Astrofisica Nucleare e Subnucleare

TeV Astrophysics – V

Astrofisica Nucleare e Subnucleare

Future detectors

2004	2005	2006	2007	2008	2009	2010

Roadmap to the Next Generation Cherenkov Gamma Ray Telescope


H.E.S.S.


H.E.S.S. II

Technology for Fully Robotic Telescope

Experimental Study of High Altitude effect

Design Study of Large Telescope

Site Survey

Characterization of Low Energy Showers

Design Study of Wide Angle Telescope

Advanced photon detector


MAGIC


MAGIC II

Science Review

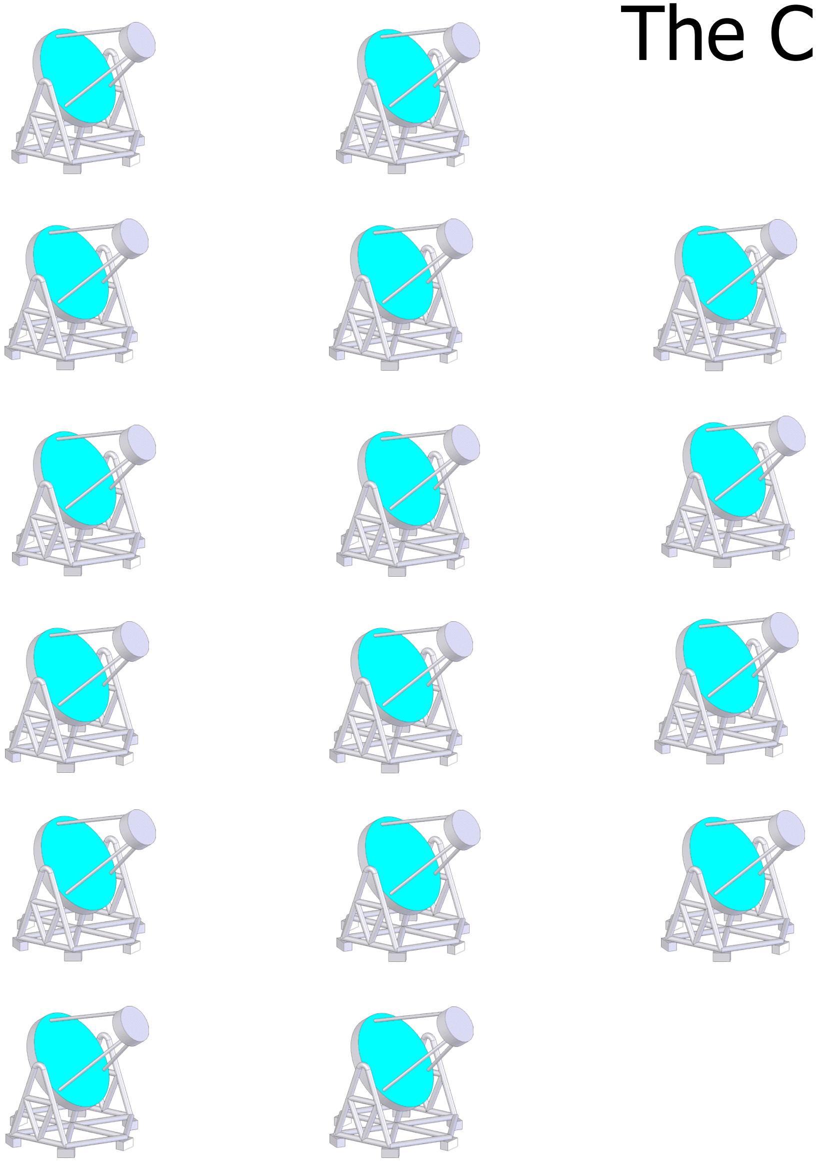
Final Conceptual Design under New collaboratio

Ultimate Ground-based Cherenkov Telescope System
Larger Dish,
High Altitude,
Advanced detector,
Wide Angle

International collaboration CANGAROO, VERITAS, etc.

Outlook: What next ?

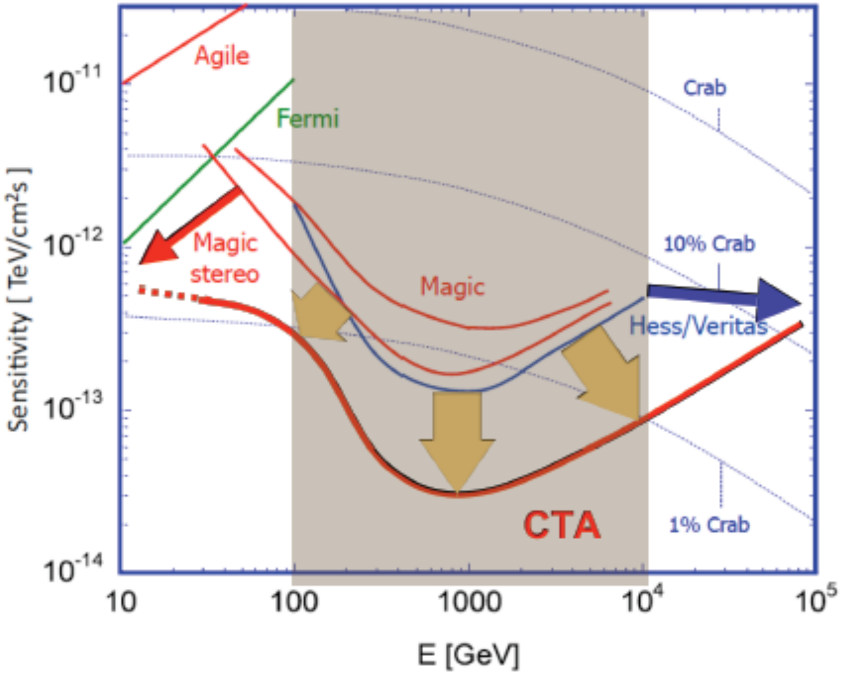
The Cherenkov Telescope Array (CTA)

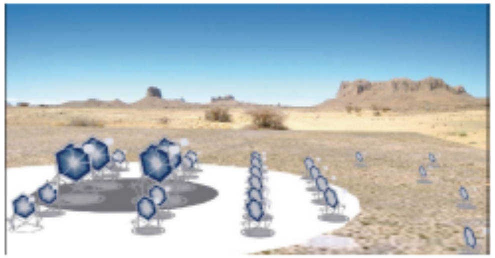


- aims to explore the sky in the 10 GeV to 100 TeV energy range
- builds on demonstrated technologies
- combines guaranteed science with significant discovery potential
- is a cornerstone towards a multi-messenger exploration of the nonthermal universe

CTA

Improve sensitivity

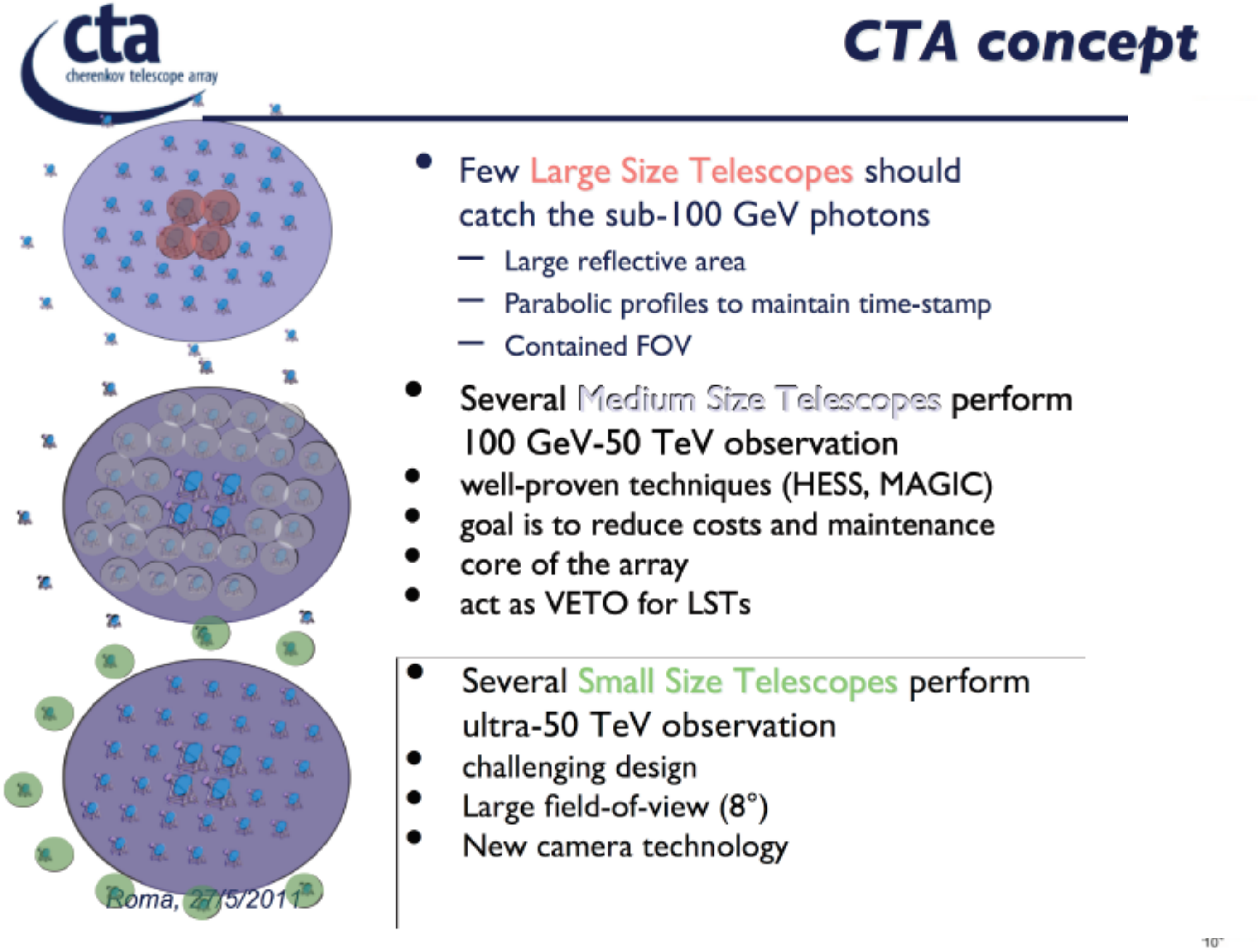




CTA will be about a factor of 10 more sensitive than any existing instrument in the 100 GeV-10 TeV energy band.

CTA will also extend the observed energy band reaching both the lower (10 GeV) and the higher (100 TeV) energies.

CTA



CTA concept

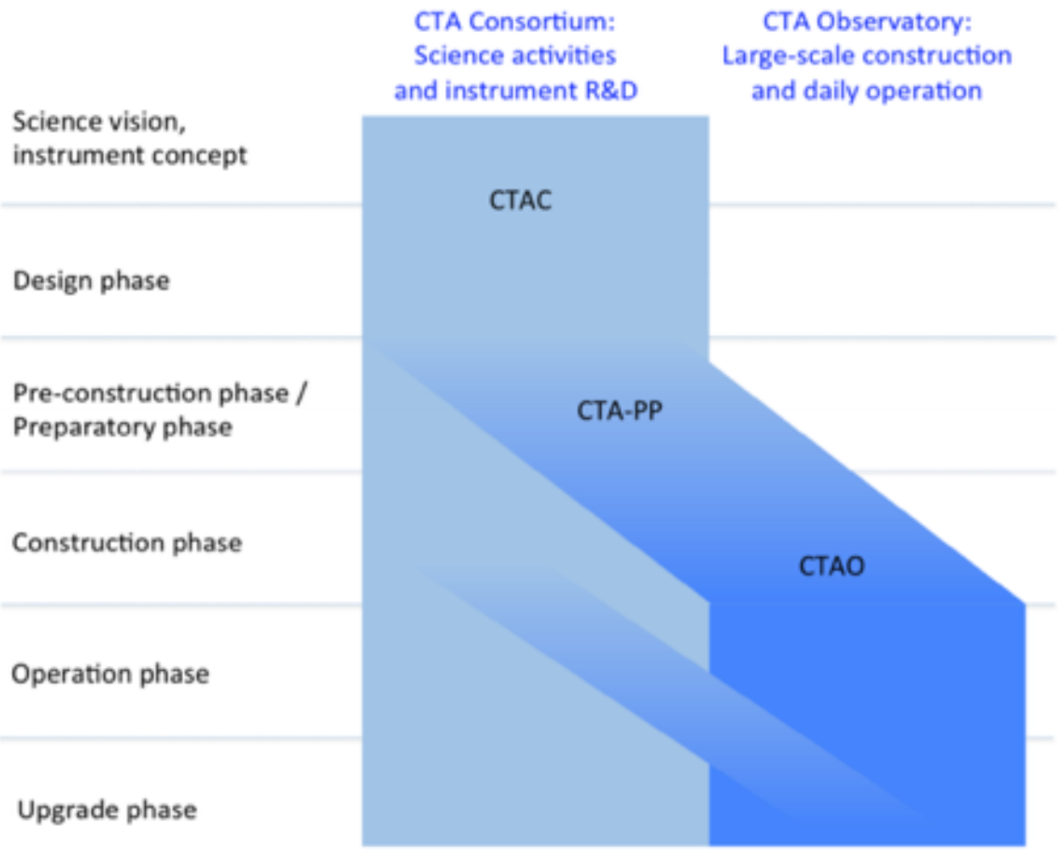
- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
- Several Medium Size Telescopes perform 100 GeV-50 TeV observation
- well-proven techniques (HESS, MAGIC)
- goal is to reduce costs and maintenance
- core of the array
- act as VETO for LSTs

- Several Small Size Telescopes perform ultra-50 TeV observation
- challenging design
- Large field-of-view (8°)
- New camera technology

Toward the future!

