Unveiling the Gamma-Ray Universe with the CTA: the Key Science Projects

Stefano Vercellone (INAF – OA Brera)

stefano.vercellone@brera.inaf.it

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

"ti sian lievi le stelle"

Outline

The γ-ray sky

The Cherenkov Telescope Array

CTA Key Science Projects

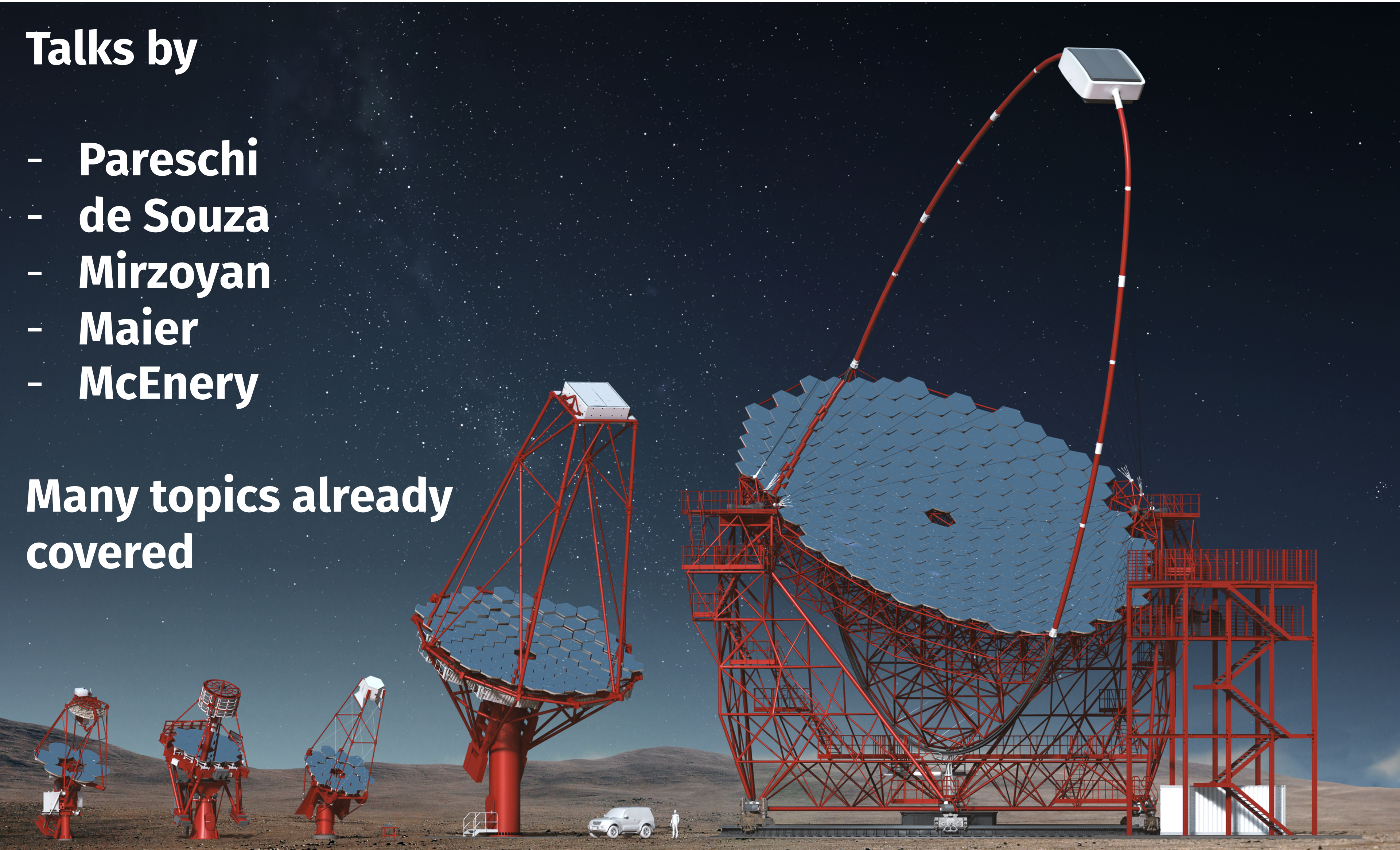
Prospects & discussion

Outline

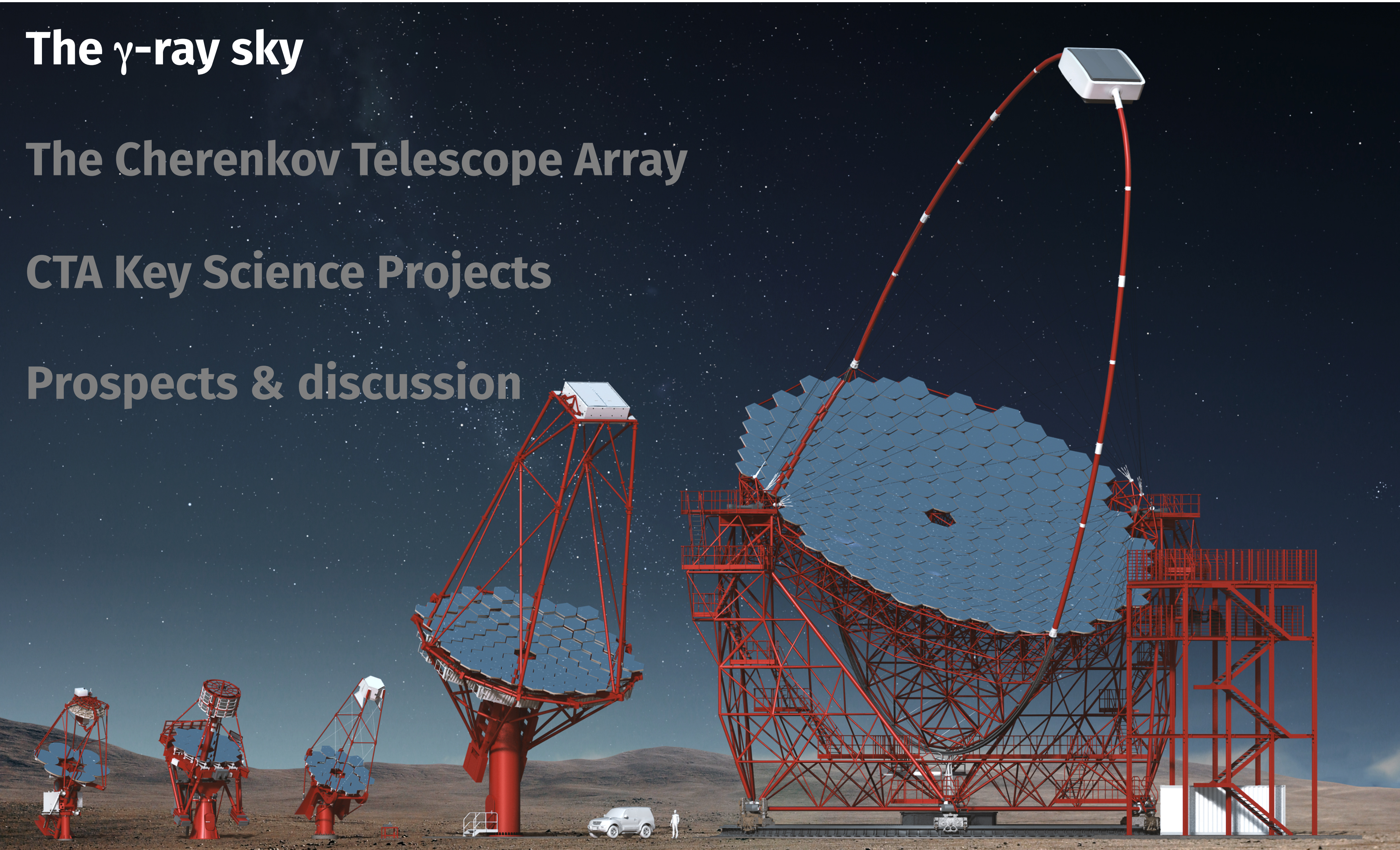
Talks by

- Pareschi
- de Souza
- Mirzoyan
- Maier
- McEnery

Many topics already covered



Outline



The γ-ray sky

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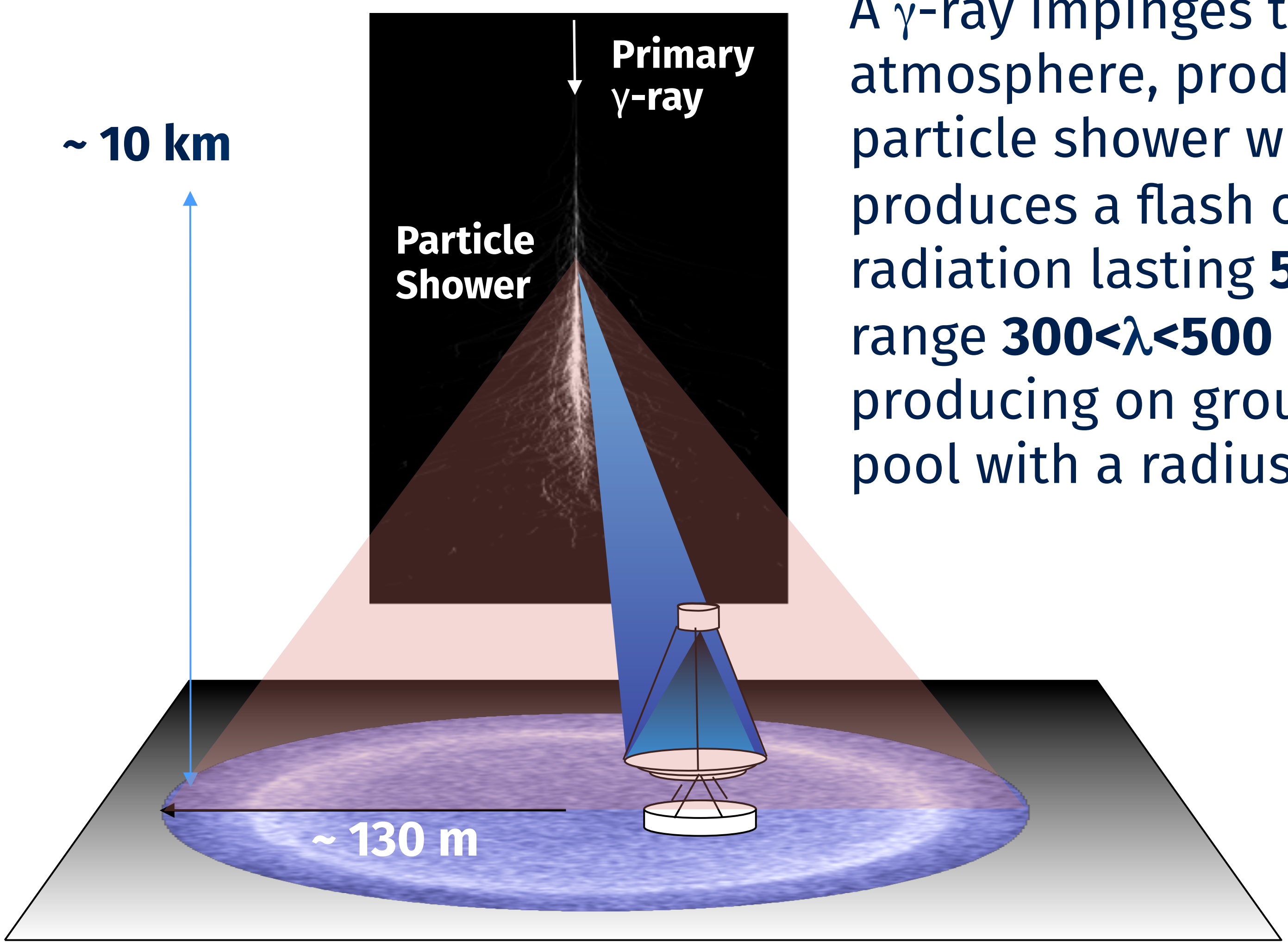
The Cherenkov Telescopes



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

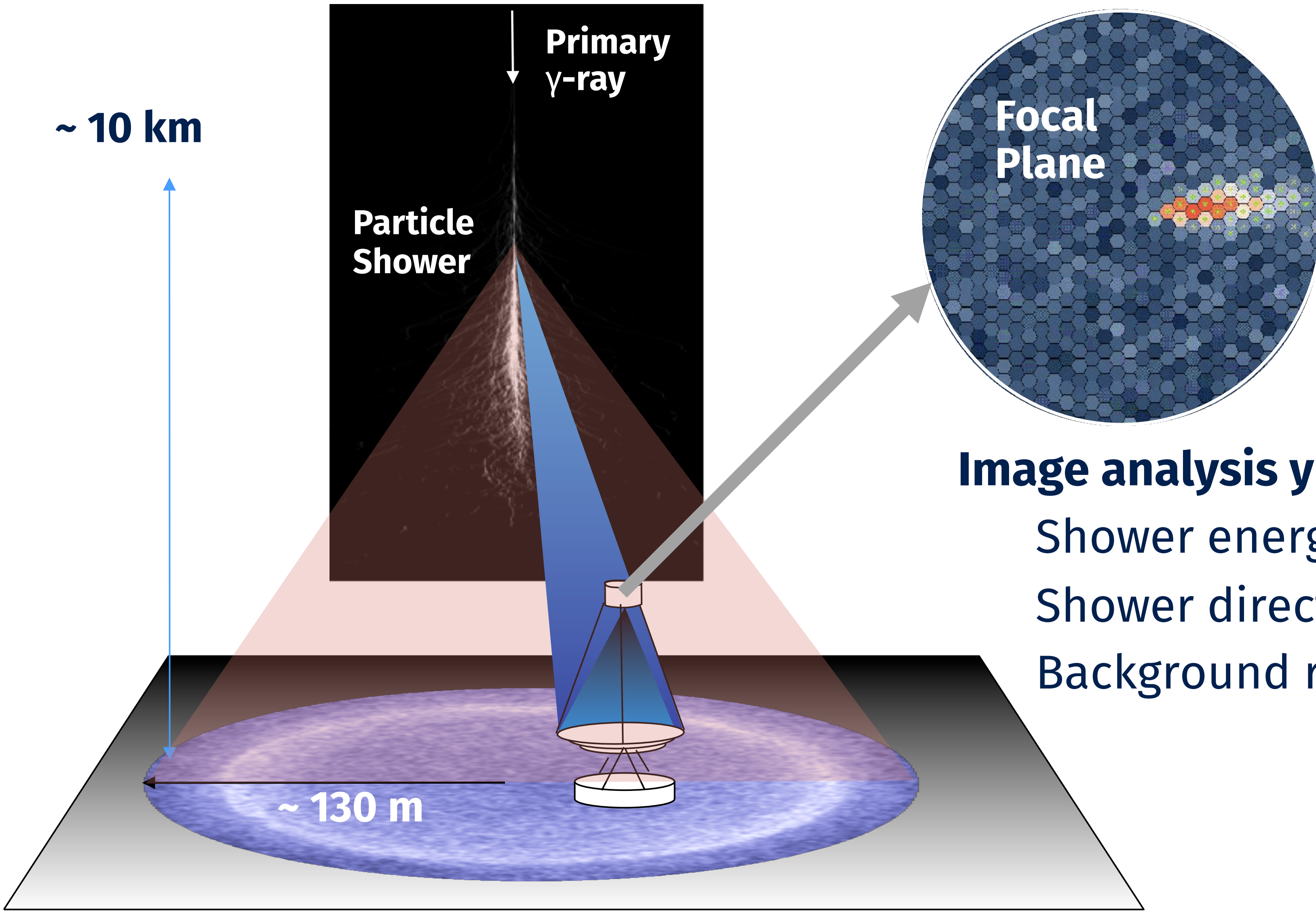


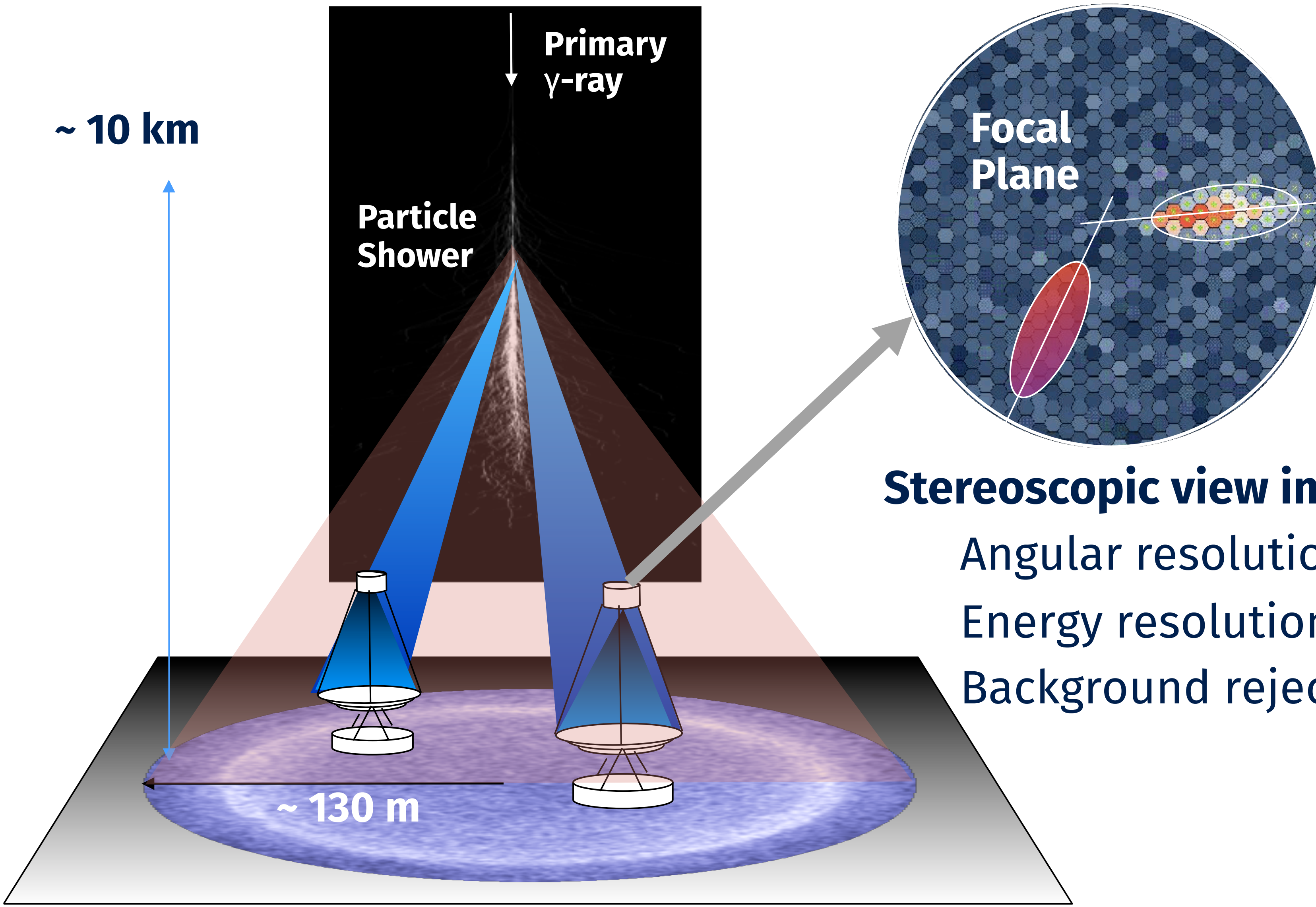
Image analysis yields

Shower energy

Shower direction

Background rejection

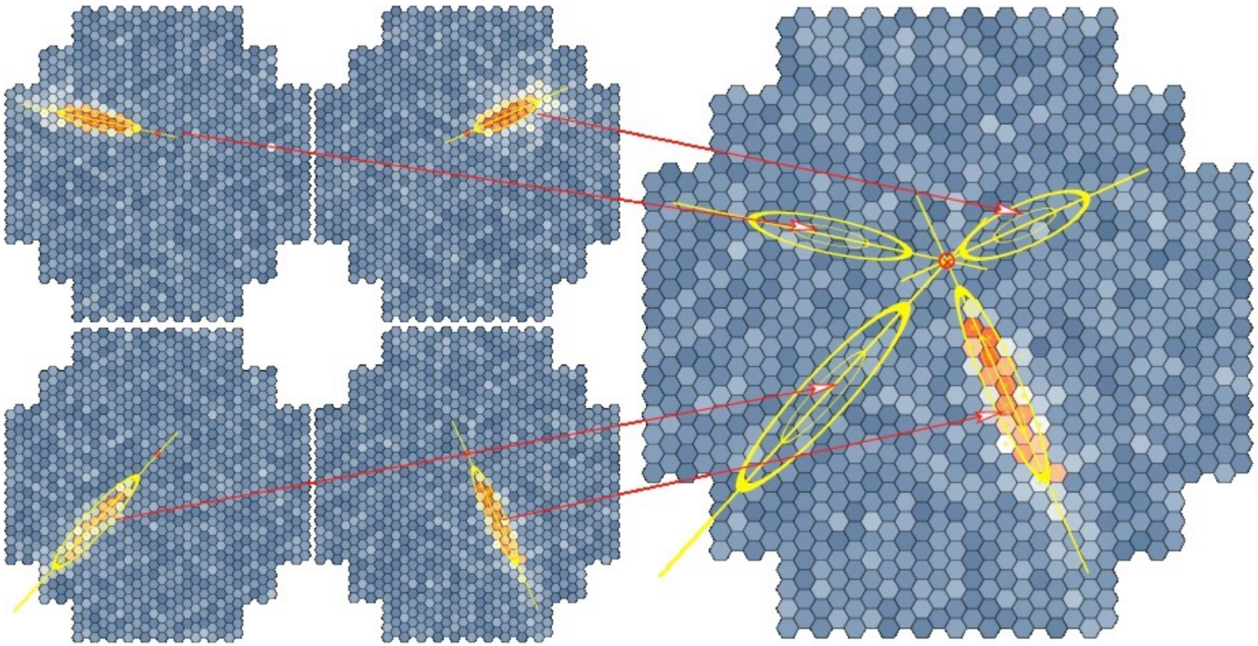
The Cherenkov Telescopes



Stereoscopic view improves

- Angular resolution
- Energy resolution
- Background rejection

The Cherenkov Telescopes

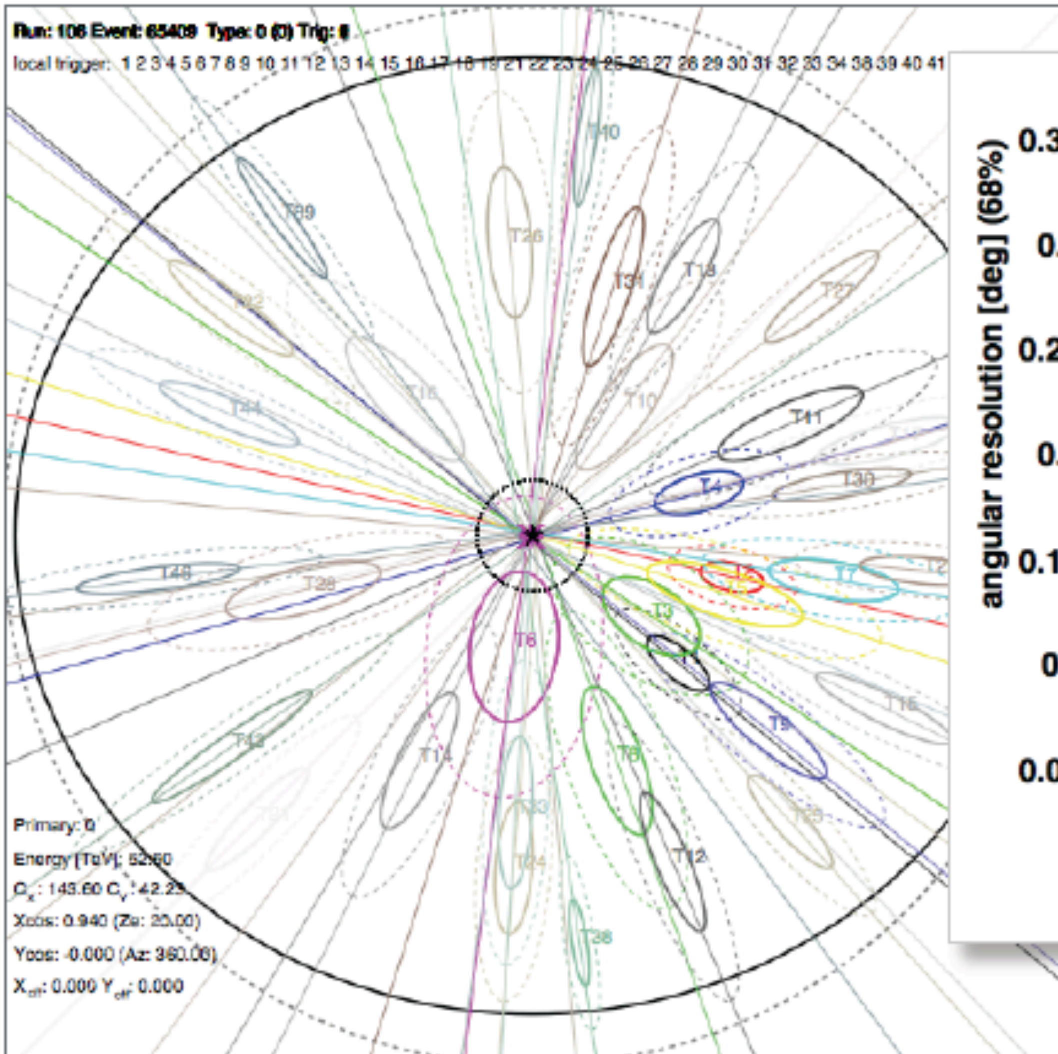


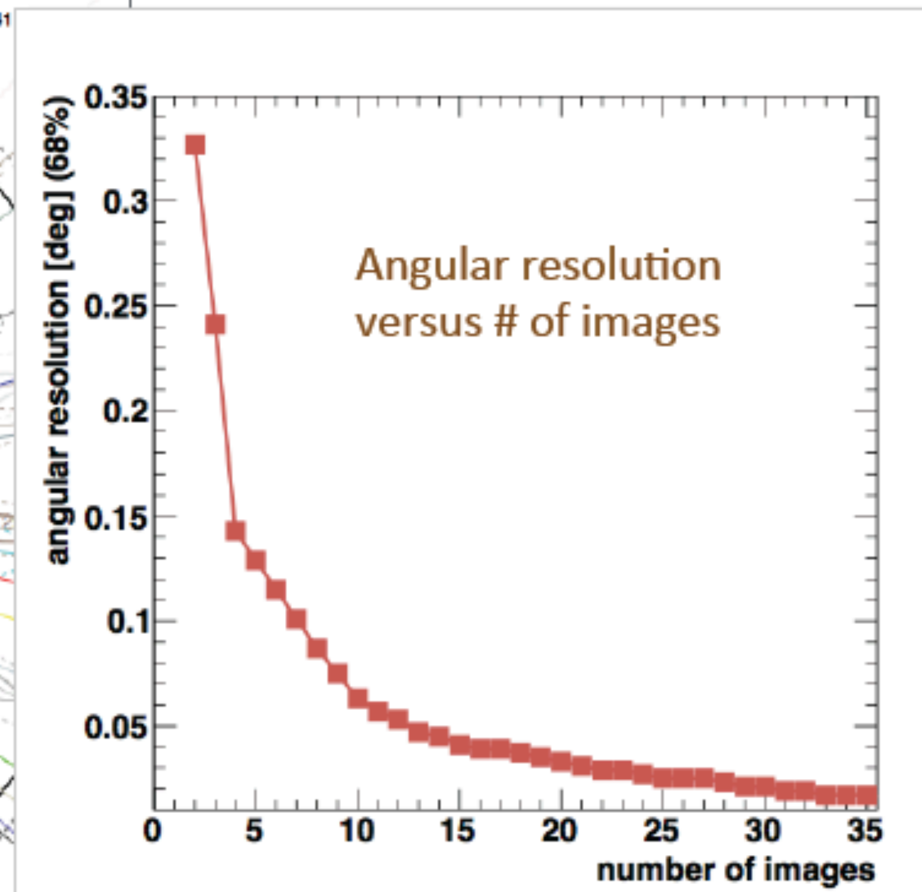
The intersection of major axes on the common FOV gives source position on the sky.

