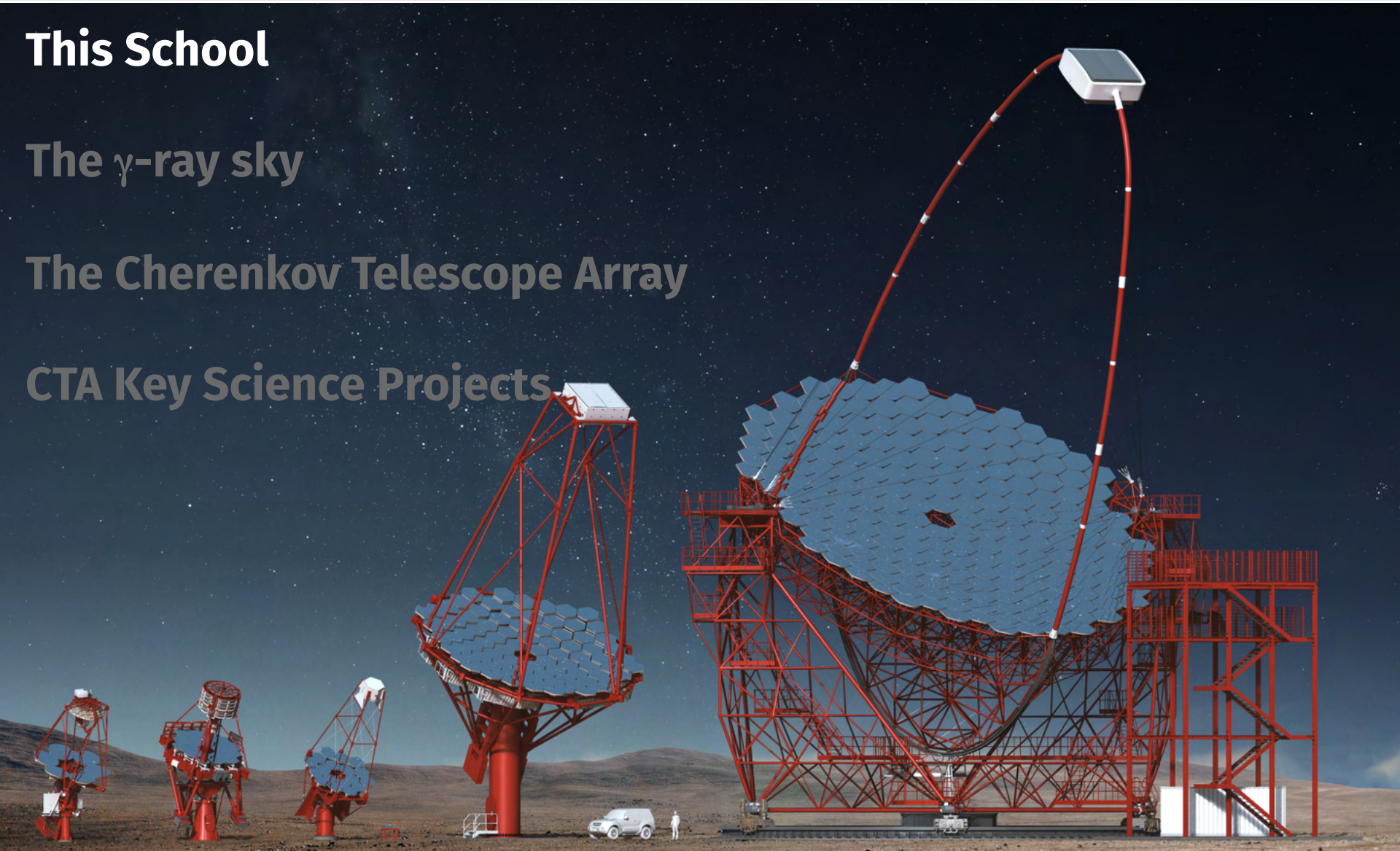

The School format

- **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*

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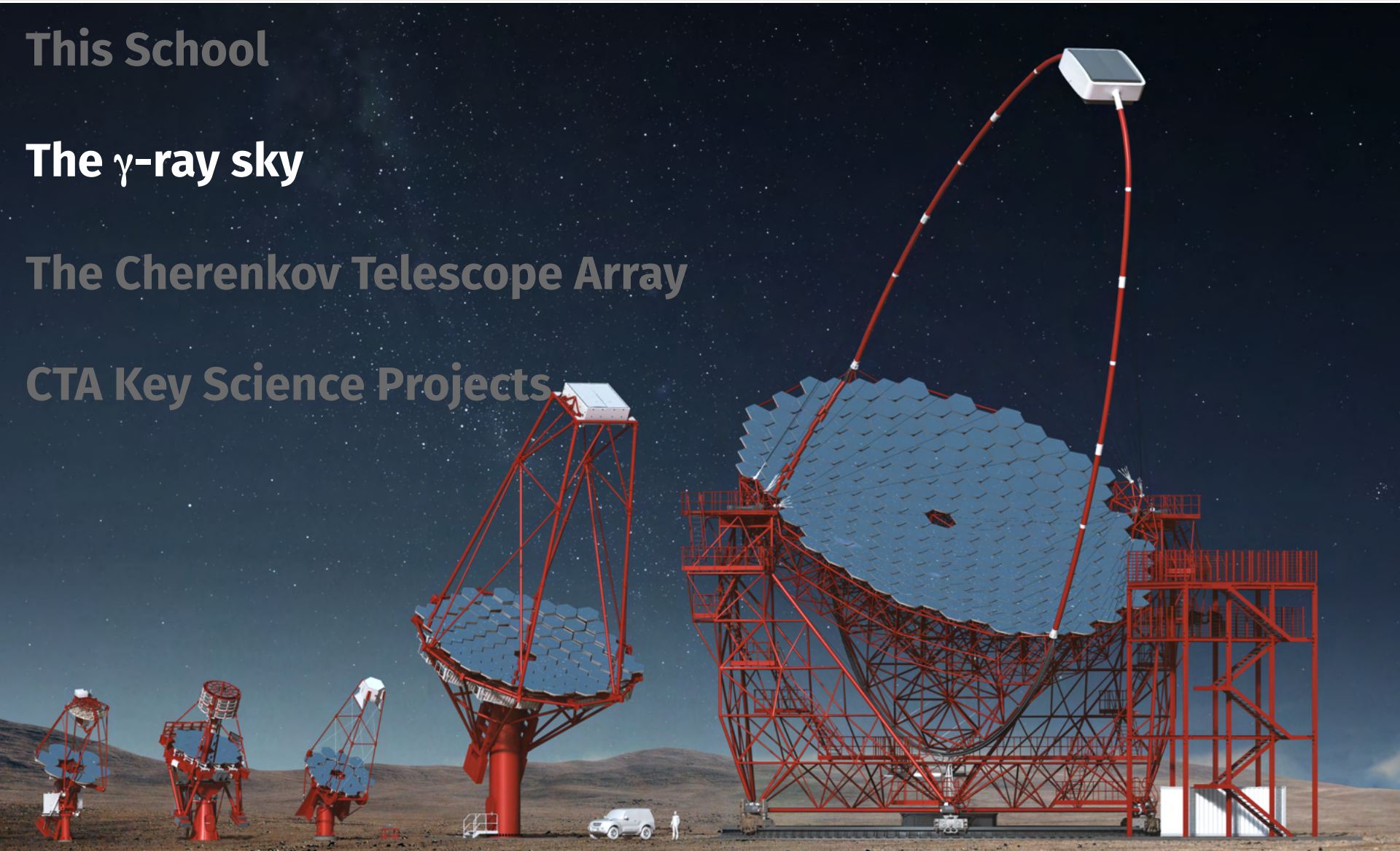
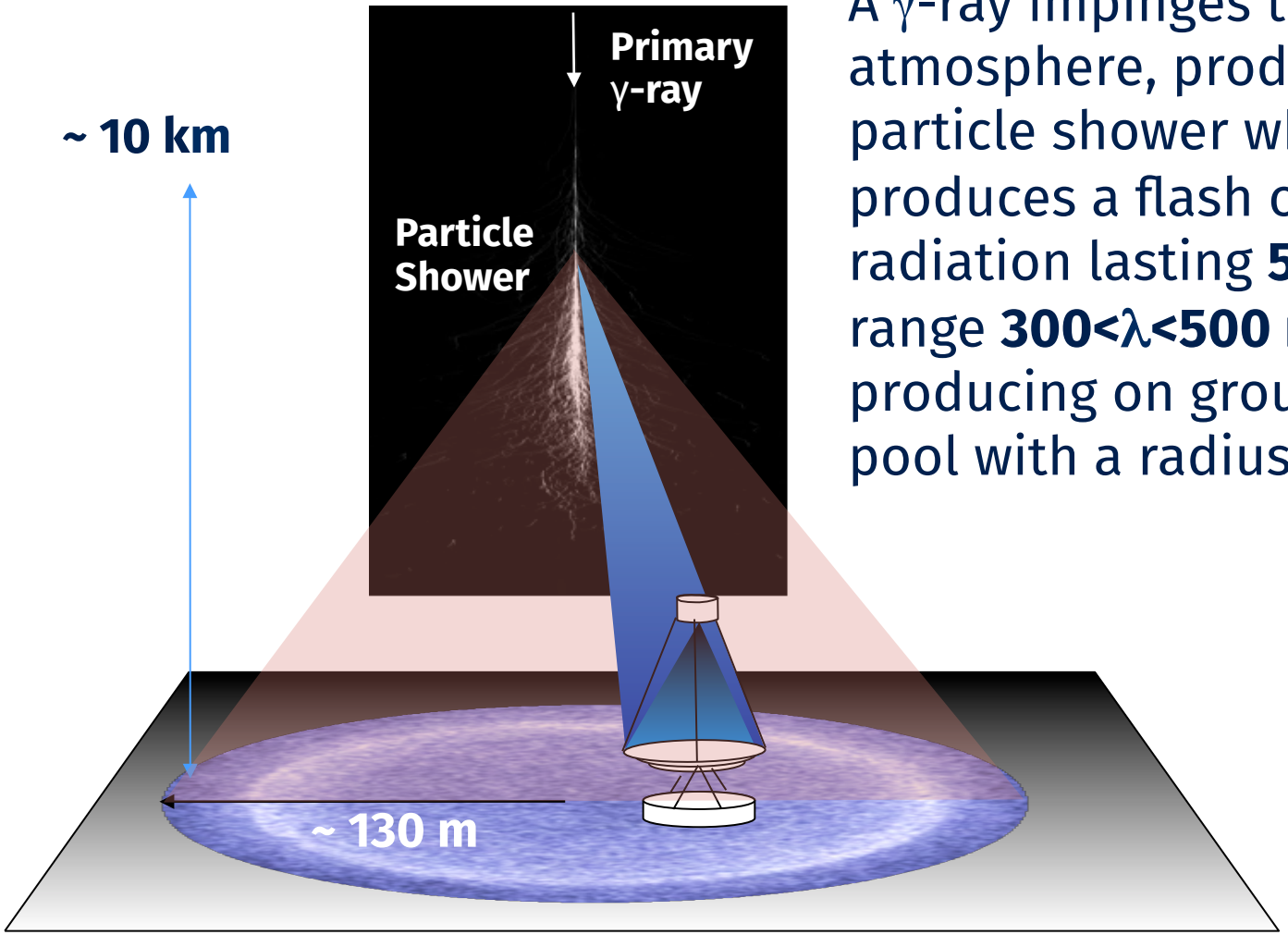


The Cherenkov Telescopes



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<λ<500 nm** and producing on ground a light pool with a radius of ~**130m**.