A next generation Cherenkov Observatory

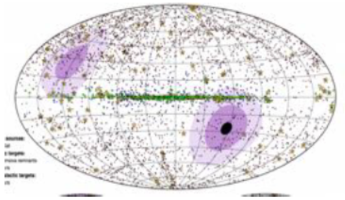
Status and observatory planning…

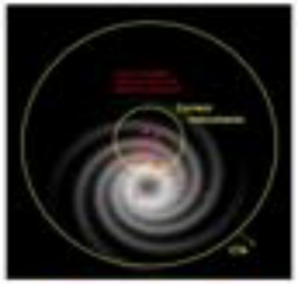


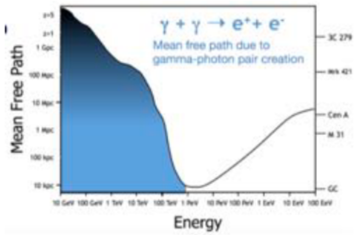
- CTA as open observatory
- Regular AOs
- Proposals evaluated by TAC
- Observations carried out in queue mode
- Fully calibrated photon lists and analysis tools provided to observers
- Data open after proprietary period of 1 year

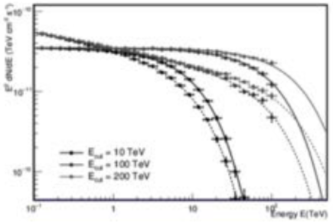
From:
Concept for CTA
construction and operation
WH 2011/12

Design drivers









Full sky coverage

10 x sensitivity

Energies down to 20 GeV

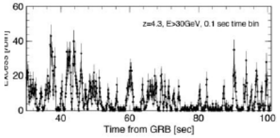
Energies up to 300 TeV

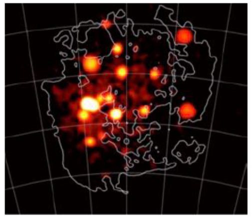
Rapid slewing 20 sec

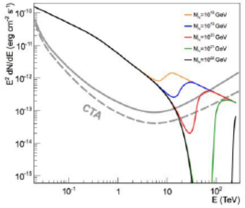
~ 10° FoV

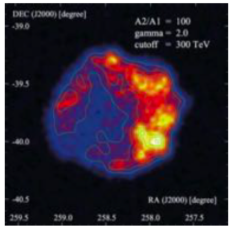
10% energy resolution

arcmin angular resolution

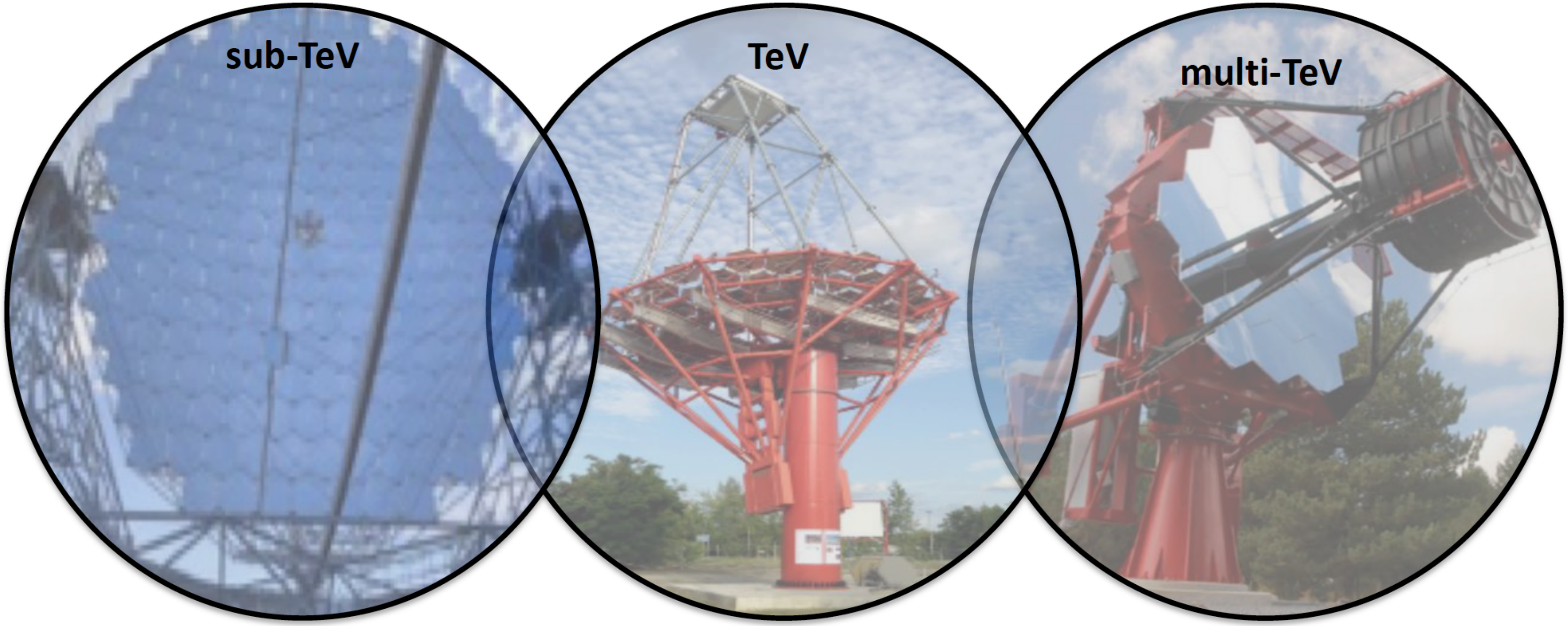








Science cases and design

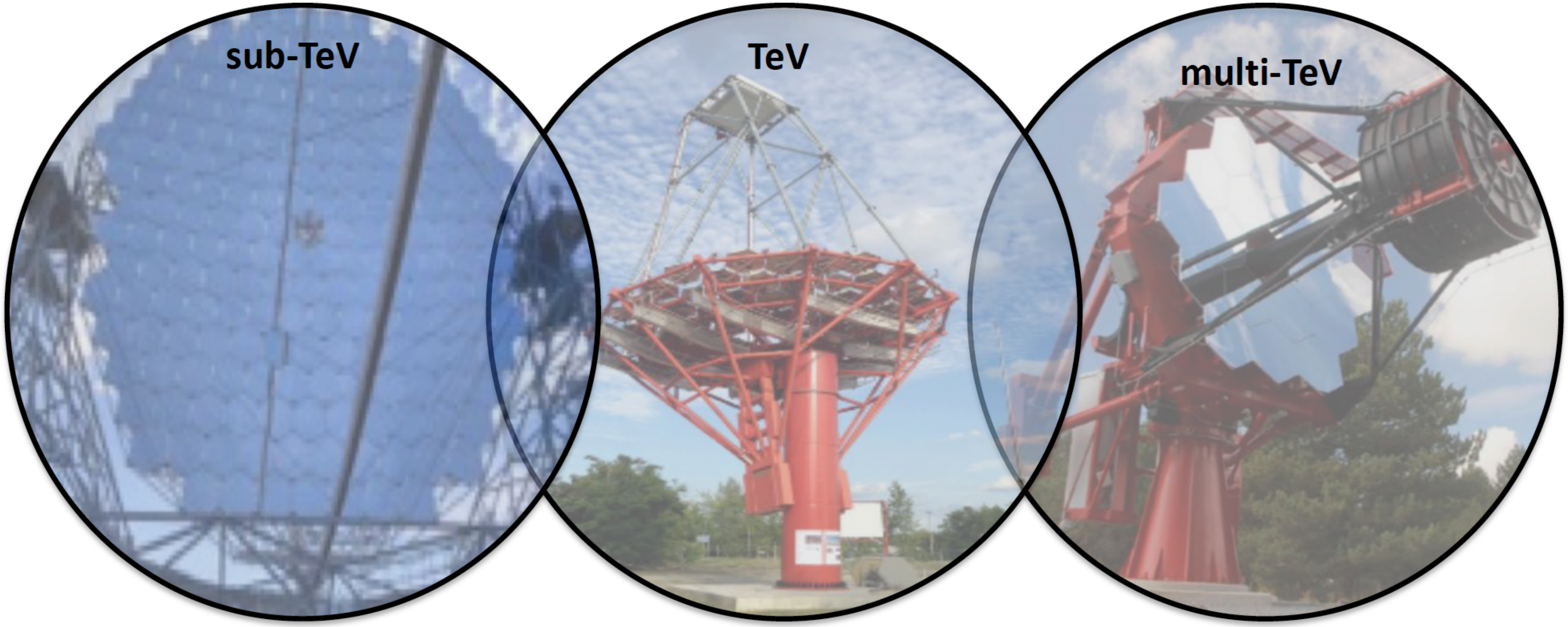


- Parabolic optical design
- 23 m mirror diameter
- PMT camera

- Davies-Cotton optical design
- 12 m mirror diameter
- PMT camera

- Schwarzschild-Couder optical design
- 4 m dual mirror
- SiPM T camera

Science cases and design



- Lowest energies (tens of GeV)
  → **cosmological sources**
- Deepest sensitivity for short timescale phenomena
  → **Time domain unexplored**

- deepest sensitivity ever
- arcmin angular resolution
- large FoV

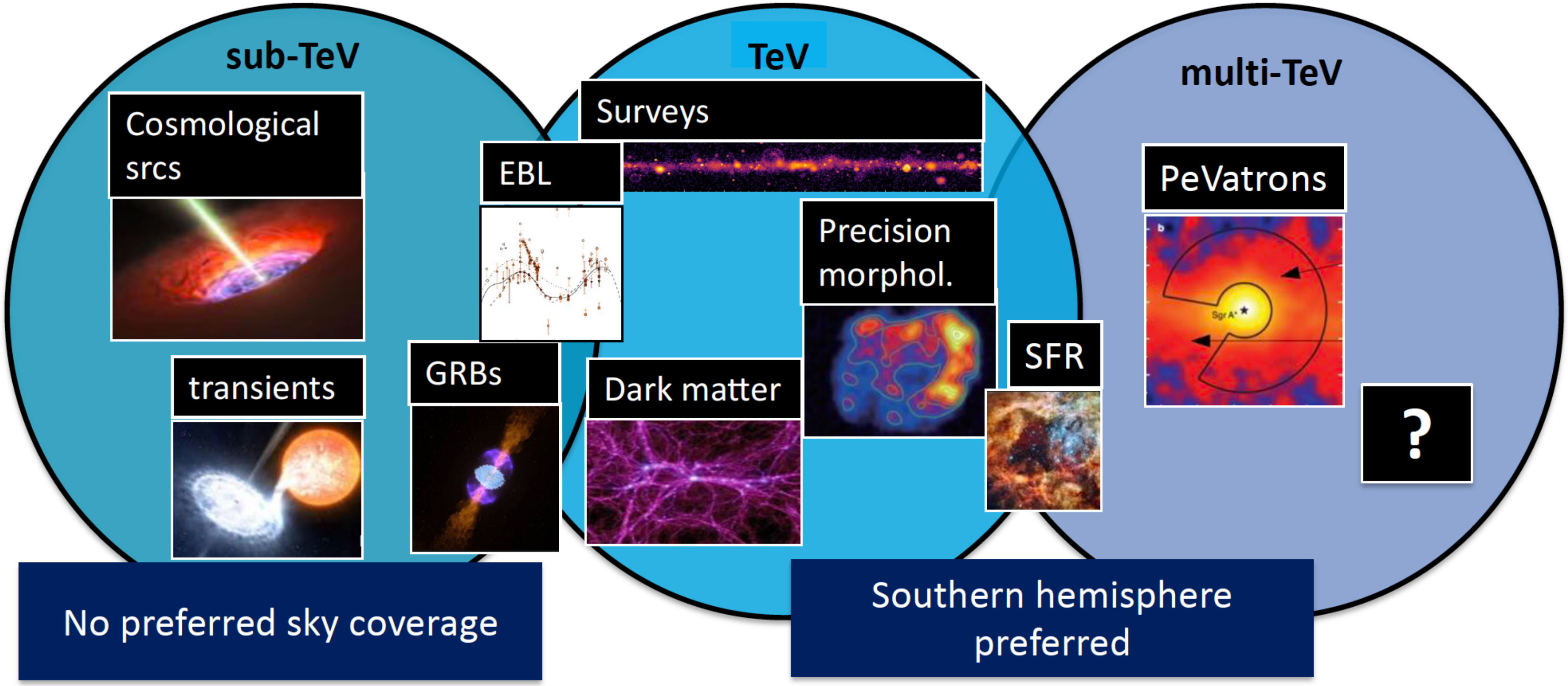
- Surveys & precision studies

- Precision measurements in a still little explored energy range

- **100 TeV range unexplored**
- **precision studies**

R.Zanin – TeVPa 2019

Science cases



sub-TeV

Cosmological srcs

transients

GRBs

EBL

TeV

Surveys

Dark matter

Precision morphol.

SFR

multi-TeV

PeVatrons

?

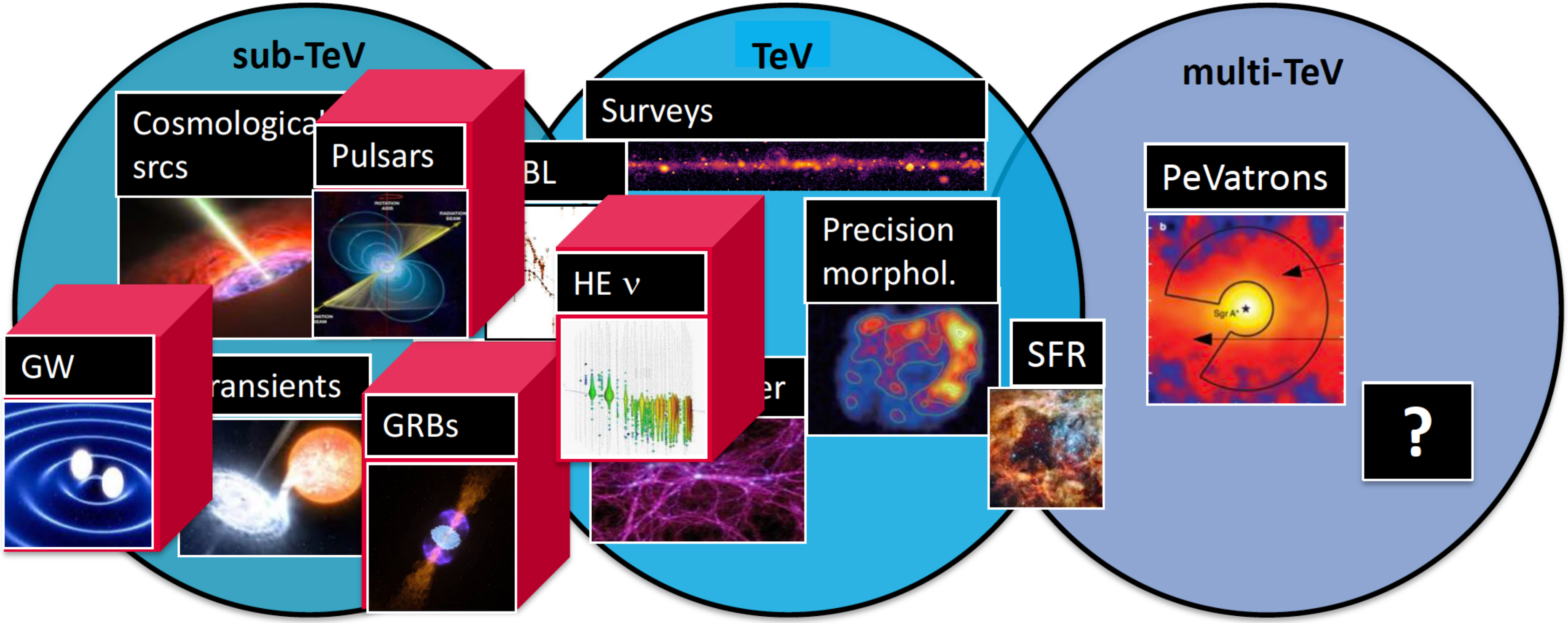
No preferred sky coverage

Southern hemisphere preferred

- **Mainly CTA consortium involved in the definition of the science cases**

  (Science with CTA, CTA Consortium 2019 - https://doi.org/10.1142/10986)

Science cases



- **Mainly CTA consortium involved in the definition of the science cases**

(Science with CTA, CTA Consortium 2019 - https://doi.org/10.1142/10986)