More on the Cherenkov technique, sources and physics in:

Hinton & Hofmann, 2009, ARAA, 47, 523

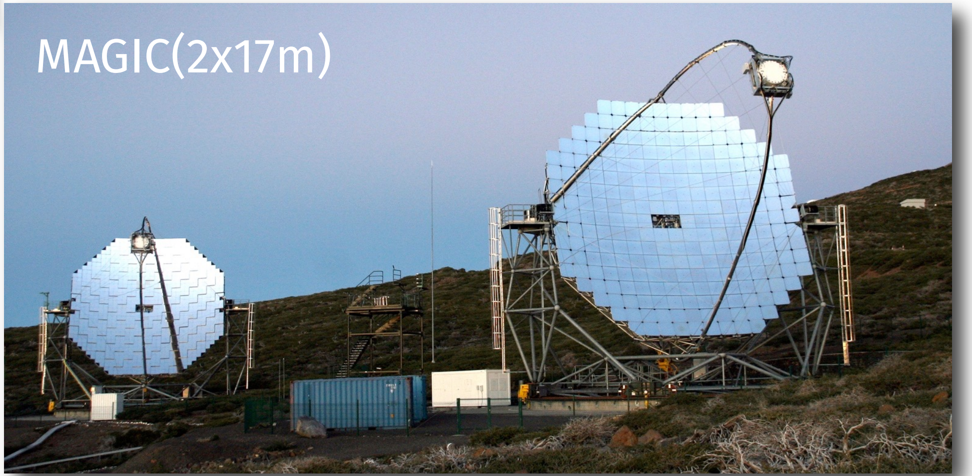
Air Shower Viewed with Many Telescopes





Hofmann, 2016

The current IACT status



VHE high-level timeline

Hillas, 1985

445

OG 9.5-3

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

Weeks et al., 1989

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,[5] D. Macomb,[5] N. A. Porter,[3] P. T. Reynolds,[1,3] and G. Vacanti[5]

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.

I. INTRODUCTION

1 source

The basics

>150 sources

Hinton & Hoffmann, 2009

Teraelectronvolt Astronomy

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

Key Words

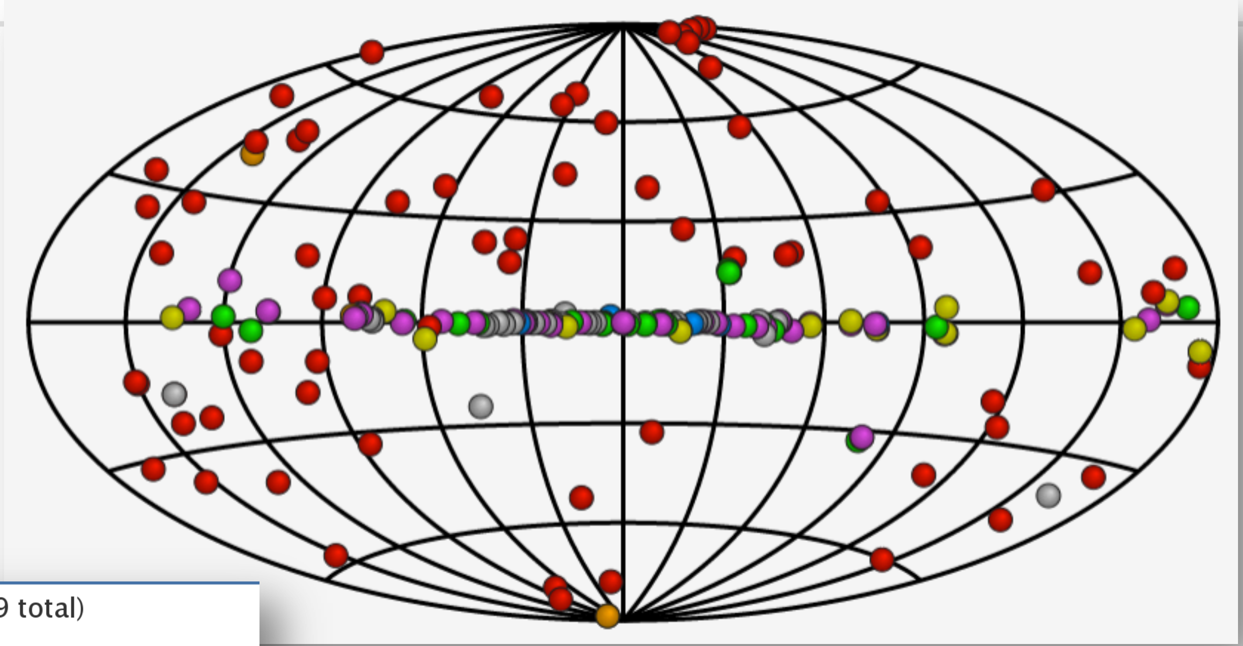
gamma-ray astronomy, high-energy astrophysics

Abstract

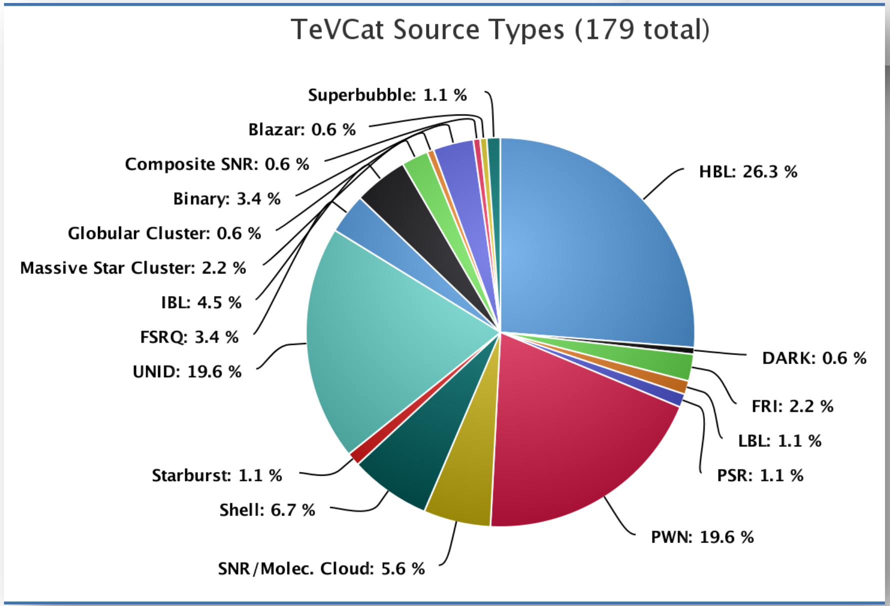
Ground-based γ-ray astronomy, which provides access to the TeV energy range, is a young and rapidly developing discipline. Recent discoveries in this waveband have important consequences for a wide range of topics in astrophysics and astroparticle physics. This article is an attempt to review the experimental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

100 GeV – 50 TeV sky

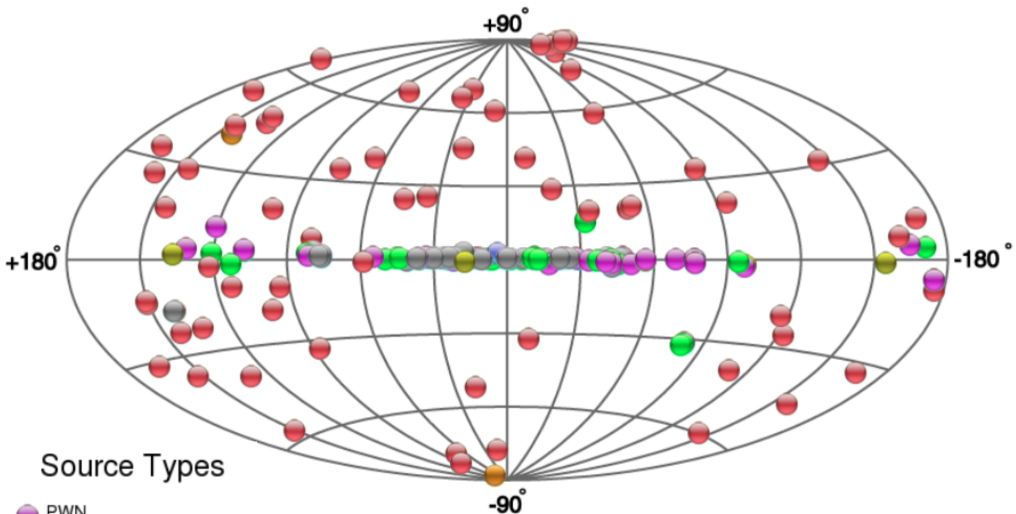
TeVCat 2
H.E.S.S., MAGIC, VERITAS
~180 sources
E>100 GeV



Wakely & Horan+16

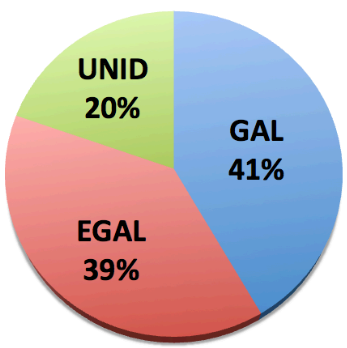


The Fermi sky above 50 GeV

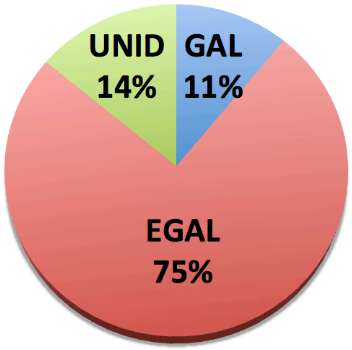


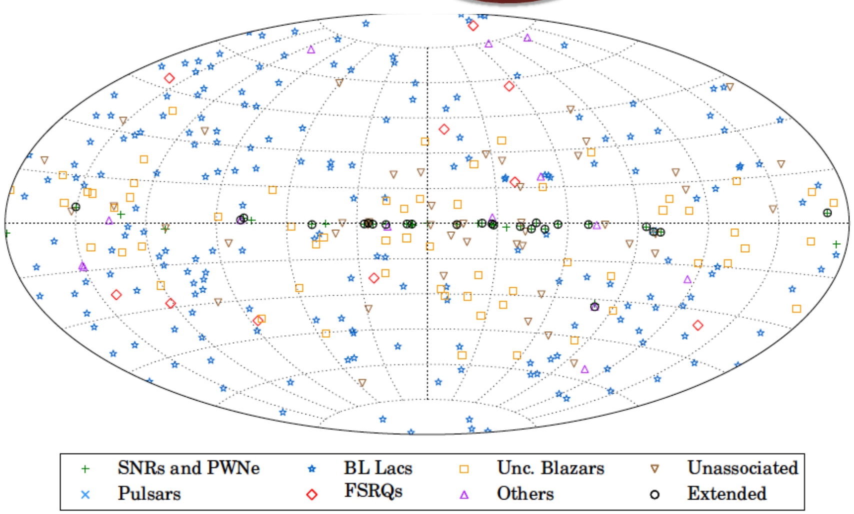
Wakely & Horan http://tevcat.uchicago.edu/

~180 TeVCat sources



360 *Fermi*-LAT sources E>50 GeV

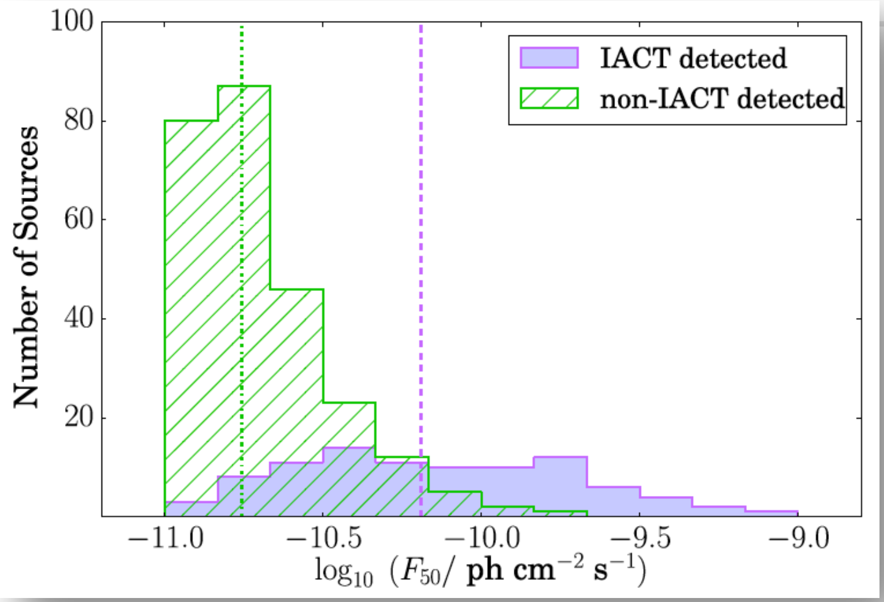


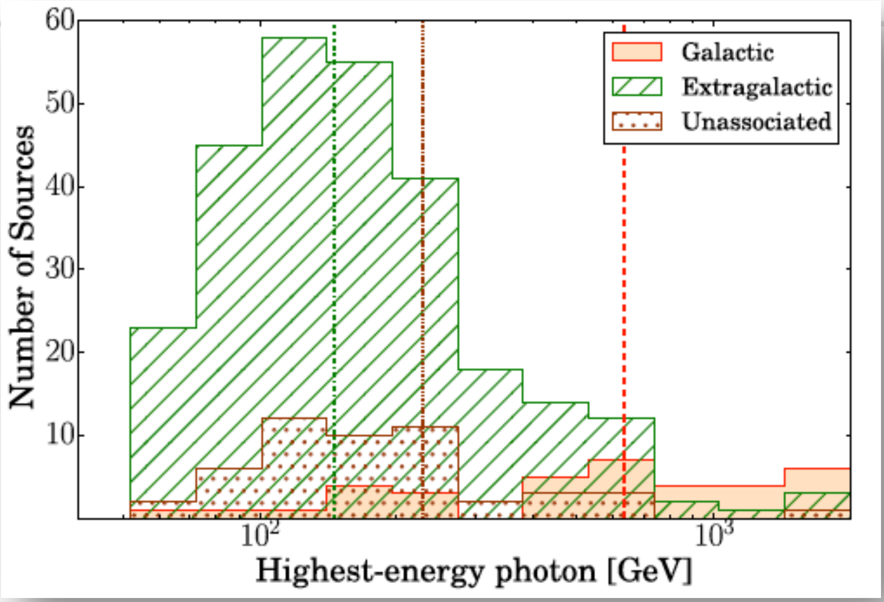


2FHL Ackermann+16

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.

The Fermi sky above 50 GeV





2FHL Ackermann+16

360 sources

282 non-IACT

216 |b|>10º

66 |b|<10º

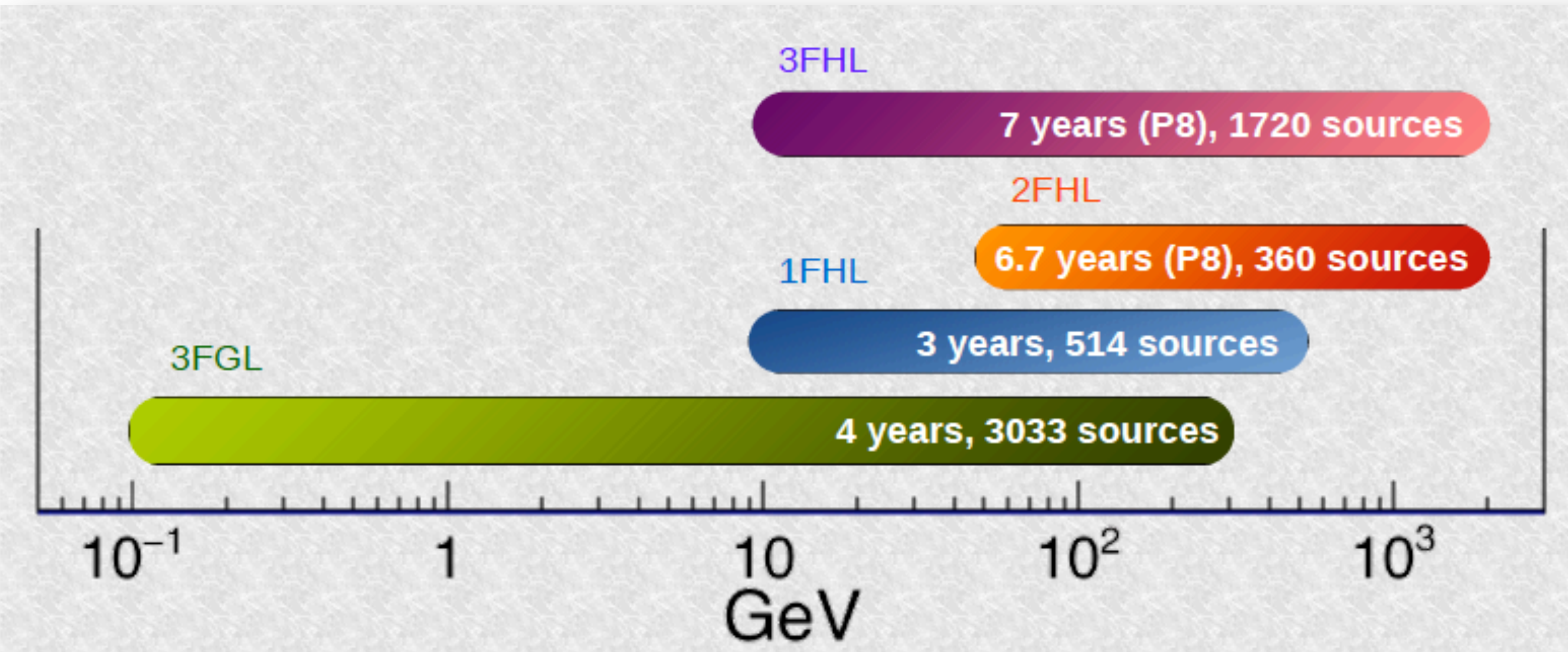
~25% of Galactic sources (20-30) has a photon index harder than 2 → high-energy SED peak in the TeV band.

Fermi-LAT detects emission from many Galactic sources well beyond 500 GeV.

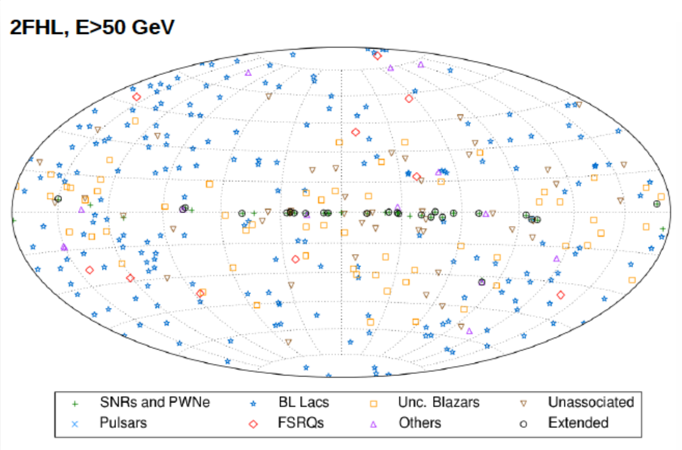
Beyond 2FHL → 3FHL

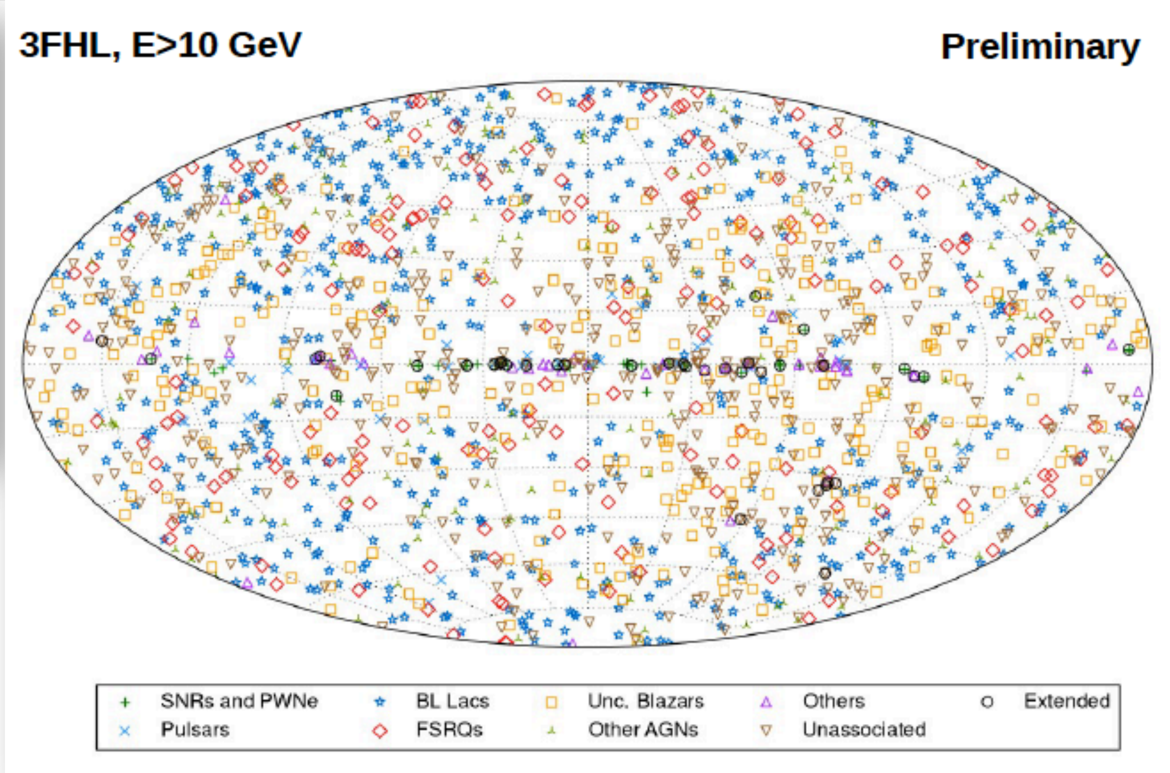
Preliminary *Fermi*/LAT results E>10 GeV