The Cherenkov Telescopes

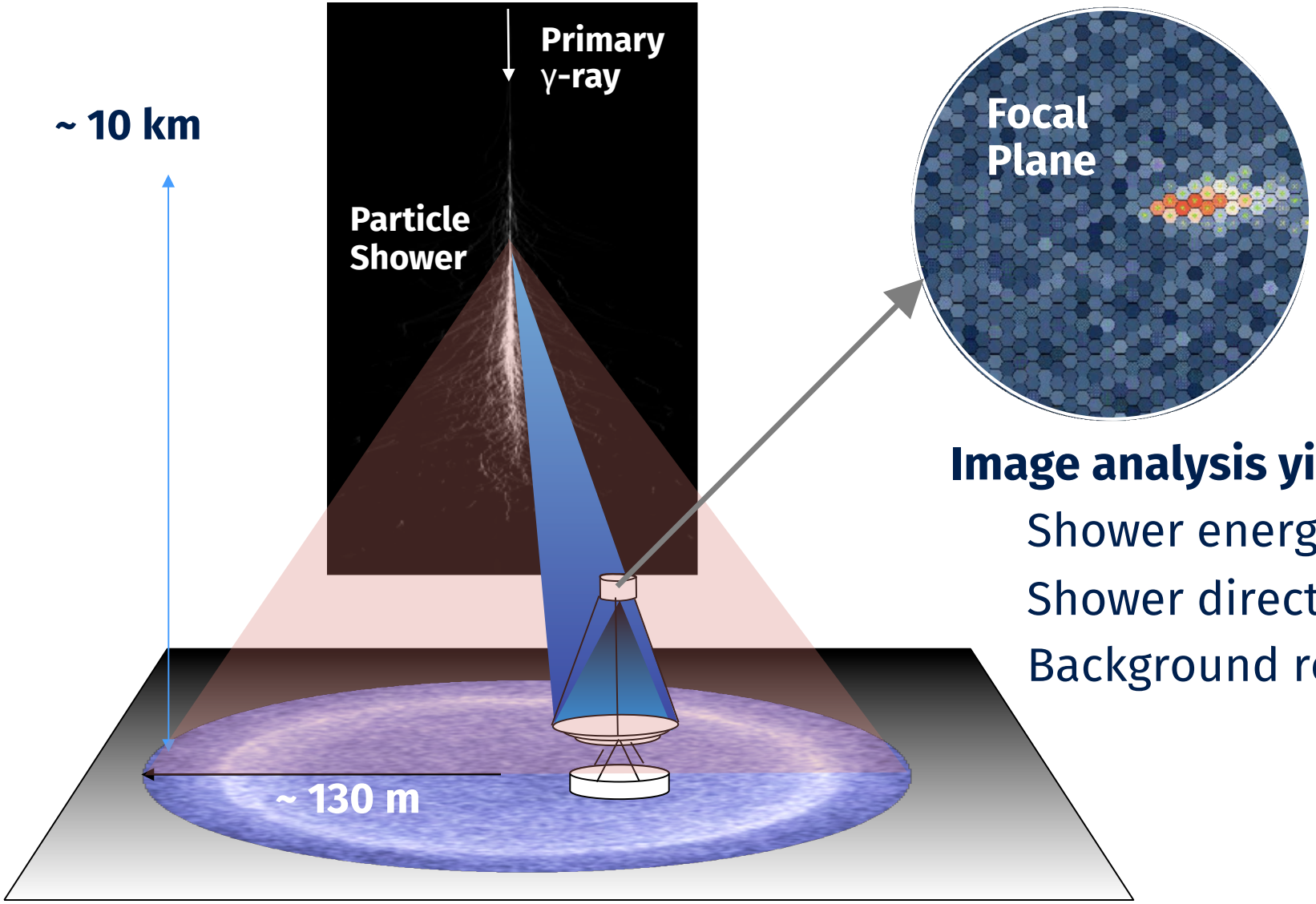


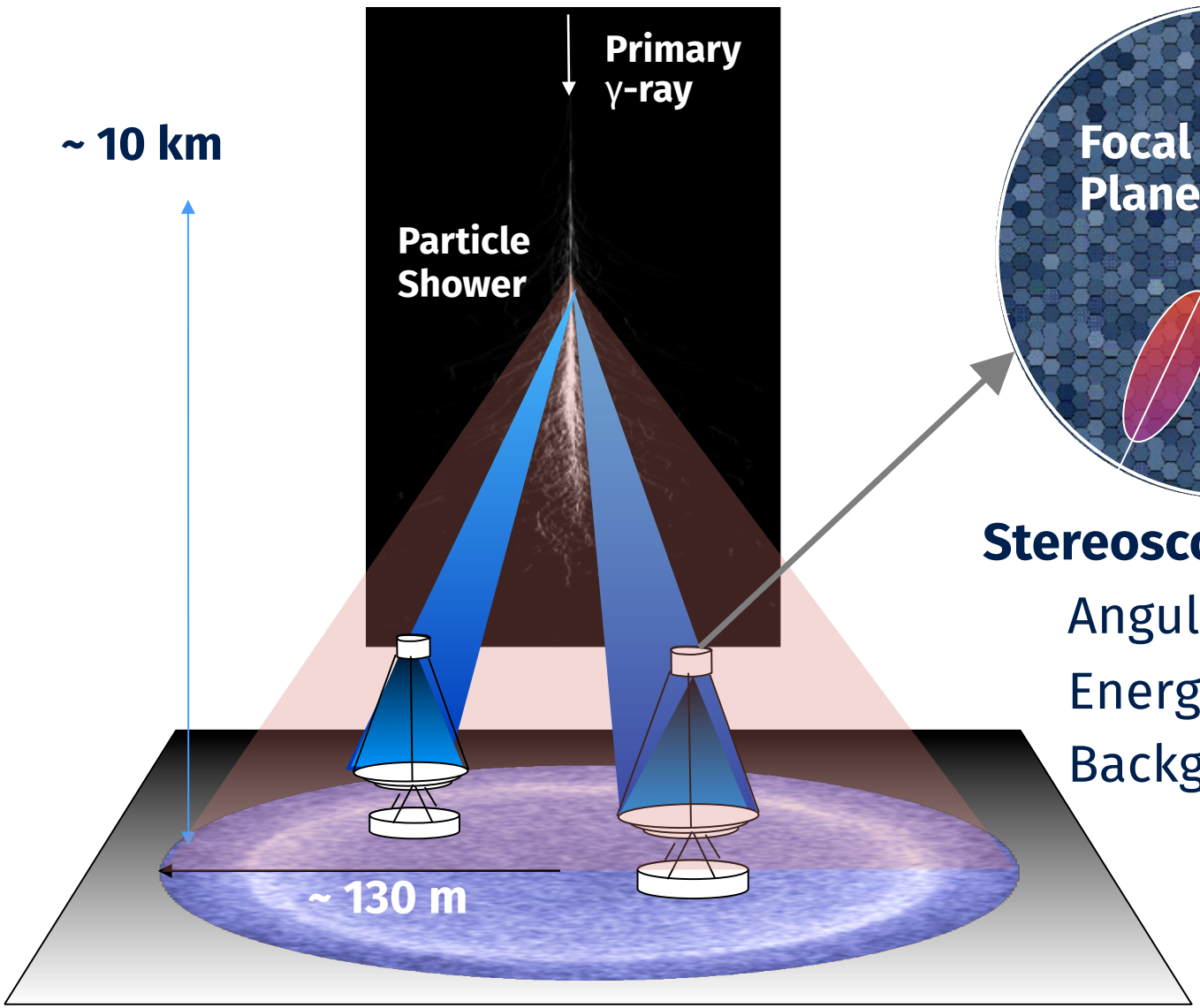
Image analysis yields

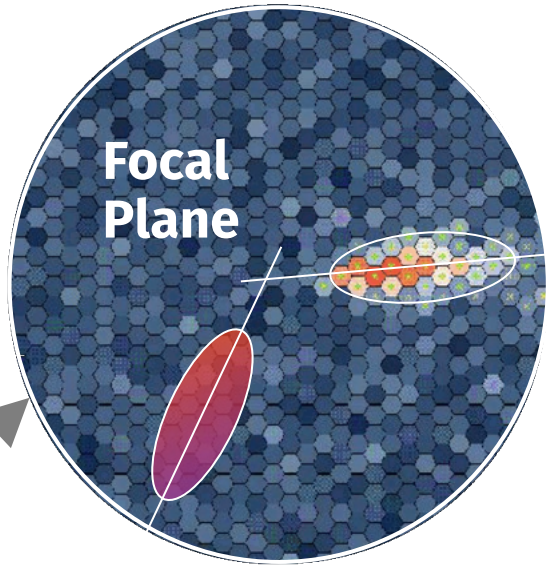
Shower energy

Shower direction

Background rejection

The Cherenkov Telescopes





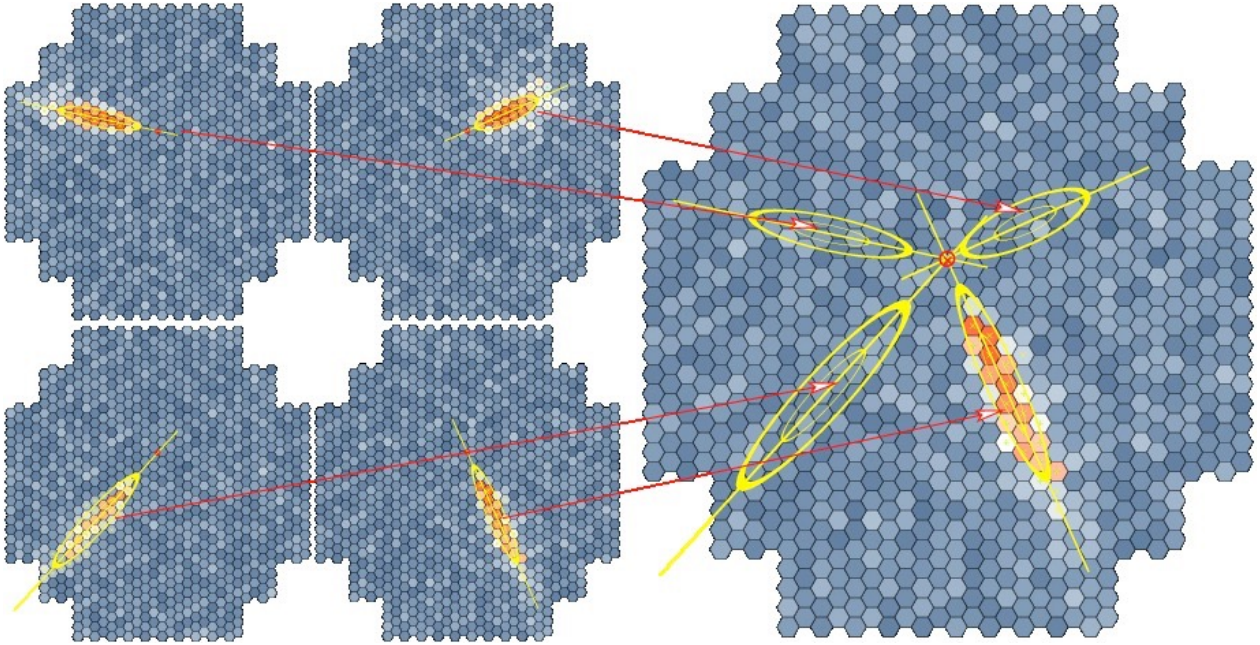
Stereoscopic view improves

Angular resolution

Energy resolution

Background rejection

The Cherenkov Telescopes

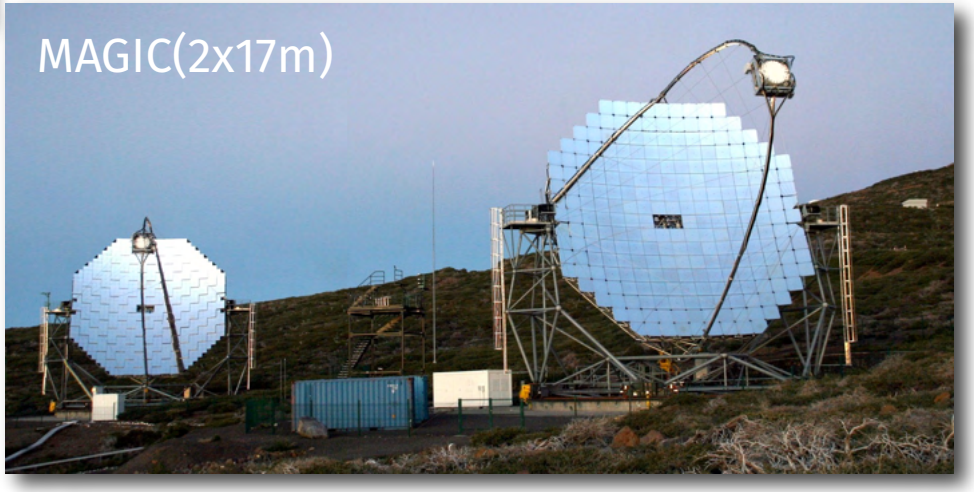


The intersection of major axes on the common FOV gives source position on the sky.

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

Hillas, 1985

445

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

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

ABSTRACT

It is shown that it should be possible to distinguish v 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 relat 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 app point sources of TeV cosmic rays — presumed to be gamma-rays ces have been detected by observing flashes of Cerenkov radi small showers 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 classes of shower, much of the background might be rejected. paper, Cawley et al. (1) describe the modification of the 10m the Whipple Observatory (Mt. Hopkins, Arizona) to record data Cerenkov image on a 0.5° grid, using 37 photomultipliers in t 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 t widths of shower images are less than 0.5°, the image dimens 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 sis development. The computer program has been used previously vestigations (2) and is much more detailed than is necessary ting Cerenkov processes, following particles down to an ener (far below the Cerenkov threshold), although "thin sampling" to follow particles below 1/4000 of the primary energy to red time. The model atmosphere is not isothermal. Hadronic coll been simulated both by a radial scaling model with rising cro and by a model with increased production of low-energy secondi tive to scaling) at high primary energies (though a less dras than proposed by Wdowczyk and Wolfendale, for example, as the particles in the fragmentation region — high x — are largel However, at TeV energies, there is little difference between constrained by accelerator data, so the simulation resu combined together in the presentations below.

Although some loss of Cerenkov light by Rayleigh and a terings is allowed for (2), scattered light is assumed not t the spread of the image (size <1°) in a clear mountain atmo

Provided by the NASA Astrophy

OG 9.5-3

The basics

Weeks et al., 1989

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

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

T. C. Weekes,[1] M. F. Cawley,[2] D. J. Fegan,[3] K. G. Gibbs,[1] A. M. Hillas,[4] P. W. Kwok,[1] R. C. Lamb,[5] D. A. Lewis,[1] D. Macomb,[5] N. A. Porter,[3] P. T. Reynolds,[1,5] and G. Vacanti[5]

Received 1988 August 1; accepted 1988 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 9.0 σ level, corresponding to a flux of 1.8×10^{-11} photons cm^2 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 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more 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

I. 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 0531, 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 Rieke 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 ~10^{-3} G.