The CTA Sites

A Global Observatory…

CTA Science Data Management Centre

CTA-North

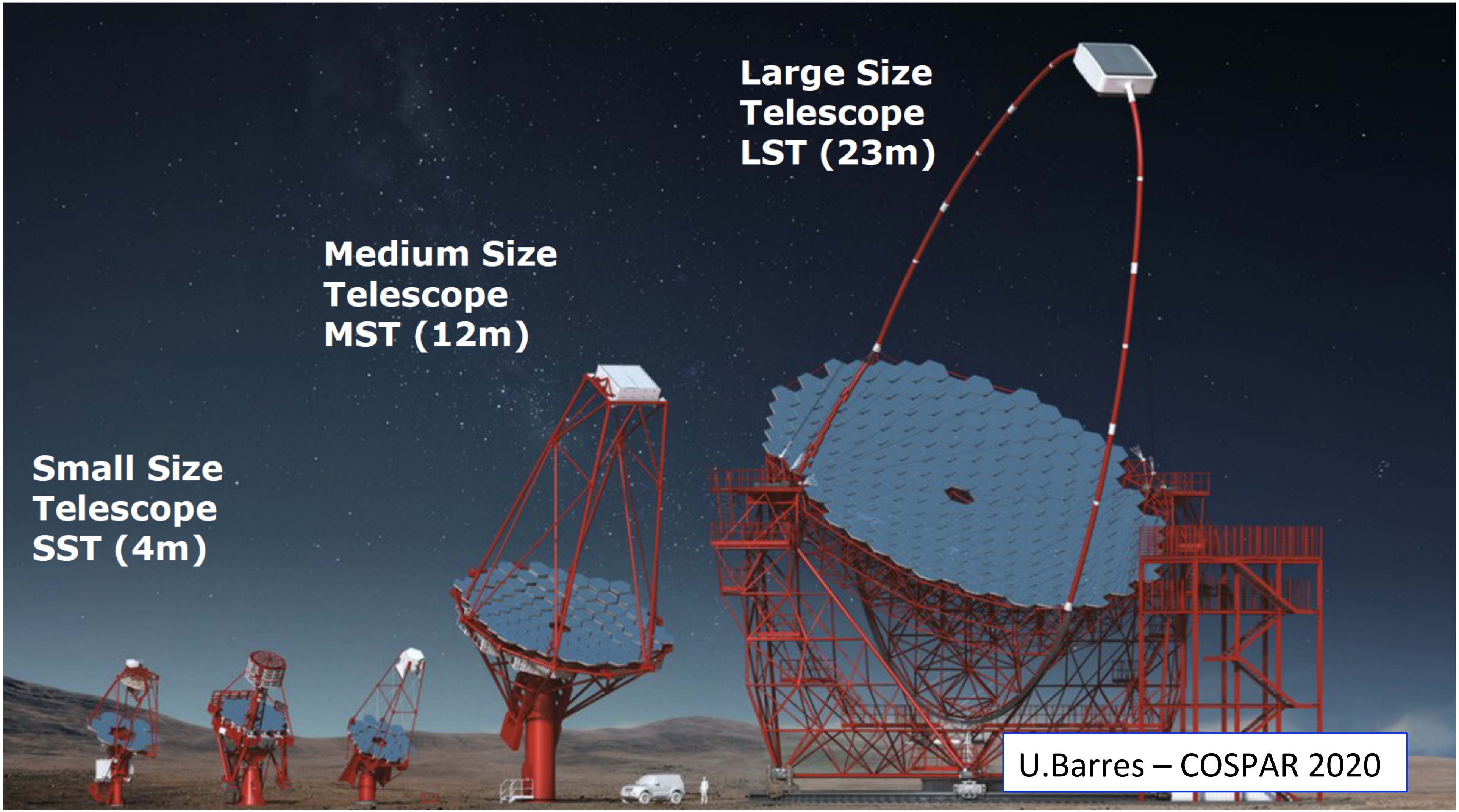
CTA HQ

CTA-South

U.Barres – COSPAR 2020

The CTA Telescopes

A Hybrid Observatory…



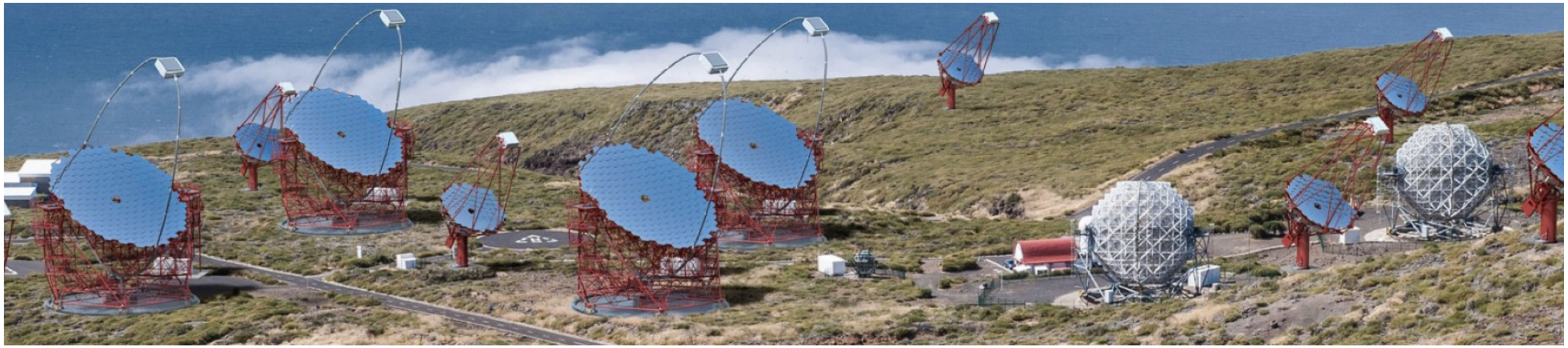
Large Size Telescope LST (23m)

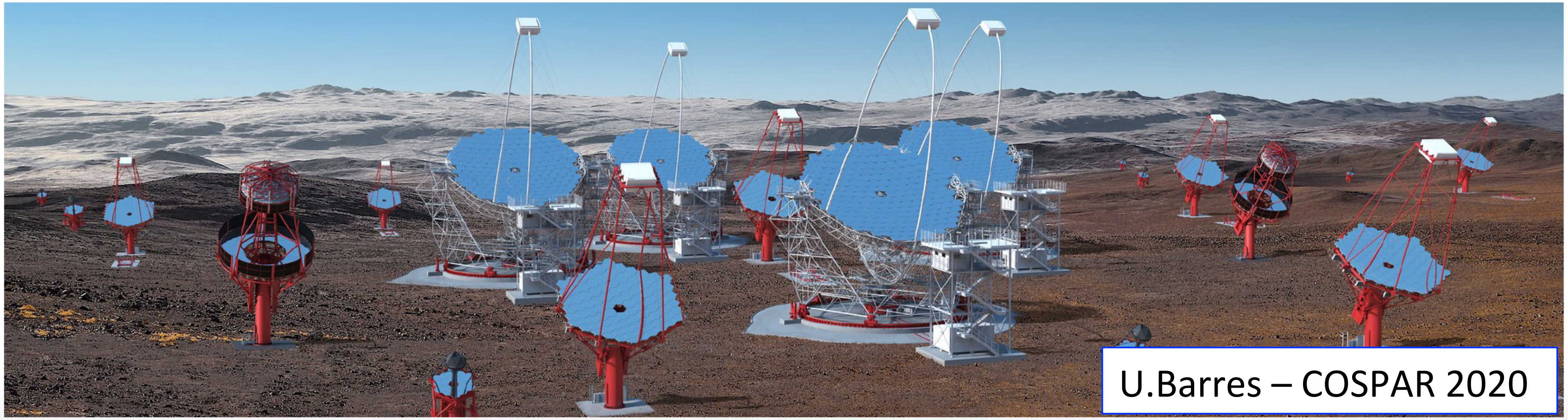
Medium Size Telescope MST (12m)

Small Size Telescope SST (4m)

CTA North &
CTA South

Phase 1		CTA Construction
Northern Array	Number of LSTs	4
	Number of MSTs	5
Southern Array	Number of LSTs	0
	Number of MSTs	15
	Number of SSTs	50
Total		**74**





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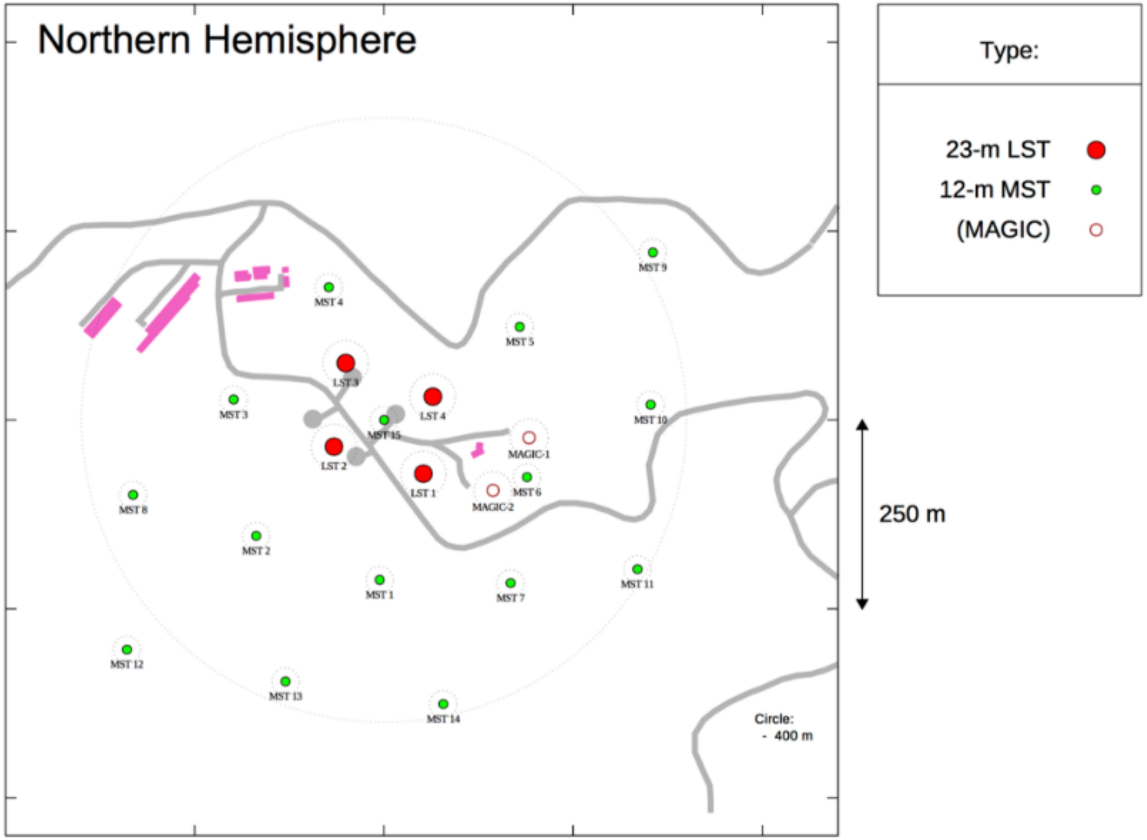
CTA - North

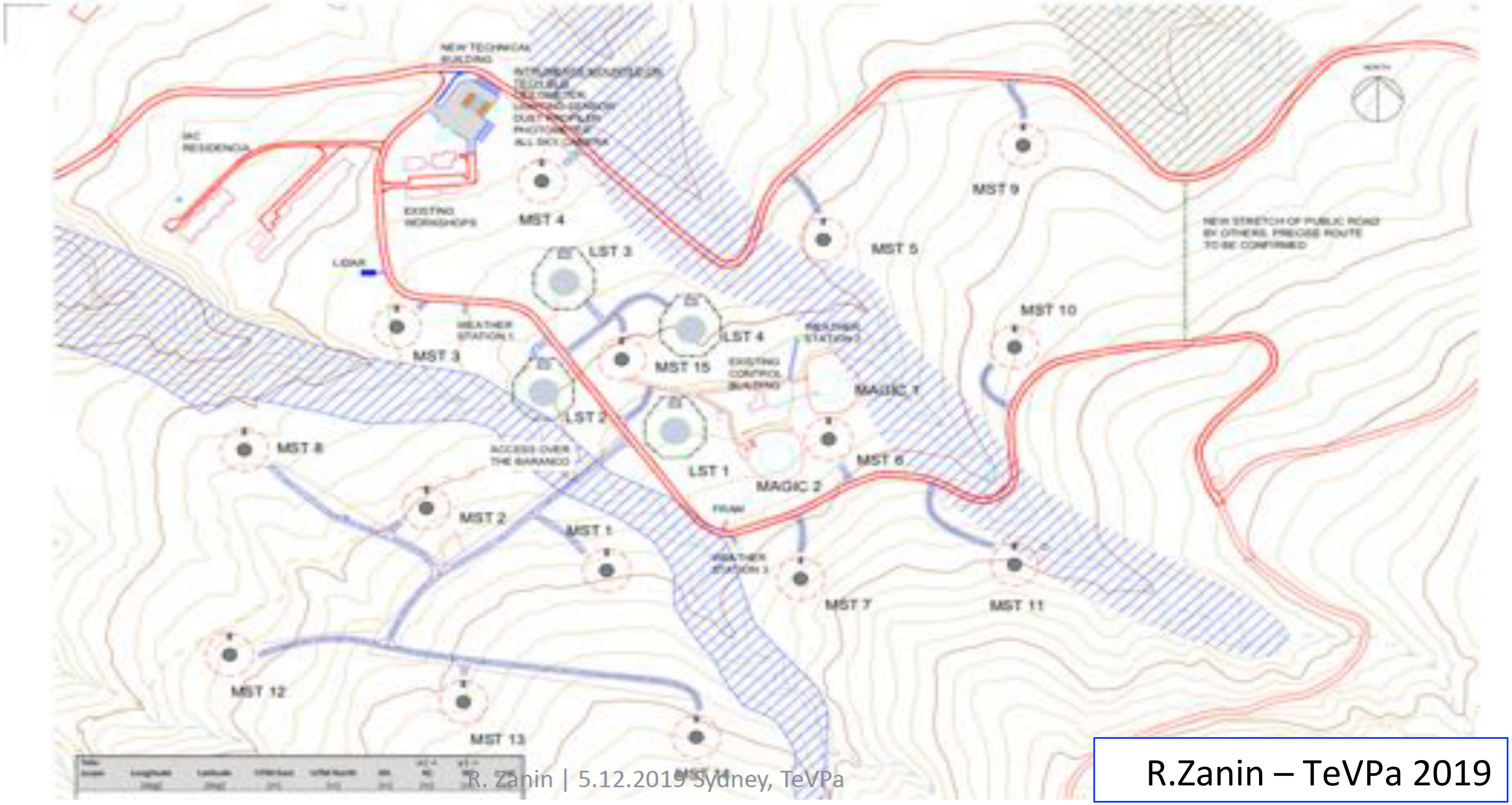


4 LS4 LSTs, 15 MSTs

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

CTA-North site

- 4 LSTs + 15 MSTs (baseline configuration)
  - Focus on sub-TeV and TeV energy range