Dominguez+16

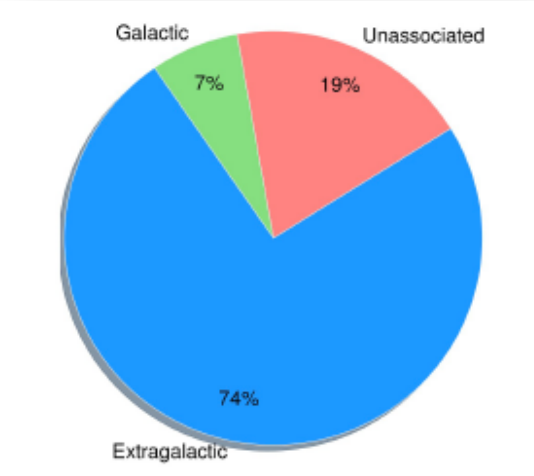


Beyond 2FHL → 3FHL





3FHL, arXiv:1702.00664



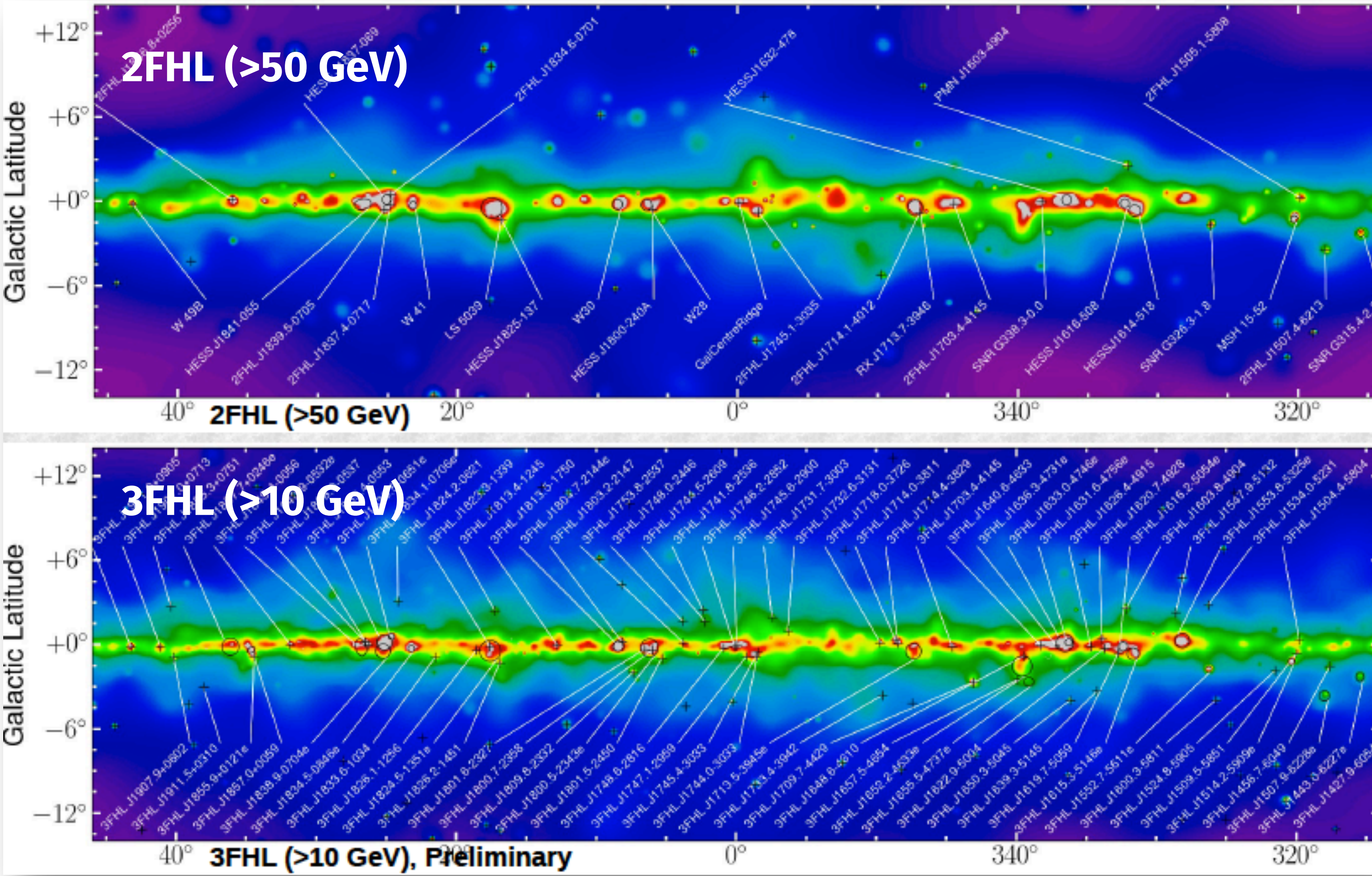
10 GeV – 2 TeV

7 years of data

1556 sources

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

Beyond 2FHL → 3FHL

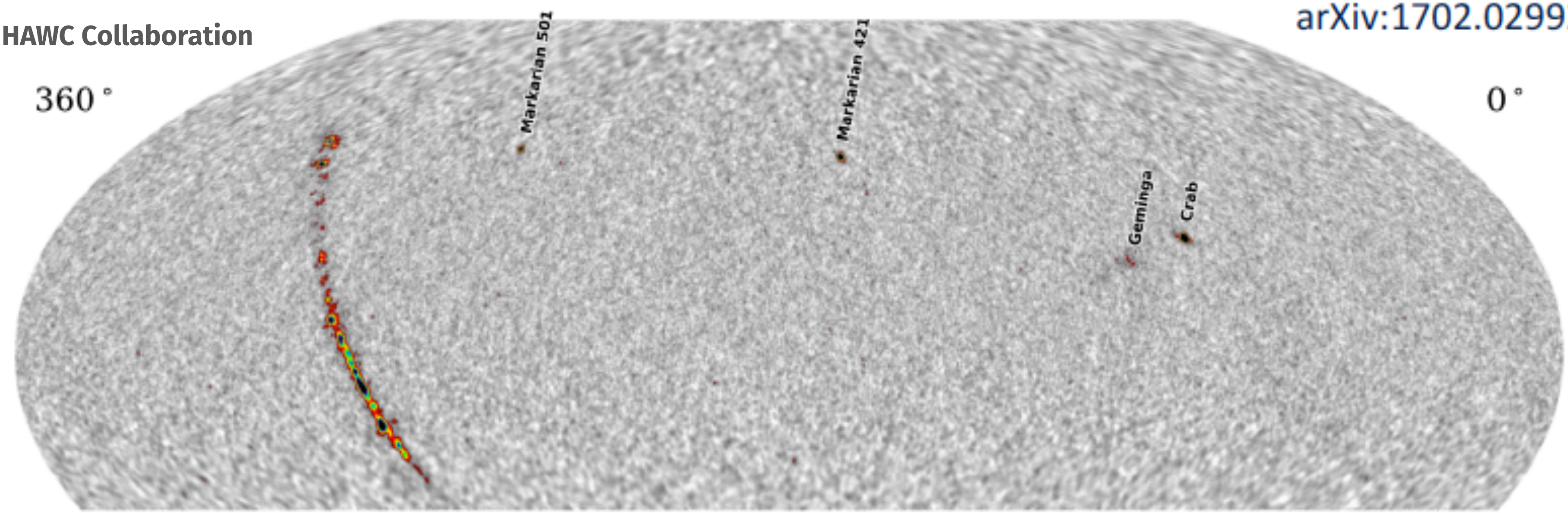


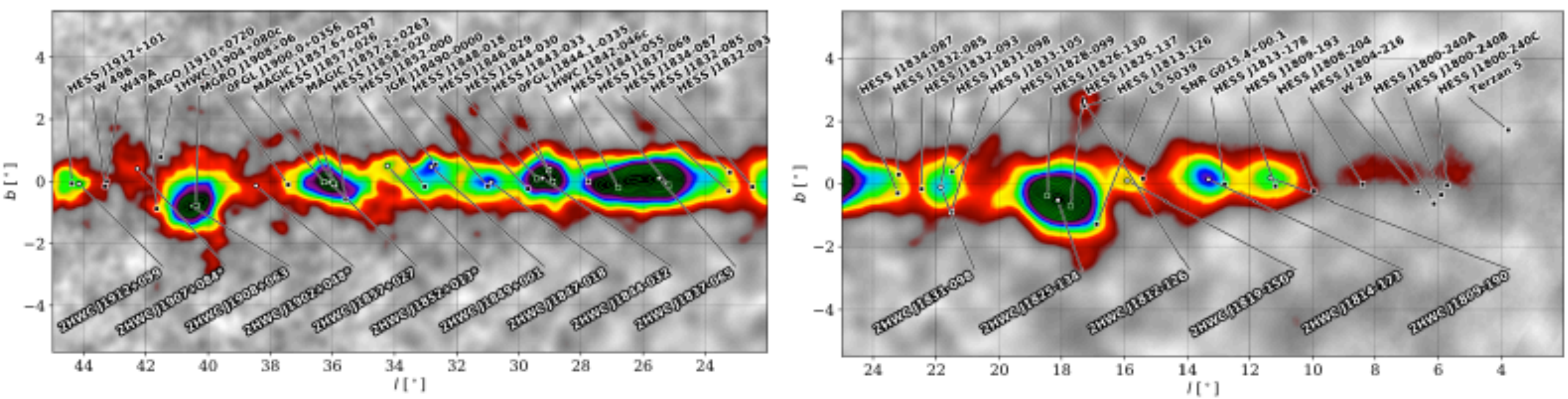
3FHL Dominguez Gamma2016

0.1 – 100 TeV sky

HAWC Collaboration

arXiv:1702.02992





Outline

The γ-ray sky

The Cherenkov Telescope Array

CTA Key Science Projects

Prospects & discussion

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

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

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

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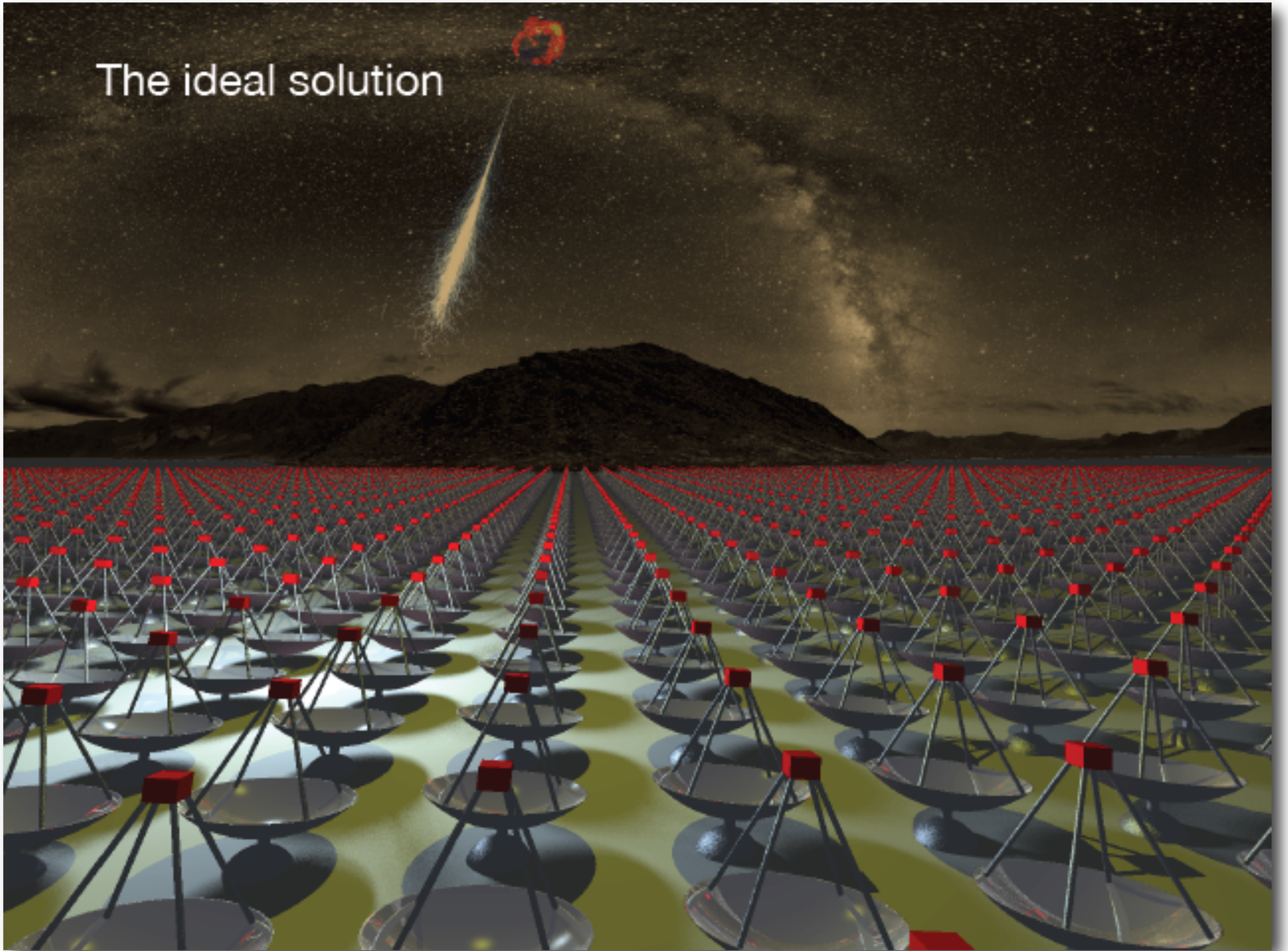
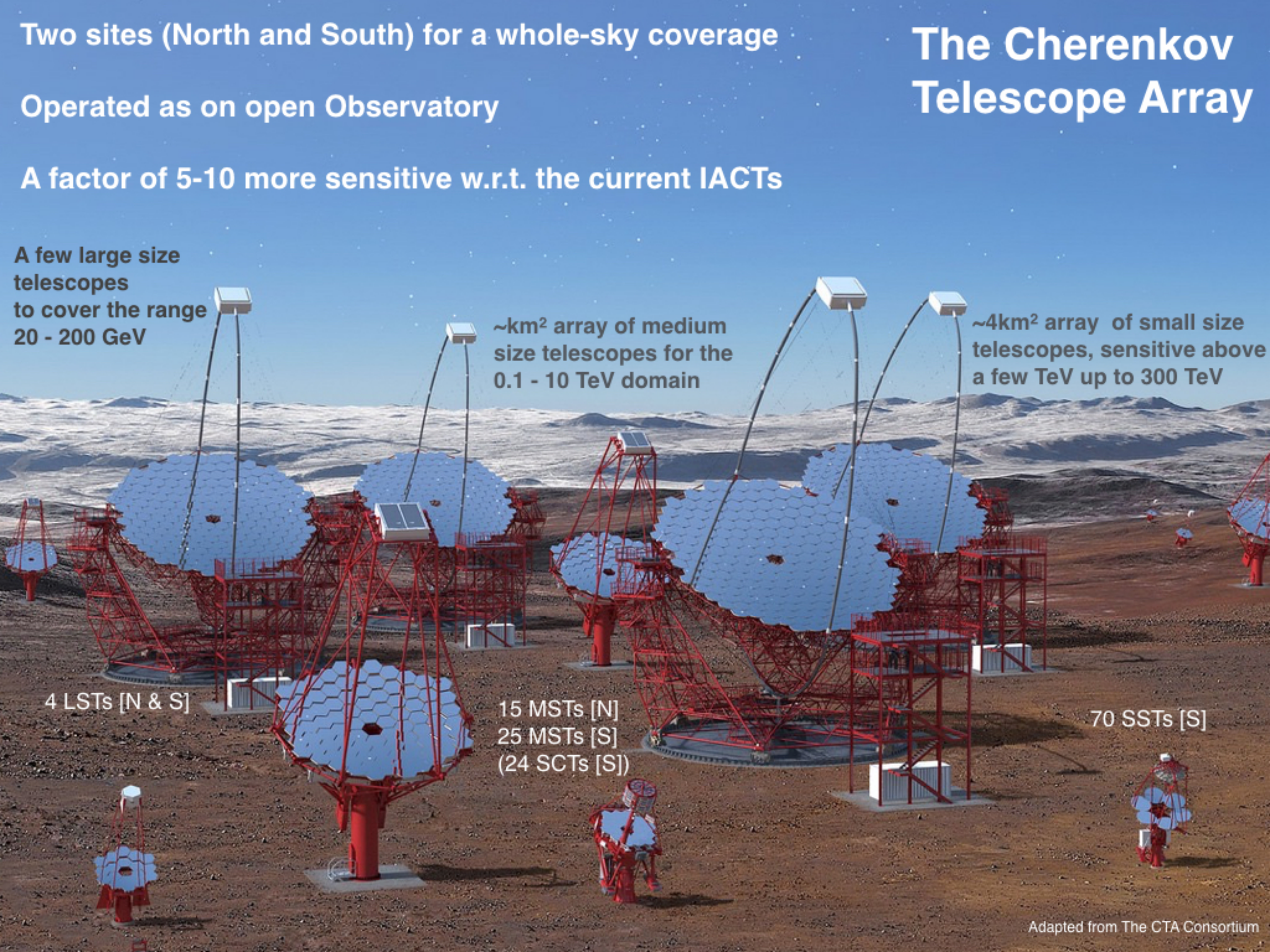
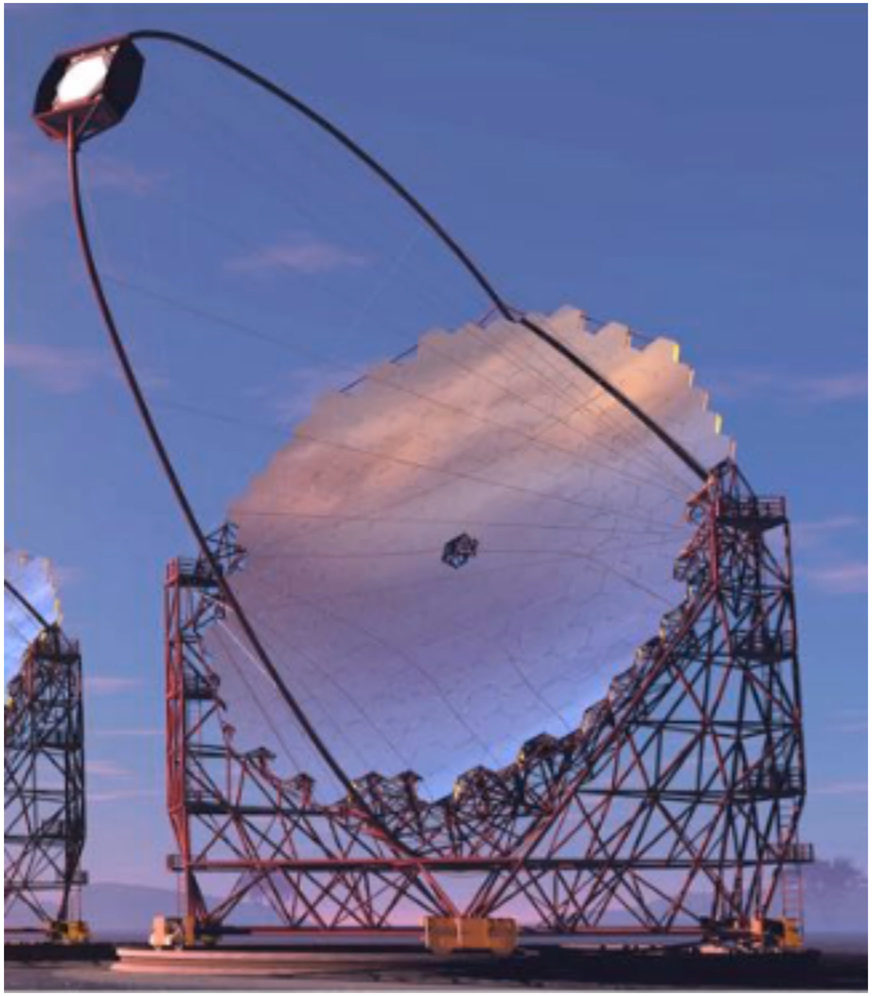



Two sites (North and South) for a whole-sky coverage
Operated as on open Observatory
A factor of 5-10 more sensitive w.r.t. the current IACTs
The Cherenkov Telescope Array
A few large size telescopes to cover the range 20 - 200 GeV
~km² array of medium size telescopes for the 0.1 - 10 TeV domain
~4km²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

Where to find us

Large Size Telescope

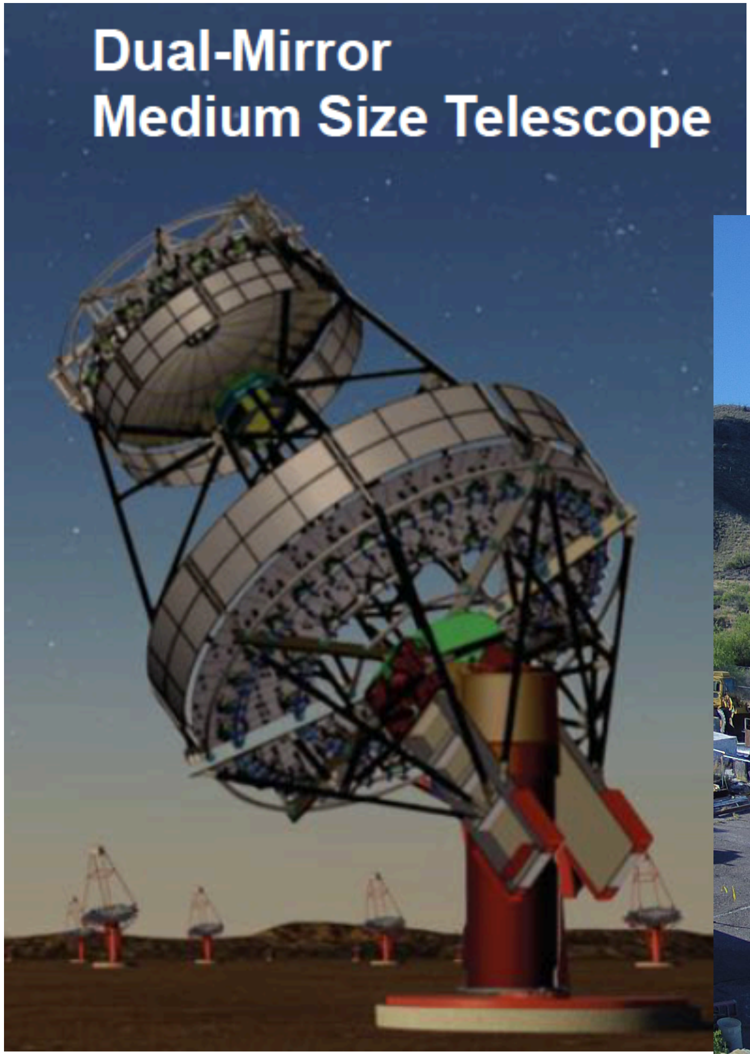


- La Palma prototype operational in 2018.
- http://webcam.lst1.iac.es/stream2view.htm

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 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

The Cherenkov Telescope Array
(South Site)

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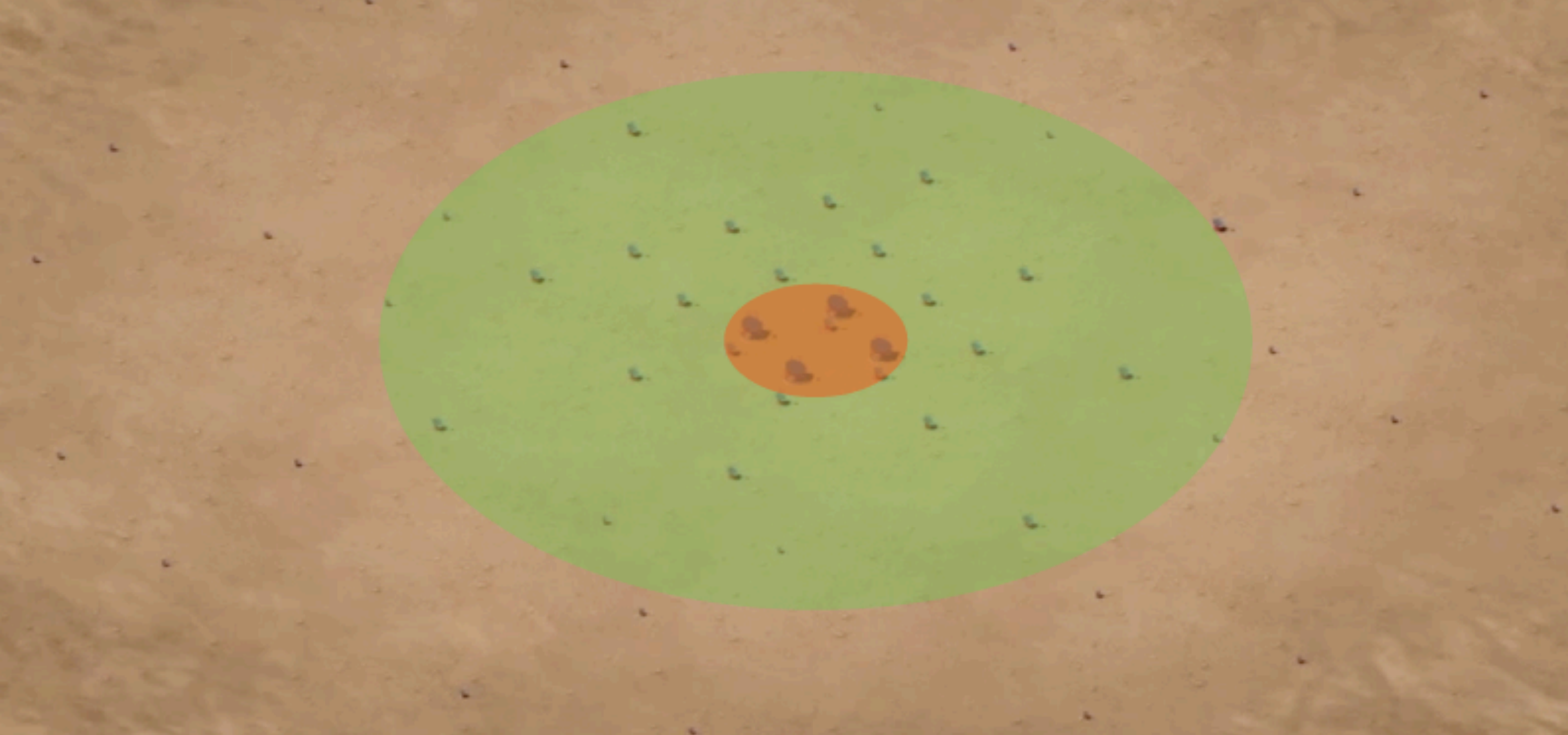
(South Site)

The Cherenkov Telescope Array

(South Site)

25 x 14 m ⌀ Medium Size Telescopes (MST)

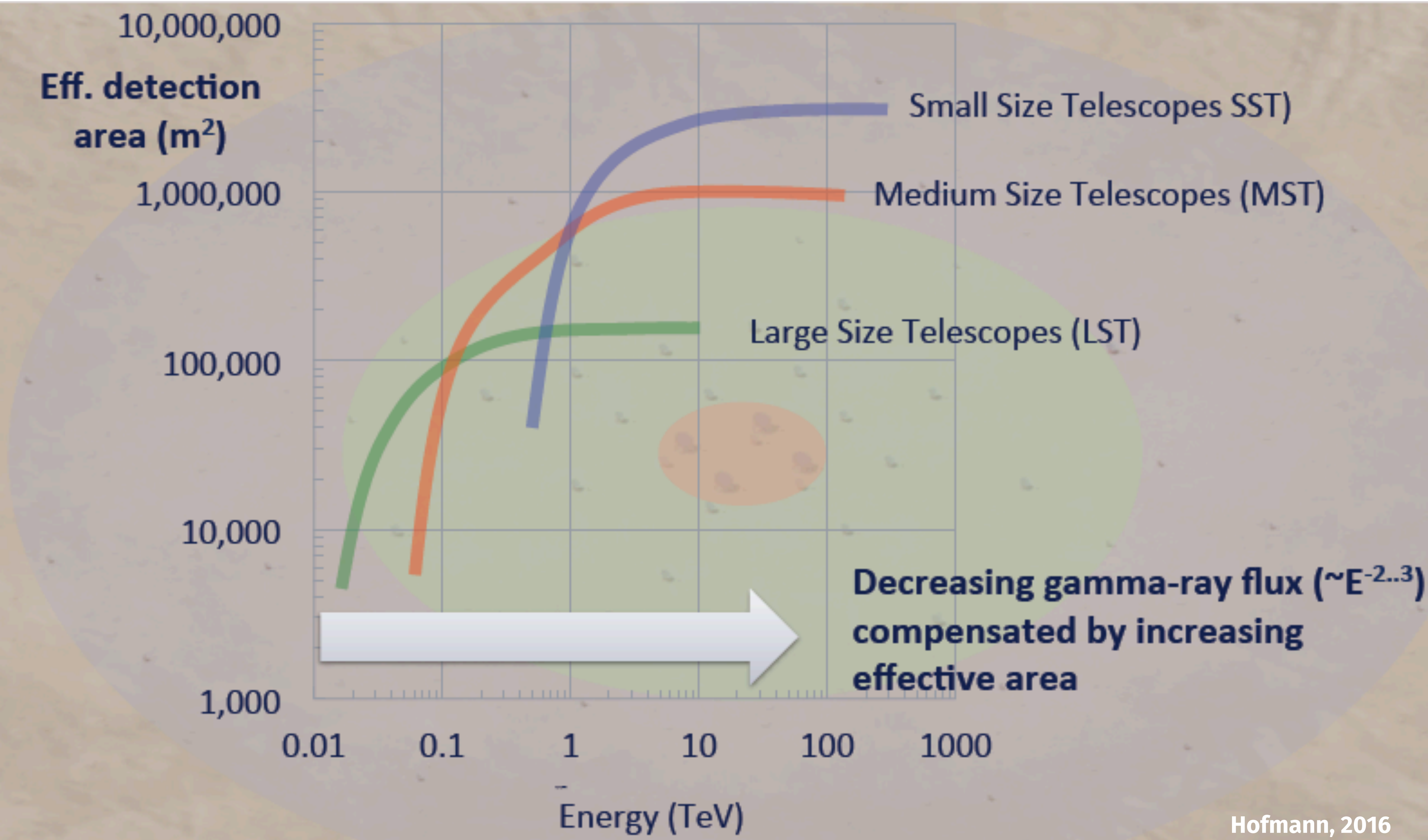
~100 GeV to ~10 TeV range



Hofmann, 2016

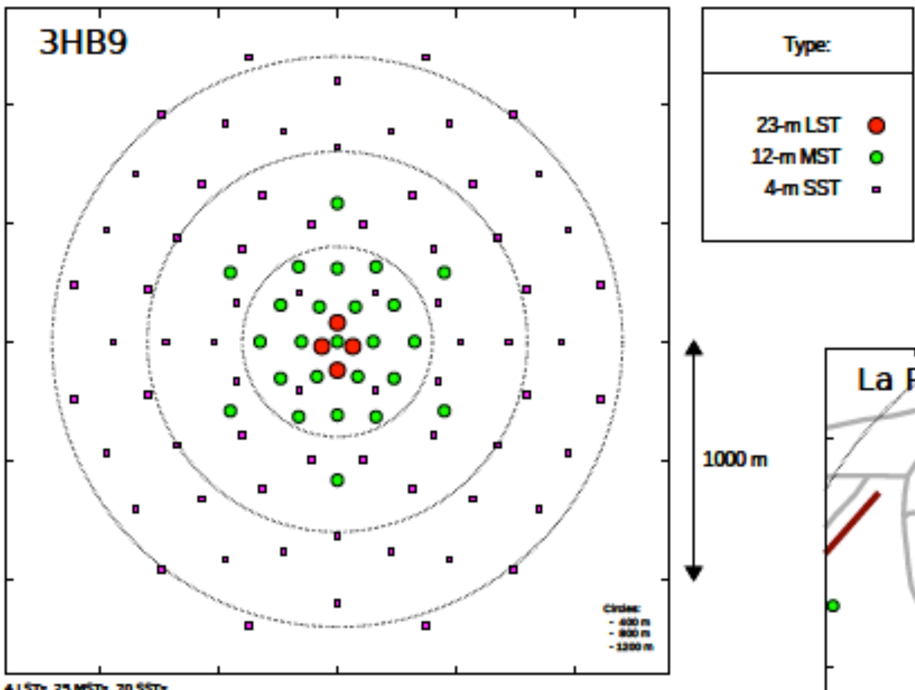
The Cherenkov Telescope Array
(South Site)