The observation of a flux of 0.14 TeV gamma rays from the Crab Nebula was reported by the Smithsonian group using the atmospheric Cerenkov technique (Weekes et al. 1972); based on observations that spanned 3 years, the detection was still only at the 3 σ level. This demonstrates the weakness of the source and the lack of sensitivity of the technique. The detection of TeV gamma rays from the Crab is also a confirmation of the Compton synchrotron model and gives a direct measure of the magnetic field. This measurement, which was conservatively interpreted as an upper limit, implies an average magnetic field of 3×10^{-4} G, or a radially symmetric (1/r) field with $B_0 = 1 \times 10^{-3}$ G at a distance of 0.1 pc from the pulsar (Grindlay 1976).

Subsequent to the discovery of PSR 0531 in the nebula, gamma-ray observations concentrated on the pulsar beca greater sensitivity could be achieved by the assumption of chronization of the gamma-ray emission with the peri radio emission. Several detections were reported at very energies (Grindlay 1972; Jennings et al. 1974; Grind Helmken, and Weekes 1976; Porter et al. 1976; Erick Fickle, and Lamb 1976; Vishwanath 1982; Vishwanath e 1985; Gupta et al. 1977; Gibson et al. 1982b; Dowthwaite 1984; Turner et al. 1985; Bhat et al. 1986), but the statis significance was not high, and upper limits were also prese which appeared to be in conflict with the reported fl (Helmken et al. 1973; Vishwanath et al. 1986; Bhat et al. 1 At energies above 1 TeV there were also reports of emis from the direction of the Crab (Mukanov 1983; Boone e 1984; Dzikowski et al. 1981; Kirov et al. 1985), but, becau the limited angular resolution and the absence of acc timekeeping, it was not possible to identify the source observed signal with the nebula or the pulsar. Again there be conflicting upper limits (Craig et al. 1981; Watson 1983 100 MeV energies (which are accessible to study by s chambers on satellites), both a pulsed and steady compo were detected (Kniffen et al. 1977; Hermsen et al. 1977; C et al. 1987); at 1 GeV the strength of the unpulsed compon (which might originate in the nebula or near the pulsar) is 6 times that of the pulsed flux.

Using a refined version of the atmospheric Cerenkov te nique, we here report the detection of gamma rays ab 0.7 TeV from the Crab Nebula at a high level of statist significance; over the epoch 1986–1988 we find no evidence variability, and the observed flux is in agreement with reported previously in 1969–1972 and in an earlier observa utilizing this same technique in 1983–5 (Cawley et al. 19 Gibbs 1987). The observed gamma-ray flux is only 0.2% cosmic-ray background. A periodic analysis using the k radio period of the pulsar indicates that less than 25% observed signal is pulsed. The detection of such a weak from a steady (nonpulsed) source with a significance of 9 date [illegible] 87) is a [illegible] in the developme ground-based gamma-ray astronomy. It demonstrate power of using atmospheric Cerenkov imager imaging a tinguish gamma-ray-initiated air shower from those g

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[2] St. Patrick's College, Maynooth.
[3] University College, Dublin.
[4] University of Leeds.
[5] Iowa State University.

379

1 source

>150 sources

Hinton & Hoffmann, 2009

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Teraelectronvolt Astronomy

J.A. Hinton[1] and W. Hofmann[2]

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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 waveband 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.

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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*

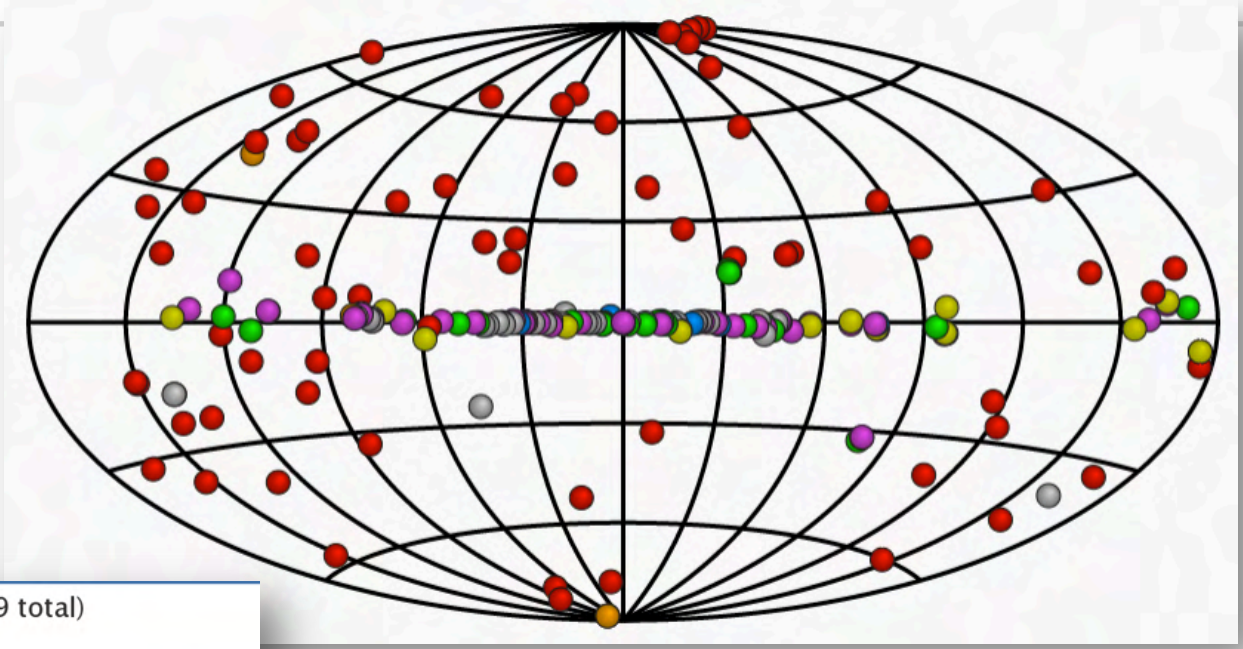
100 GeV – 50 TeV sky

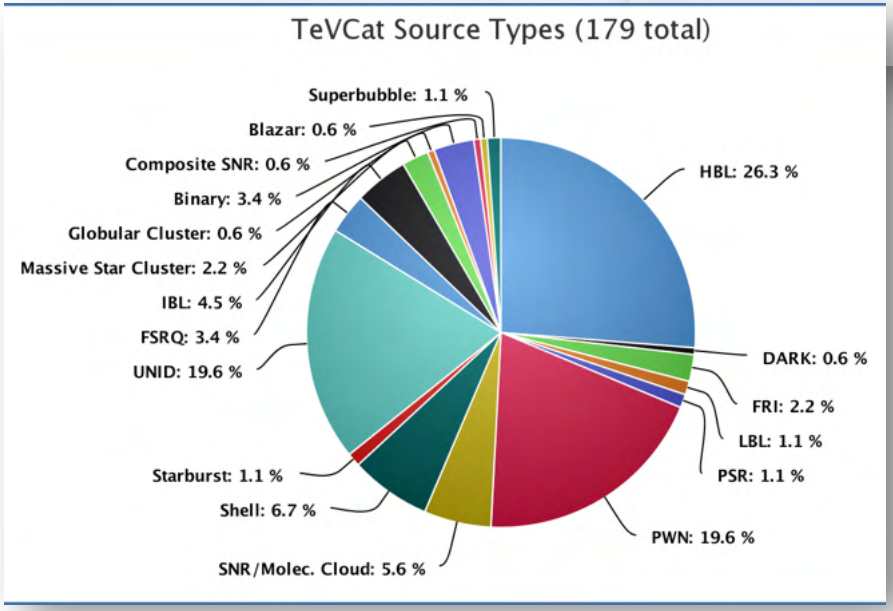
TeVCat 2

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

~180 sources

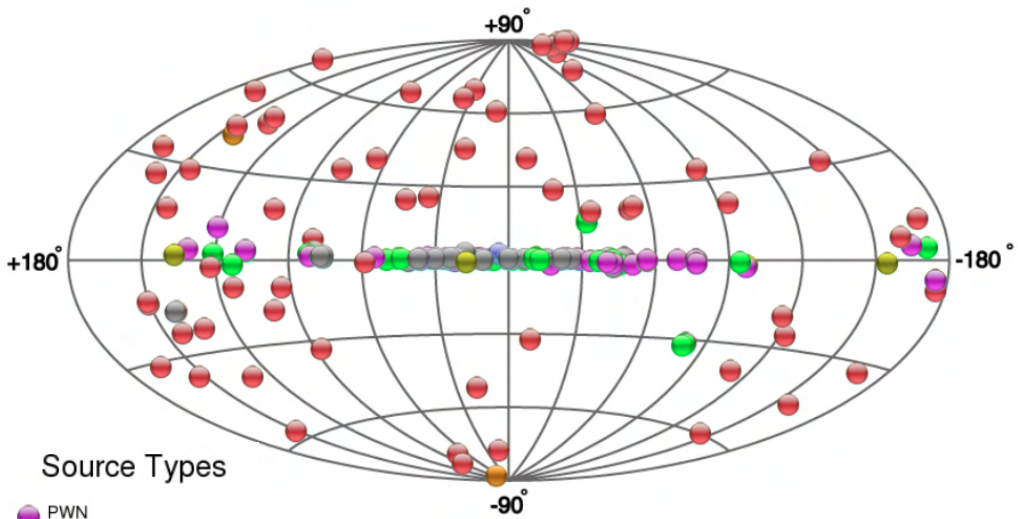
E>100 GeV





Wakely & Horan+16

The Fermi sky above 50 GeV

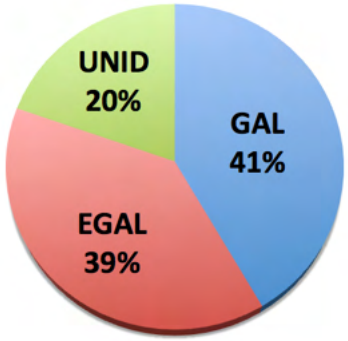


Source Types

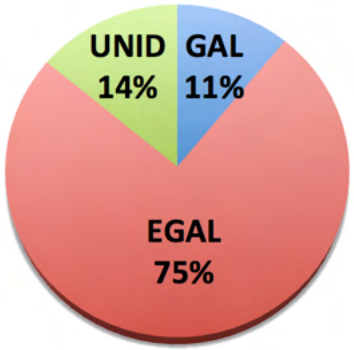
- PWN
- Binary XRB PSR Gamma BIN
- HBL IBL FRI FSRQ Blazar LBL AGN (unknown type)
- Shell SNR/Molec. Cloud Composite SNR Superbubble
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR

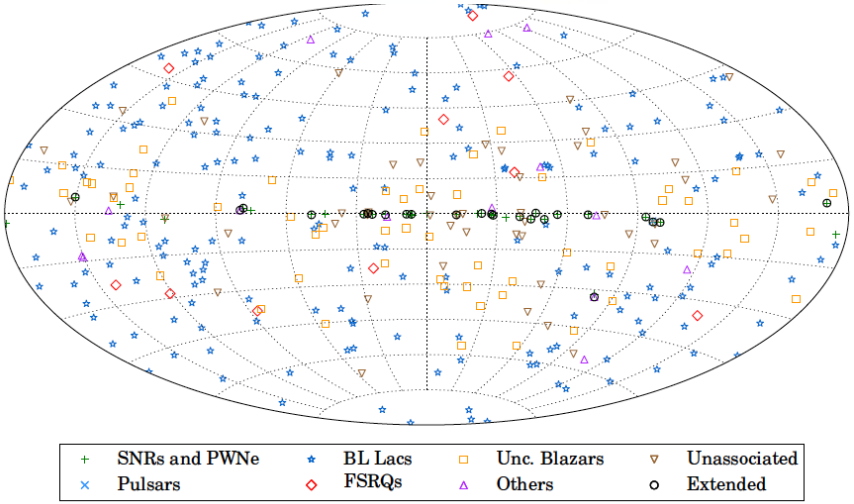
Wakely & Horan http://tevcat.uchicago.edu/