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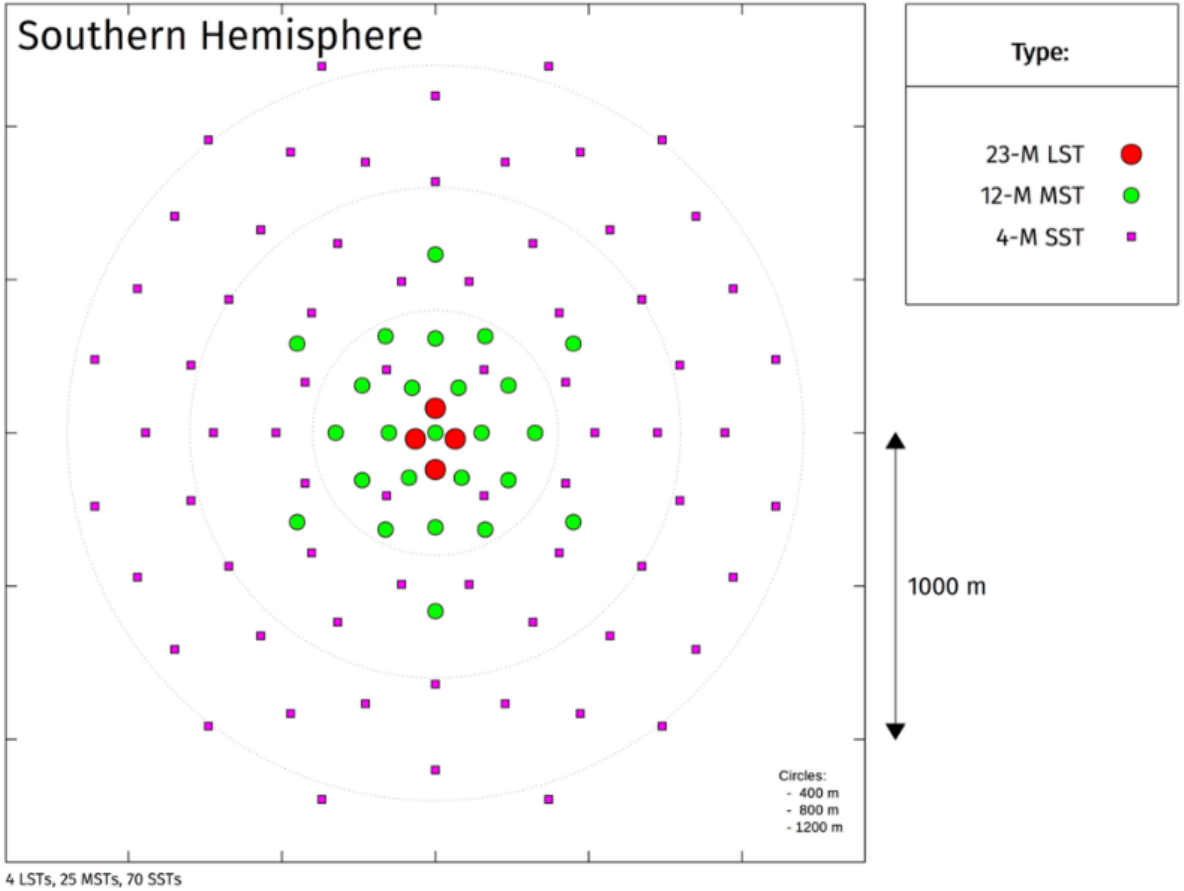
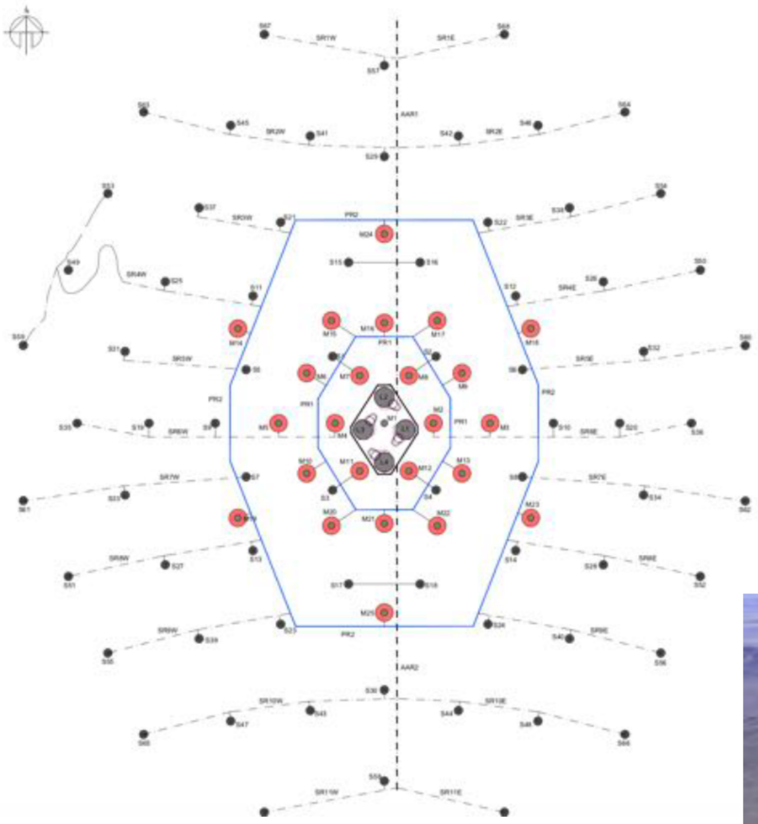
CTA – South



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

CTA-South site

- **4 LSTs + 25 MSTs + 70 SSTs (baseline-configuration)**



- **Site agreement signed in Dec 2018**
- **Aim to start with site infrastructure construction soon**

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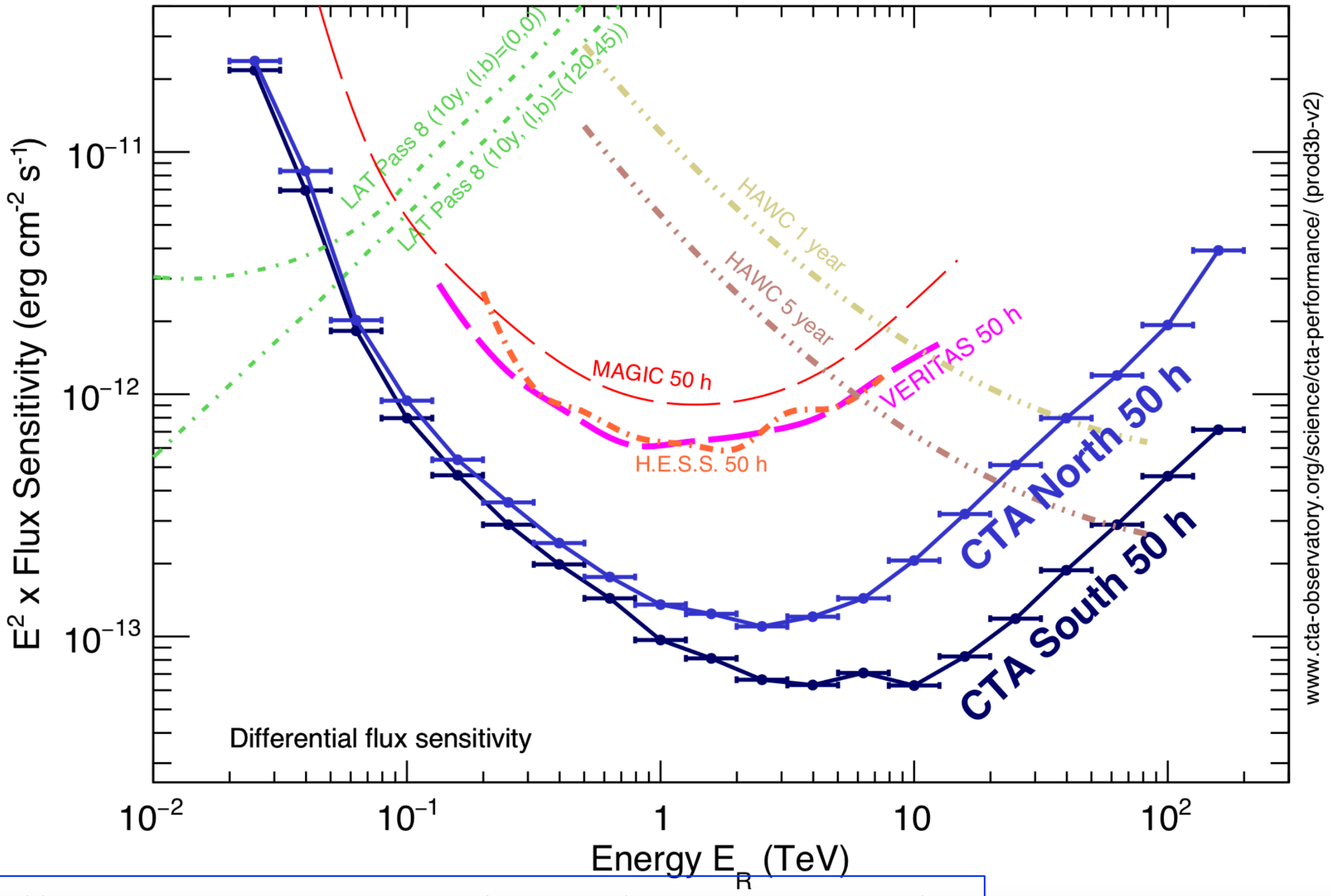
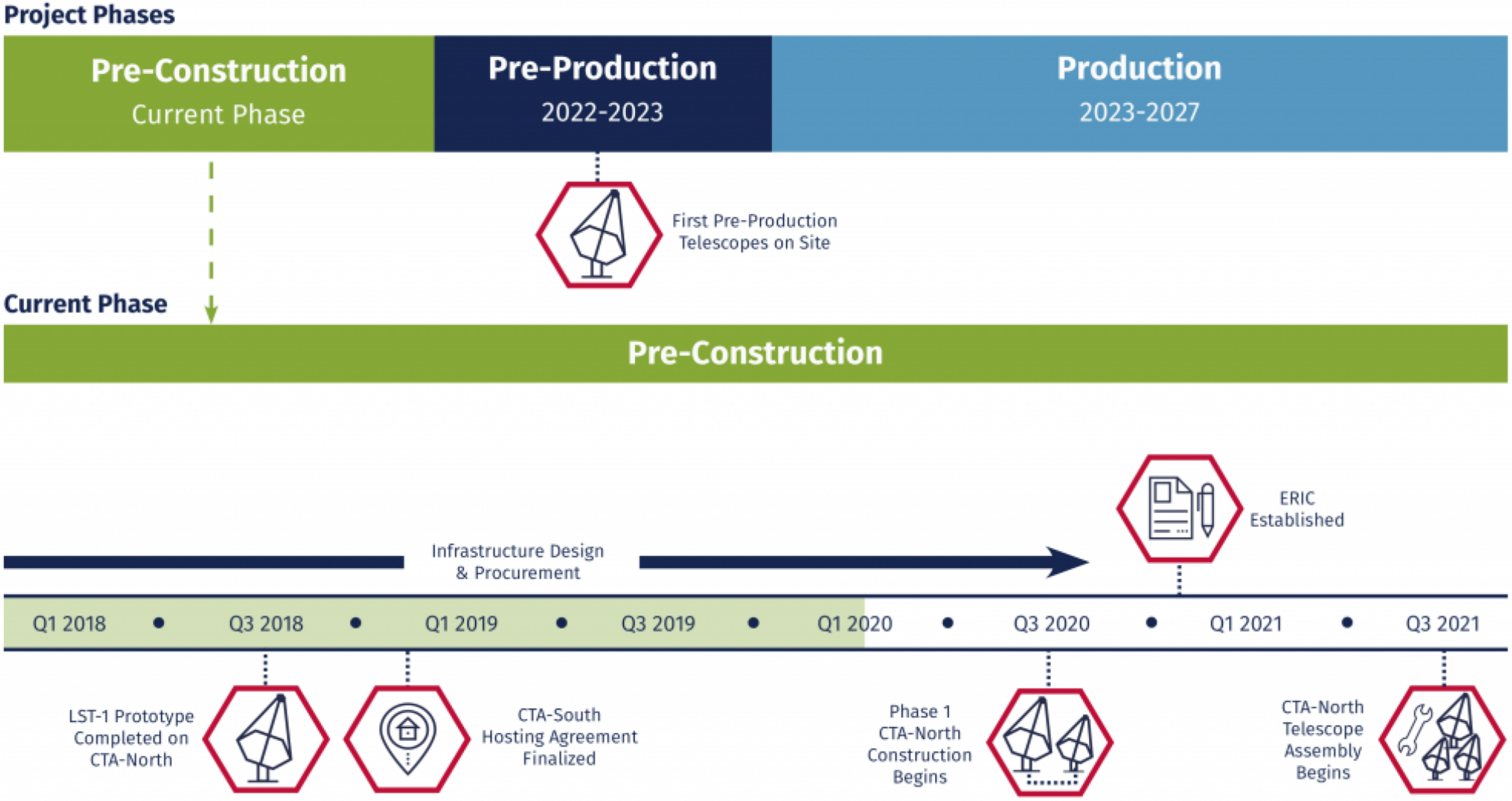
CTA performance