Effective area for gamma-ray detection



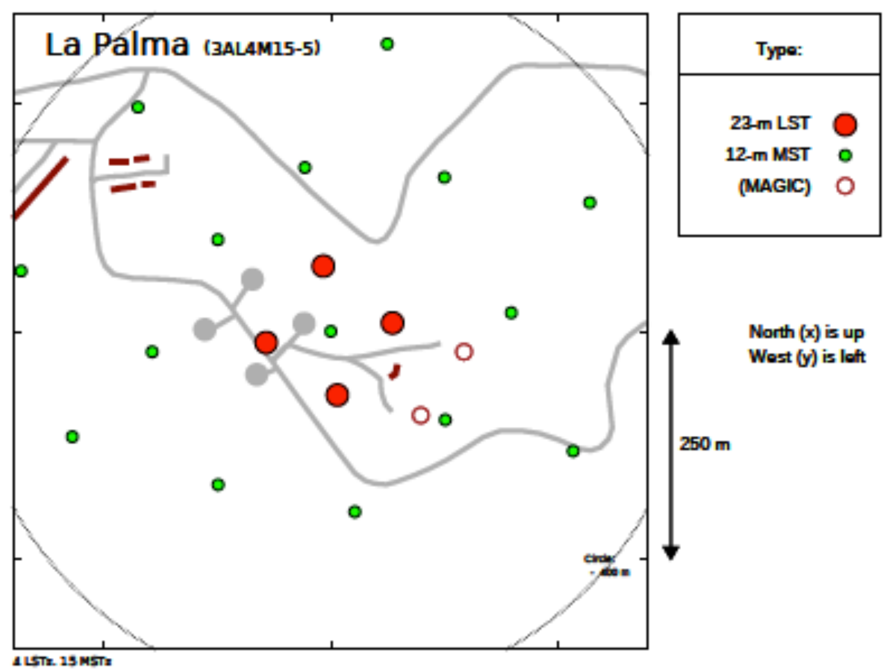
Hofmann, 2016

CTA Telescope layout



South:
4 LST
25 MST
70 SST

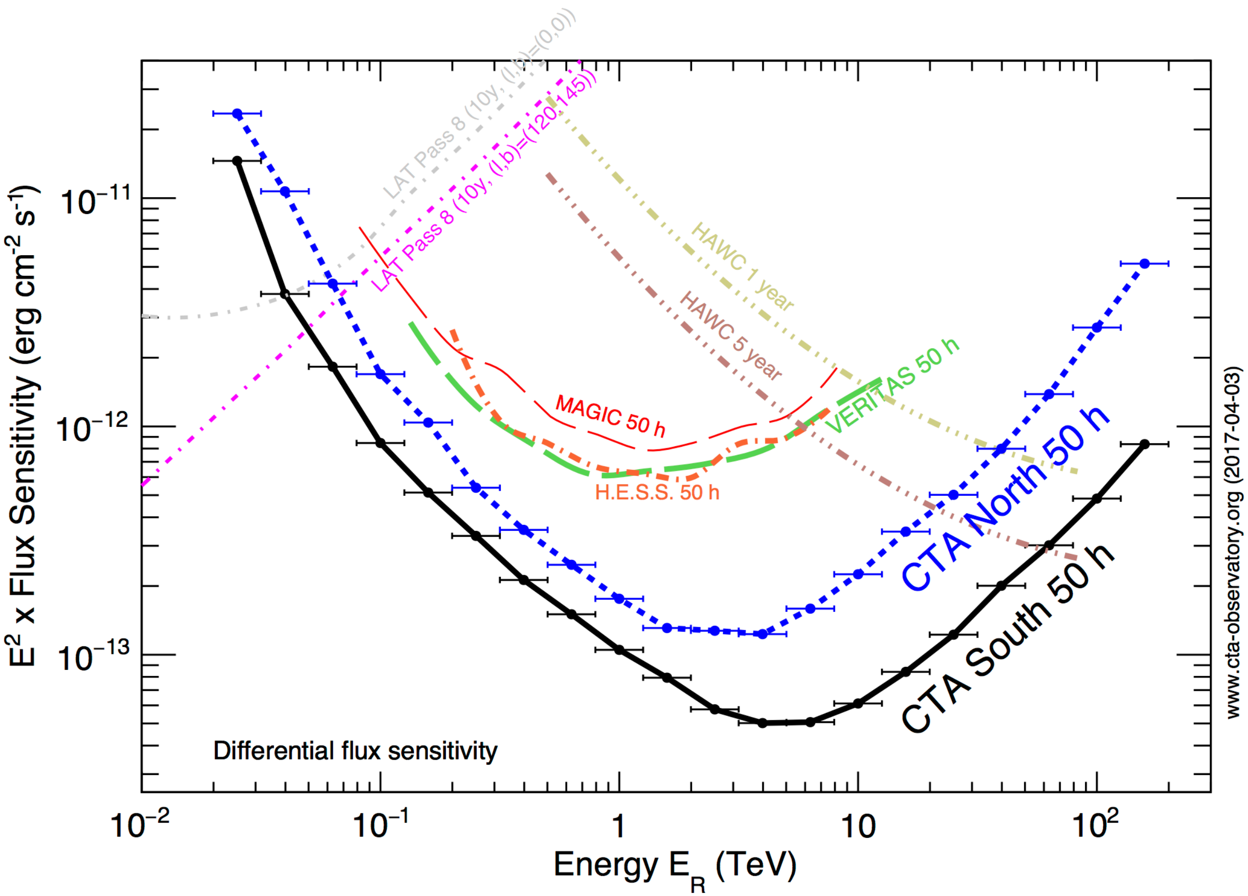
North:
4 LST
15 MST



Credits: The CTA Consortium

CTA Performance

Differential Sensitivity

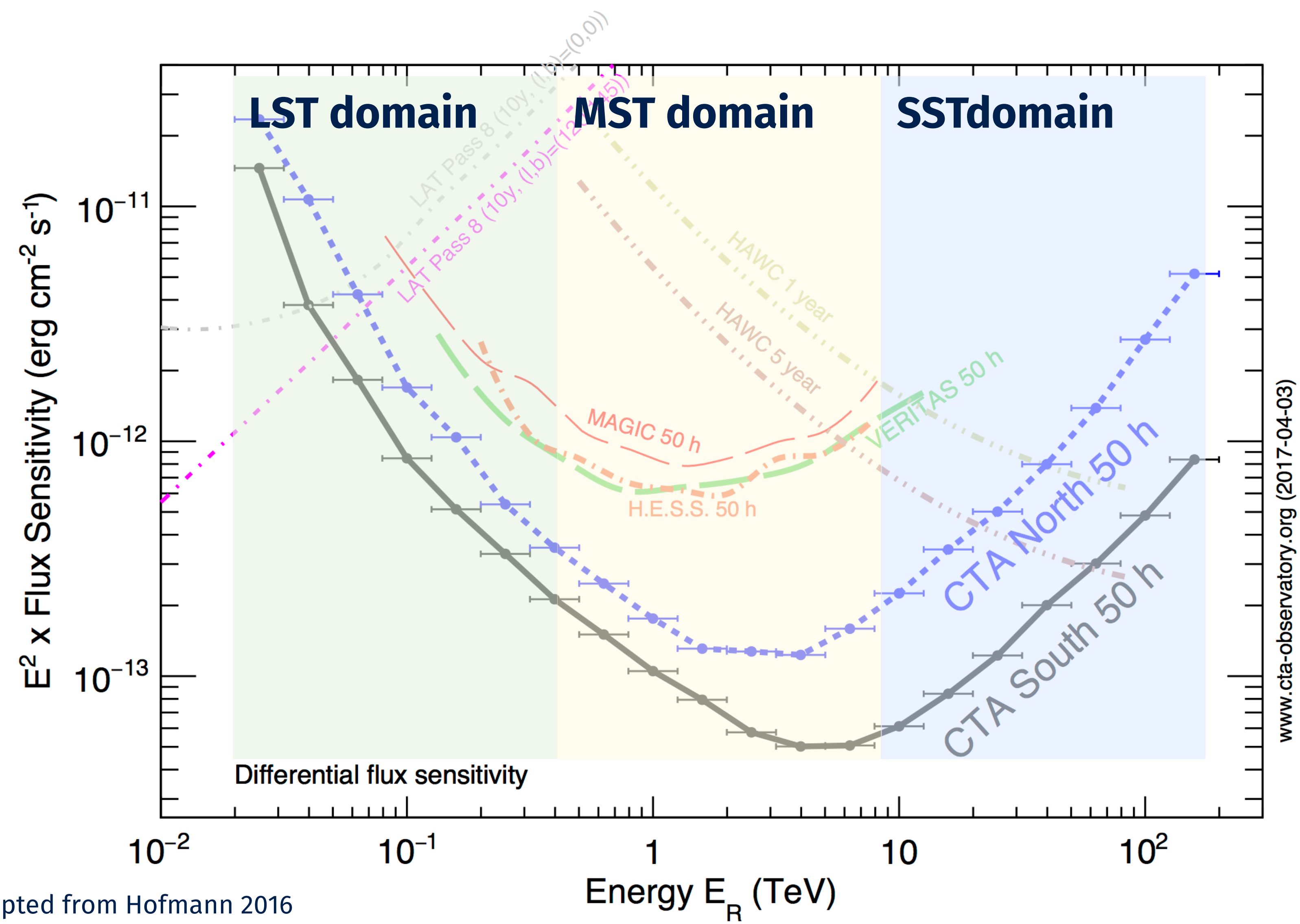


A factor of **5-10 improvement** in sensitivity in the domain of **about 100 GeV to some 10 TeV.**

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

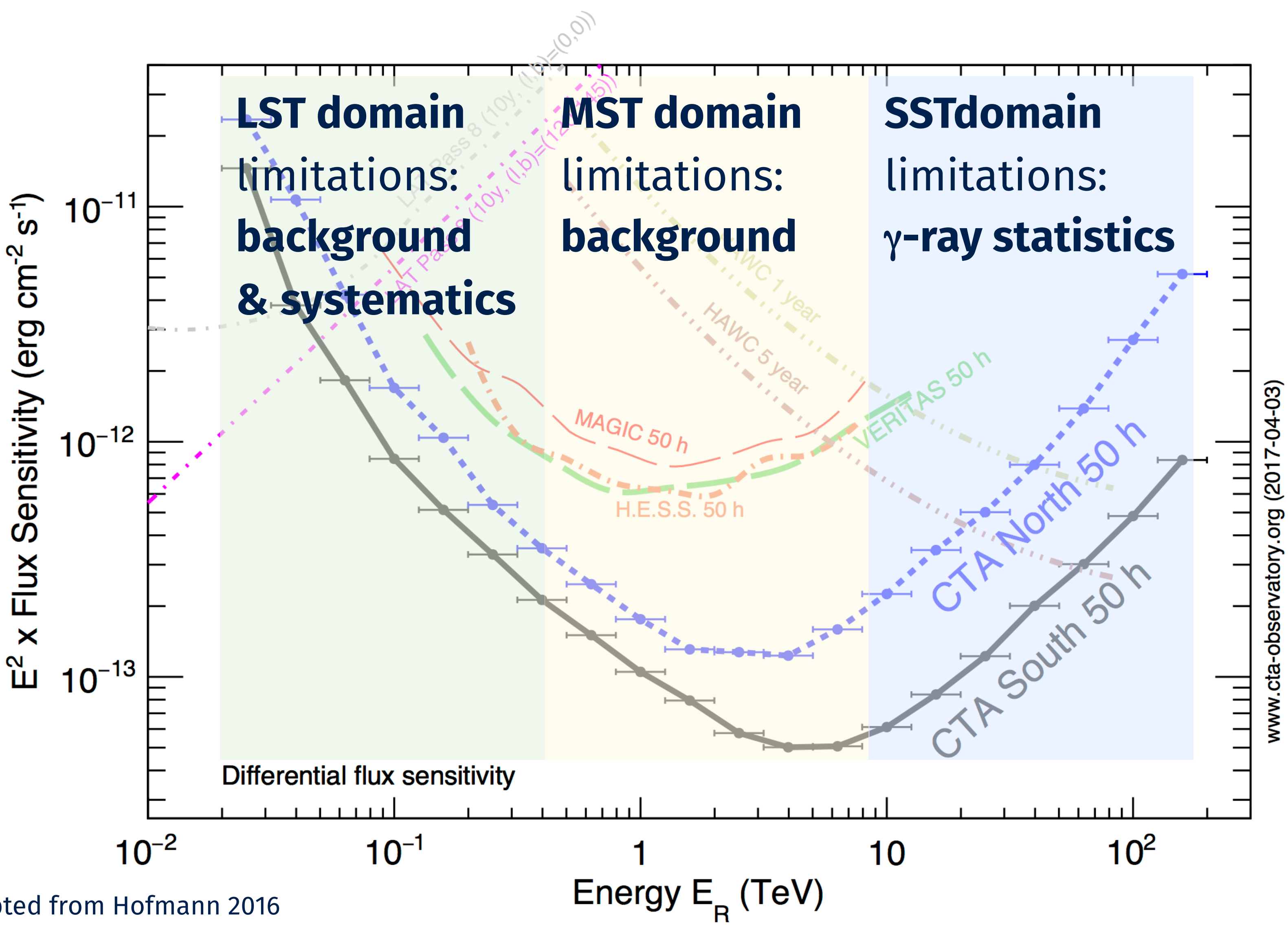
Credits: The CTA Consortium

CTA Performance



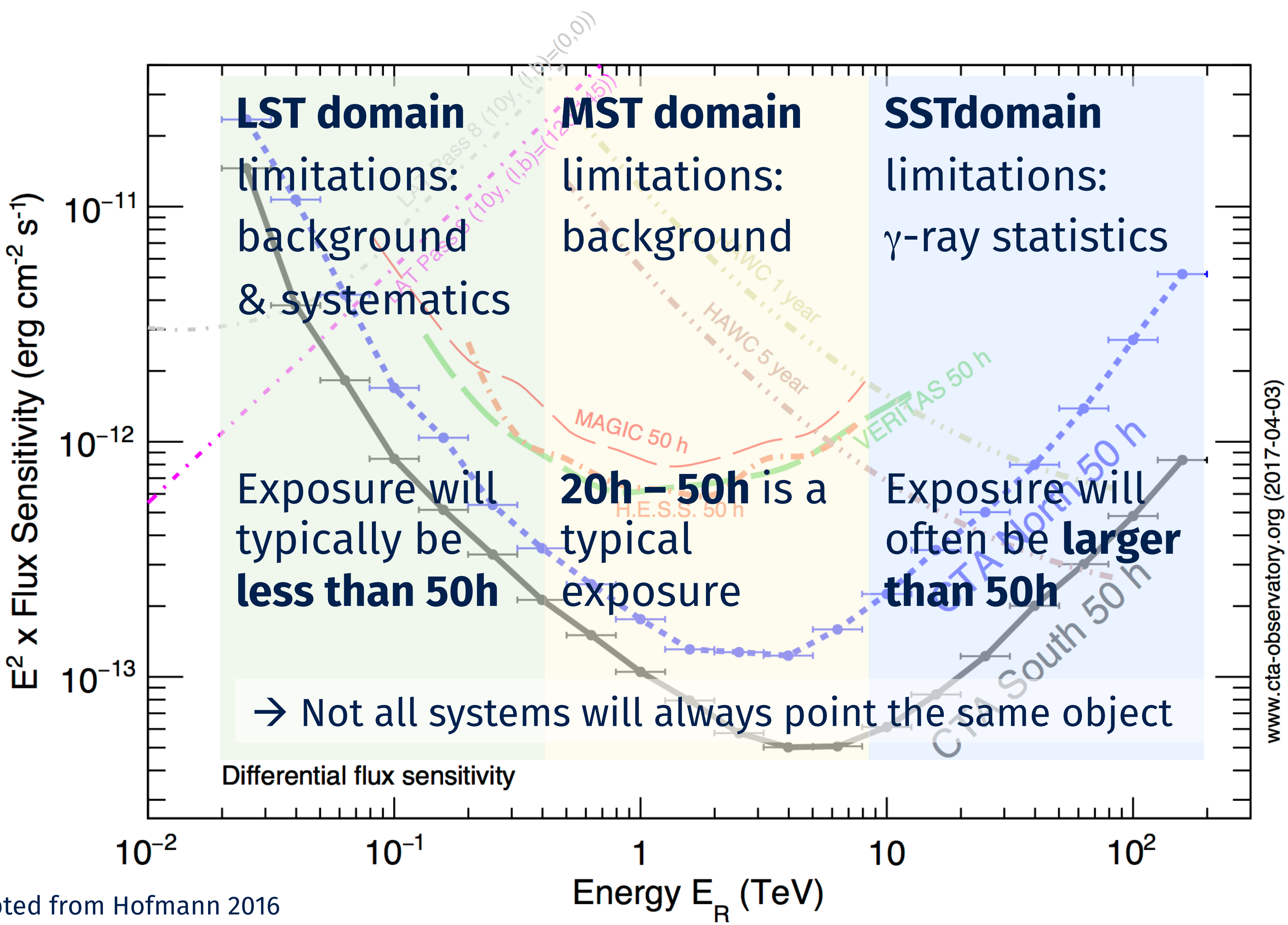
Adapted from Hofmann 2016

CTA Performance



Adapted from Hofmann 2016

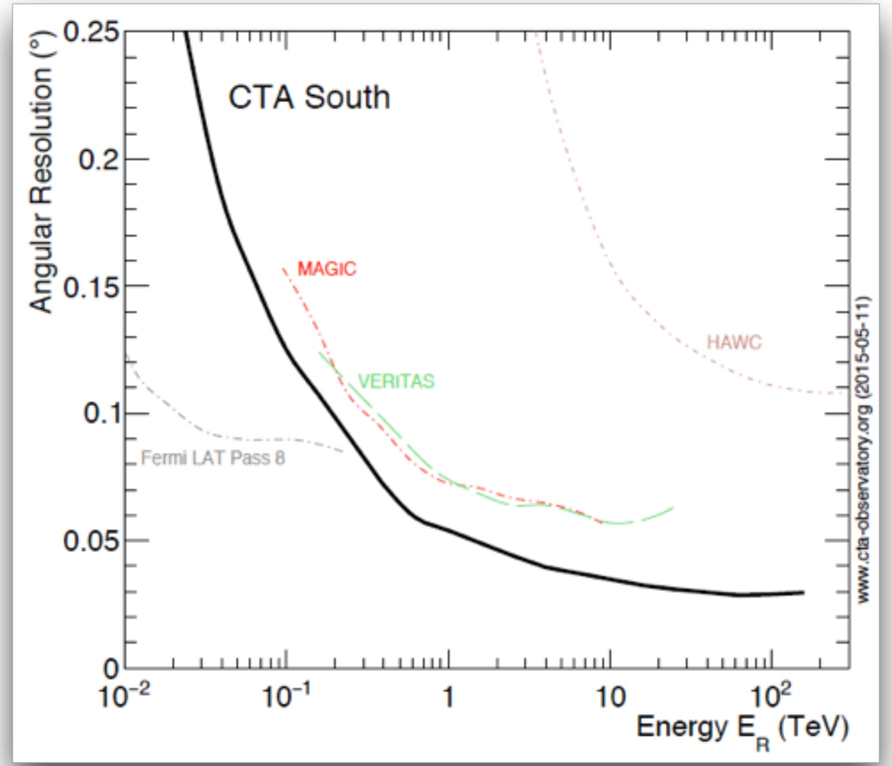
CTA Performance



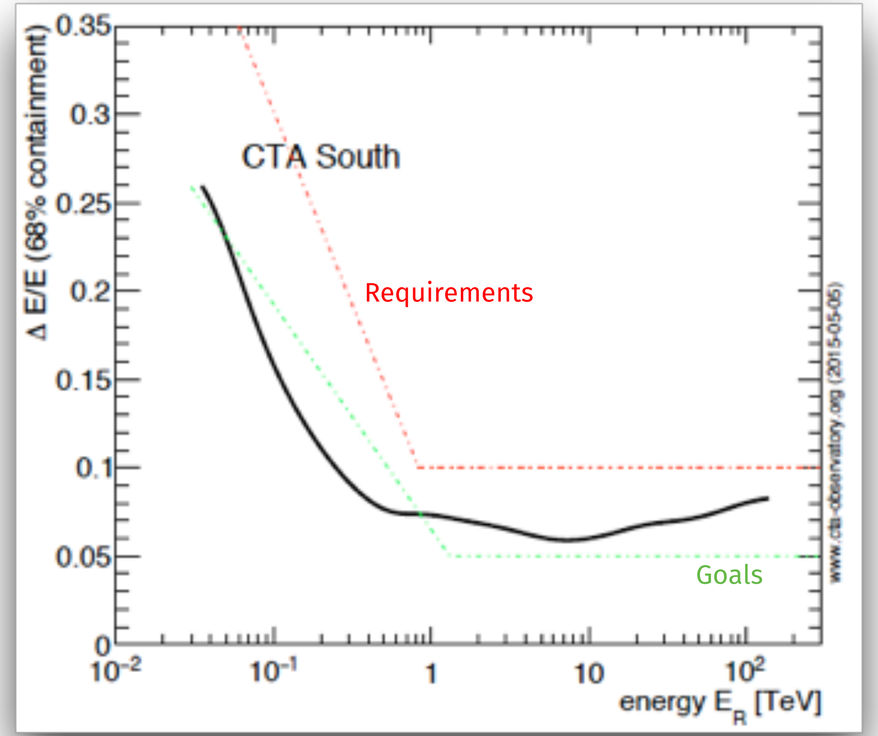
Adapted from Hofmann 2016

CTA Performance

Angular Resolution



Energy Resolution

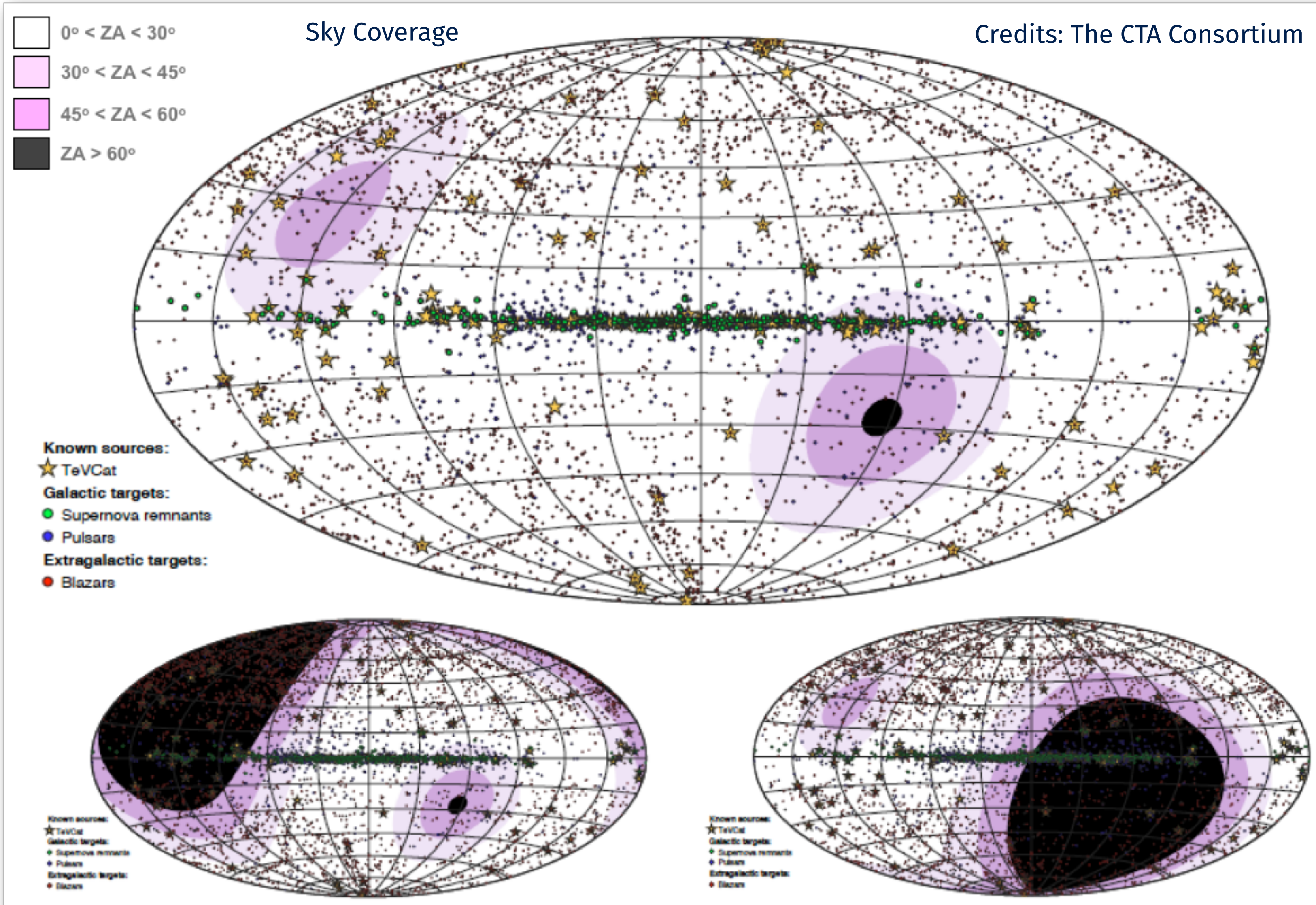


Further improvements of shower reconstruction algorithms and optimization of event selection can improve the IRFs.

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

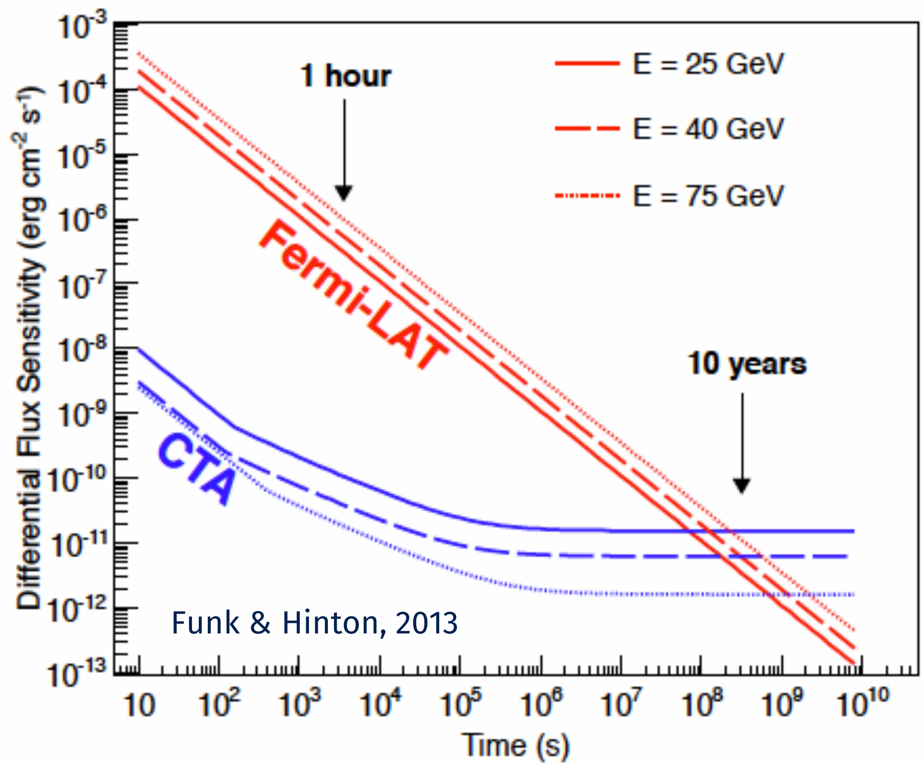
Credits: The CTA Consortium

CTA as an *all-sky* Observatory



CTA as a *transient factory*

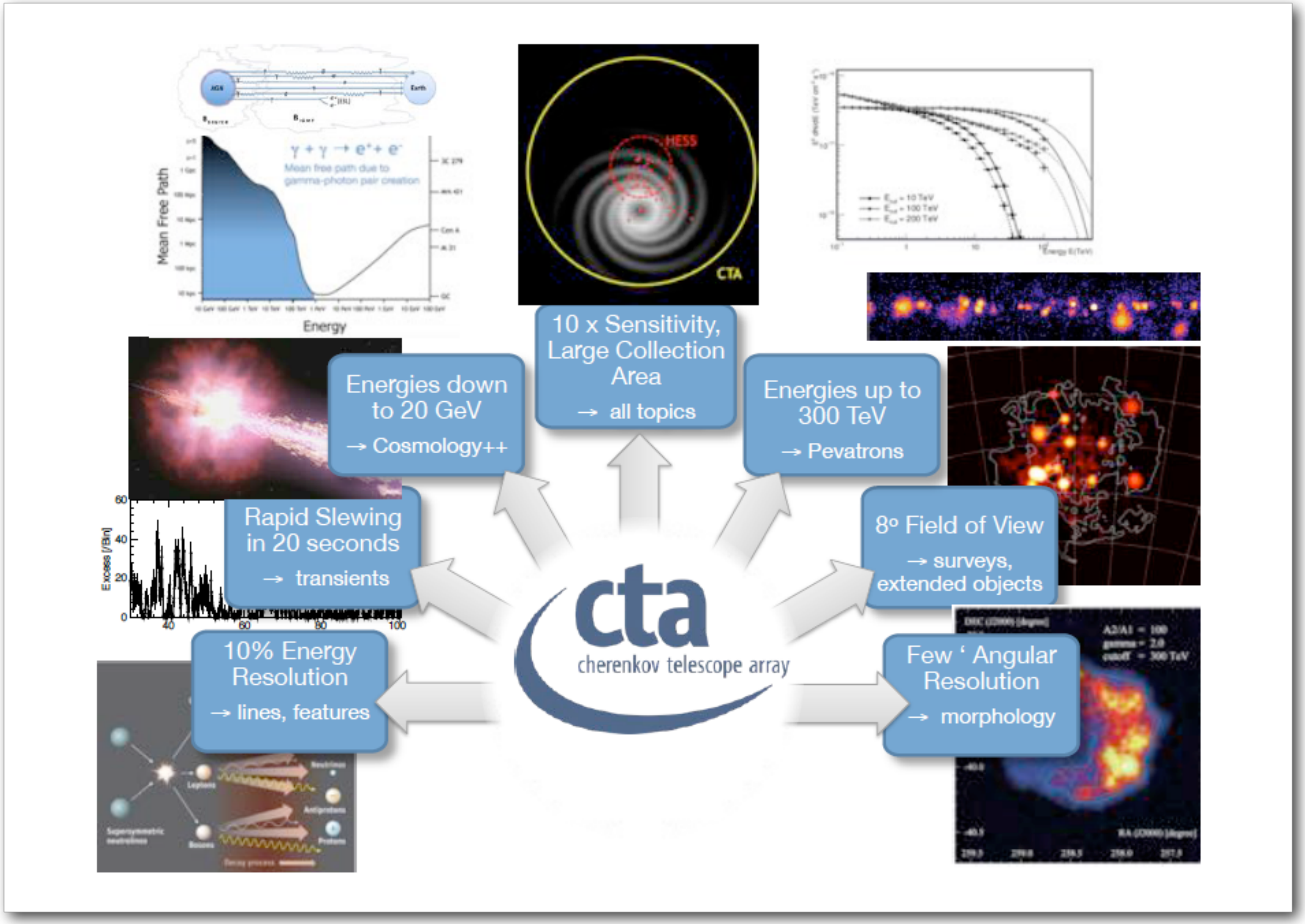
- **Huge advantage over Fermi** in energy range of overlap for ~minute to ~week timescale phenomena
  - Explosive transients
  - AGN flares
  - Binary systems



Funk & Hinton, 2013

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

CTA Science



Credits: W. Hofmann, MG 2015

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 progress status

CTA as an Open Observatory

The modes of user access to CTA will be:

- The Guest Observer (GO) Programme – by which users can obtain access to proprietary observation time, submitting proposals in response to Announcements of Opportunity (AOs).
- The Key Science Projects (KSPs) – are large programmes that ensure that some of the key science issues for CTA are addressed in a coherent fashion, with a well-defined strategy.
- Director's Discretionary Time (DDT) – a small fraction of observation time may be reserved for, e.g., unanticipated targets of opportunity, or outstanding proposals from non-member countries.
- Archive Access – under which all CTA gamma-ray data will be openly available, after a proprietary period.