~180 TeVCat sources



360 *Fermi*-LAT sources E>50 GeV

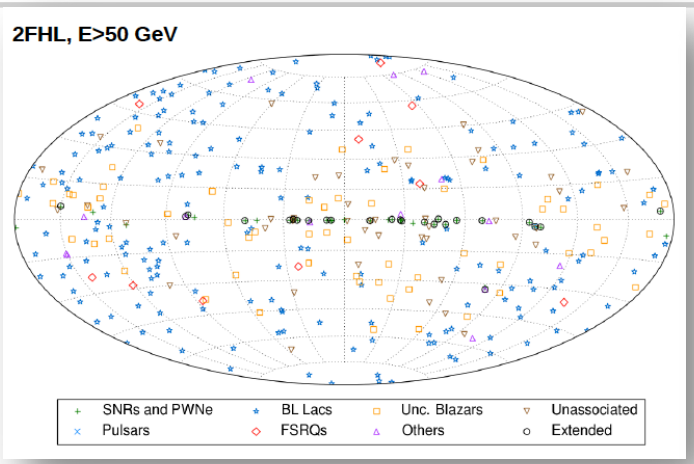


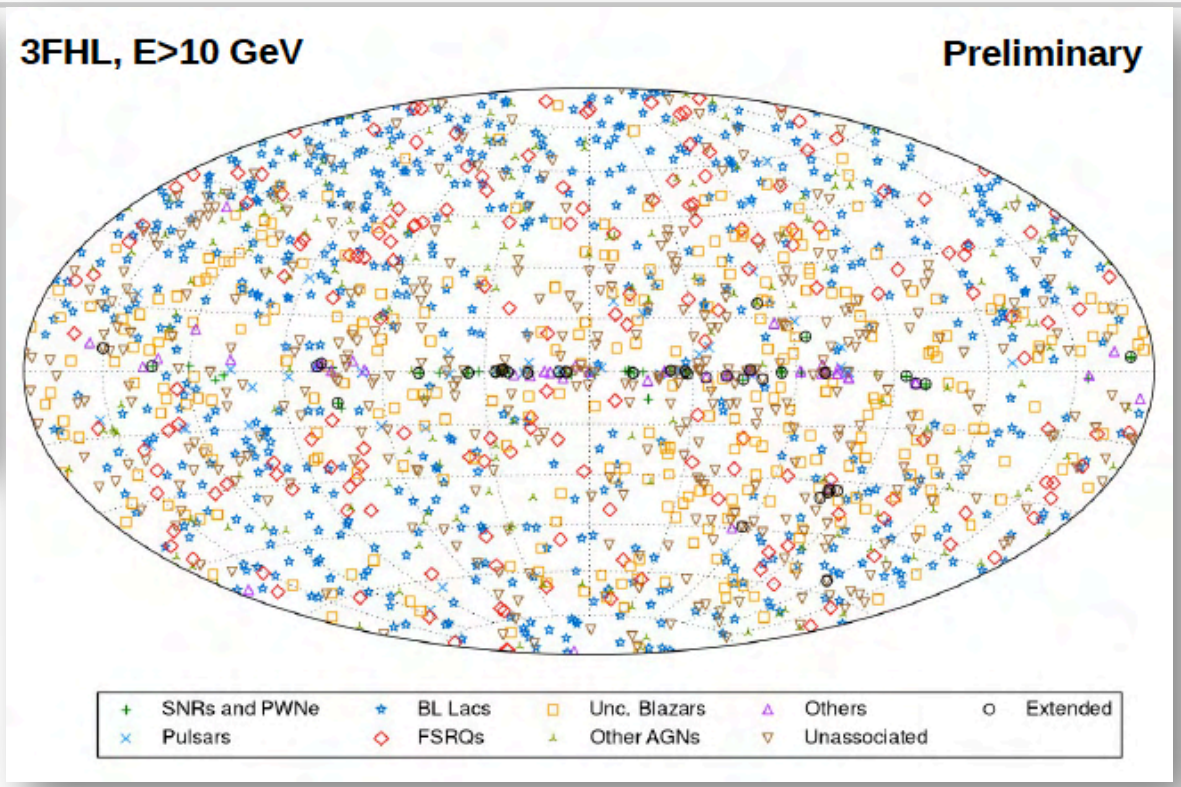


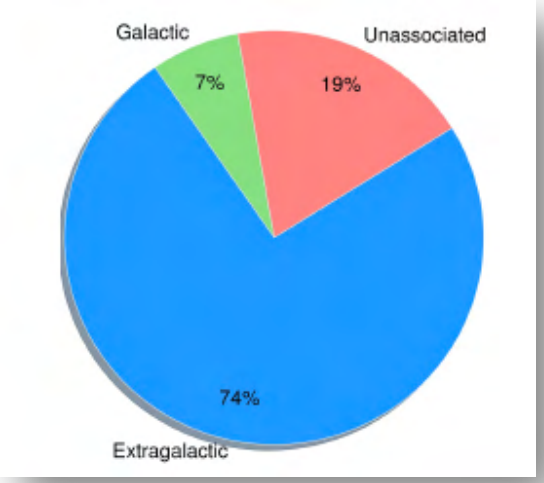
2FHL Ackermann+16

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







3FHL, arXiv:1702.00664

10 GeV – 2 TeV

7 years of data

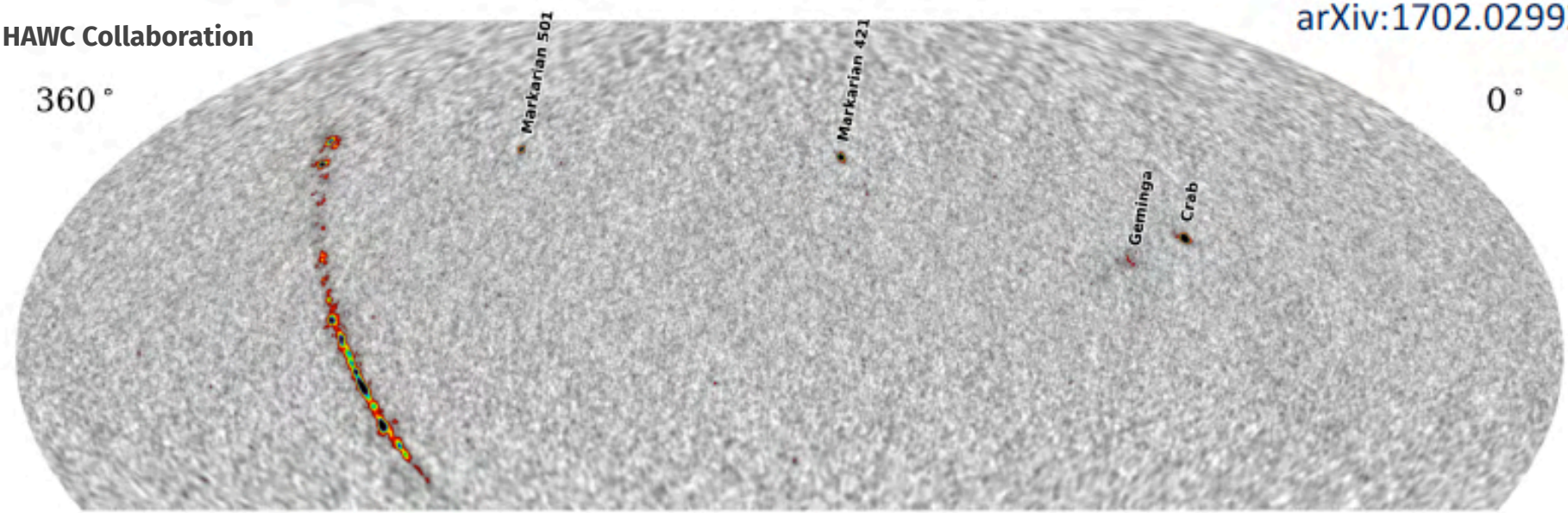
1556 sources

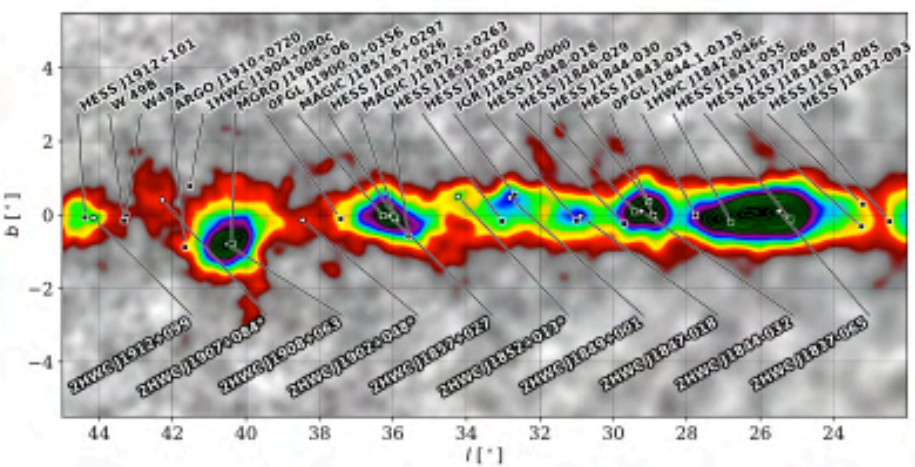
214 brand new (not in 1FHL/2FHL/3FGL)

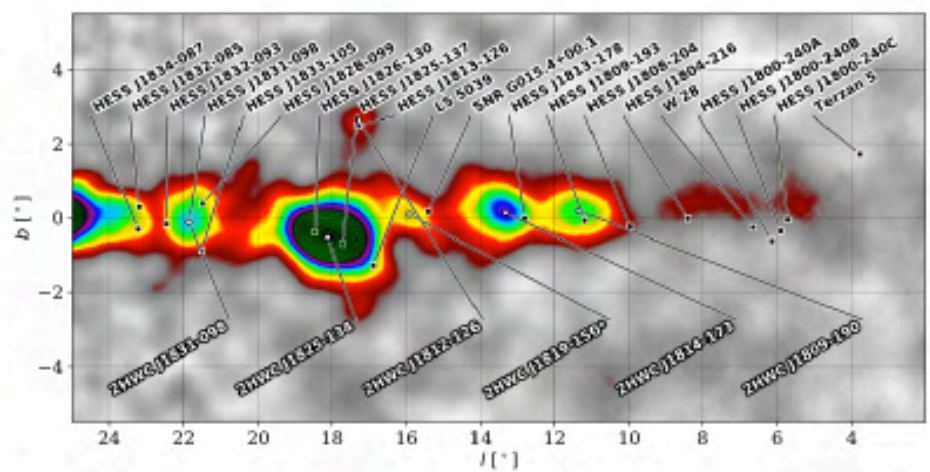
0.1 – 100 TeV sky

HAWC Collaboration

arXiv:1702.02992







HE & VHE sky

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*

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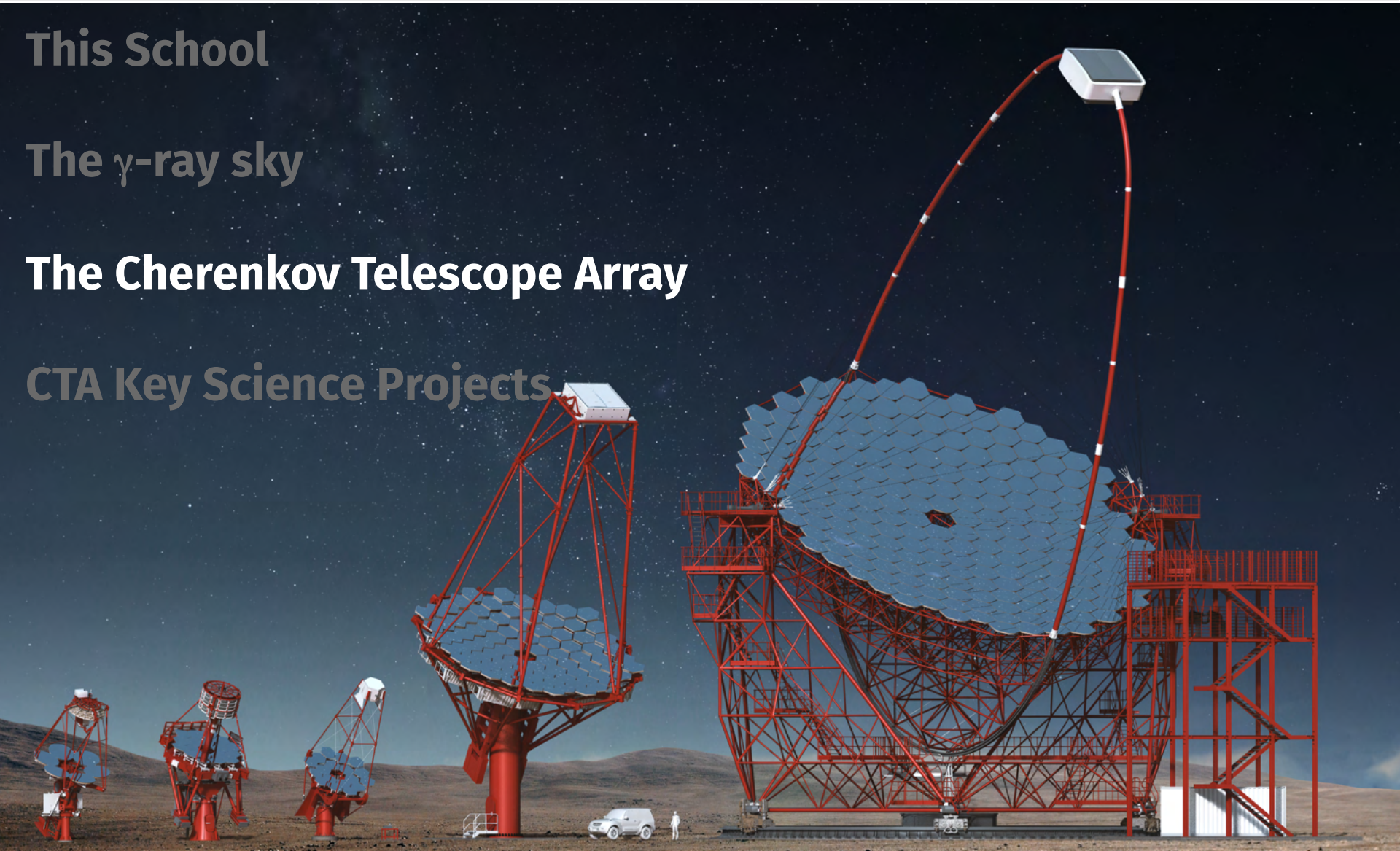