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

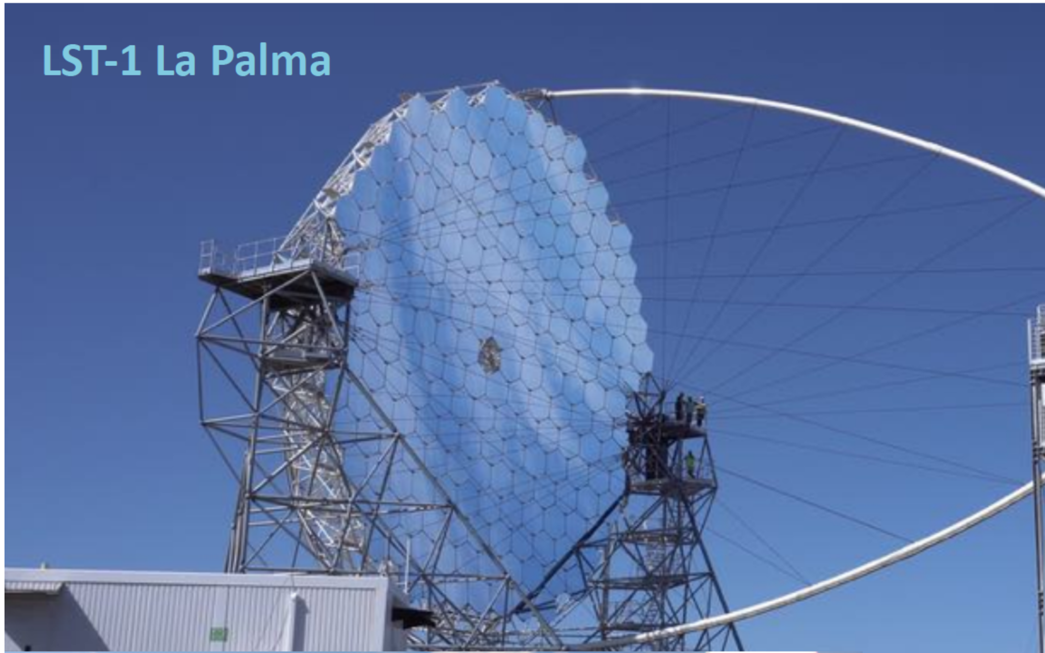
CTA Timeline

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

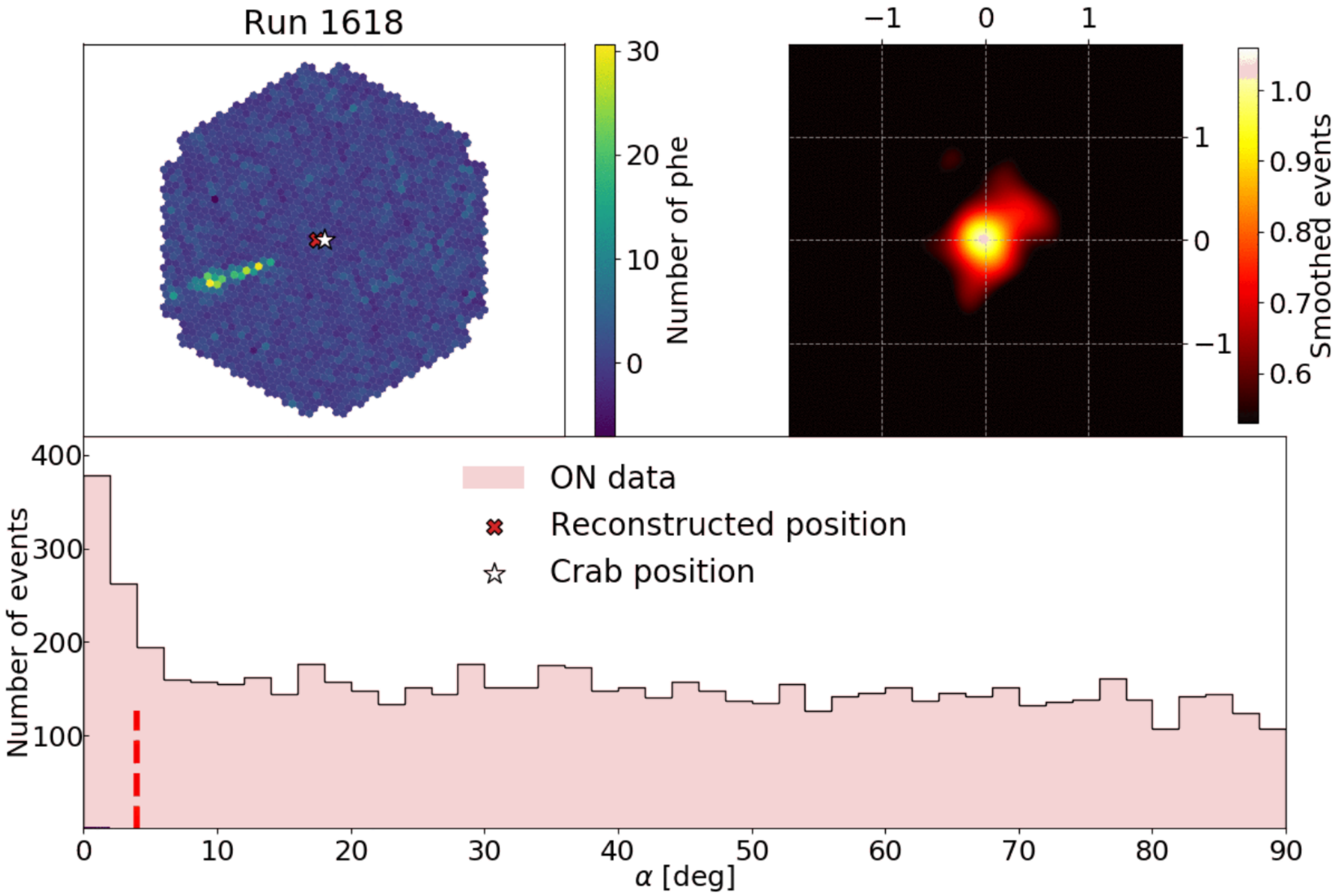


an updated timeline is in draft for 2021

The CTA Telescopes

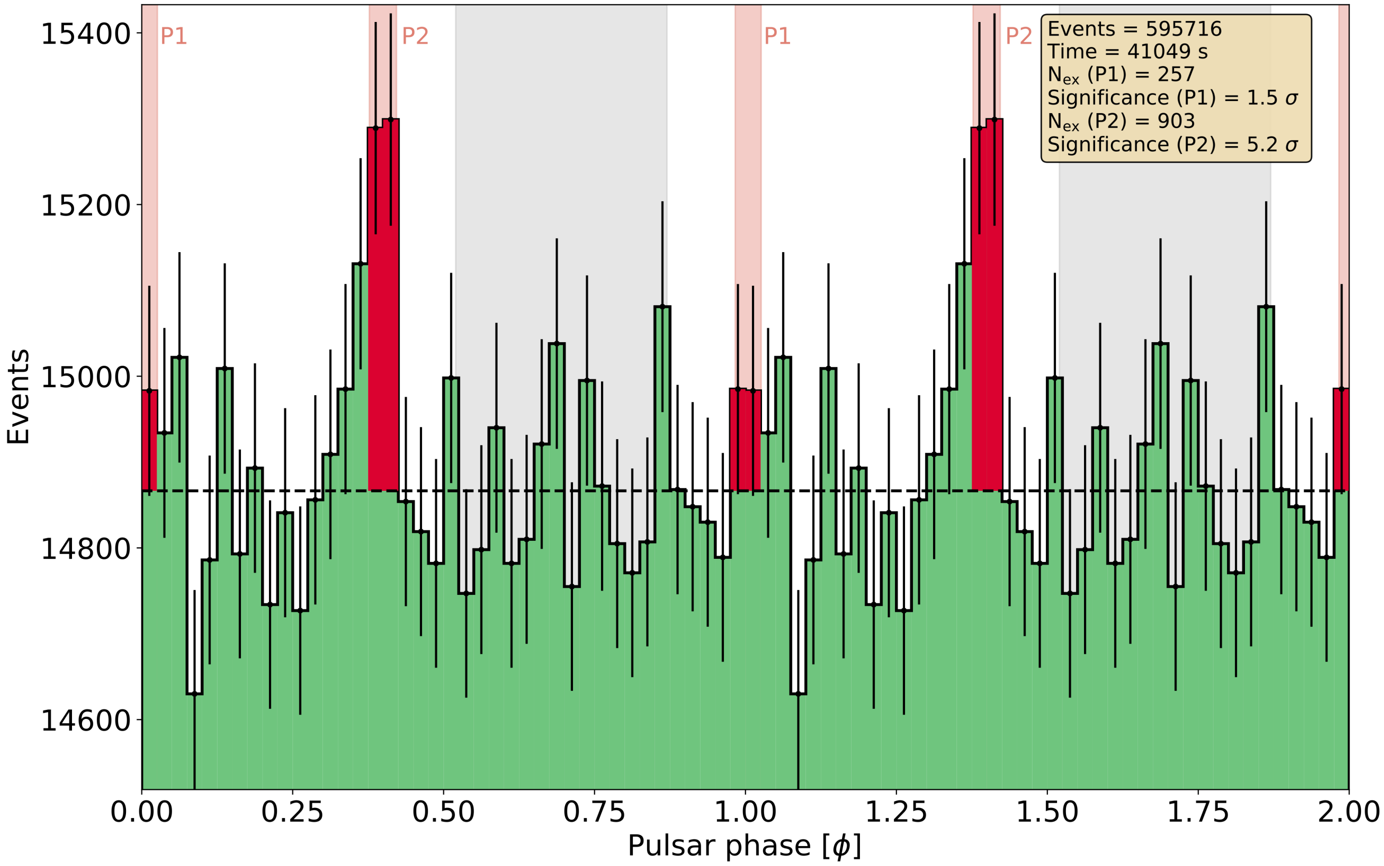


CTA telescopes – first results



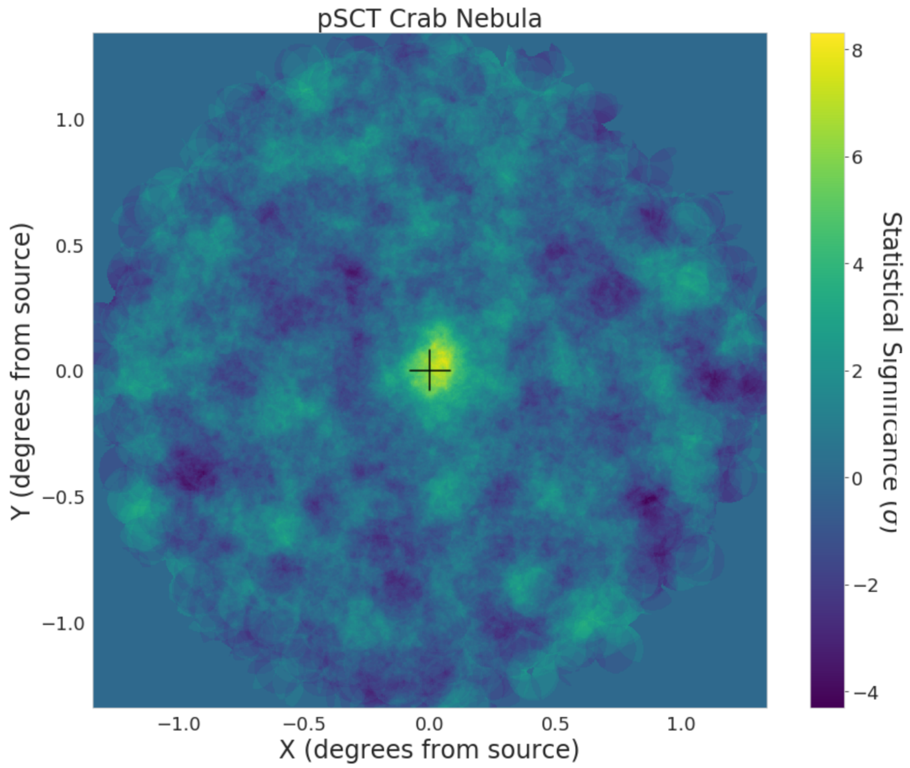
https://www.cta-observatory.org/lst1-detects-first-gamma-ray-signal/

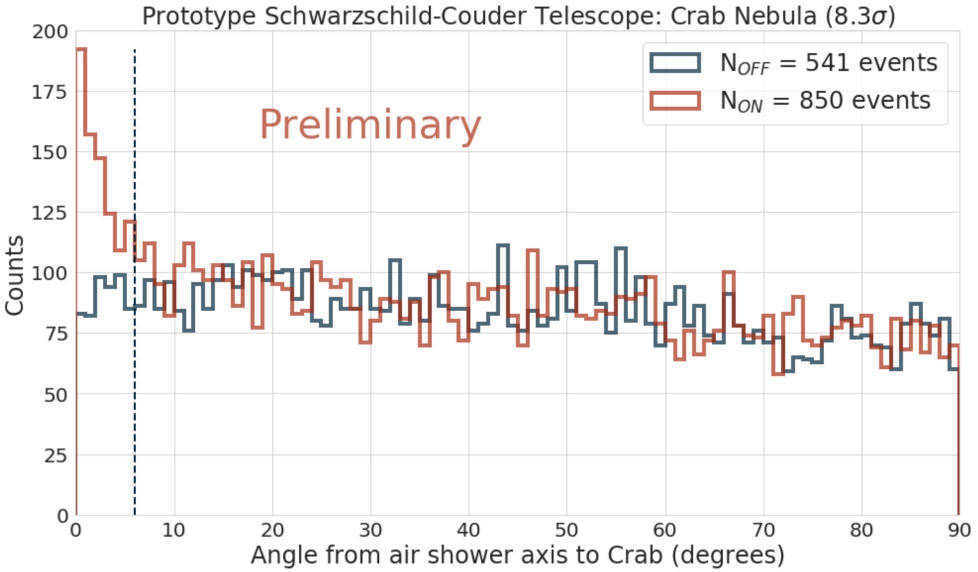
CTA telescopes – first results



https://www.cta-observatory.org/lst1-detects-vhe-emission-from-crab-pulsar/

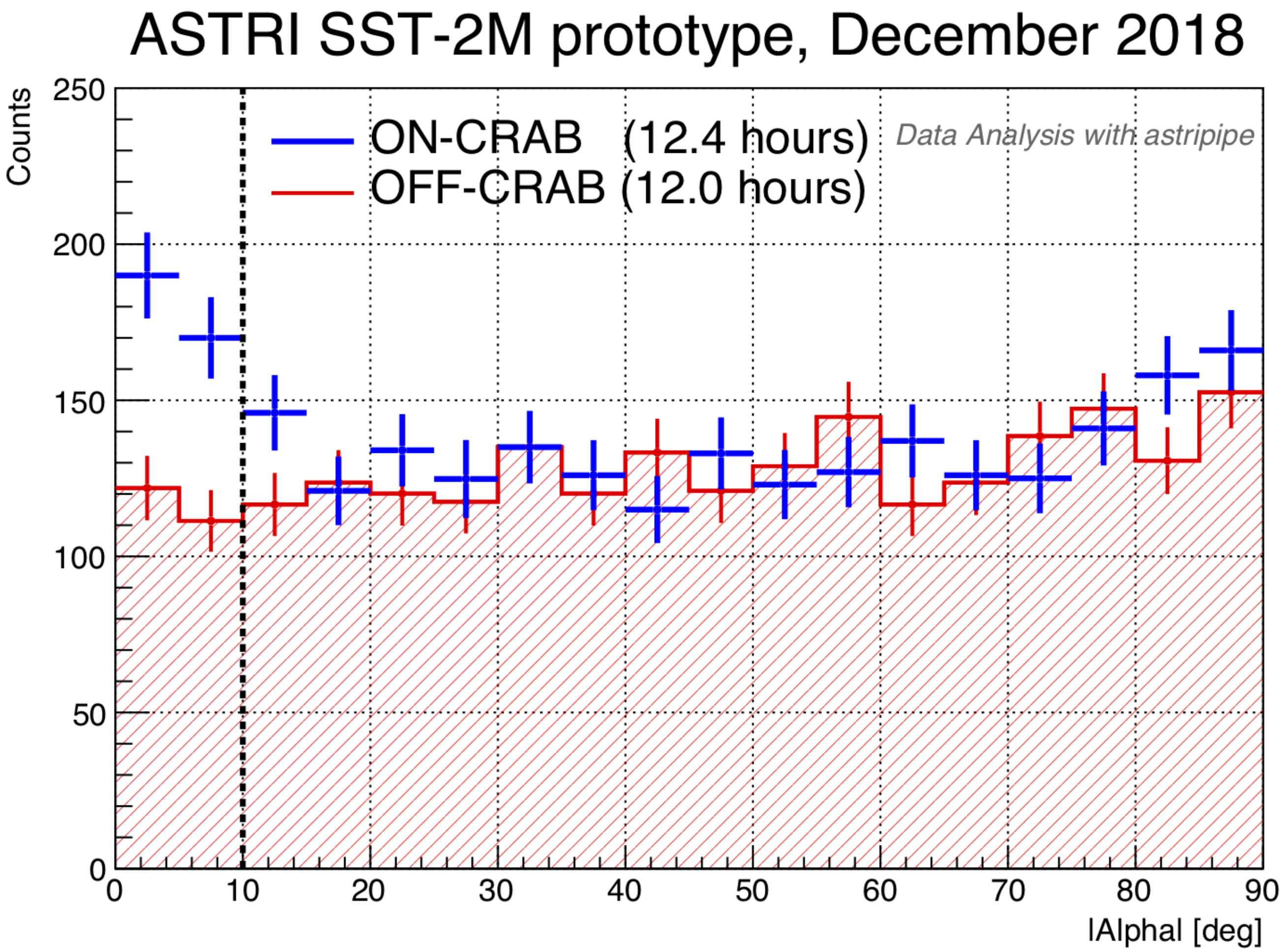
CTA telescopes – first results





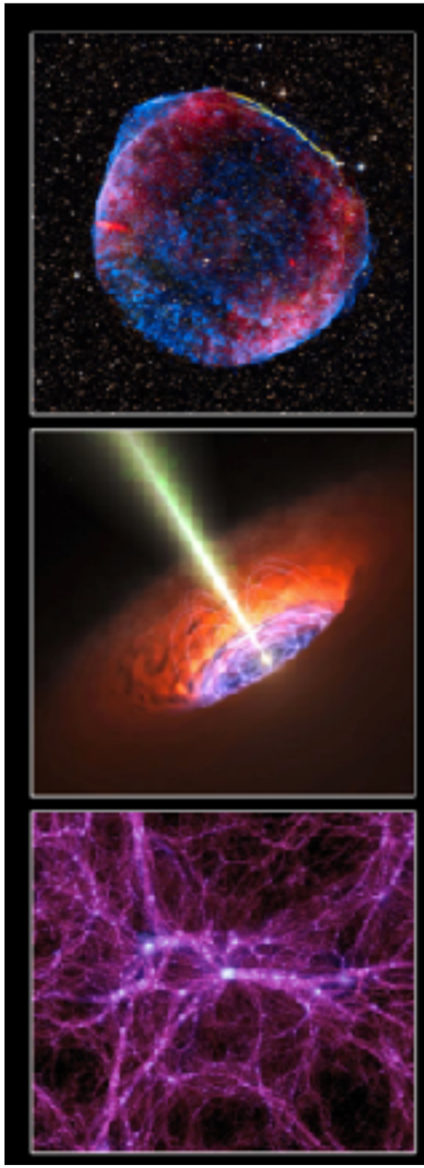
https://www.cta-observatory.org/sct-detects-crab-nebula/

CTA telescopes – first results



https://www.cta-observatory.org/astri-detects-crab-at-tev-energies/

Astrophysics with IACTs



- **COSMIC PARTICLE ACCELERATION**

What are the sites and mechanisms of particle acceleration in the cosmos?

- **EXTREME ASTROPHYSICAL ENVIRONMENTS**

The physics of neutron stars, black holes and their energetic environments, such as relativistic jets, winds and stellar explosions.