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The γ-ray sky

The Cherenkov Telescope Array

CTA Key Science Projects

Prospects & discussion

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.

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

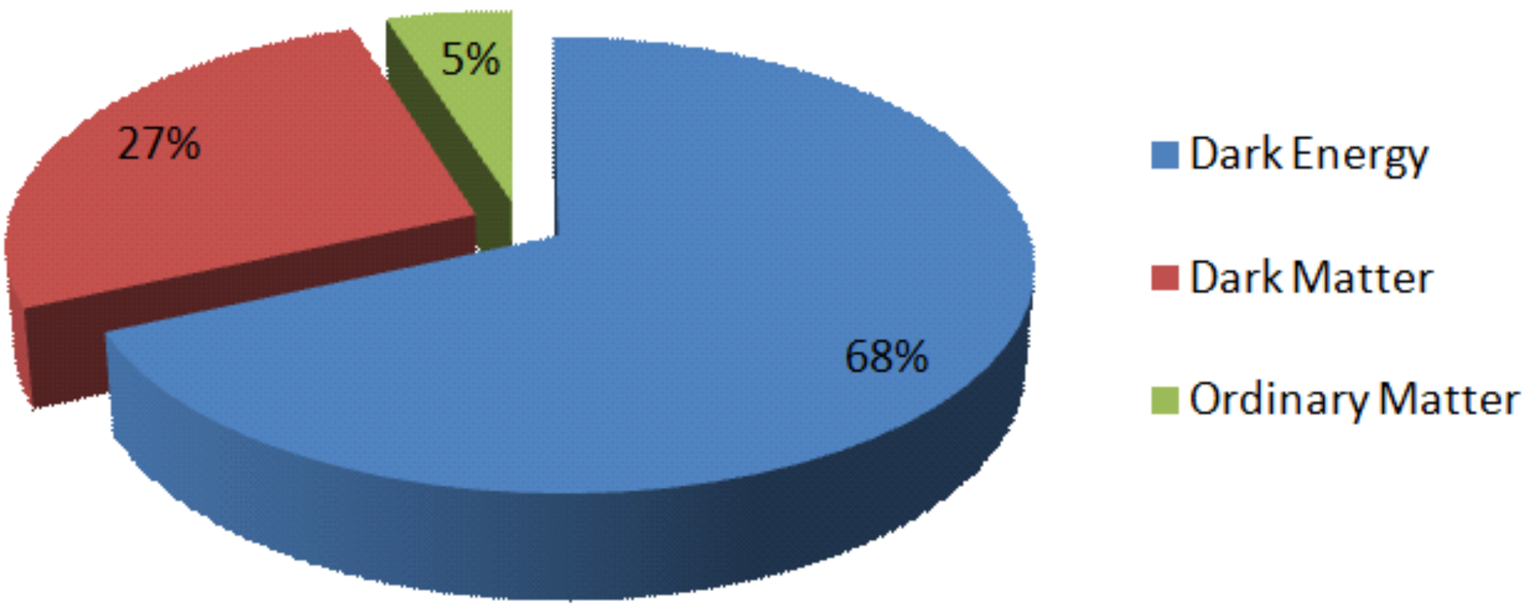
CTA Key Science Projects

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

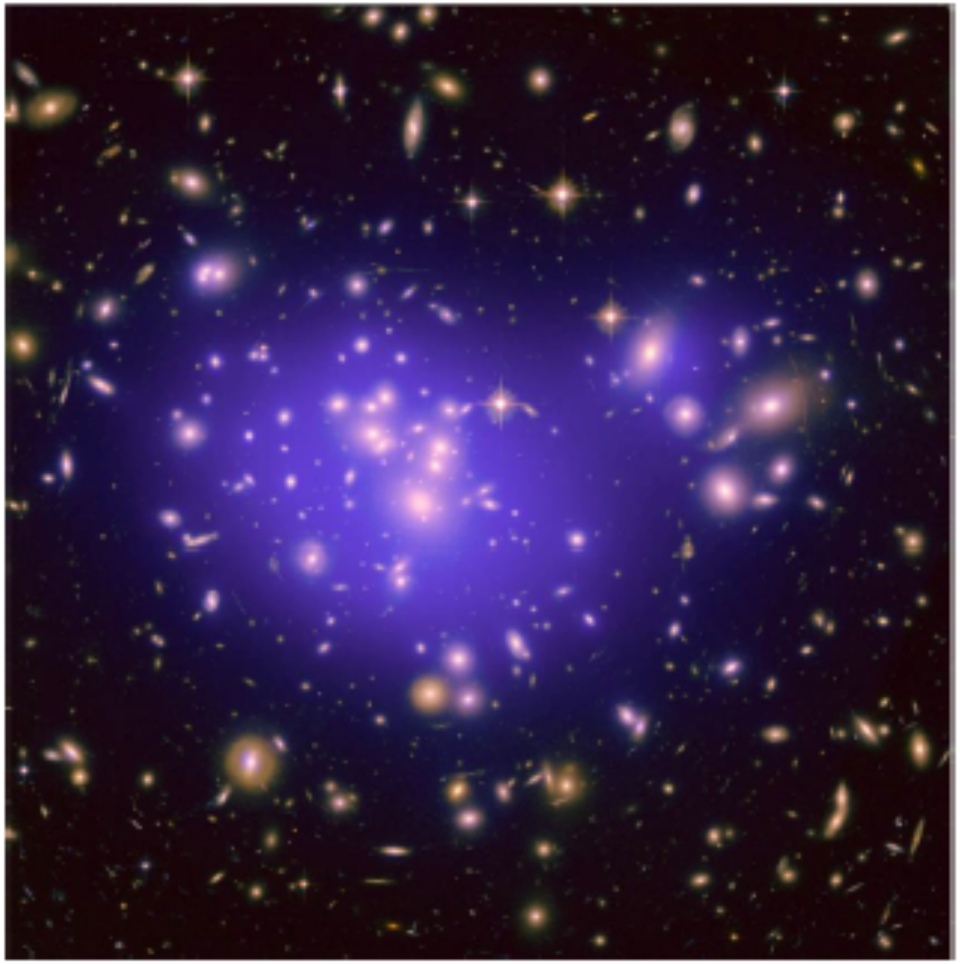
Science questions & KSPs

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
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?		✔		✔				✔✔	✔	✔
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?					✔	✔			✔✔	
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?					✔	✔			✔✔	

The Dark Matter Programme



The Dark Matter Programme



Hubble Space Telescope image of the inner region of the galaxy cluster Abell 1689.

The blue overlay shows the dark matter distribution reconstructed by gravitational lensing using the multiple galaxy images seen in the telescope image.

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 established** but the detailed **nature of dark matter is at present still unknown.**

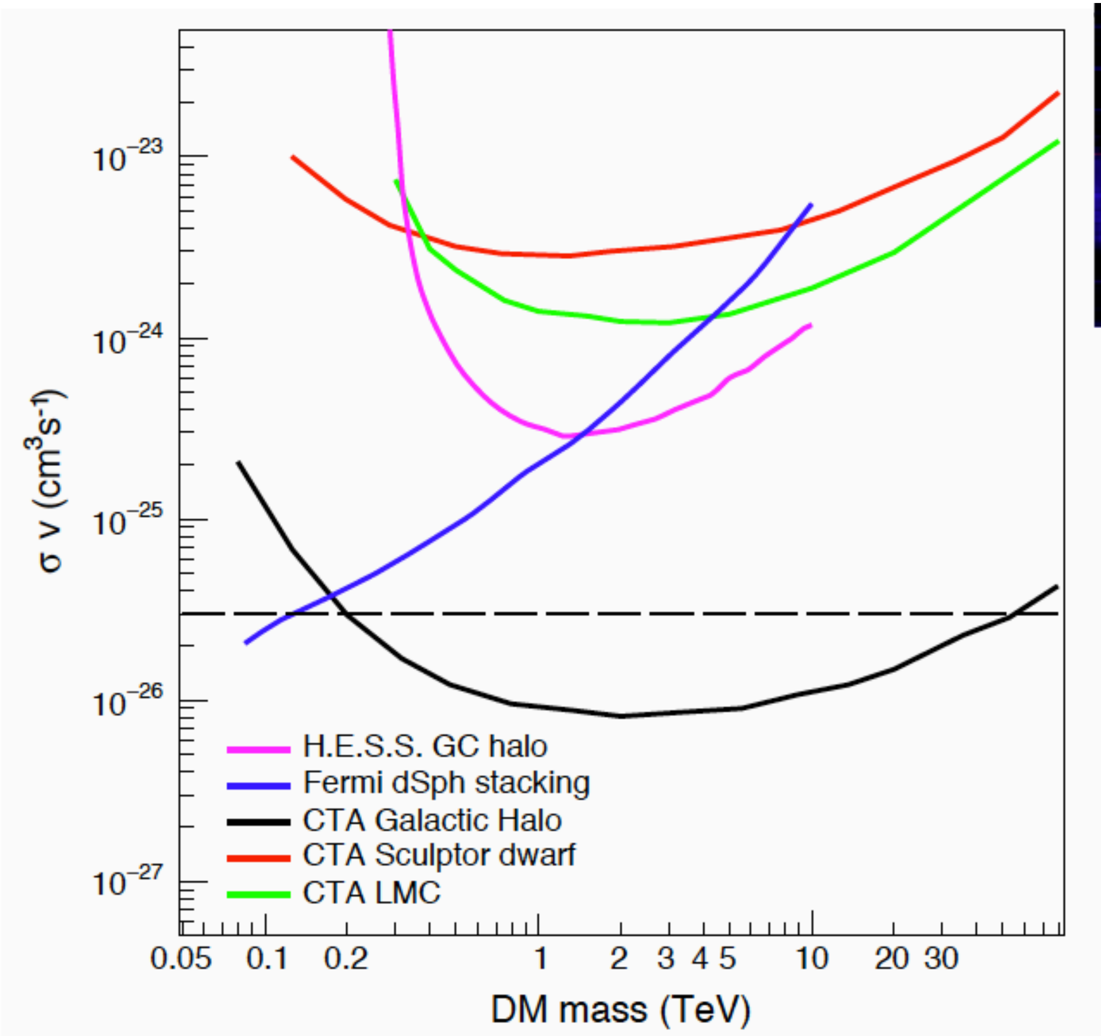
The priority for the CTA dark matter program is to **discover the nature of dark matter** with a positive observation.

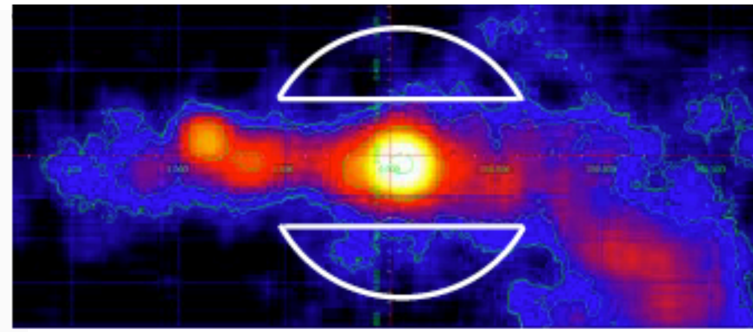
The principal target for dark matter observations in CTA **is the Galactic halo**.

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





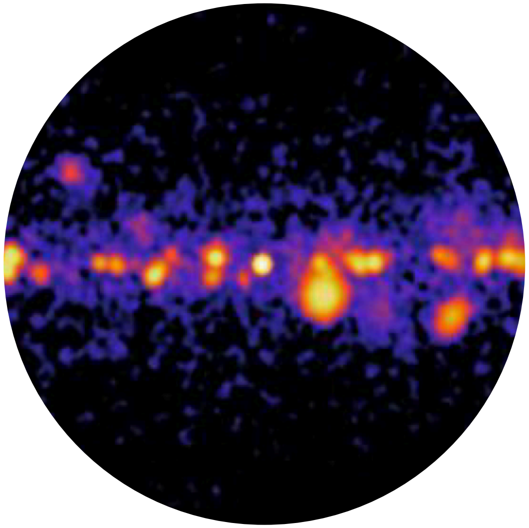
The plan is to avoid the inner Galactic region because of its

- 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

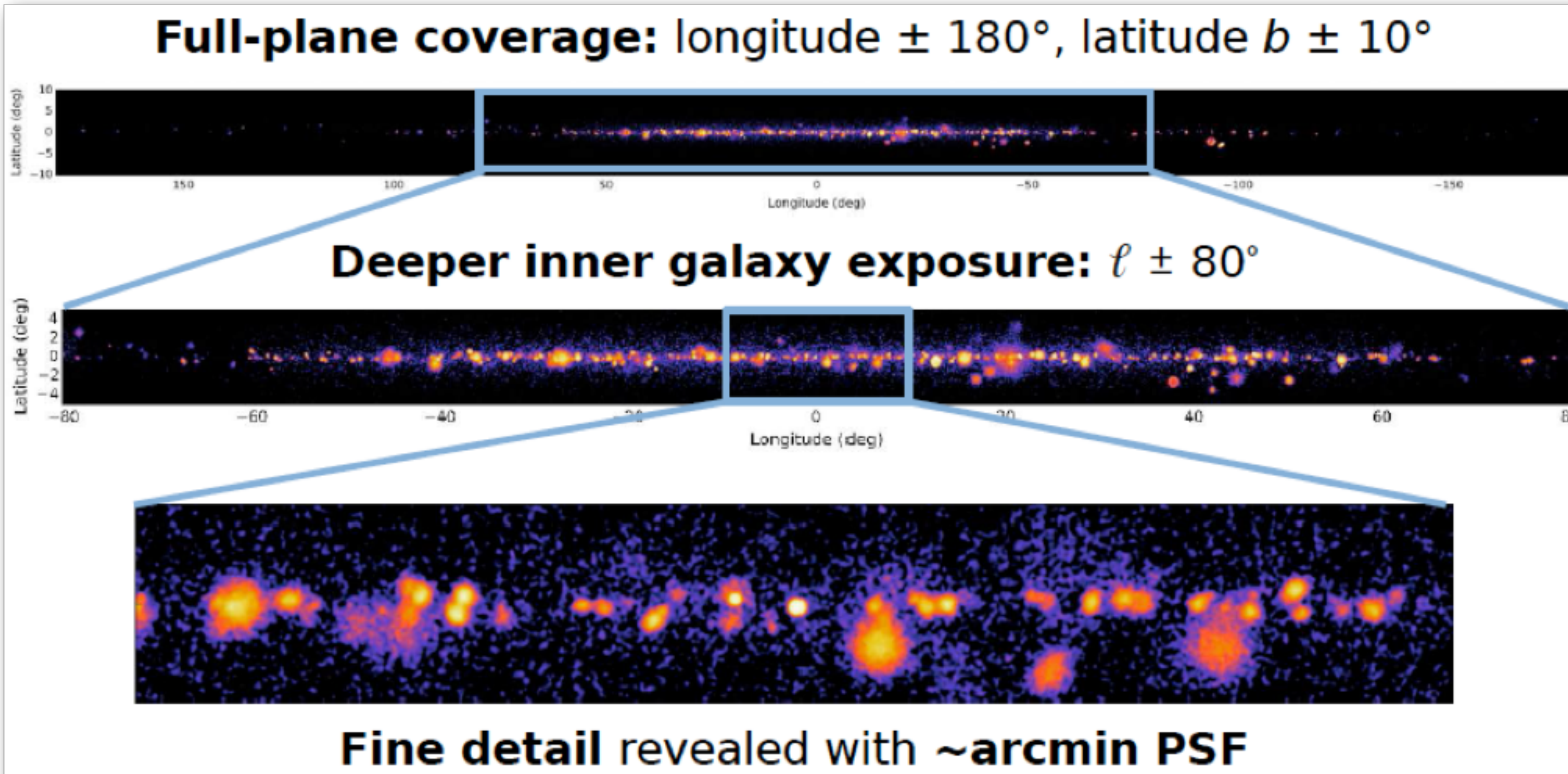
CTA will carry out a **survey of the full Galactic** plane using both the southern and northern CTA observatories.

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.

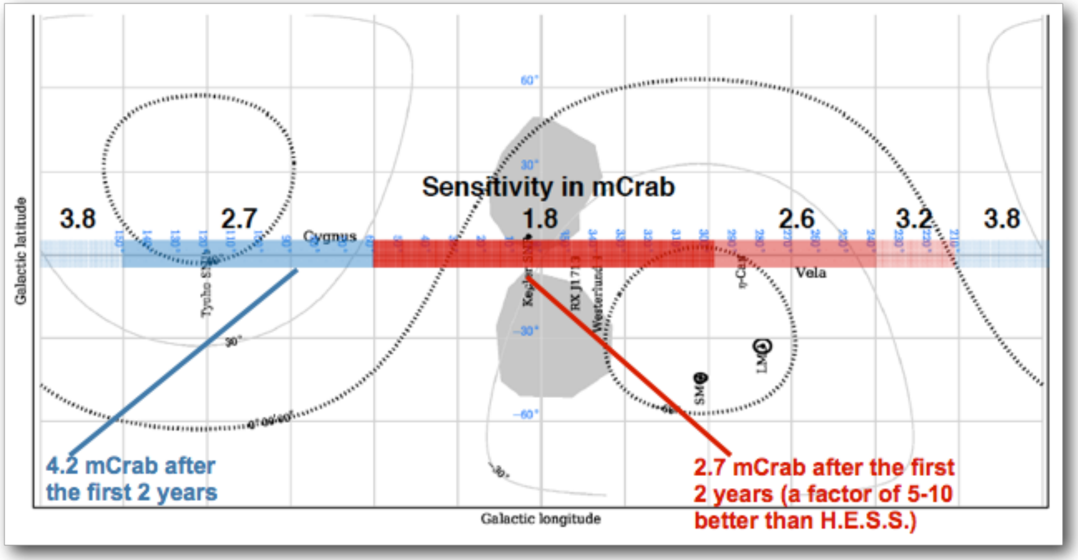
In the Northern Hemisphere, the CTA will complement/extend observations made by HAWC at much lower energy and with substantially better angular resolution.

Galactic Plane Survey

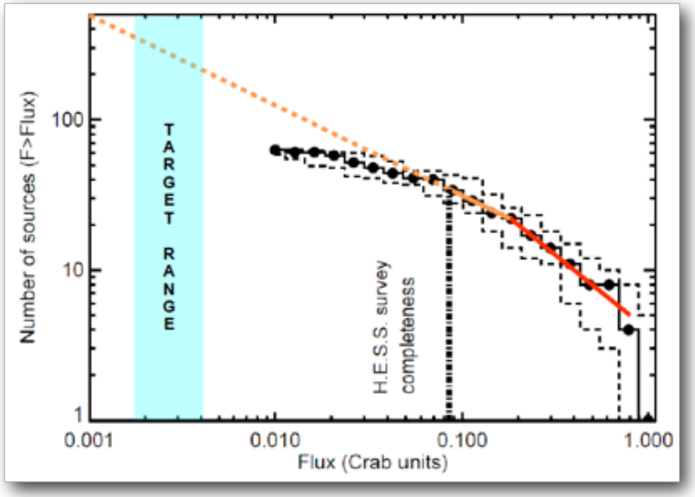


J. Knödlseder and CTA Consortium

Galactic Plane Survey



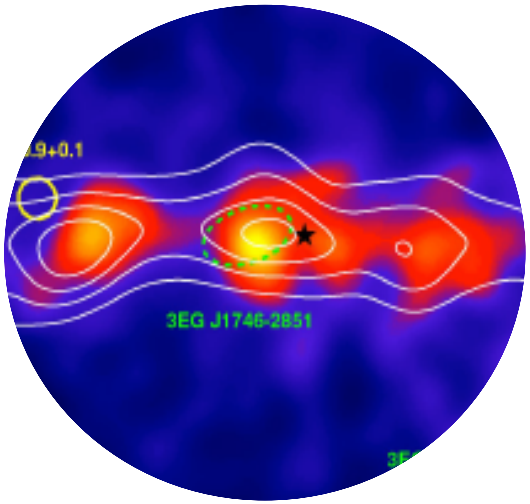
The CTA Consortium



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

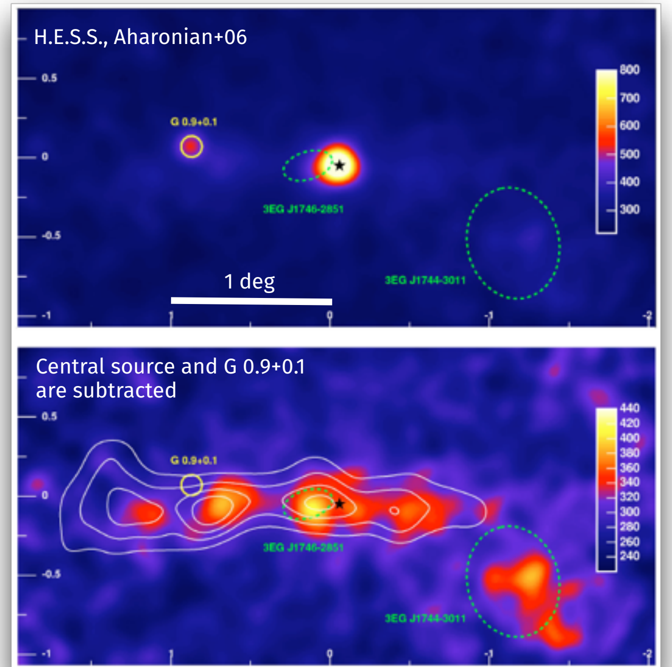
The region within a few degrees from the **Galactic Centre** is full of a **wide variety of high-energy emitters.**

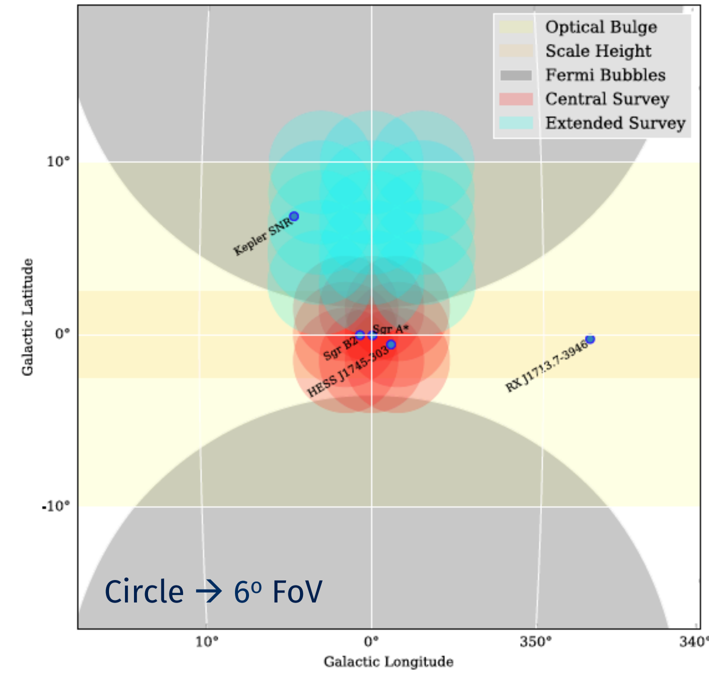
The central VHE source has been well studied with H.E.S.S., VERITAS, and MAGIC, but **still remains unidentified due to source confusion and limited sensitivity to variability and small-scale morphology.**

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

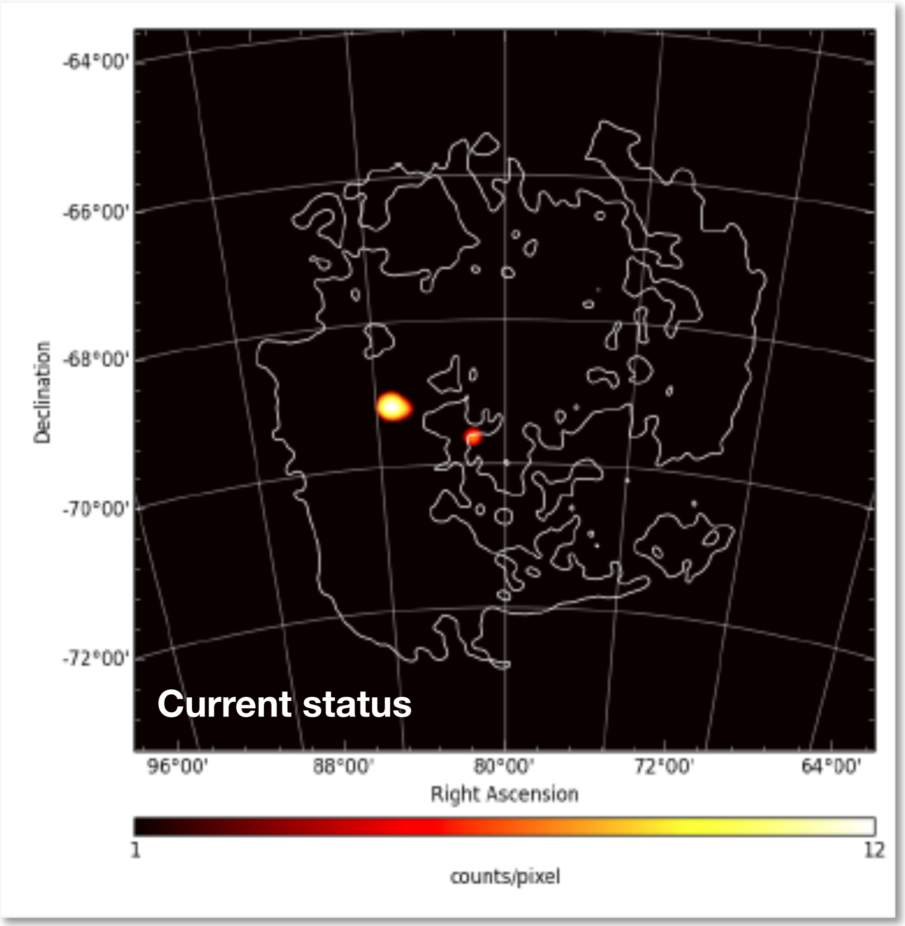
Credits: Schaefer 2015

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.