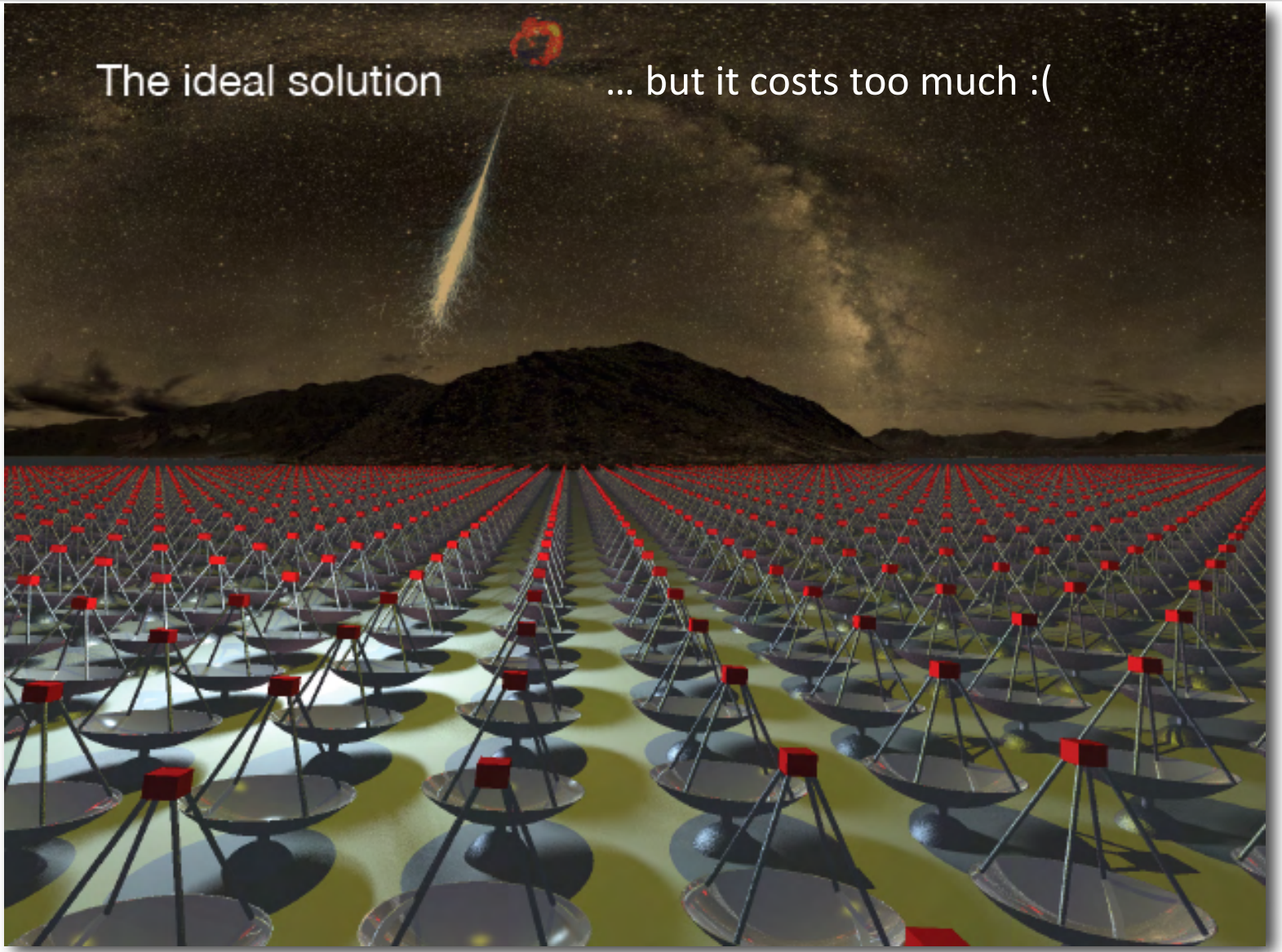
How to improve w.r.t. current IACTs ?

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 ?