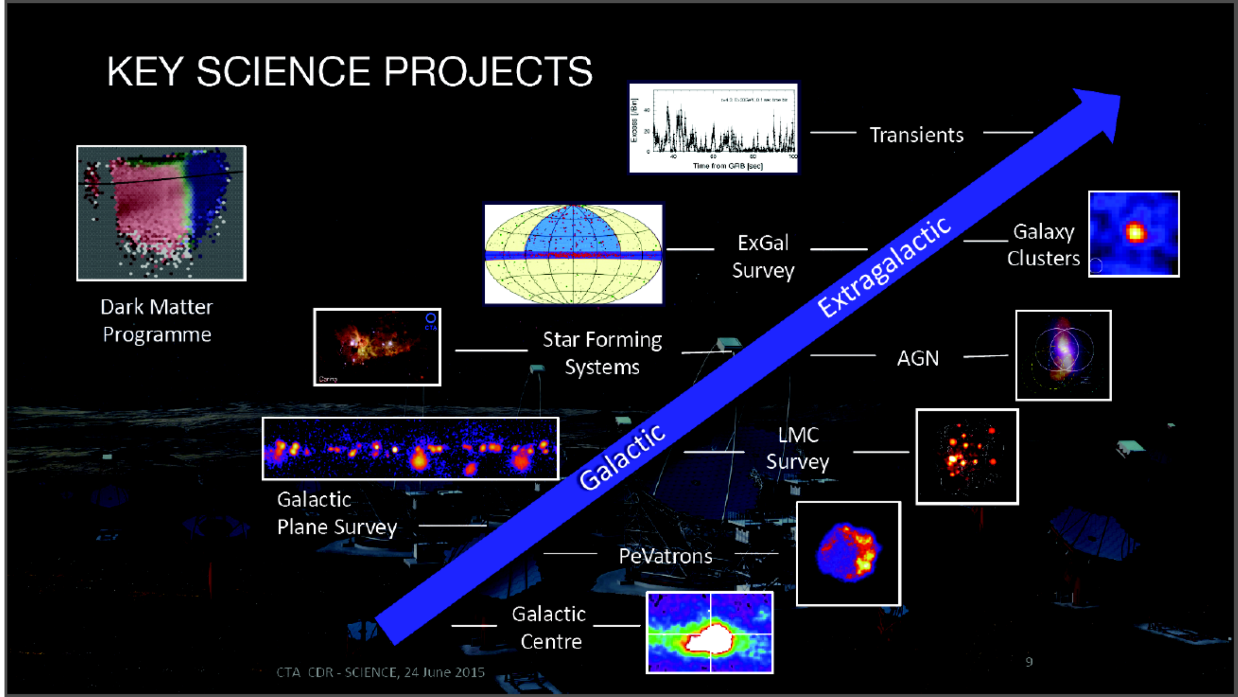
- **FUNDAMENTAL PHYSICS FRONTIERS**

Probing the nature of Dark Matter, the existence of axion-like particles, and Lorentz invariance violation

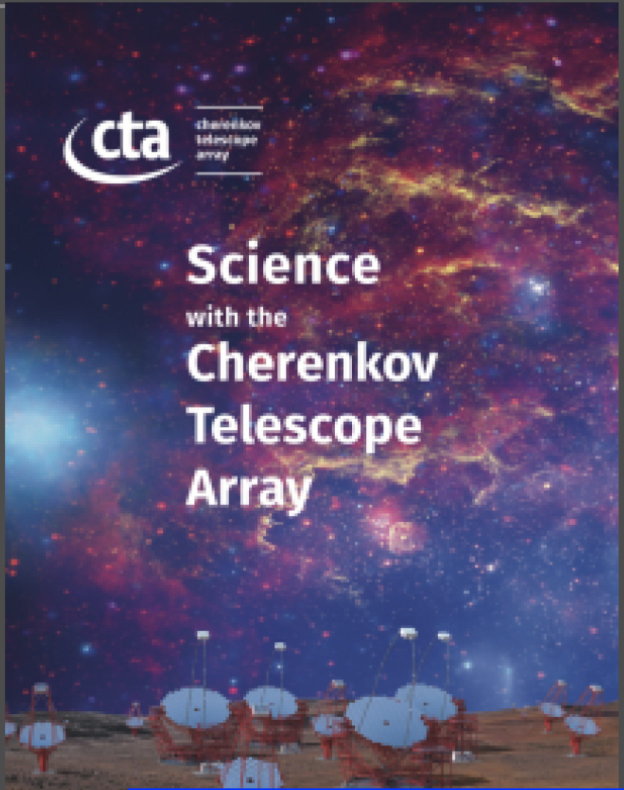
CTA's Science

Key Science Projects: ~40% of observing time in first 10 yrs devoted to major projects.

https://www.worldscientific.com/worldscibooks/10.1142/10986



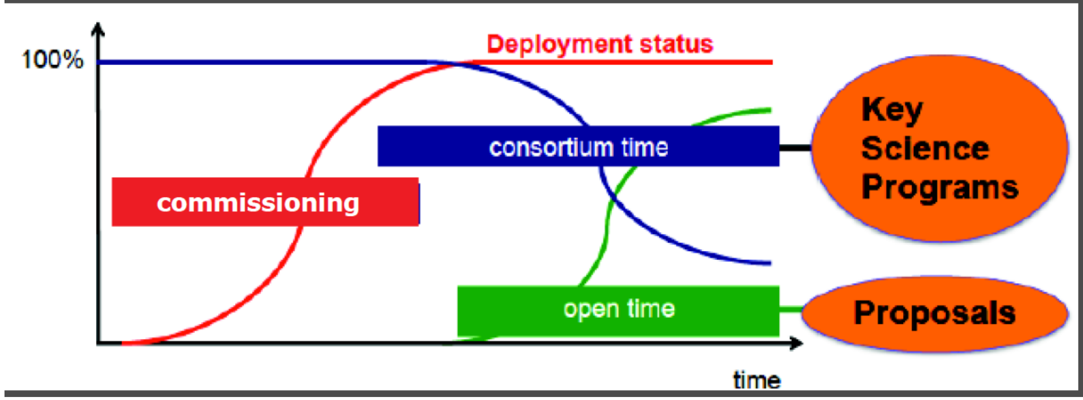
KEY SCIENCE PROJECTS



cta cherenkov telescope array

Science
with the
Cherenkov
Telescope
Array

G. Rowell – COSPAR 2020



Signficant multi-wavelength support needed.

e.g optical/radio coverage > 500 hr/yr

cta
cherenkov
telescope
array

The Science of CTA

CTA will target major science questions in high-energy astrophysics, through a large observational programme.

Sky Surveys

- Galactic and X-Gal Scan
- Dark Matter Programme
- Magellanic Clouds

Deep Targeted Observations

- PeVatrons
- Star-forming Systems
- Radio Galaxies & Clusters

Follow-ups of Transient and Multi-messenger events

Monitoring of Variability notably of AGN

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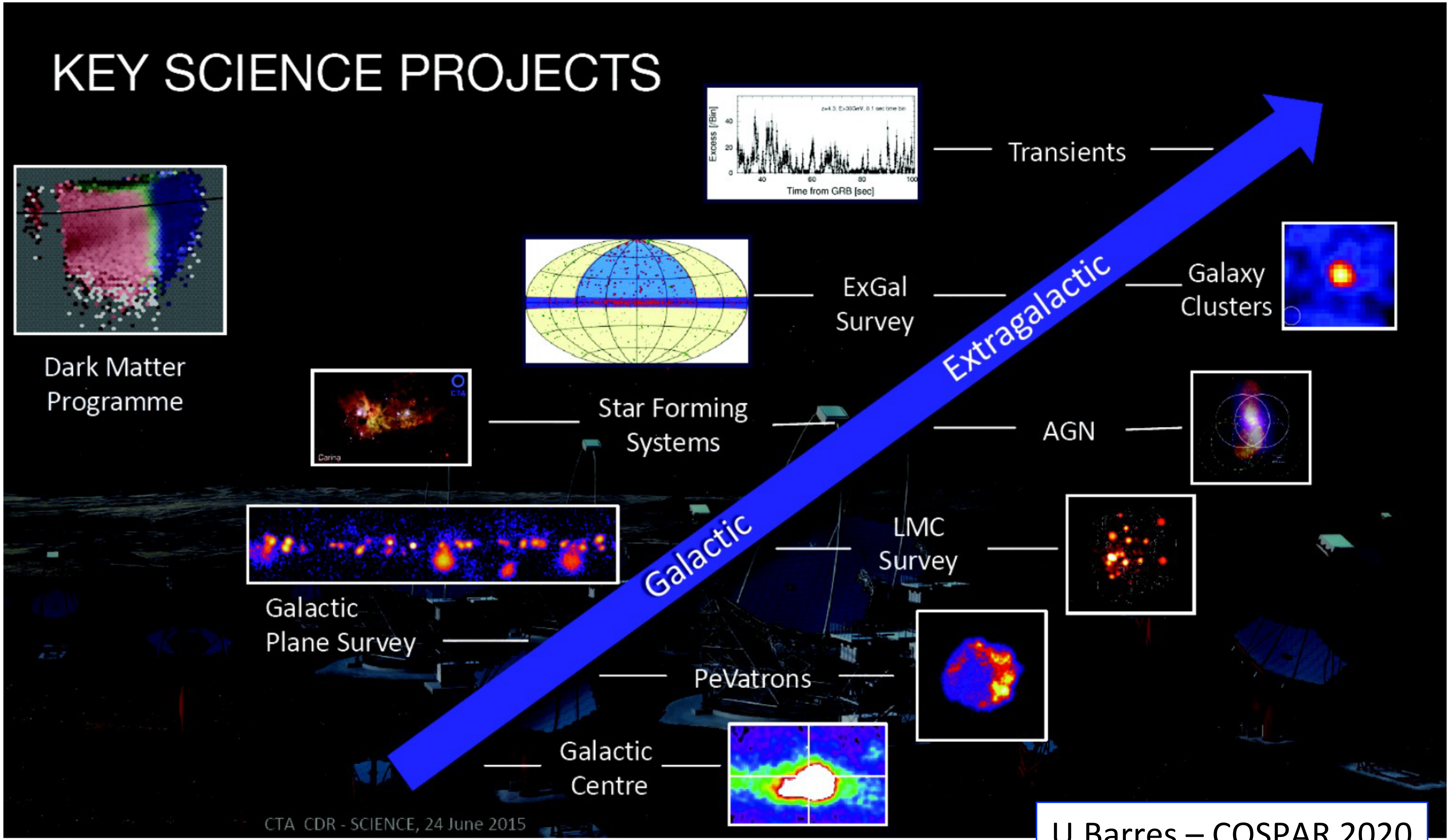
A Census of particle accelerators across all cosmic scales



KEY SCIENCE PROJECTS

Dark Matter Programme

Galactic Plane Survey

Star Forming Systems

ExGal Survey

Transients

Galaxy Clusters

AGN

LMC Survey

PeVatrons

Galactic Centre

Galactic

Extragalactic

CTA CDR - SCIENCE, 24 June 2015

U.Barres – COSPAR 2020

Science with CTA

cta
cherenkov
telescope
array

Science
with the
Cherenkov
Telescope
Array

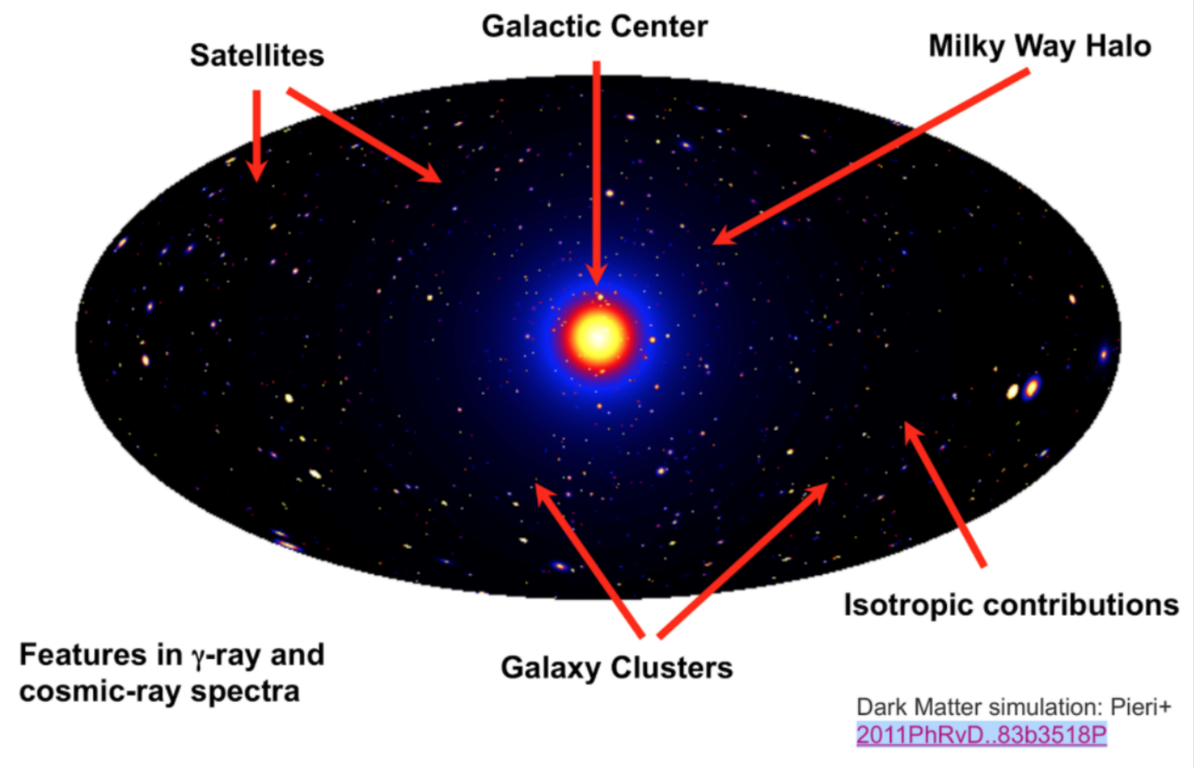
997v2 [astro-ph.IM] 22 Jan 2018

CTA will have important synergies with many of the new generation of major astronomical and astroparticle observatories. Multi-wavelength and multi-messenger approaches combining CTA data with those from other instruments will lead to a deeper understanding of the broad-band non-thermal properties of target sources, elucidating the nature, environment, and distance of gamma-ray emitters. Details of synergies in each waveband are presented.

https://arxiv.org/abs/1709.07997

The Dark Matter Programme

Gamma-rays trace annihilating Dark Matter



Dark Matter simulation: Pieri+ 2011PhRvD..83b3518P

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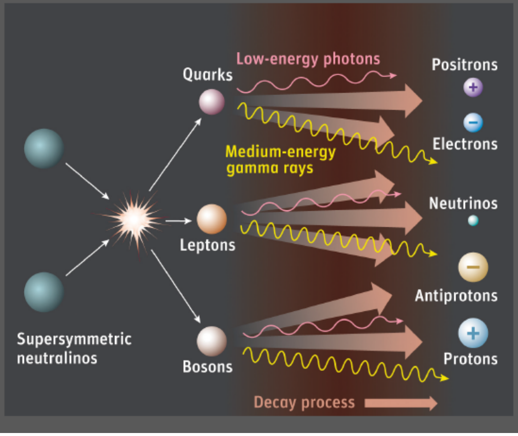
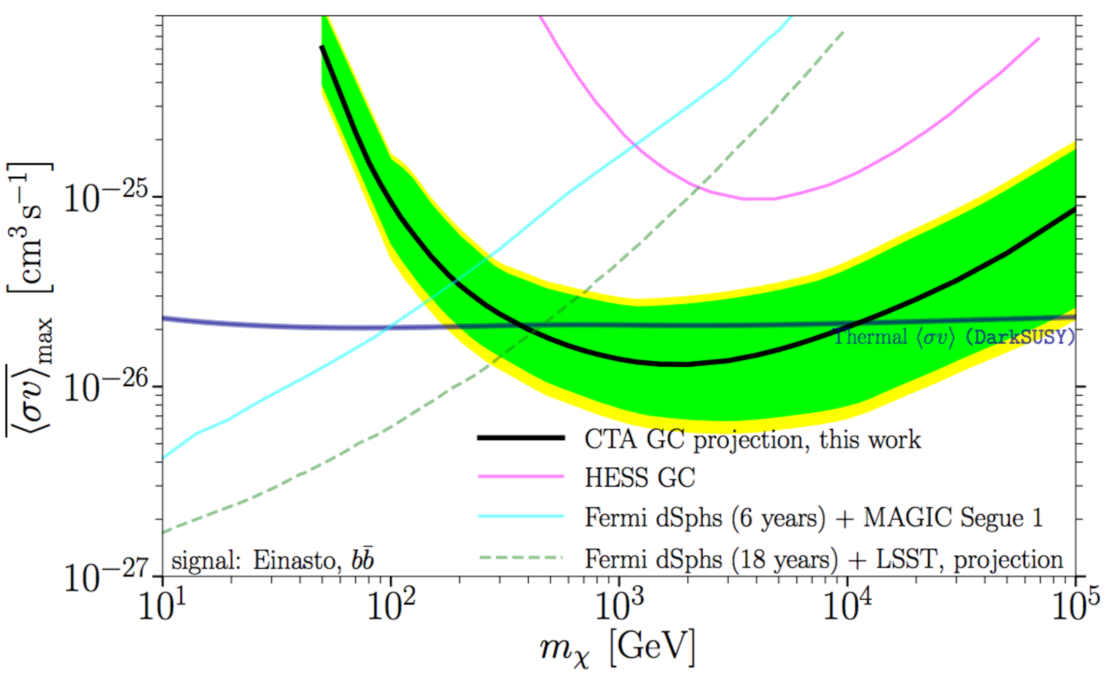
- Weakly-interacting massive particles (WIMPs)
- Candidate with masses at TeV-scale, ideal for CTA searches
- Annihilation and decay of DM-particles to give out spectral signatures in gamma-rays such as continuum edges and line-emissions features