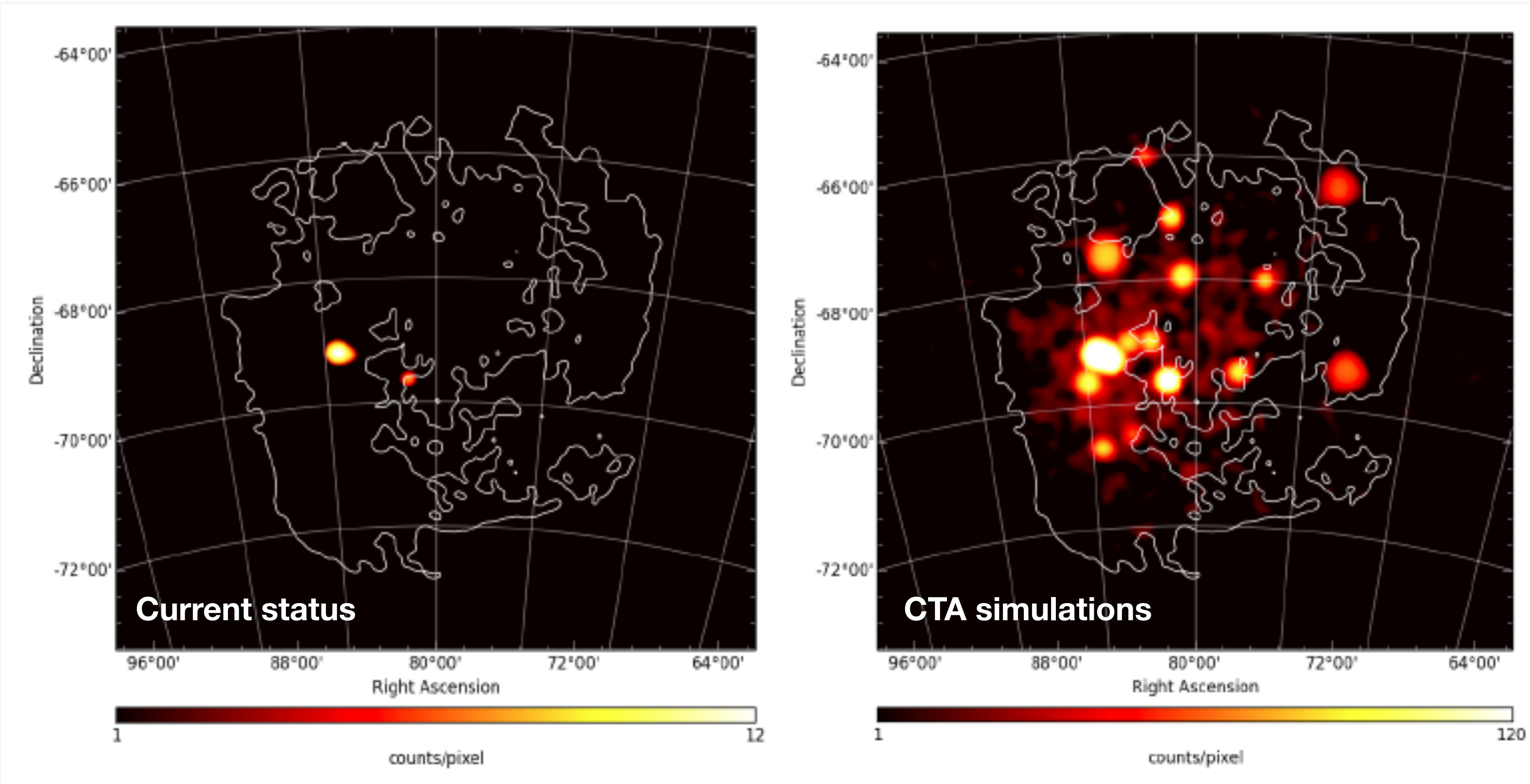
It is a unique place to obtain a resolved, global view of a star-forming galaxy at TeV energies.

LMC Survey



Credits: The CTA Consortium

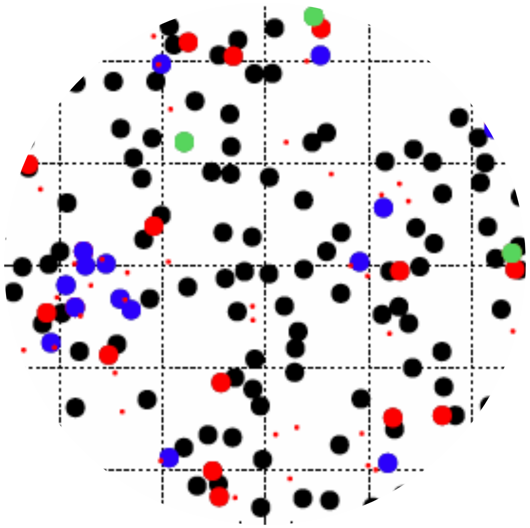
LMC Survey



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



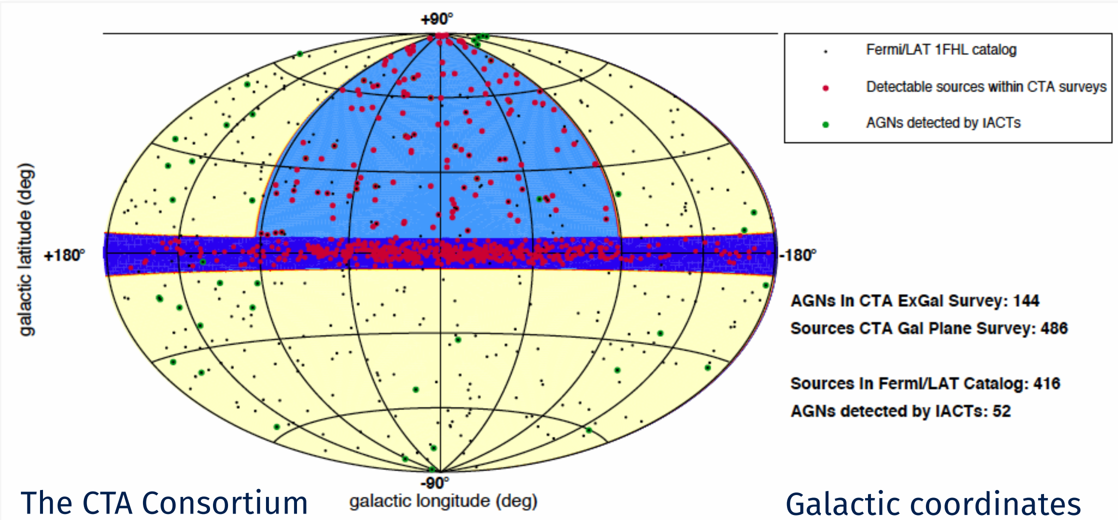
Credits: The CTA Consortium

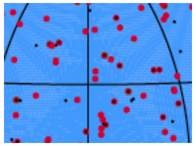
The aim is to perform a blind survey of 25% of the sky, and to construct an unbiased VHE extragalactic source catalogue with an integral sensitivity limit of ~5 mCrab.

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





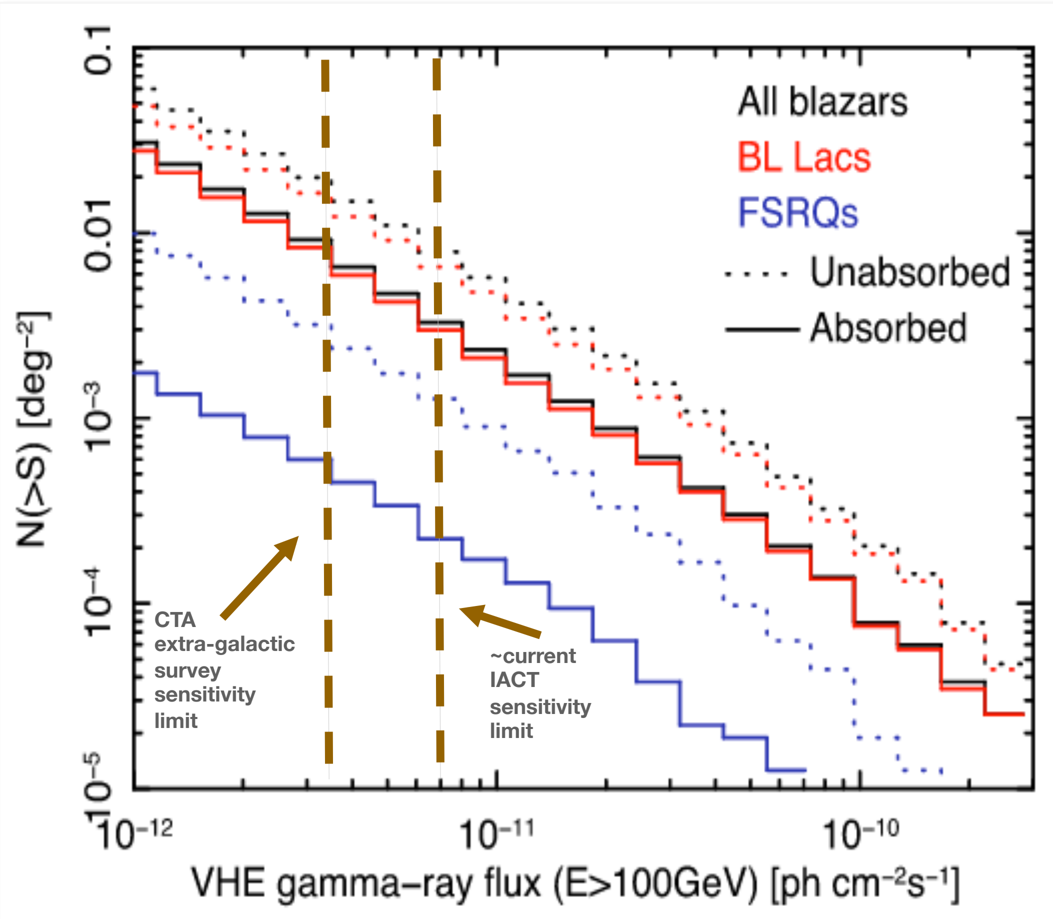
1/4 of the sky (~10^4 deg^2)
Limiting flux ~ 5 mCrab

The survey would connect with the Galactic Plane Survey (|b| < 5°) over Galactic longitude −90° < l < 90°.

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

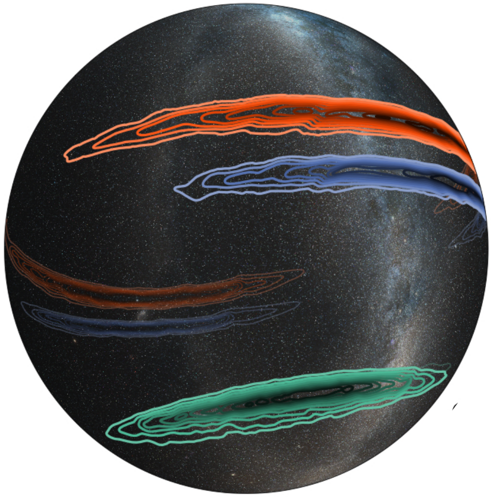


Padovani & Giommi (2015)

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.**

Transients



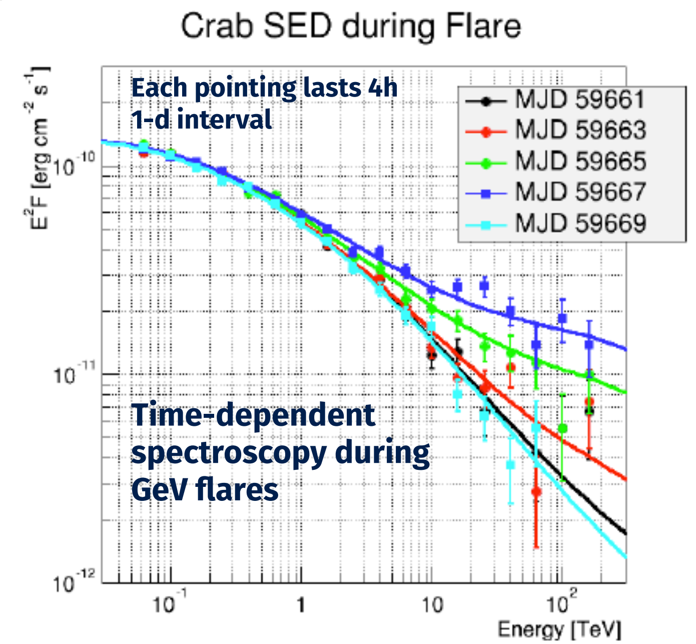
Credits: The LIGO Scientific Collaboration

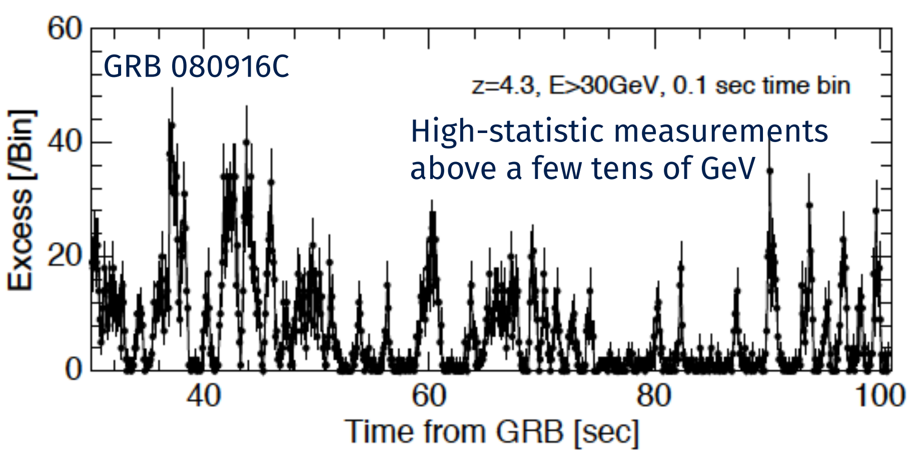
Transients are a diverse population of astrophysical objects. Some are known to be prominent **emitters of high-energy gamma-rays**, while others are sources of non-photonic, multi-messenger signals such as cosmic rays, **neutrinos and/or gravitational waves**.

Possible classes of targets

- Gamma-ray bursts
- Galactic transients
- High-energy neutrino transients
- Gravitational wave transients
- Radio, optical, and X-ray transients
- Serendipitous VHE transients

Transients





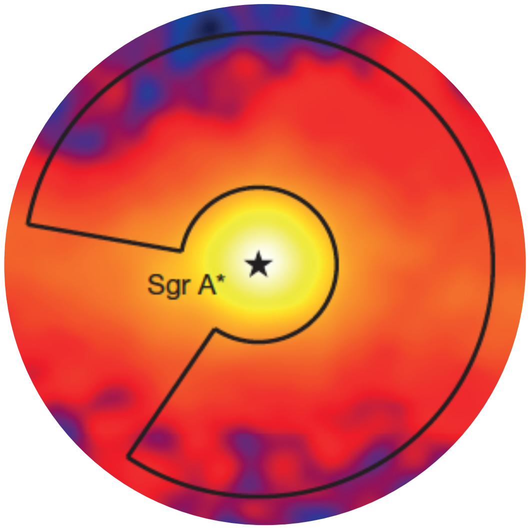
Assuming that the Crab nebula high-energy flares are due to synchrotron emission, to detect the **variable inverse-Compton component at multi-TeV energies**, we would need to monitor the source for **4 h/night during approximately 10 nights.** With this strategy we could unveil the nature of these flares.

Inverse-Compton component of the 2011 April Crab flare assuming Γ=70. **The variable tail from 10 to 100 TeV is clearly detectable.**

CTA is potentially capable of **resolving GRBs light curve in exquisite detail** for such bright bursts. The assumed GRB template is the measured Fermi-LAT light curve above 0.1 GeV, extrapolating the intrinsic spectra to VHE with power-law indices as determined by Fermi-LAT.

We expect to detect ~1 GRB yr^{-1} site^{-1}.

Cosmic-ray PeVatrons



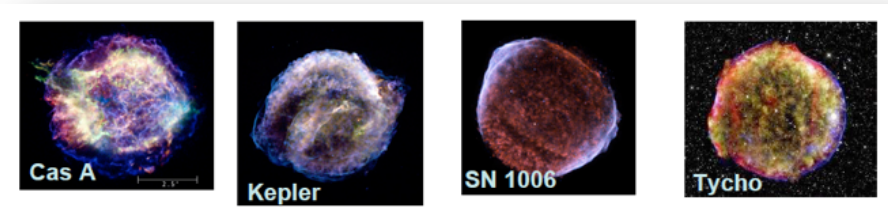
Credits: The H.E.S.S. Collaboration

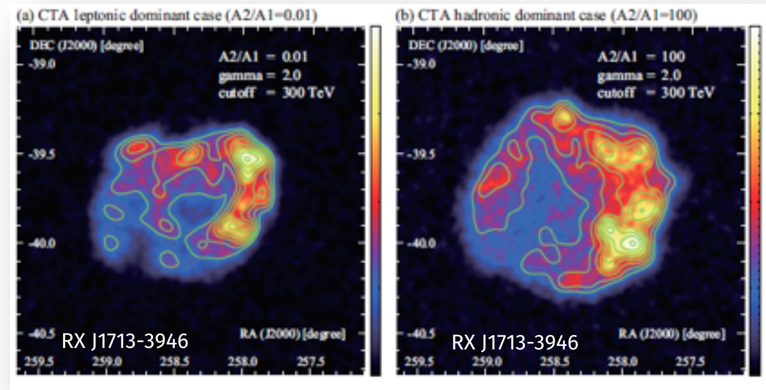
Supernova remnants might be able to satisfy the cosmic-ray energy requirement if they can somehow convert ~10% of the supernova kinetic energy into accelerated particles.

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.**

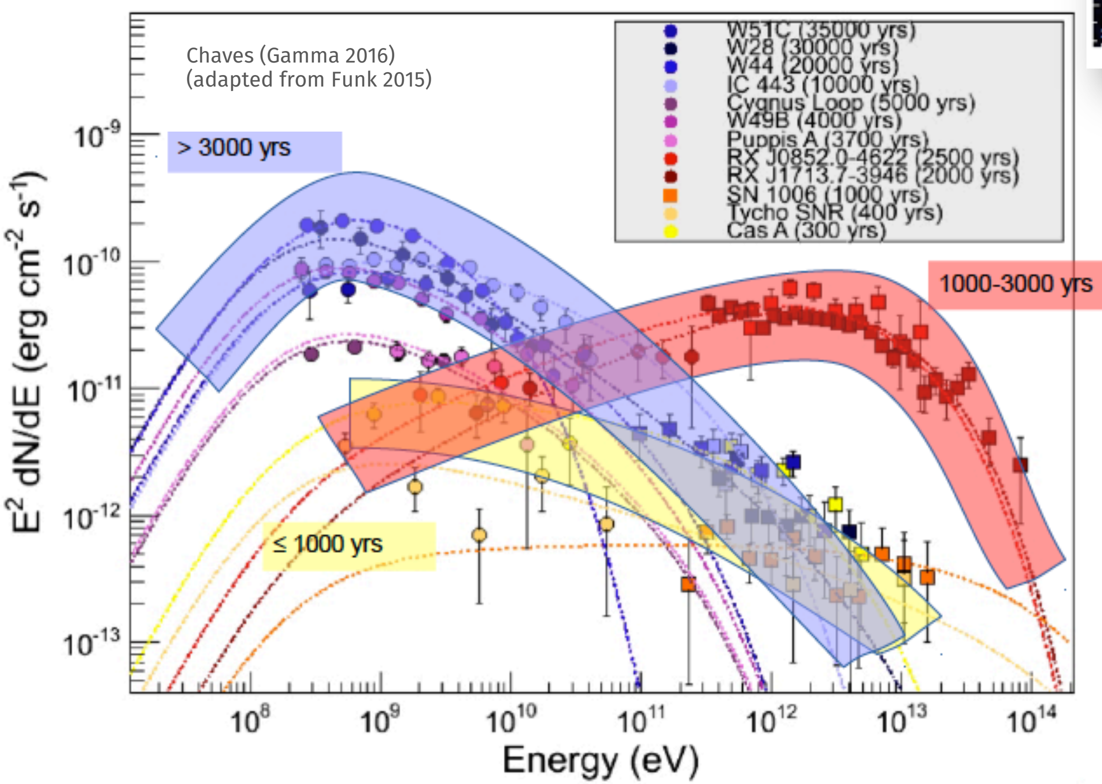
The interactions of such runaway **PeV particles** with the ambient gas produce **gamma rays** with a characteristic hard spectrum extending **up to ~100 TeV.**

Cosmic-ray PeVatrons





Nakamori et al., 2015 50hr CTA simulation

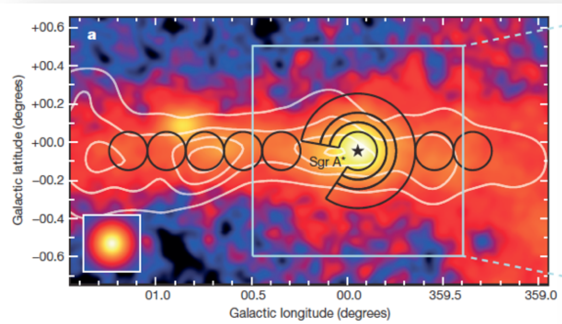


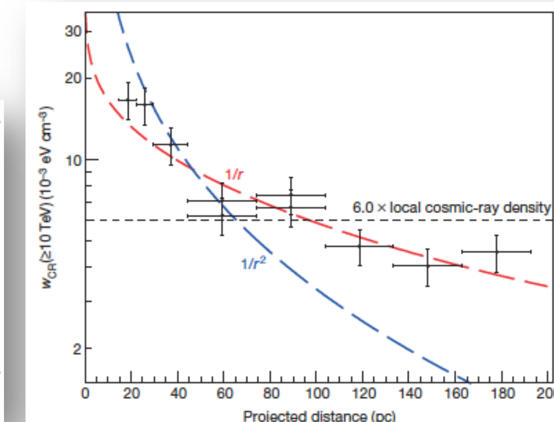
The detection up to E ~100 TeV would imply:

- **the emission is hadronic**, because the leptonic emission is strongly suppressed at such high energies due to the Klein-Nishina effect;
- **the SNR is a PeVatron**, because ~100 TeV photons are produced by ~PeV protons.

Cosmic-ray PeVatrons

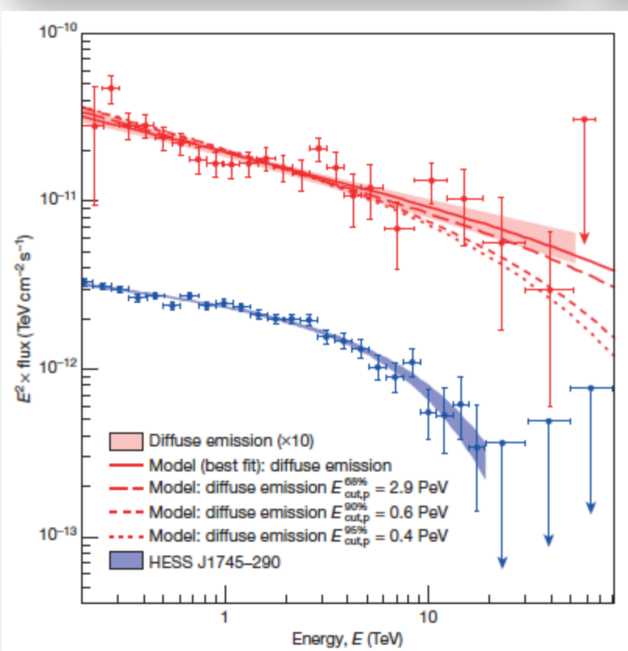
H.E.S.S. Collaboration, 2016





Evidence of the **acceleration of PeV protons** in the **Galactic Centre (GC)**.

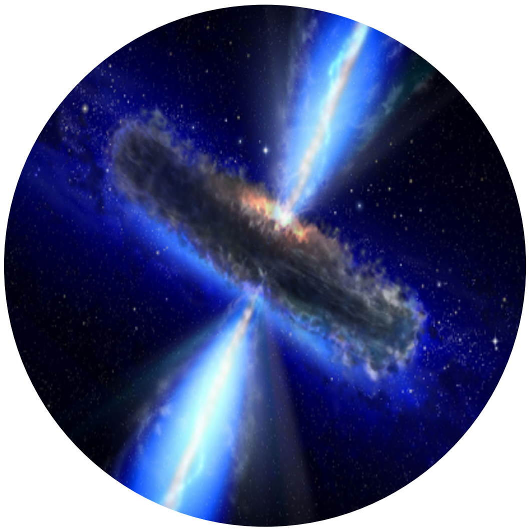
The 1/r profile (red line) of the cosmic-ray density up to 200 pc indicates a **quasi continuous injection of protons** into the central molecular zone from a centrally located accelerator (located in the inner 10pc region from the GC).



The best fit to the data: a power-law extending with a photon index of ~2.3 to energies up to tens of TeV, without a cut-off or a break in the central tens of pc.

The SMBH Sgr A* is the most plausible supplier of ultra-relativistic protons and nuclei that could have been accelerated either in the accretion flow, or at the site of termination of an outflow during phases of enhanced accretion rate.

Active Galactic Nuclei



Credits: ESA/NASA

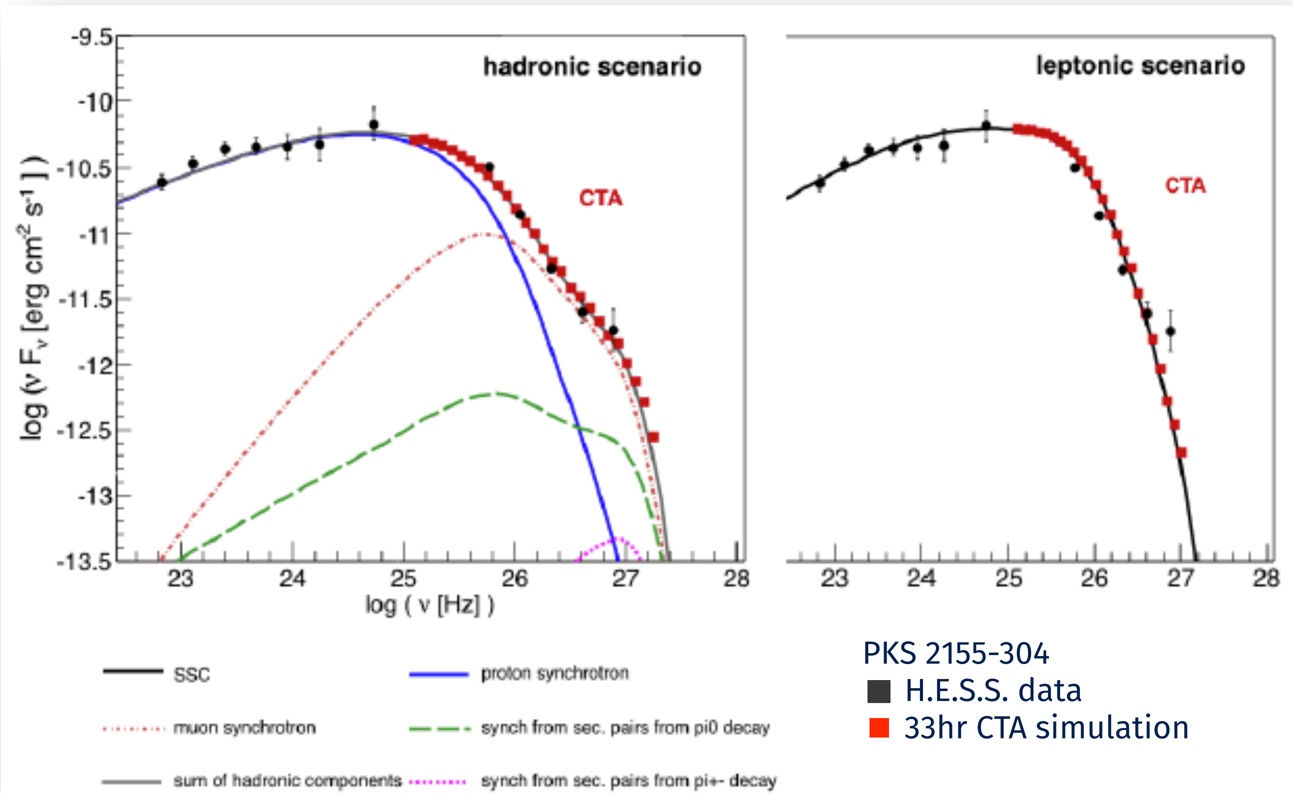
AGNs are known to emit **variable radiation** across the entire electromagnetic spectrum up to multi-TeV energies, with fluctuations **on time-scales** from **several years** down to **a few minutes.**

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**.