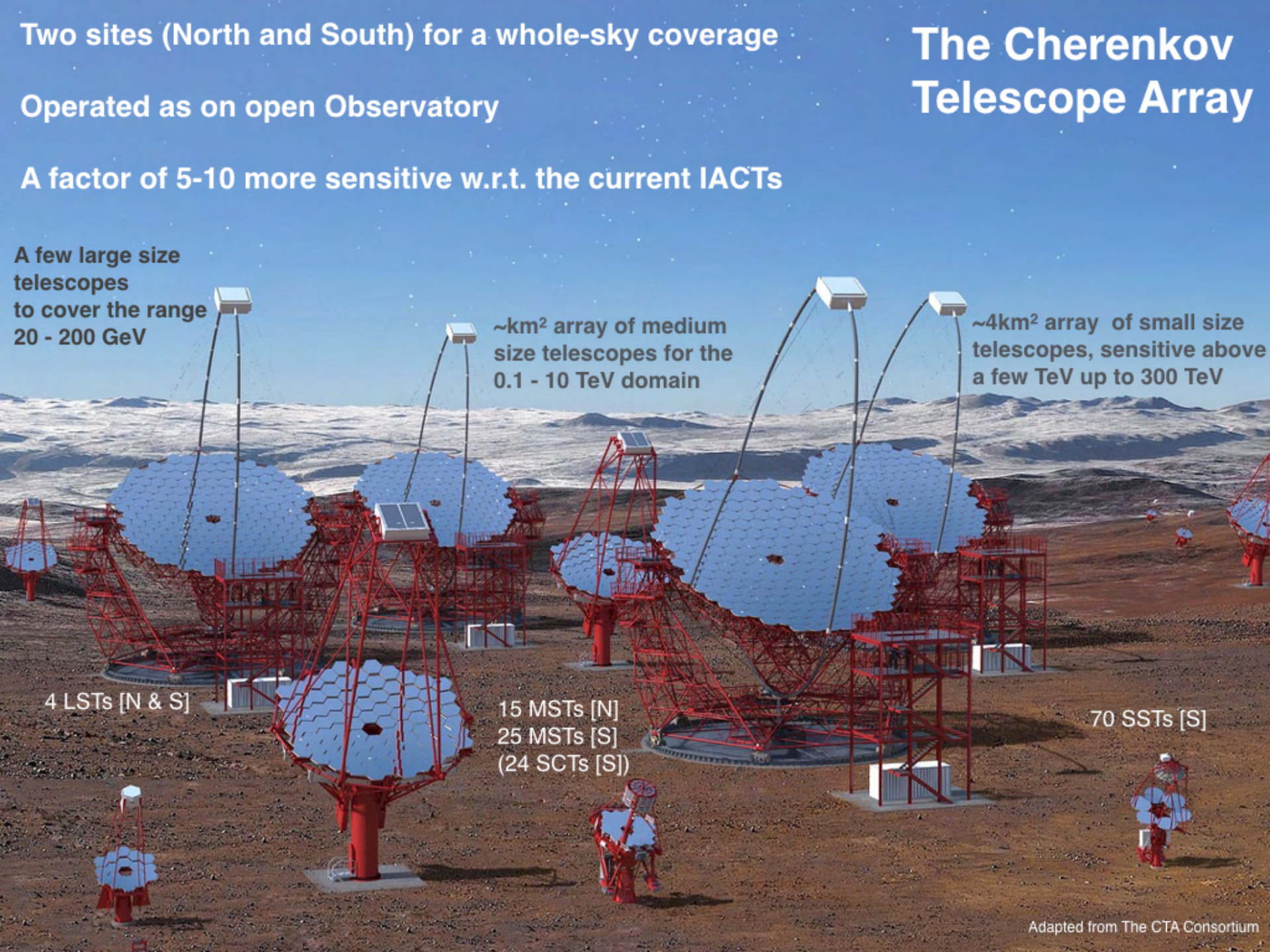


The Cherenkov Telescope Array

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

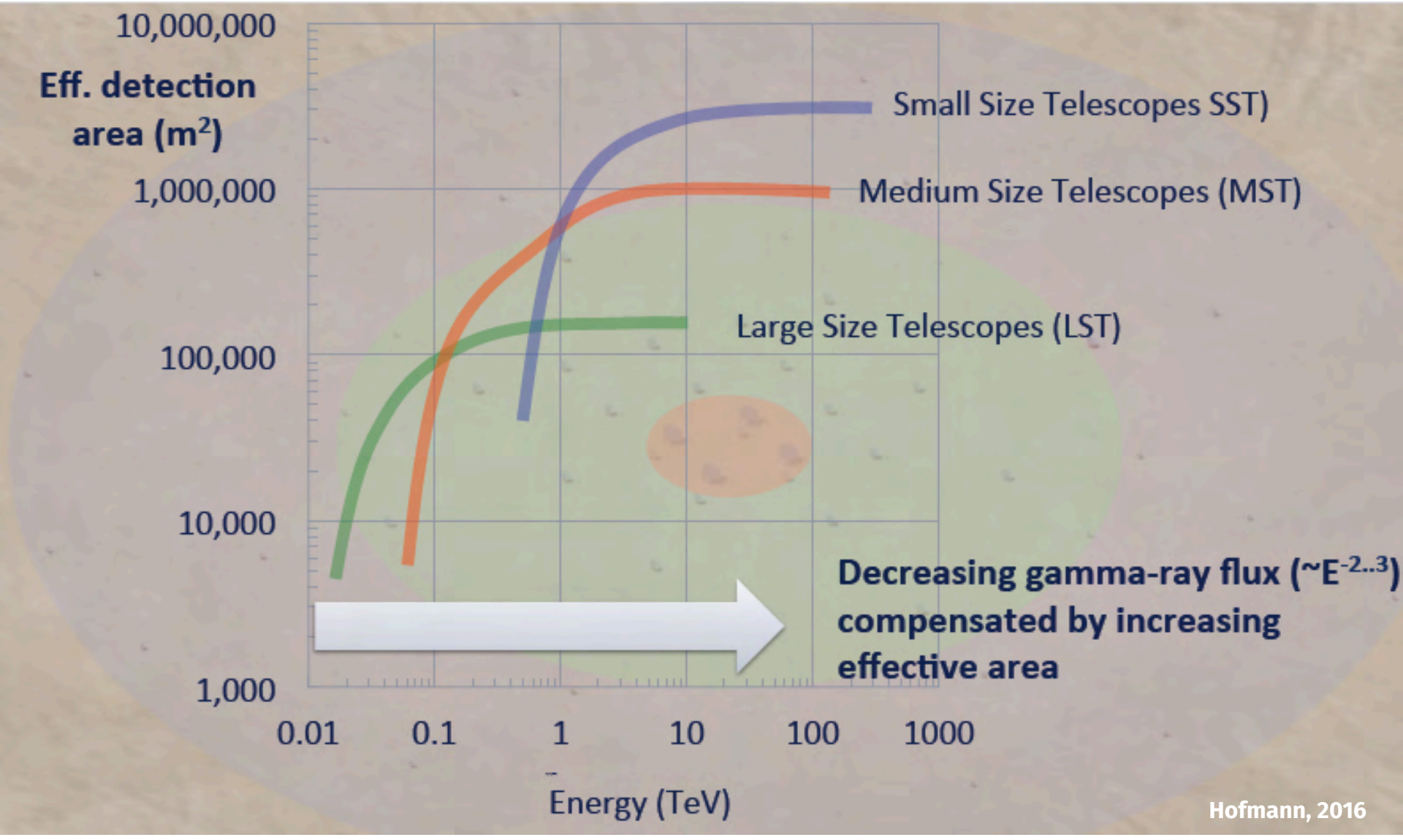
Operated as on open Observatory

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



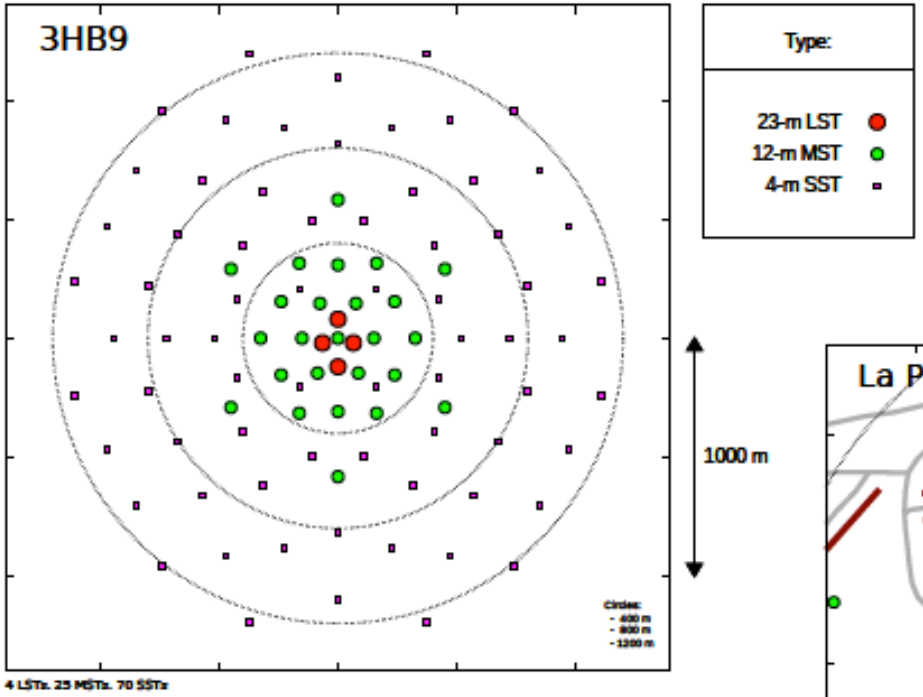
Adapted from The CTA Consortium

Effective area for gamma-ray detection



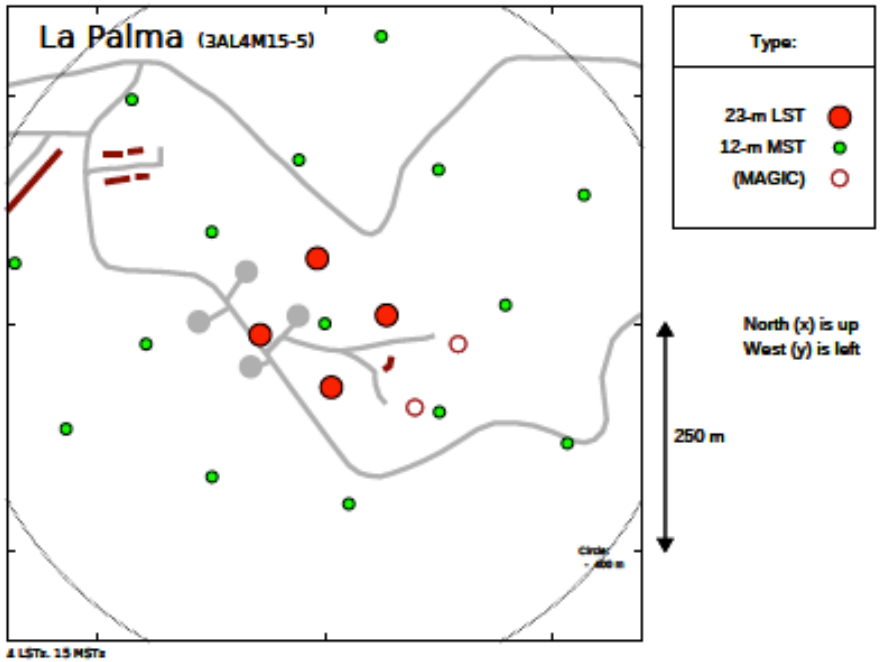
Hofmann, 2016

CTA Telescope layout



South:
4 LST
25 MST
70 SST

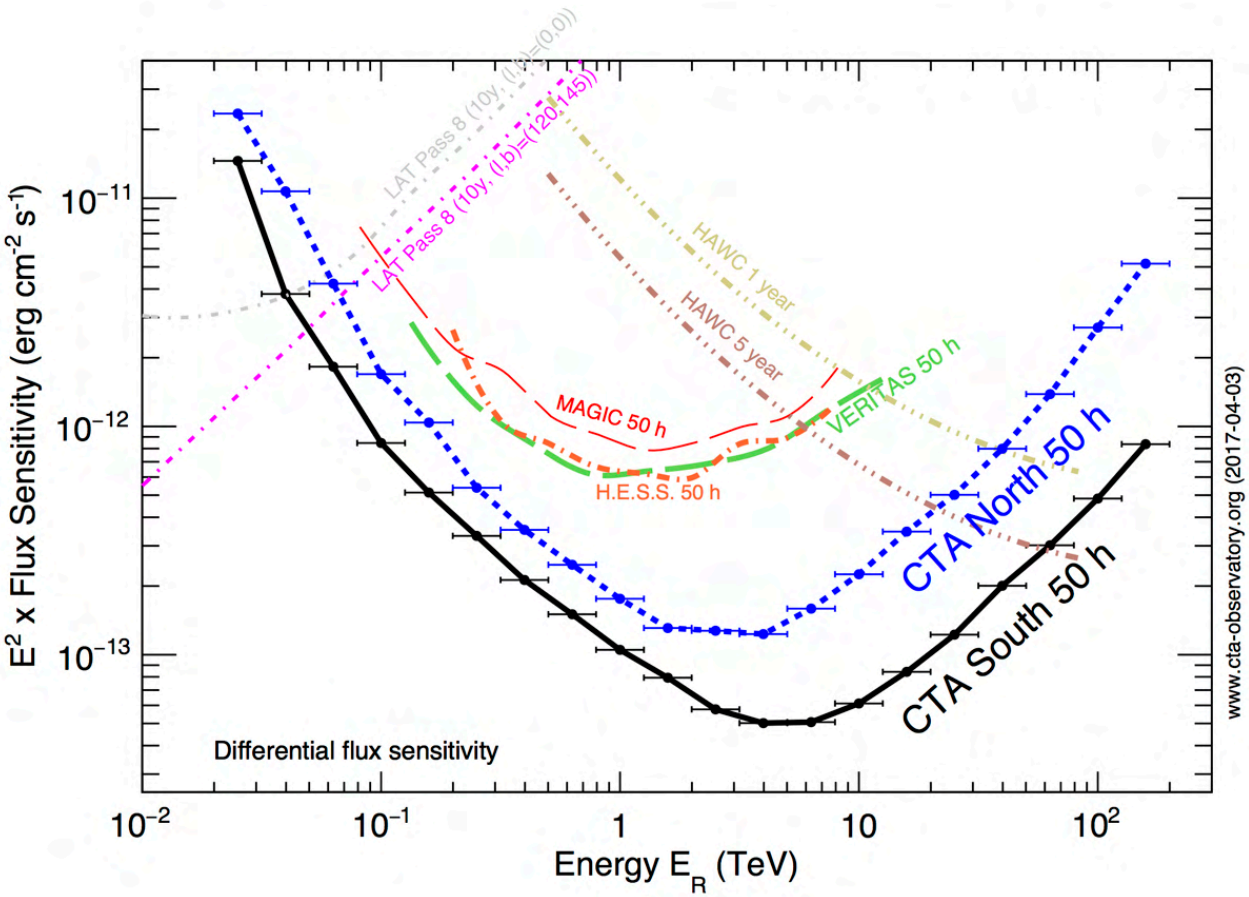
North:
4 LST
15 MST



Credits: The CTA Consortium

CTA Performance

Differential Sensitivity

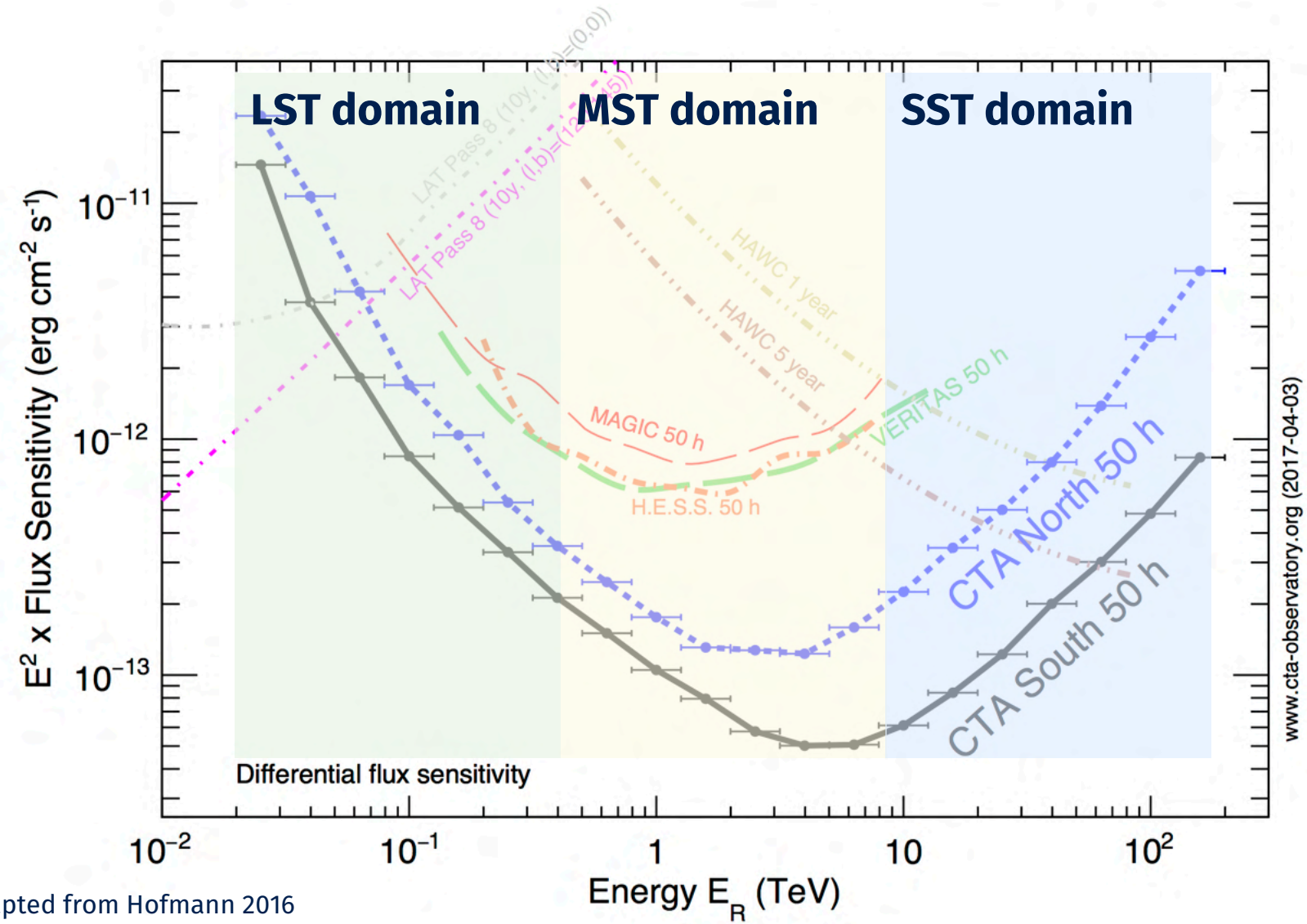


A factor of **5-10 improvement** in sensitivity in the domain of **about 100 GeV to some 10 TeV.**