The Dark Matter Programme

Comparison with other experiments

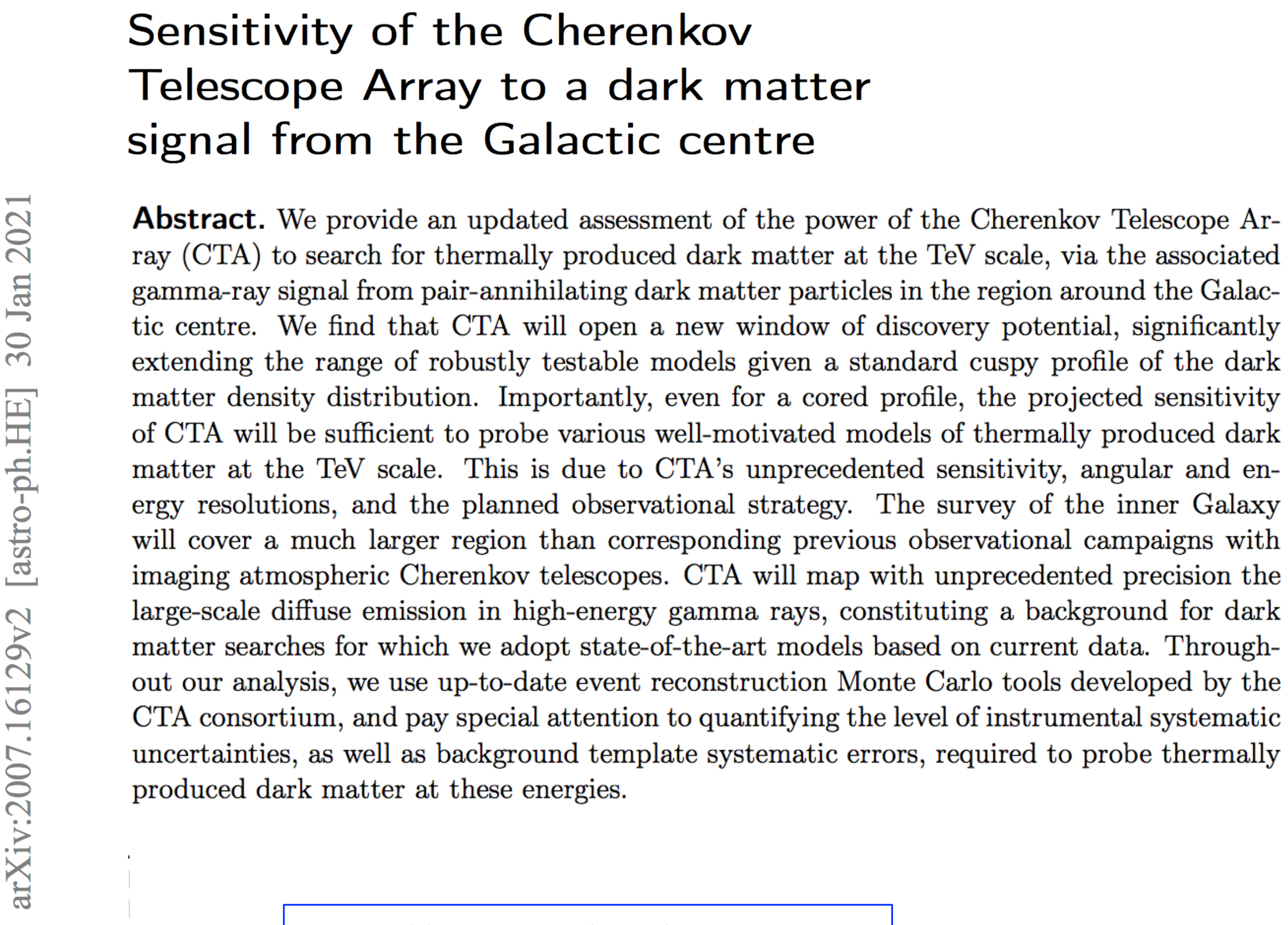
- The GC and Halo provide the most promising sites for CTA Dark Matter searches
- Over 500 h planned observation time at the GC
- CTA will complement data from direct DM detection and other indirect experiments in the energy range of 10s of TeV



U.Barres – COSPAR 2020

arXiv:2007.16129

Dark Matter with CTA



arXiv:2007.16129v2 [astro-ph.HE] 30 Jan 2021

Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre

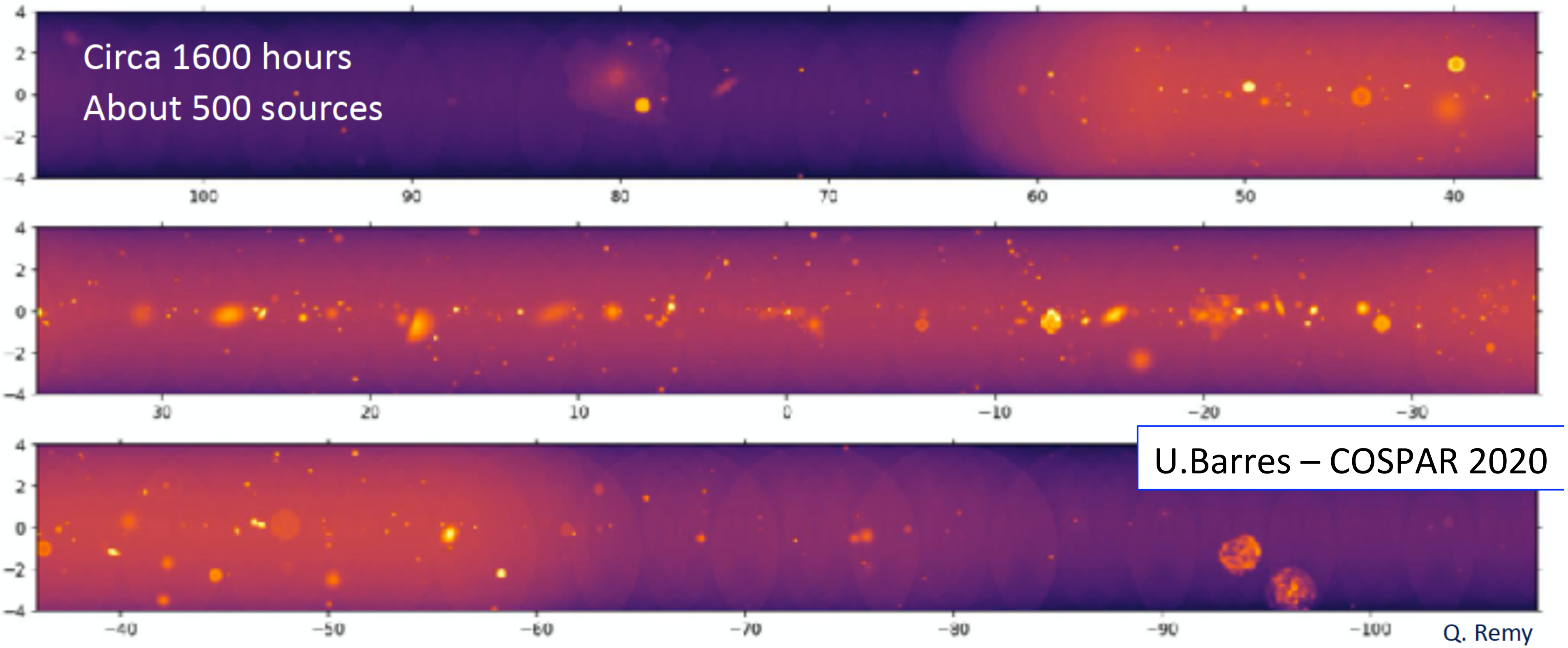
Abstract. We provide an updated assessment of the power of the Cherenkov Telescope Array (CTA) to search for thermally produced dark matter at the TeV scale, via the associated gamma-ray signal from pair-annihilating dark matter particles in the region around the Galactic centre. We find that CTA will open a new window of discovery potential, significantly extending the range of robustly testable models given a standard cuspy profile of the dark matter density distribution. Importantly, even for a cored profile, the projected sensitivity of CTA will be sufficient to probe various well-motivated models of thermally produced dark matter at the TeV scale. This is due to CTA's unprecedented sensitivity, angular and energy resolutions, and the planned observational strategy. The survey of the inner Galaxy will cover a much larger region than corresponding previous observational campaigns with imaging atmospheric Cherenkov telescopes. CTA will map with unprecedented precision the large-scale diffuse emission in high-energy gamma rays, constituting a background for dark matter searches for which we adopt state-of-the-art models based on current data. Throughout our analysis, we use up-to-date event reconstruction Monte Carlo tools developed by the CTA consortium, and pay special attention to quantifying the level of instrumental systematic uncertainties, as well as background template systematic errors, required to probe thermally produced dark matter at these energies.

https://arxiv.org/abs/2007.16129

cherenkov
telescope
array

CTA Galactic Science

- Survey speed about 300x greater than H.E.S.S.
- Much deeper reach, to scan the entire galaxy for PWNe and SNRs, as opposed to the few-kpc reach of current instruments.



Circa 1600 hours

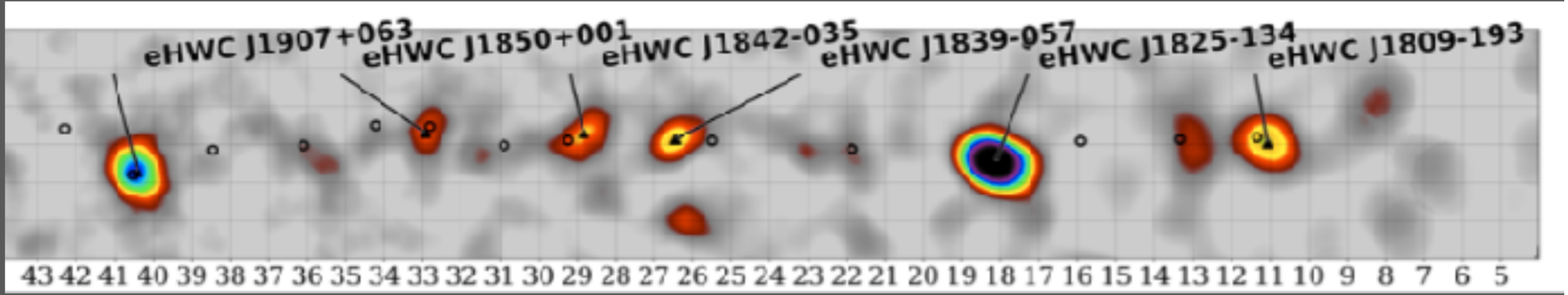
About 500 sources

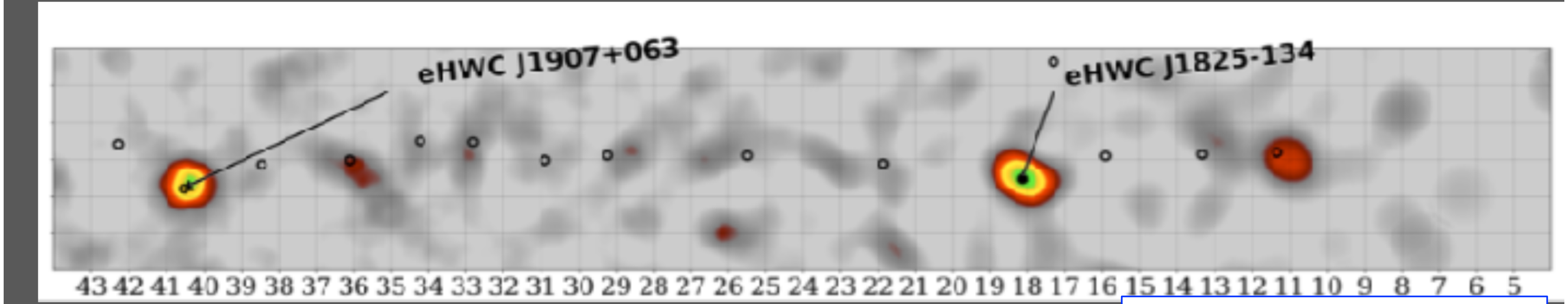
U.Barres – COSPAR 2020

Q. Remy

PeVatrons: the extreme energy frontier

HAWC (arXiv:1909.08609) has opened a window into the PeVatron frontier that can be extensively probed and expanded by CTA





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CTA's Prospects for AGN

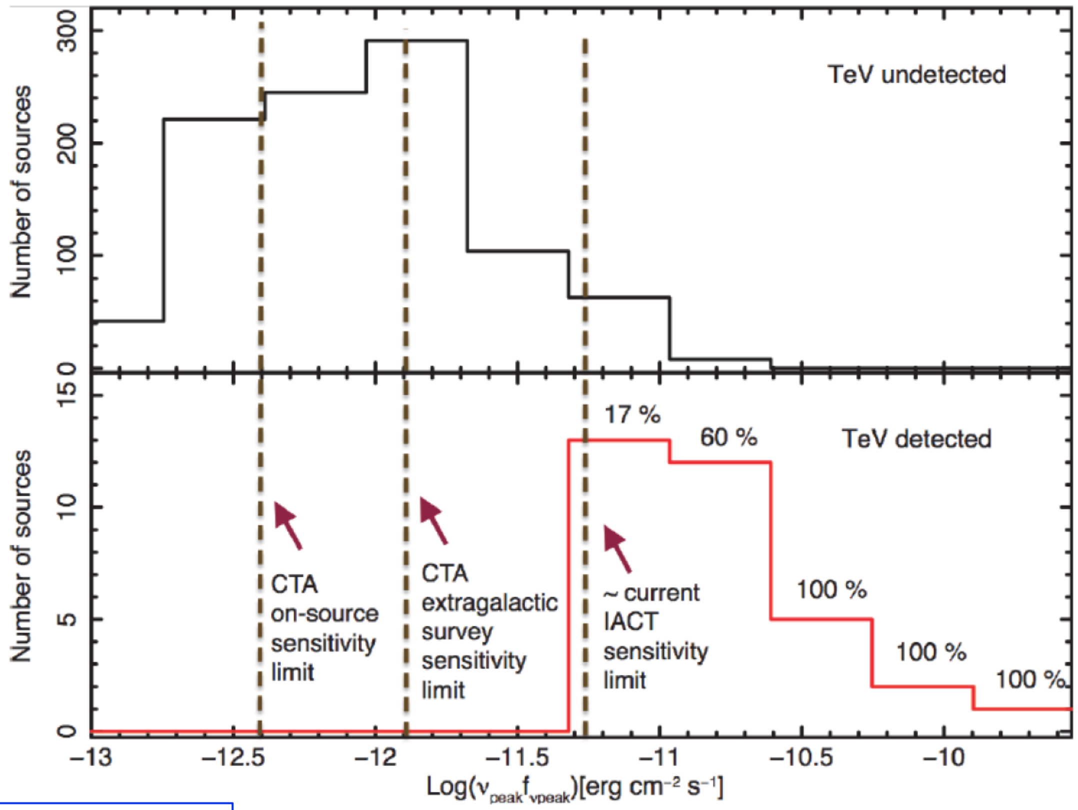
CTA will detect many 100s of AGN to z~2

FoV up to 10 degrees → several AGN in FoV at same time.