Active Galactic Nuclei

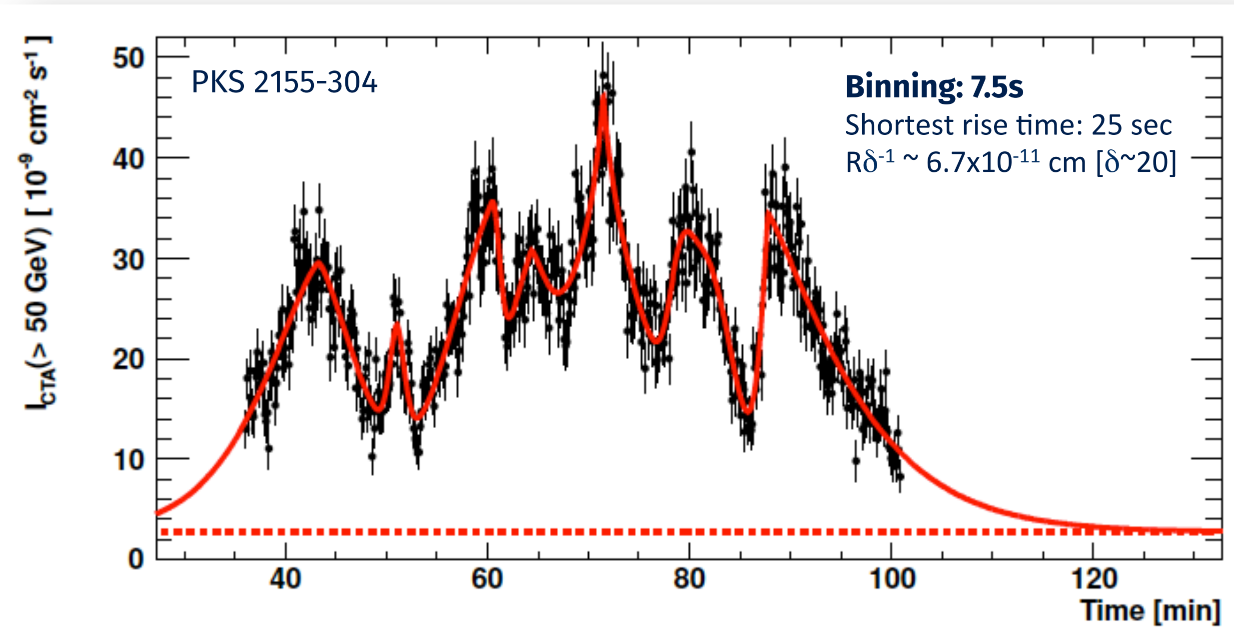
Testing emission scenarios



A set of **high-quality spectra** from different blazar types and different redshifts is needed to **unambiguously distinguish intrinsic spectral features**, such as shown here**, from external absorption**.

Active Galactic Nuclei

Testing variability in AGNs



Such measurements put strong constraints on the bulk Doppler factor, as well as on particle acceleration and cooling processes.

Outline

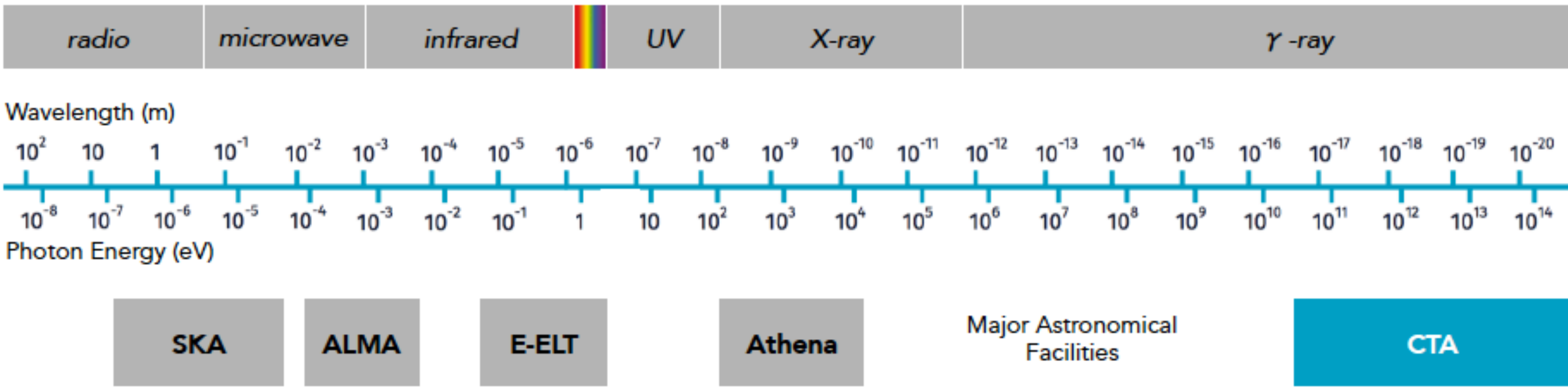
The γ-ray sky

The Cherenkov Telescope Array

CTA Key Science Projects

Prospects & discussion

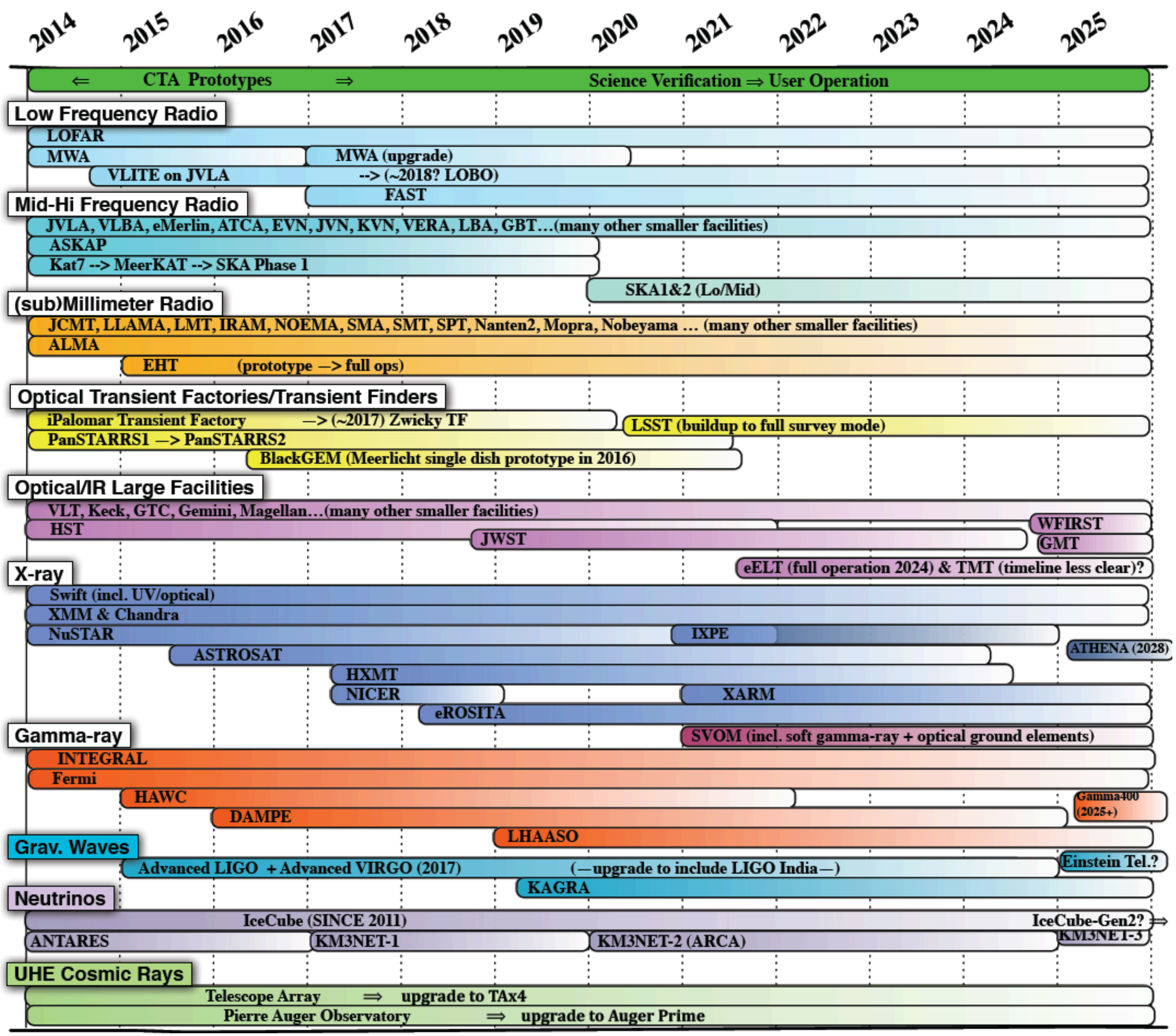
Synergies during CTA operation



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

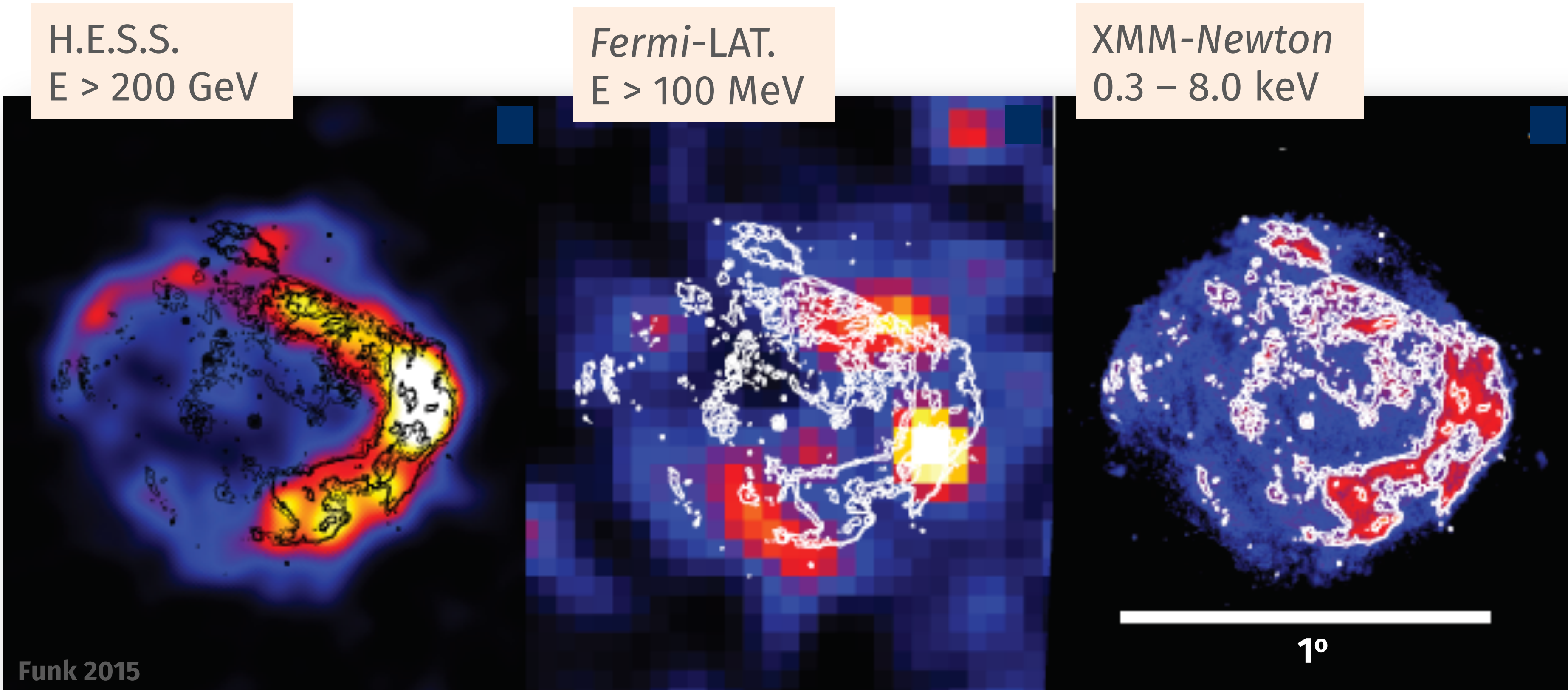
Next slide shows...

Synergies during CTA operation



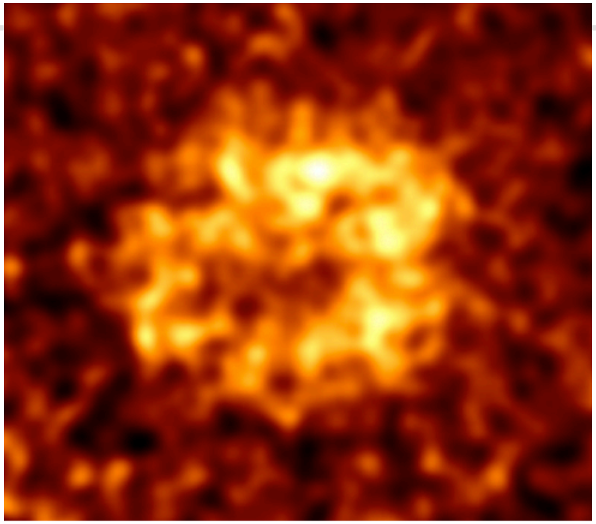
RX J1713.7-3946 – a multi-wavelength view

Ideal laboratory for particles propagation studies (see Abdalla+16)



RX J1713.7-3946 over time

Chaves 2016



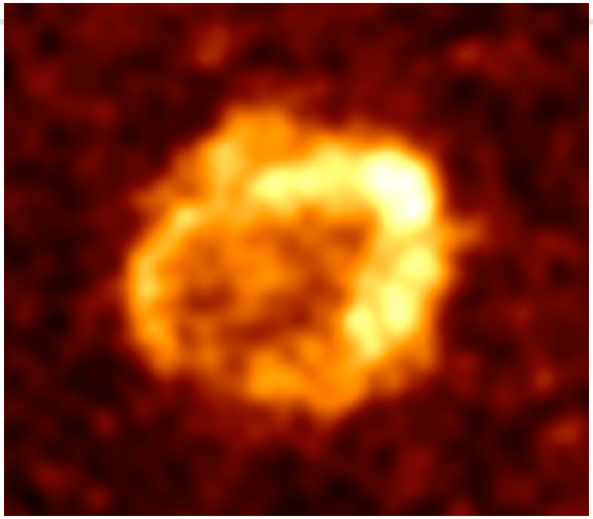
2004

18 h livetime

E_{min} = 1 TeV

γ-ray excess: 1430

PSF ($R_{68\%}$) = 4.8’



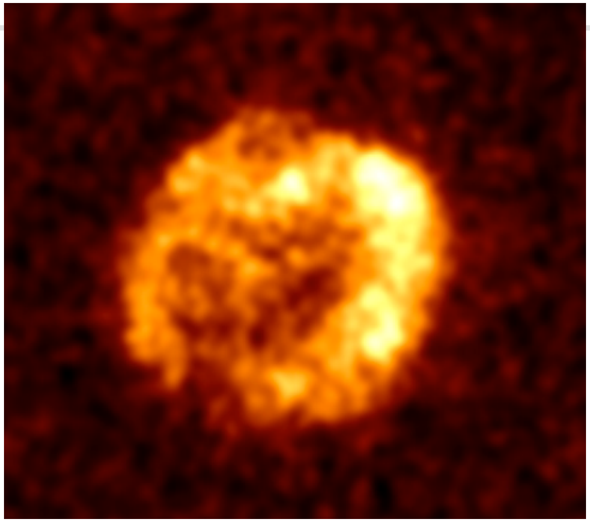
2006

63 h livetime

E_{min} = 0.3 TeV

γ-ray excess: 6700

PSF ($R_{68\%}$) = 3.6’



2016

164 h livetime

E_{min} = 0.25 TeV

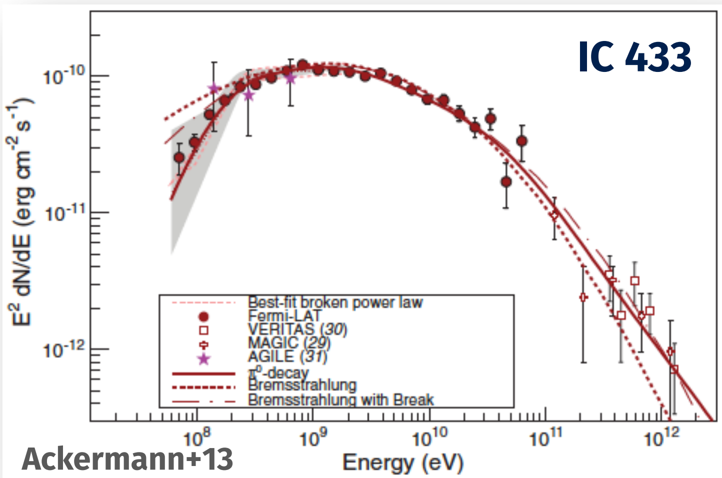
γ-ray excess: 31000

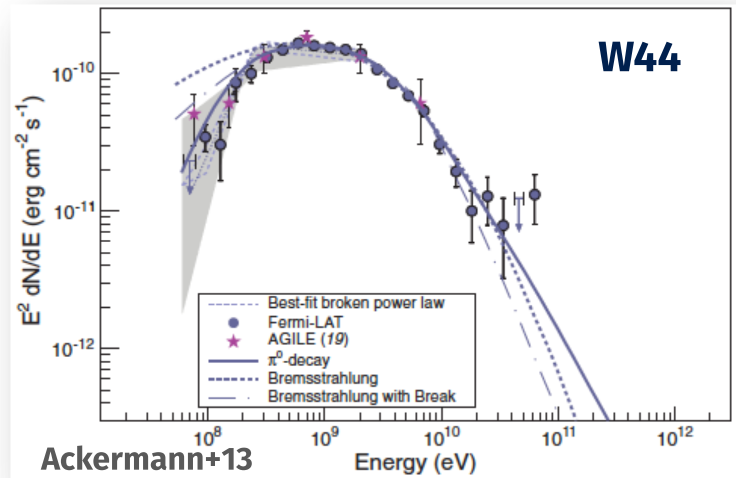
PSF ($R_{68\%}$) = 2.9’

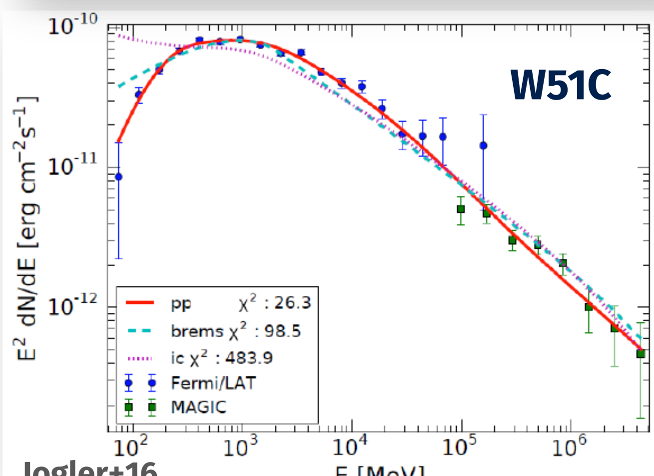
Better err_{sys} control

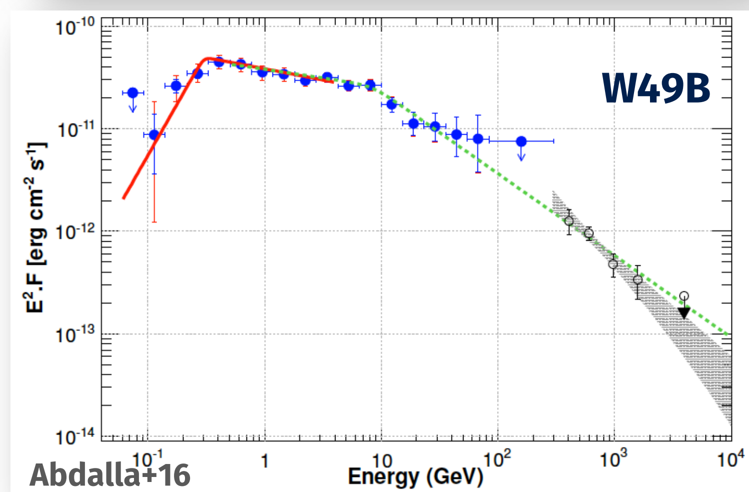
The “Fab-four” pion-bumbers

Pion-decay signature in the AGILE & Fermi-LAT data

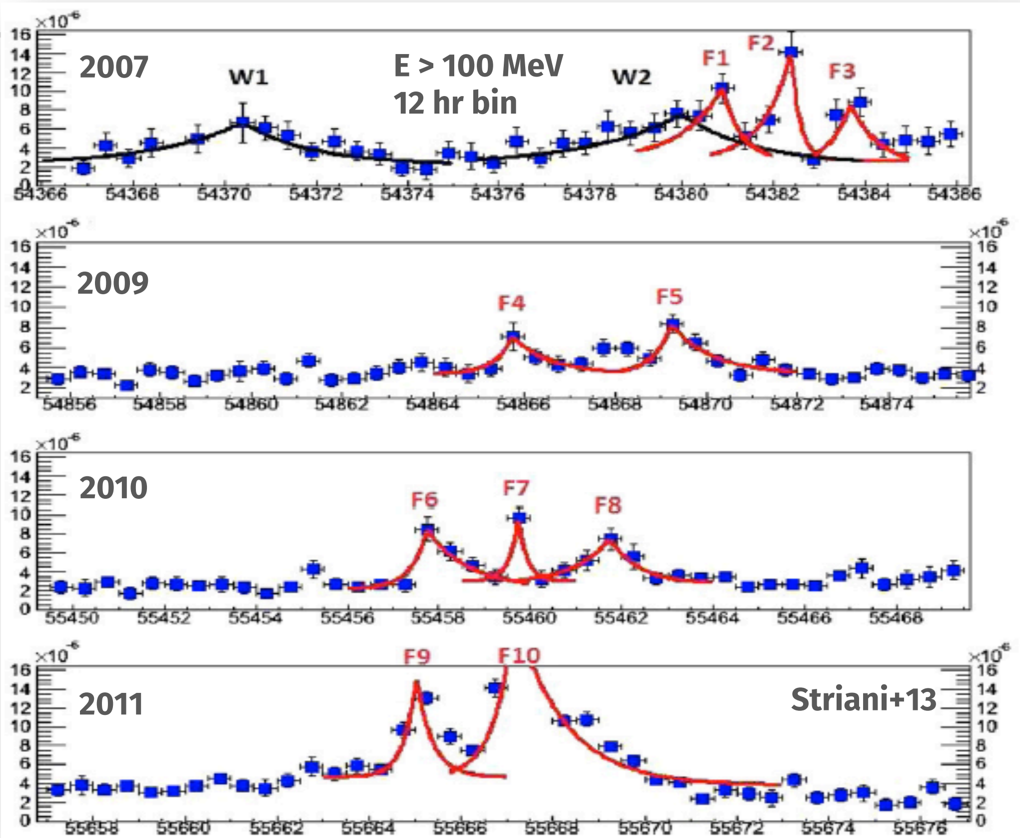






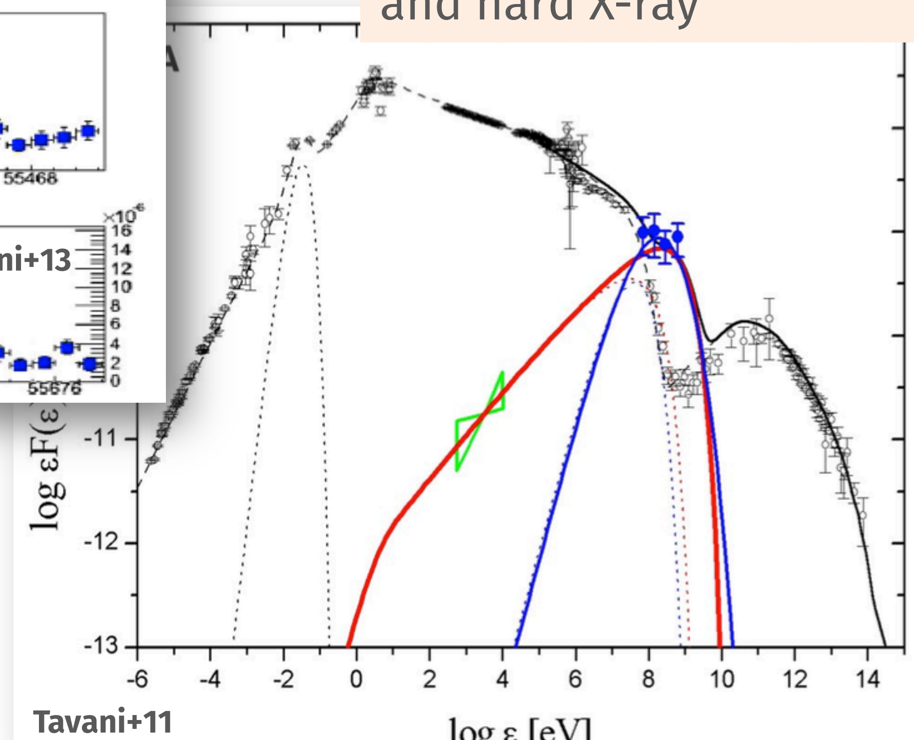


PWN – the "violently quiet" Crab



Crab is highly variable (a factor of 5-10) in the AGILE and *Fermi*-LAT energy band.