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

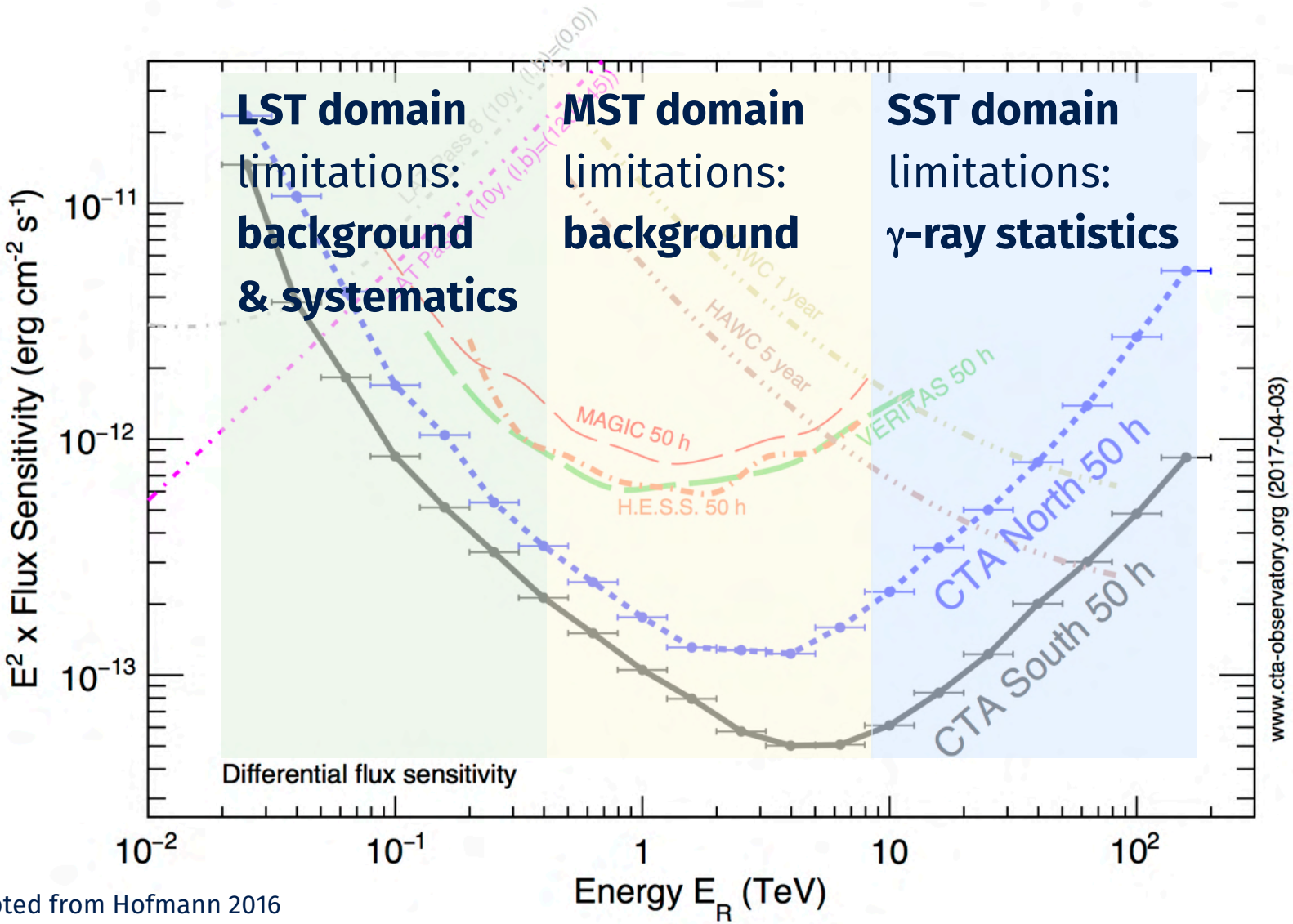
Credits: The CTA Consortium

CTA Performance



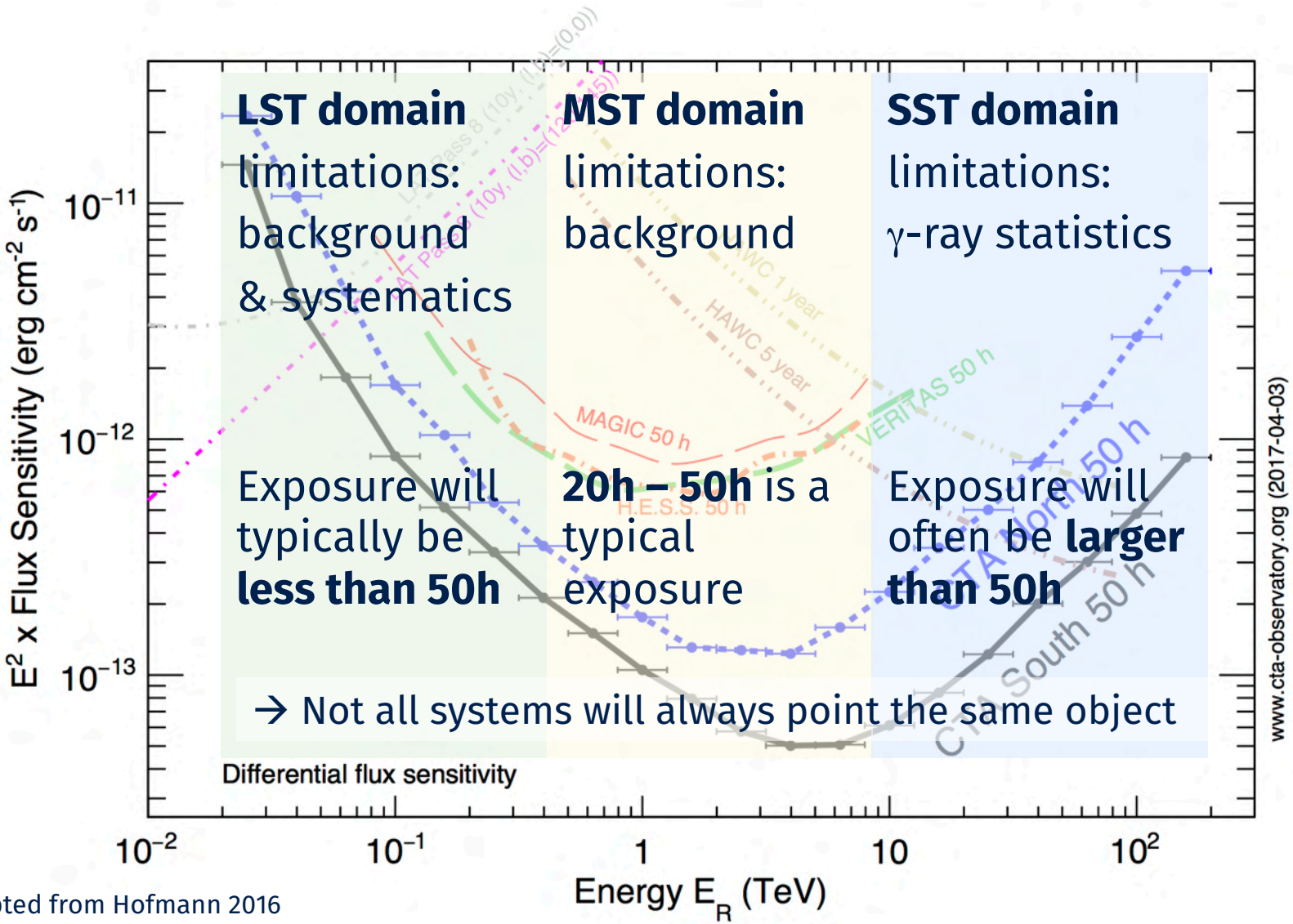
Adapted from Hofmann 2016

CTA Performance



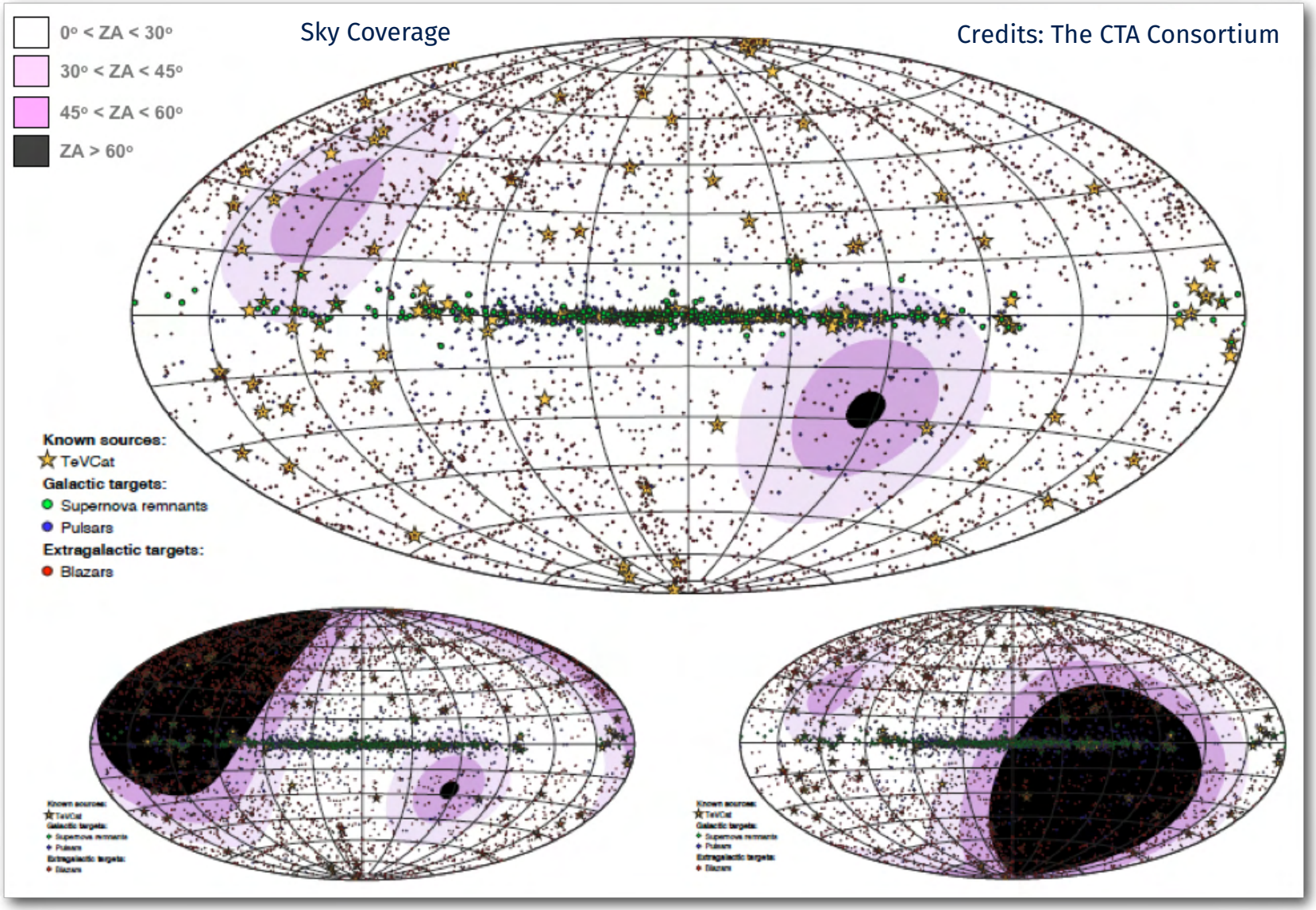
Adapted from Hofmann 2016

CTA Performance



Adapted from Hofmann 2016

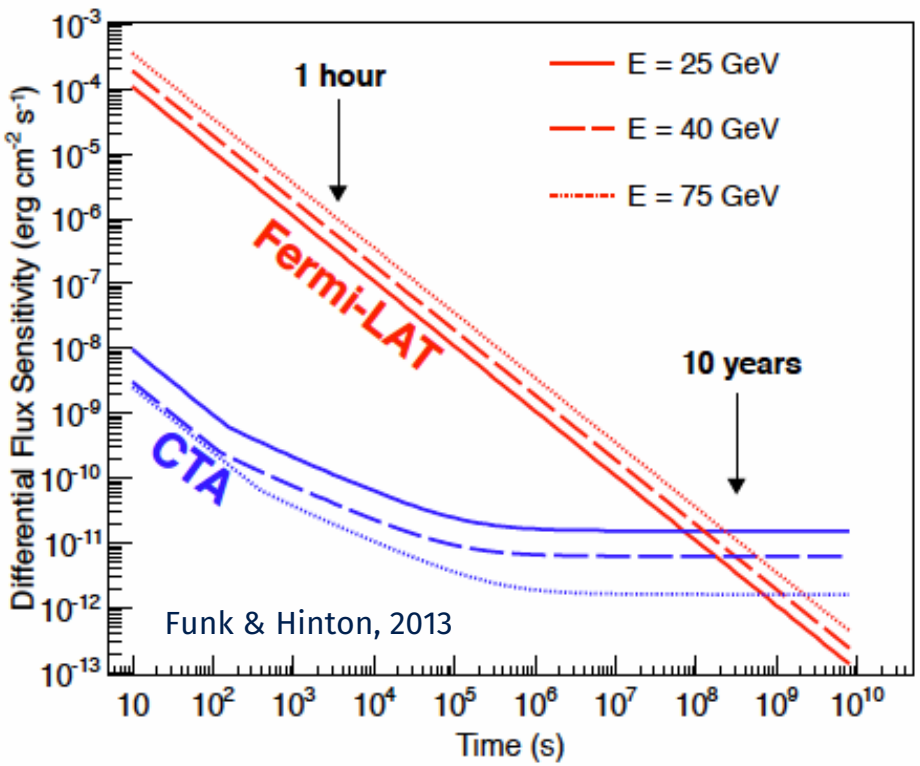
CTA as an *all-sky* Observatory



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

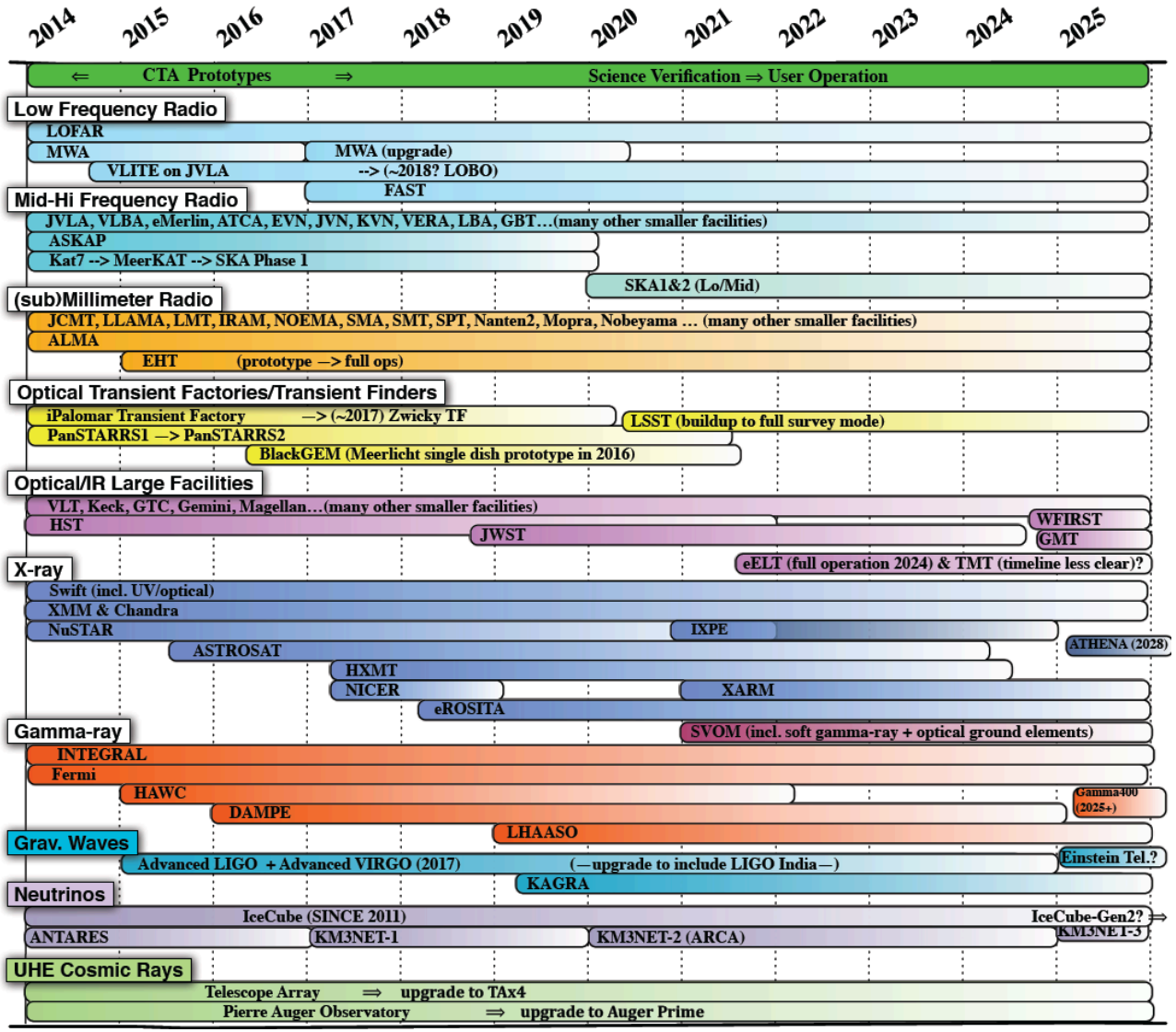
M. Martinez – *Overview of the CTA*

M. Teshima – *LST status*

S. Schlenstedt – *MST status*

G. Pareschi – *SST status*

Synergies during CTA operation



CTA and MWL synergies

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*

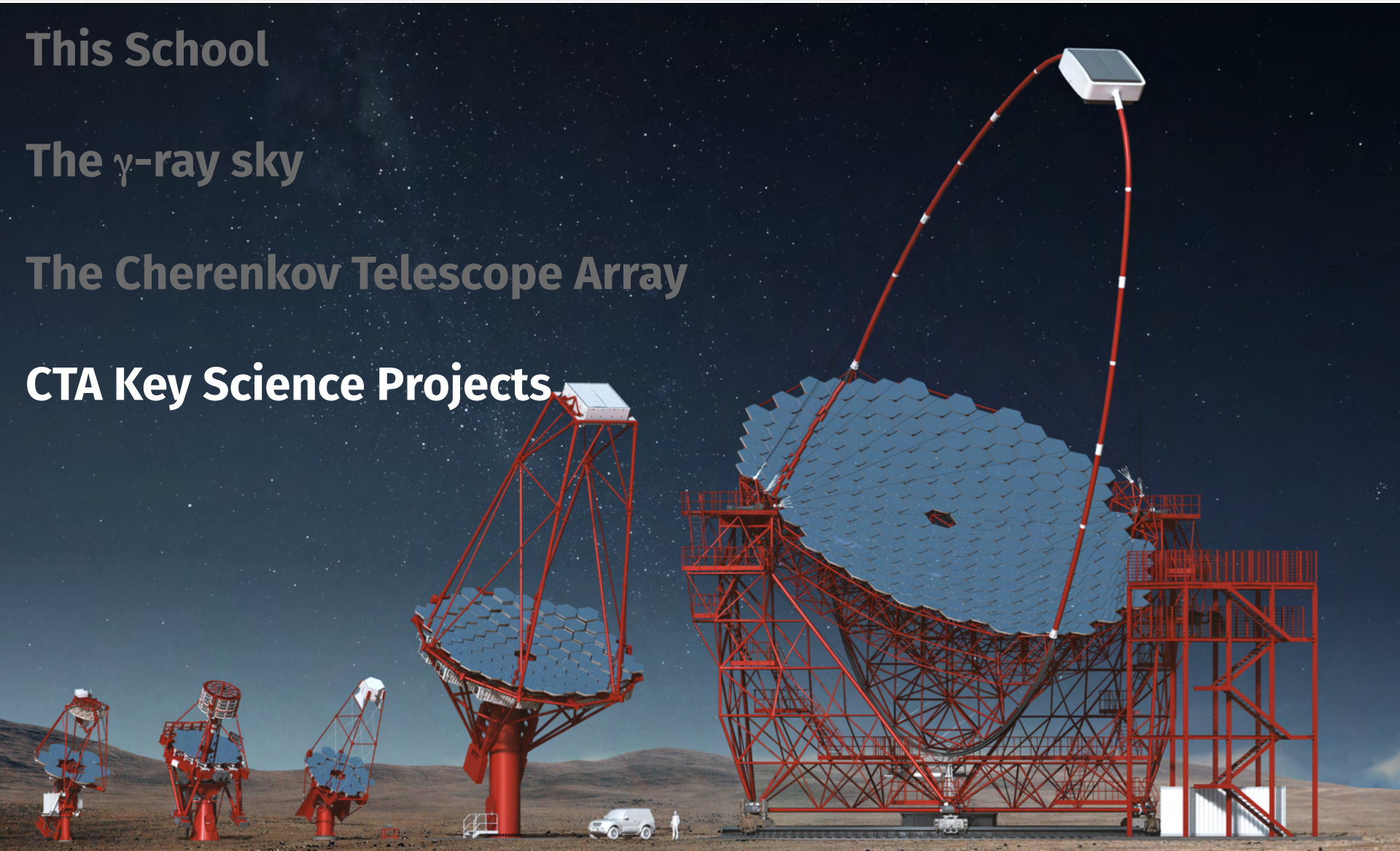
Outline

This School

The γ-ray sky

The Cherenkov Telescope Array

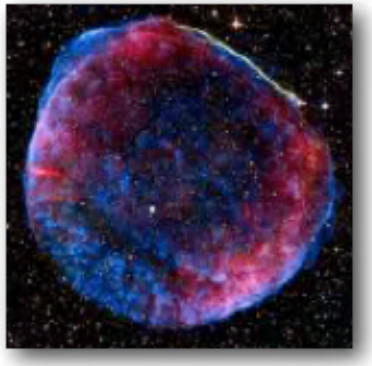
CTA Key Science Projects