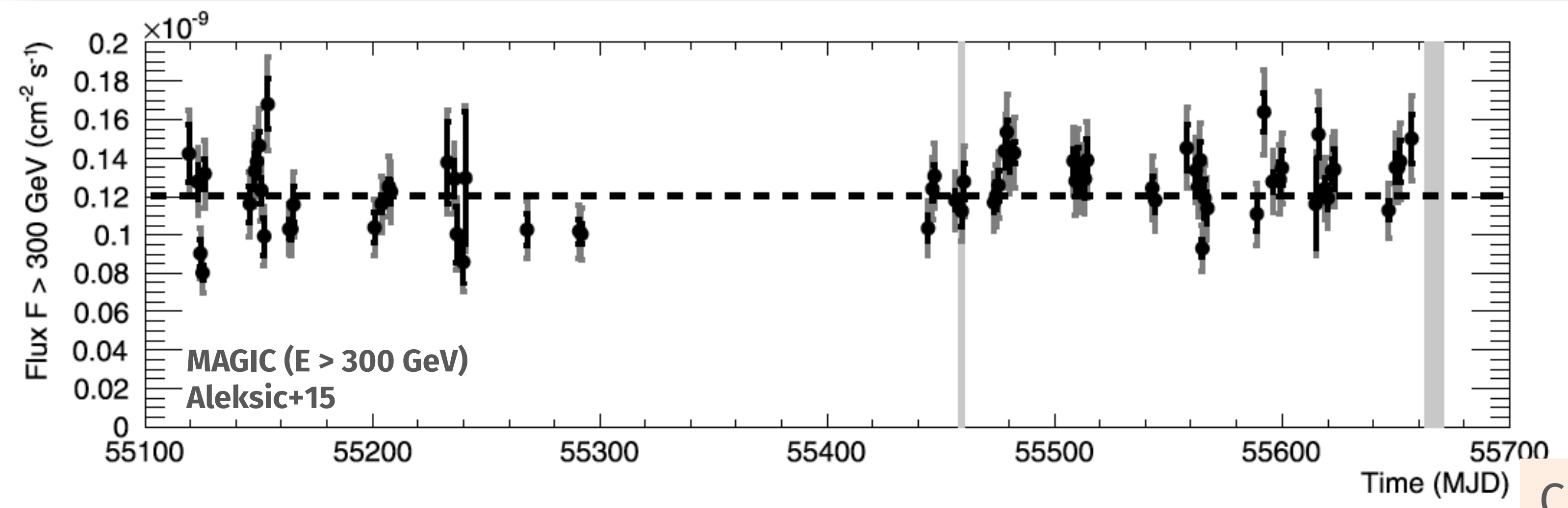
No variability in the soft and hard X-ray

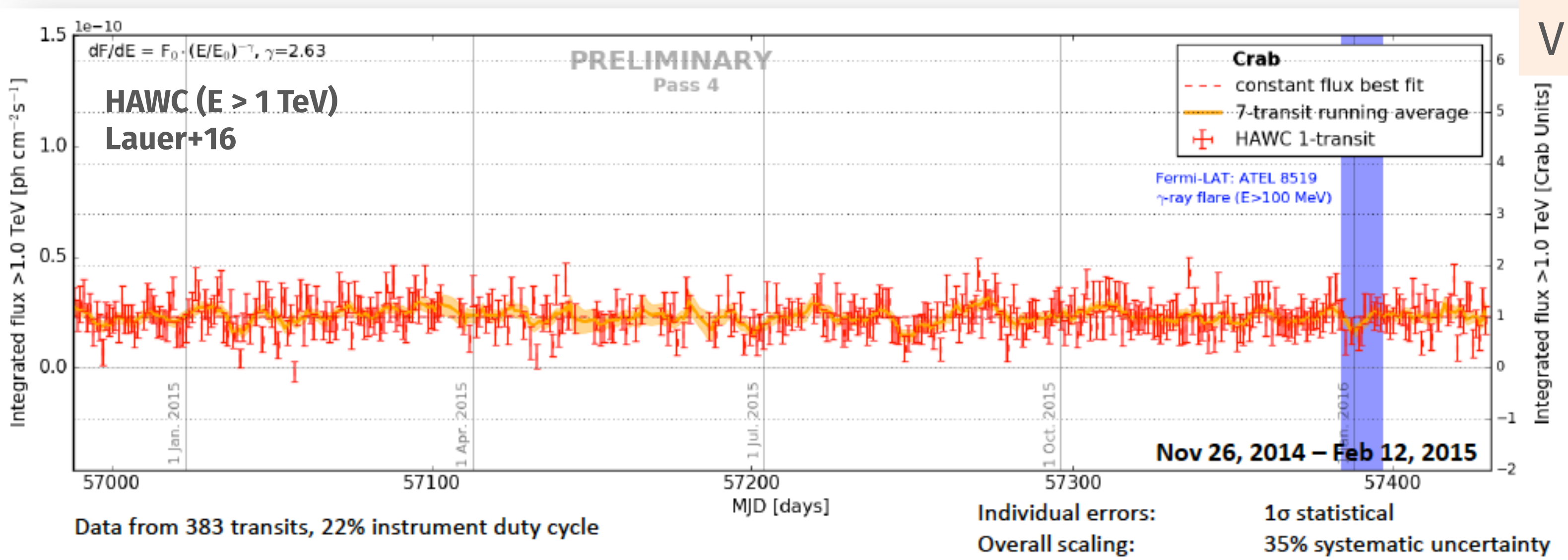


Power-law acceleration by shock- driven plasma wave turbulence within a ~1-day timescale?

Several tens of theoretical papers!

PWN – the "violently quiet" Crab



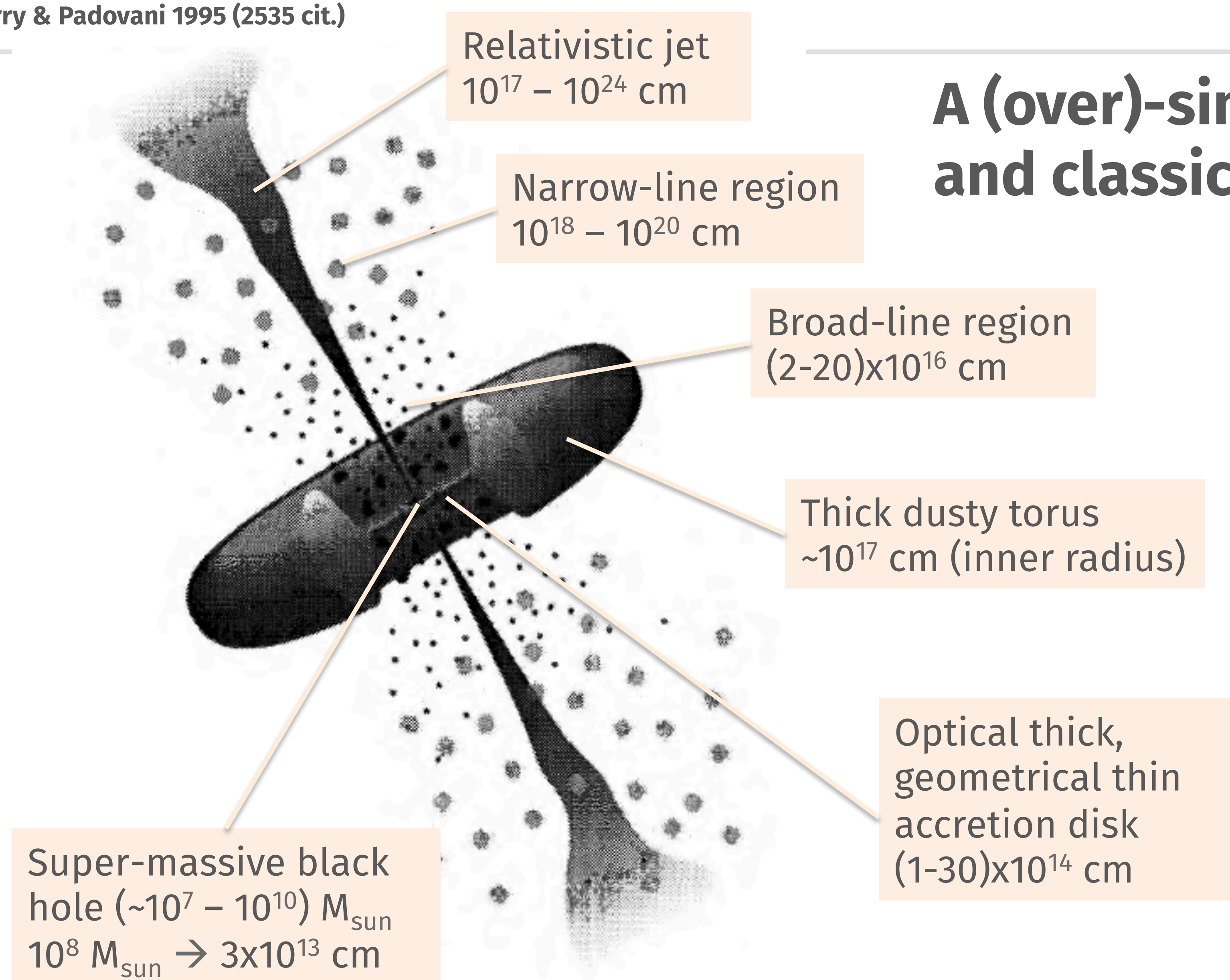


Crab is stable at VHE !

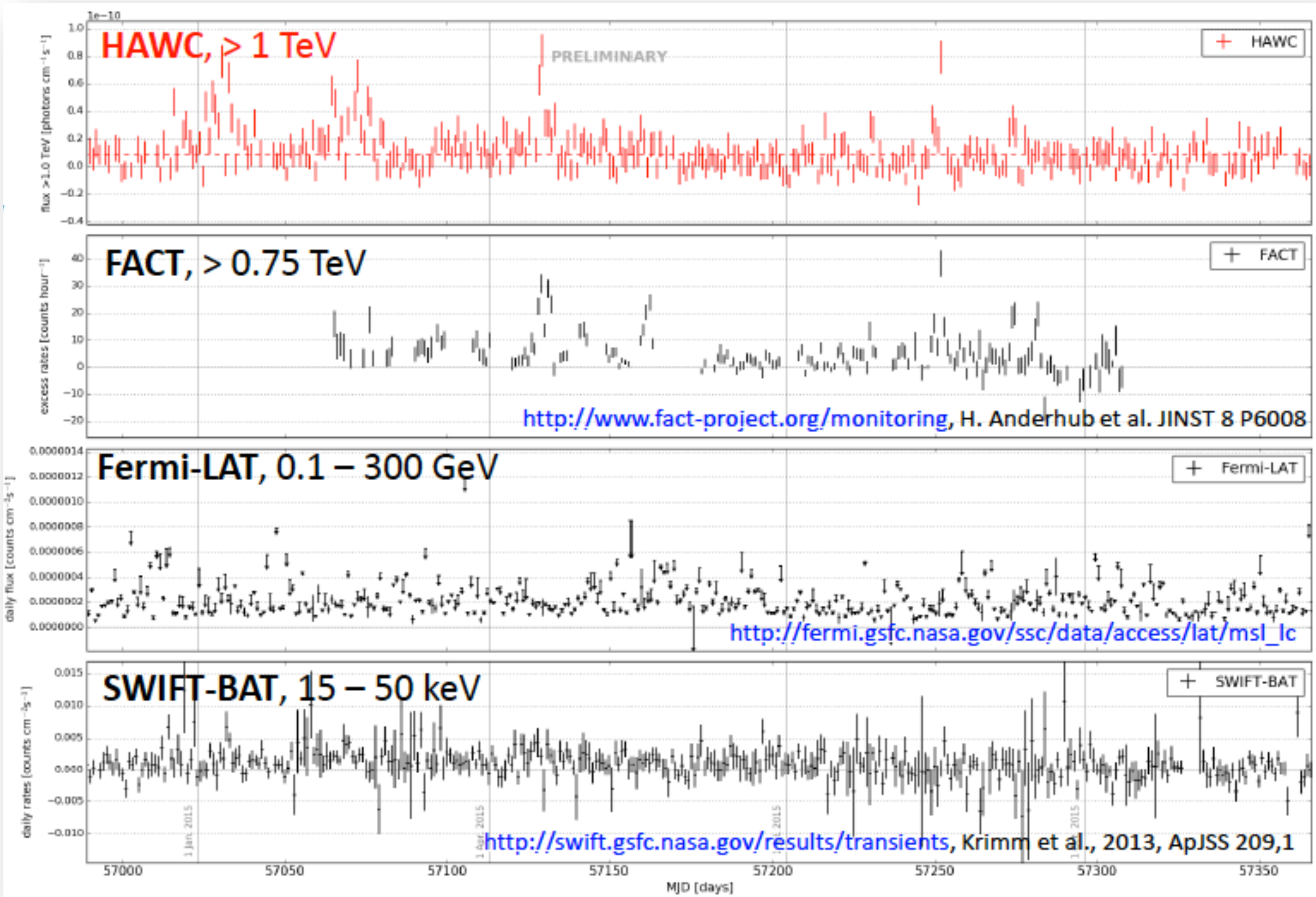
Active Galactic Nuclei

Urry & Padovani 1995 (2535 cit.)

A (over)-simplified and classical view

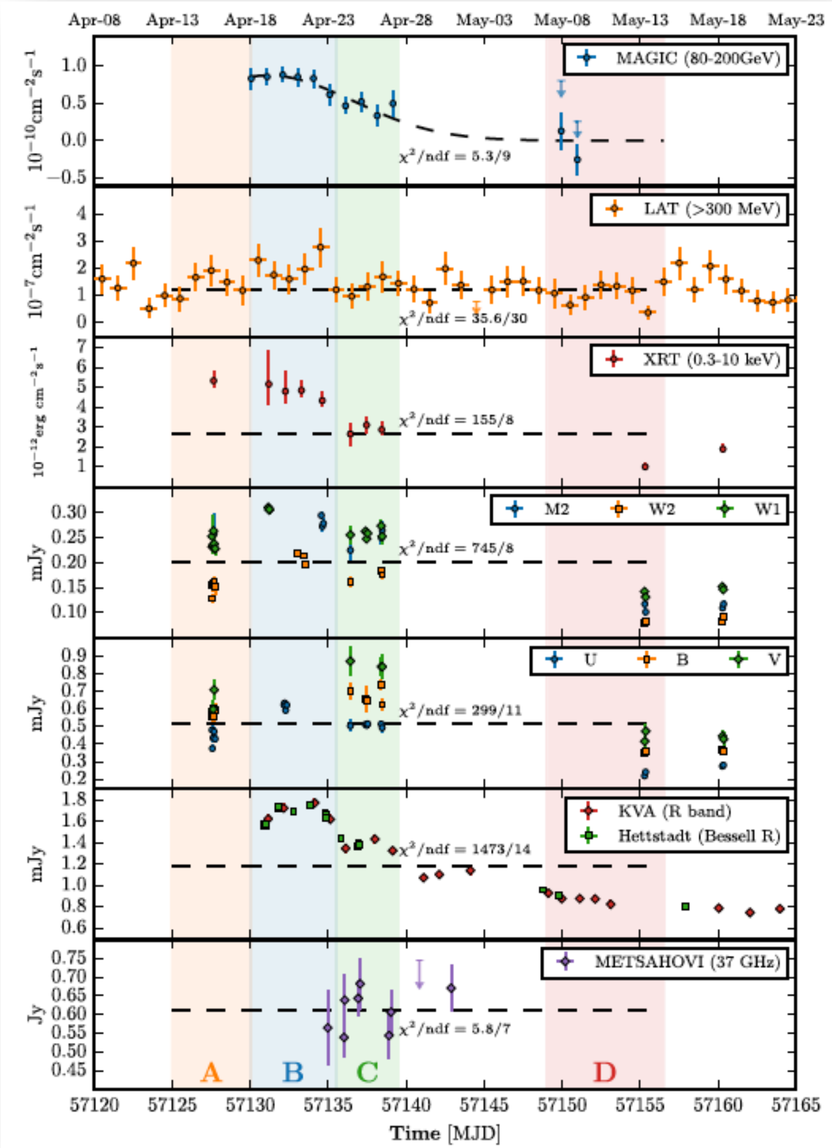


Blazar monitoring at HE/VHE



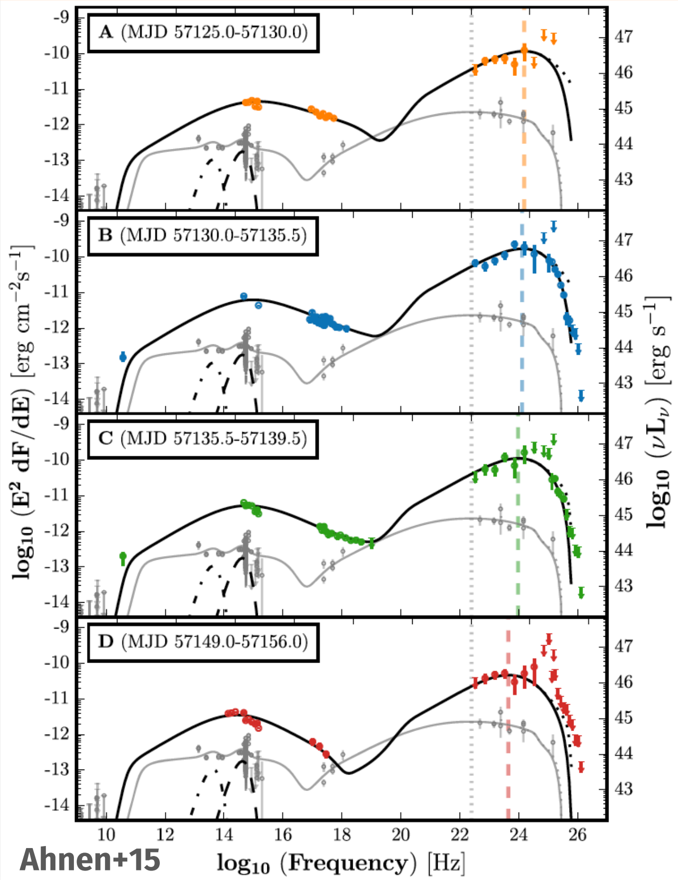
Lauer+16

FSRQs – PKS 1441+25



The location of the emitting region:

- in the jet outside the BLR during the period of high activity
- partially within the BLR during the period of low (typical) activity



Ahnen+15

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

CTA PHYS SWGs

1. **Galactic**
   1. Jamie Holder (Coordinator)
   2. Roberta Zanin (Deputy)
2. **Cosmic-rays**
   1. Stefan Ohm (Coordinator)
   2. Sabrina Casanova (Deputy)
3. **Extra-galactic**
   1. Elina Lindfors (Coordinator)
   2. Fabrizio Tavecchio (Deputy)
4. **Transients**
   1. Catherine Boisson (Coordinator)
   2. Daniela Hadasch (Deputy)
5. **Dark matter and exotic physics**
   1. Fabio Zandanel (Coordinator)
   2. Aldo Morselli (Deputy)
6. **Intensity interferometry**
   1. Dainis Dravins (Coordinator)
   2. Michael Daniel (Deputy)

Multi-wavelength and synergies

1. Sera Markoff (Coordinator)
2. Emma de Oña Wilhelmi (Deputy)

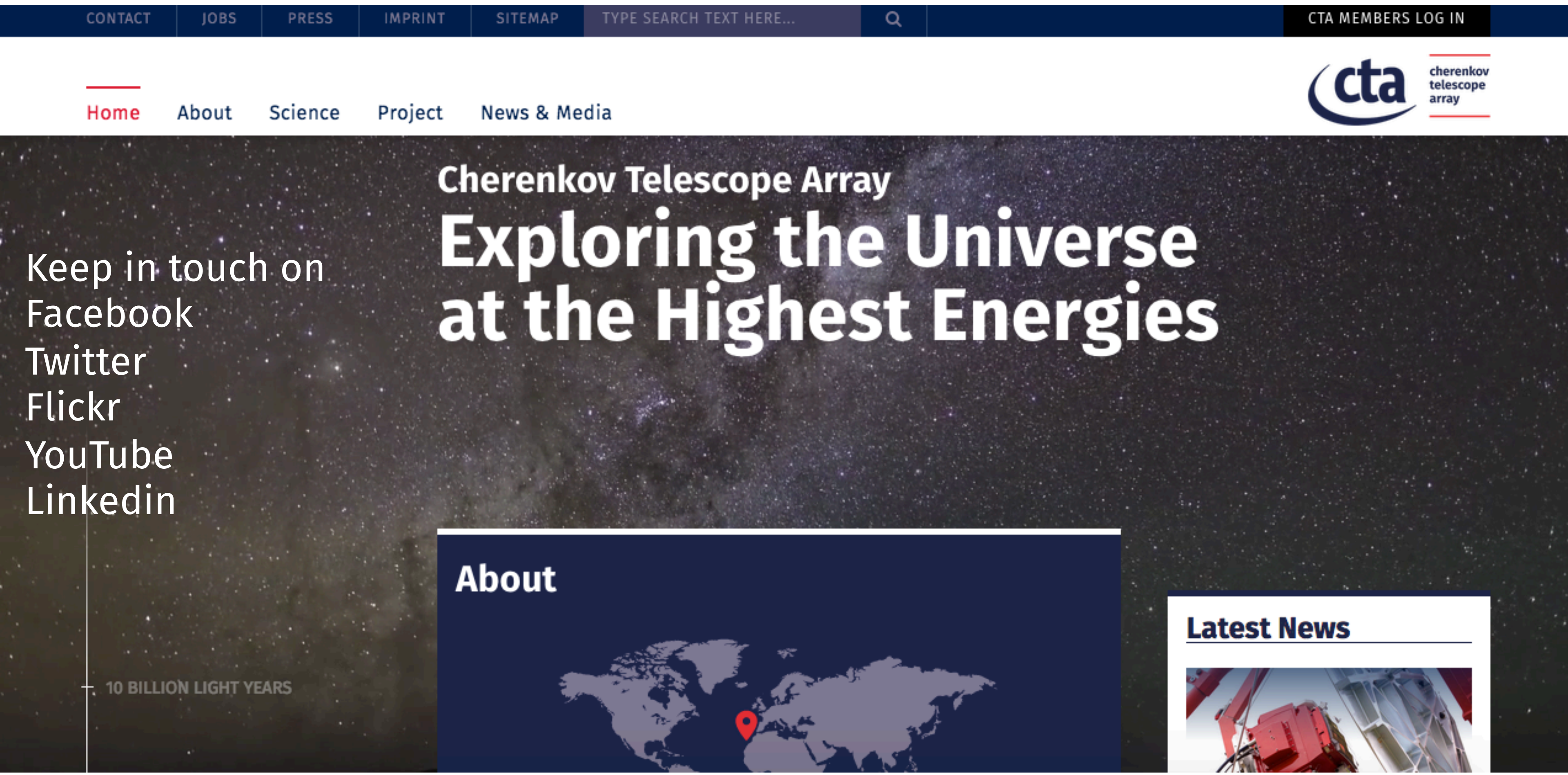
Collaborations/Contributions

Among others, collaborations and contributions may be on

- **Science activities**
  - We have established the 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

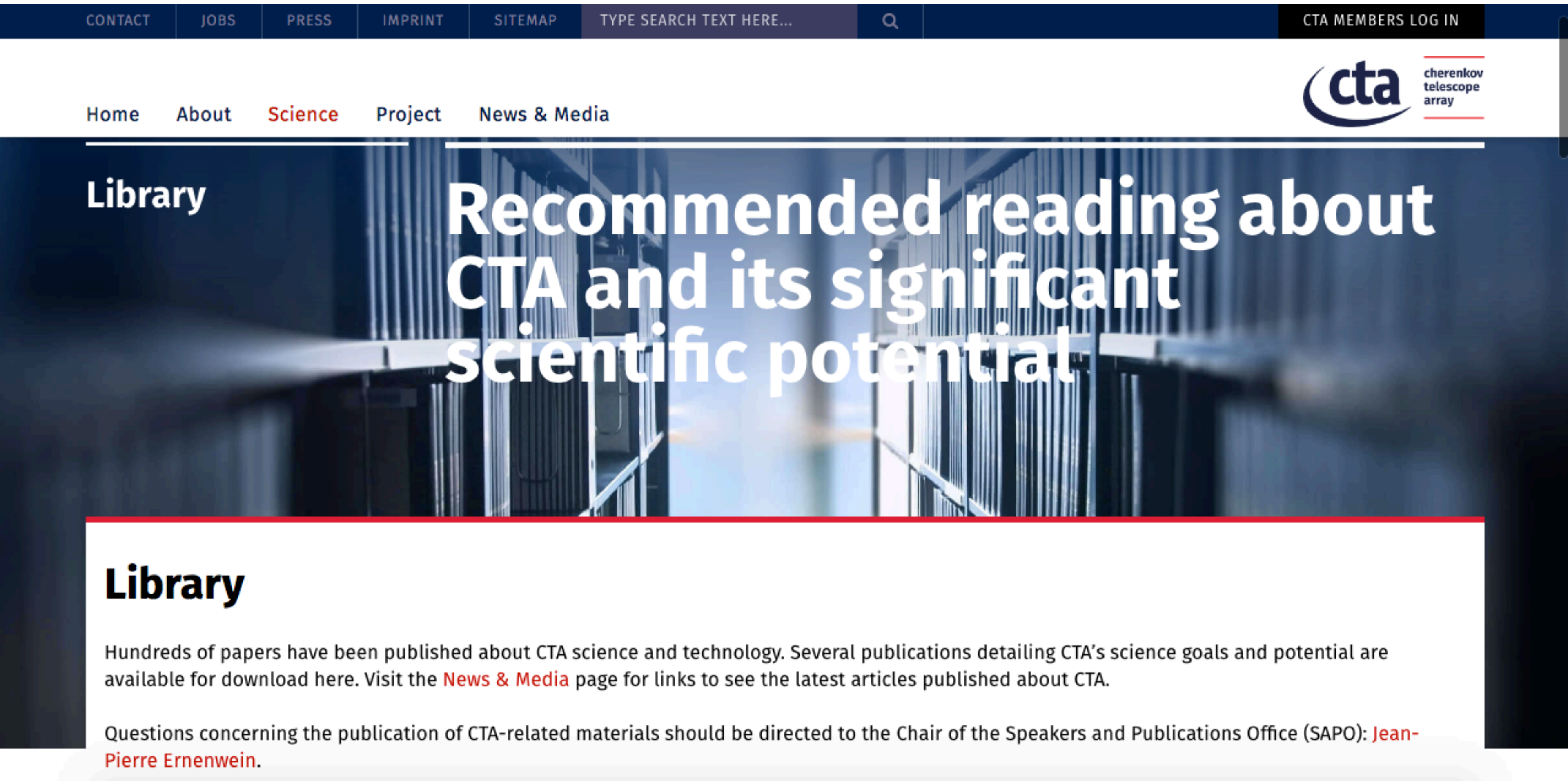
CTA Main webpage

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



CTA Library webpage

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



CTA Performance webpage

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

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Home About Science Project News & Media

CTA Performance

CTA's expected baseline performance

CTA Performance

CTA will provide very wide energy range and excellent angular resolution and sensitivity in comparison to any existing gamma-ray detector. Energies up to 300 TeV will push CTA beyond the edge of the known electromagnetic spectrum, providing a completely new view of the sky. Here is how CTA's energy range will compare to some of the existing astronomical instruments:

Expected Baseline Performance Plots

- Sensitivity
- Angular Resolution
- Energy Resolution and Energy Dispersion Matrix
- Collection Area
- Background Rate
- Off-Axis Sensitivity

ASCII files

- CTA-Performance-South-20150511.ASCII.tar.gz
- CTA-Performance-North-20150511.ASCII.tar.gz

ROOT format:

- CTA-Performance-South-20150511.tar.gz
- CTA-Performance-North-20150511.tar.gz

References

- **Teraelectronvolt Astronomy**
  - Hinton and Hofmann, Annual Review of Astronomy and Astrophysics, 47, 523 (2009)
- **Seeing the High-Energy Universe with the Cherenkov Telescope Array - The Science Explored with the CTA**
  - Edited by Hinton, Sarkar, Torres and Knapp, Astroparticle Physics Volume 43, Pages 1-356 (March 2013)
- **CTA Contributions to the 2015 ICRC Conference**
  - [arXiv:1508.05894]
- **Science with the Cherenkov Telescope Array**
  - Edited by Hinton, Ong and Torres, to appear soon !

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!

Title of the Proposal

Group 1

1. Abstract

Type a concise (less than 5 lines) abstract of your proposal.

2. Scientific Rationale

Here you can give the scientific background of your proposed study.

3. Immediate Objectives

Here you should state what you are proposing to observe and what the goals of the proposed study are.

4. Justification of Requested Observing Time and Feasibility

The requested observing time, intrument modes, and any constraints have to be explained in detail here.

Proposers must clearly describe how their proposal capitalizes on the unique capabilities of CTA.

If more than one target is proposed, give the priority of each target in case only some of your targets are accepted.

If this is a monitoring program, give the cadence of observations and all time constraints.

If this is a ToO proposal, explain and justify the trigger criteria and give a realistic estimate of the probability that the ToO will be triggered.

5. Report on Previous and Related Programs

Here you can report on your previous studies that are related to this proposal.

Thanks !

Feel free to contact me during this days, I will be around for the whole period !

e-mail: stefano.vercellone@brera.inaf.it