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

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.

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

CTA science and KSPs

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

Restricted | Europe

CTA PHYS WG Face-to-Face Meeting

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
- Accomodation
- 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
Saupfercheckweg 1
69117 Heidelberg
Germany

Stefan Funk
Stefano Vercellone

Materials

MPI 19.9.2017_Menu.pdf

Registration
Registration for this event is currently open.
Register now

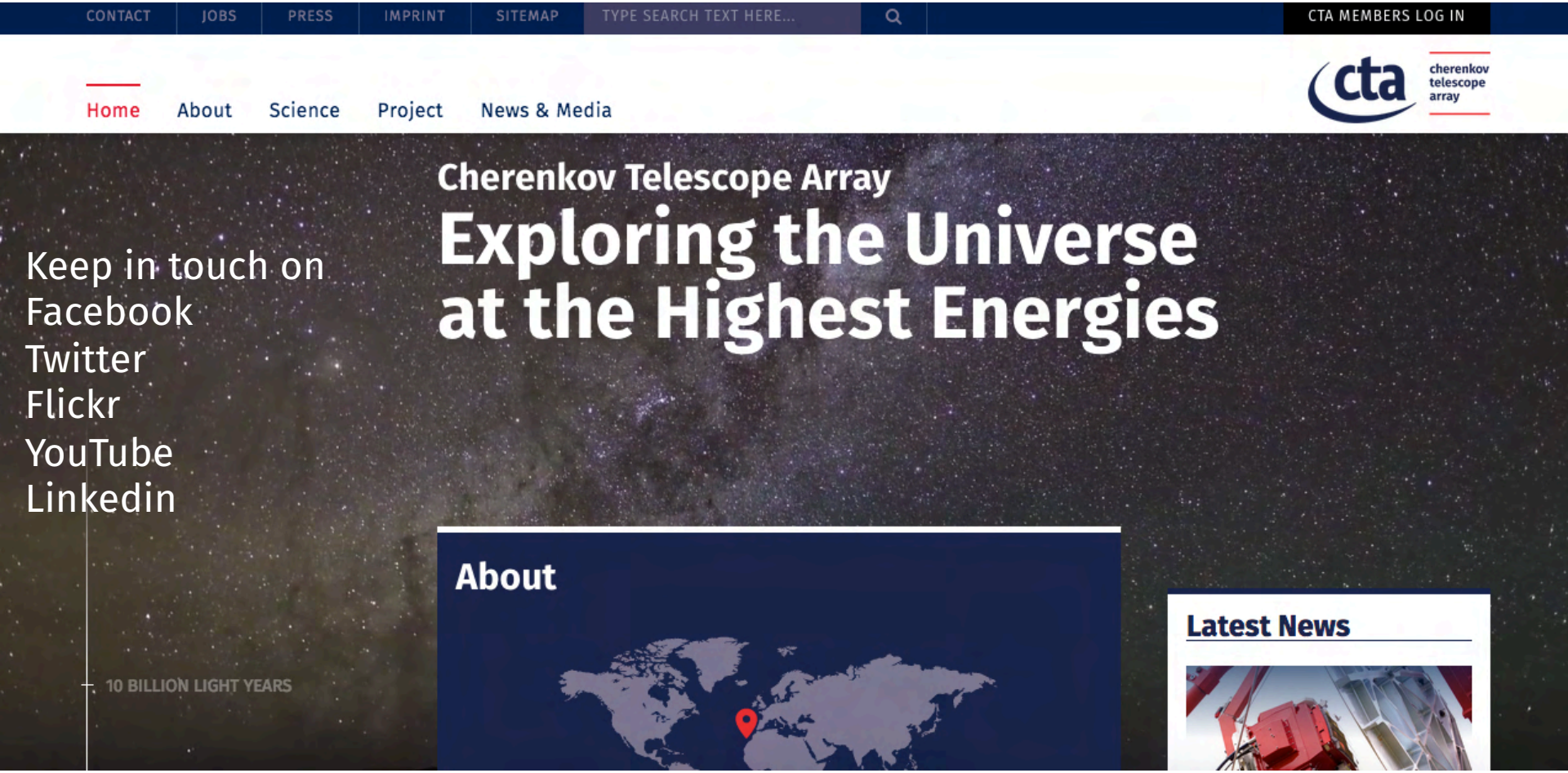
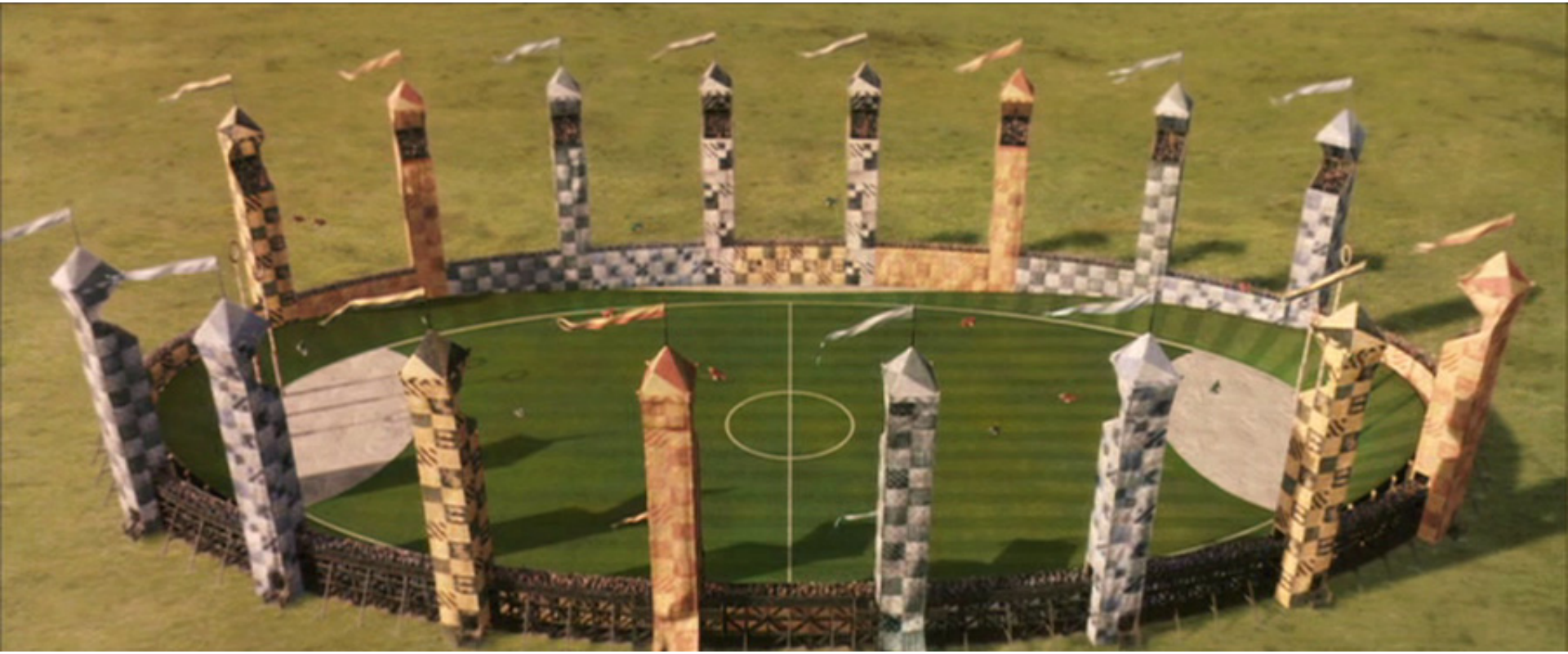
The call for abstracts is open
You can submit an abstract for reviewing.
Submit new abstract

Local Organizers

Roberta.Zanin@mpi-hd....
sabrina.casanova@mpi-...

CTA Main webpage

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



And now... let’s have fun !