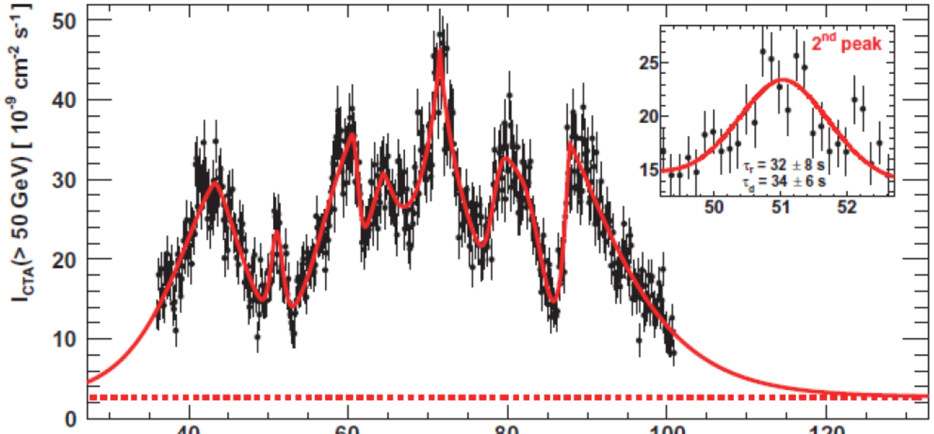
Light curve details down to sub-minutes.

Spectral resolution to reveal sub-components:

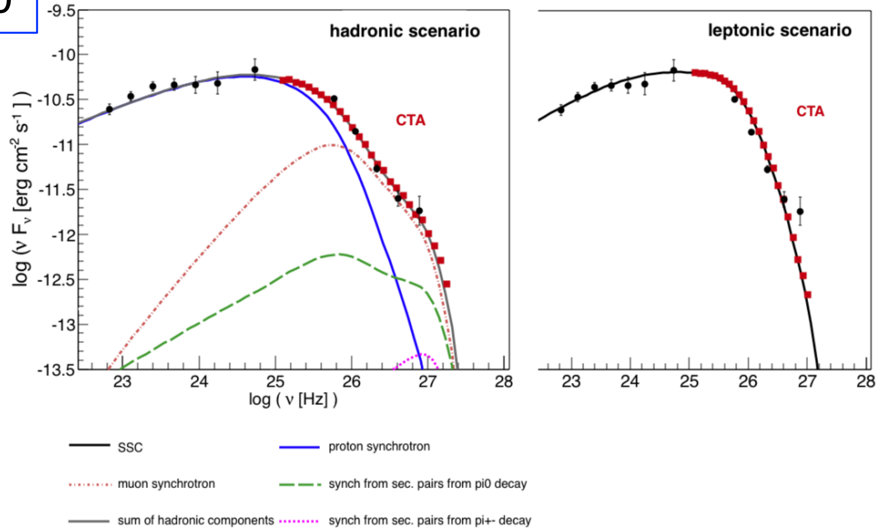
- Hadronic (synchrotron from protons, muons, + secondaries)
- Leptonic (SSC)



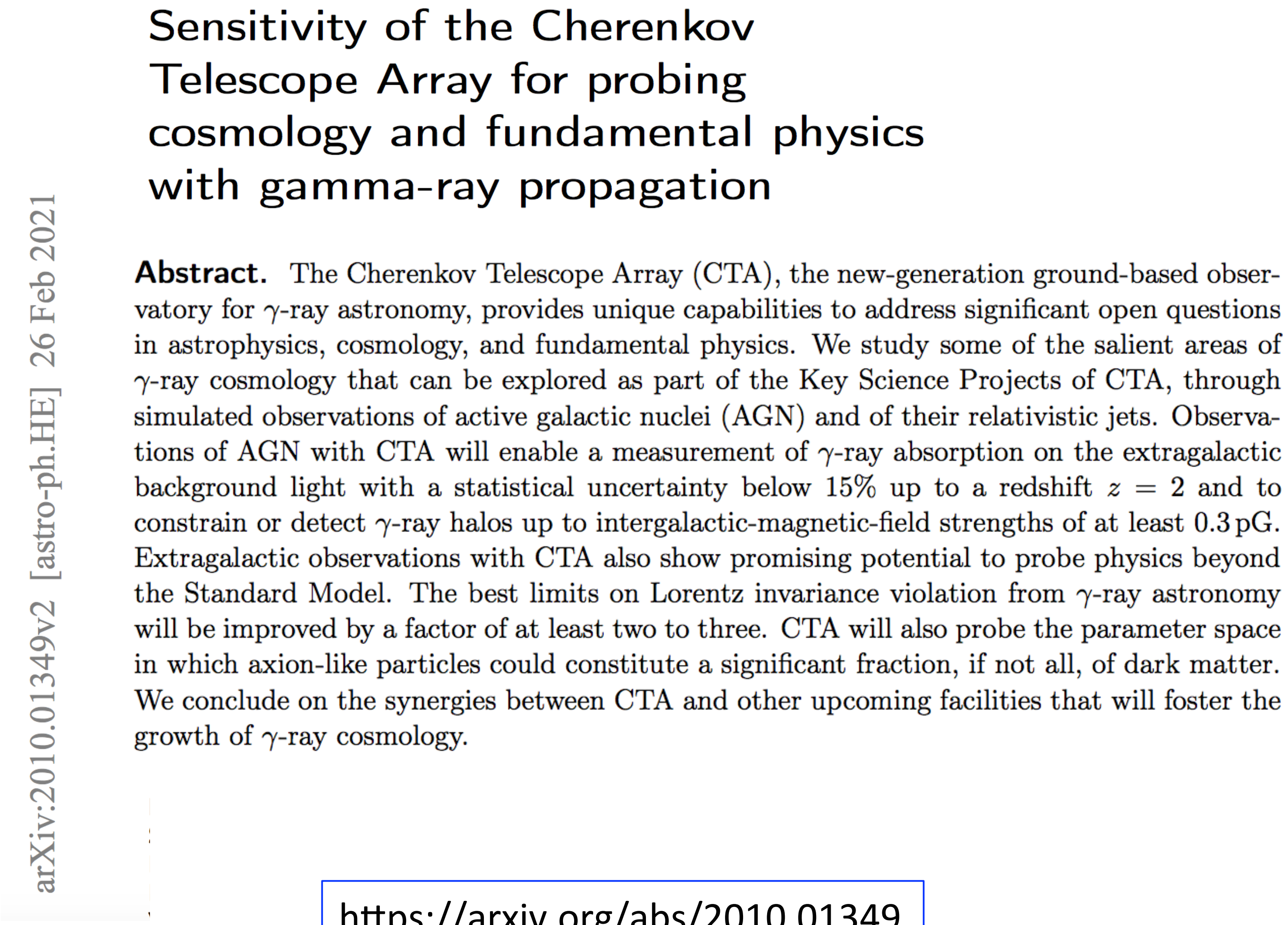
G. Rowell – COSPAR 2020



Simulated light curve for CTA based on an extrapolation of the spectrum of the 2006 flare from PKS 2155-304



Cosmology and Fundamental Physics



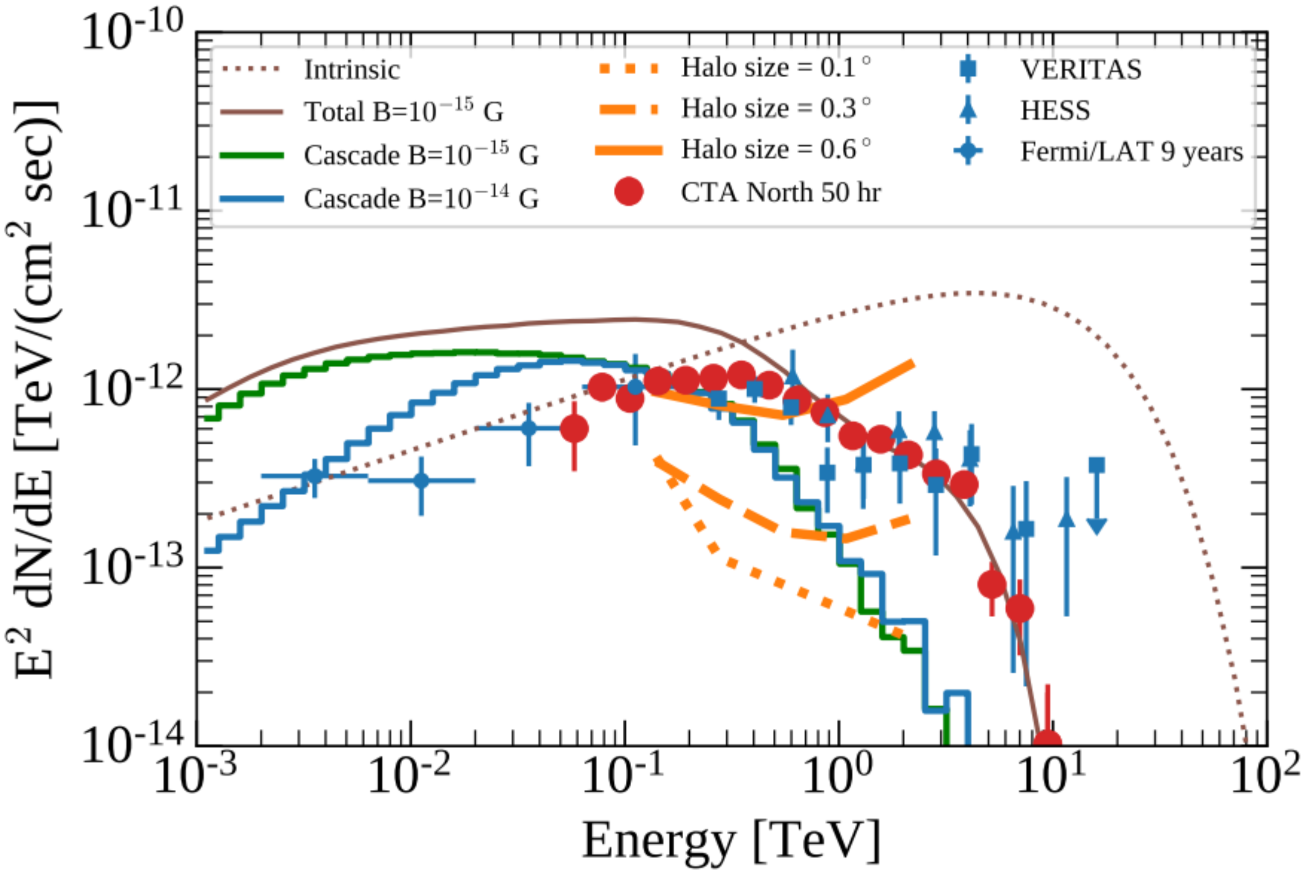
Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation

arXiv:2010.01349v2 [astro-ph.HE] 26 Feb 2021

Abstract. The Cherenkov Telescope Array (CTA), the new-generation ground-based observatory for γ-ray astronomy, provides unique capabilities to address significant open questions in astrophysics, cosmology, and fundamental physics. We study some of the salient areas of γ-ray cosmology that can be explored as part of the Key Science Projects of CTA, through simulated observations of active galactic nuclei (AGN) and of their relativistic jets. Observations of AGN with CTA will enable a measurement of γ-ray absorption on the extragalactic background light with a statistical uncertainty below 15% up to a redshift $z = 2$ and to constrain or detect γ-ray halos up to intergalactic-magnetic-field strengths of at least 0.3 pG. Extragalactic observations with CTA also show promising potential to probe physics beyond the Standard Model. The best limits on Lorentz invariance violation from γ-ray astronomy will be improved by a factor of at least two to three. CTA will also probe the parameter space in which axion-like particles could constitute a significant fraction, if not all, of dark matter. We conclude on the synergies between CTA and other upcoming facilities that will foster the growth of γ-ray cosmology.

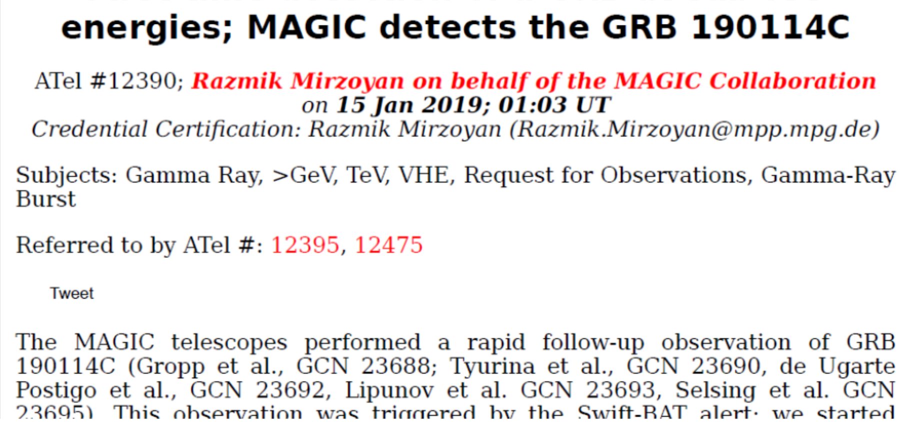
https://arxiv.org/abs/2010.01349

Cosmology and Fundamental Physics



https://arxiv.org/abs/2010.01349

The new window of VHE Gamma-ray Bursts



First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

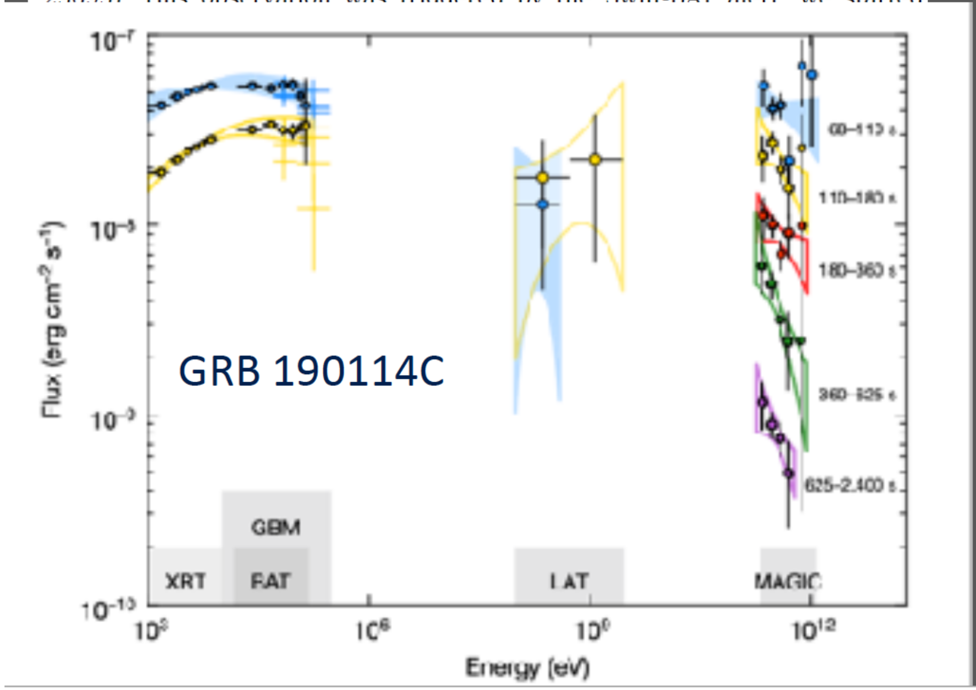
ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started



Three long GRBs detections announced in the past two years:

GRB 180720B (z=0.65)

GRB 190114C (z=0.42)

- Afterglow detected > 300 GeV
- Huge statistics (1000s gammas)
- Sub-minute timescale spectra

GRB 190829A (z=0.08)

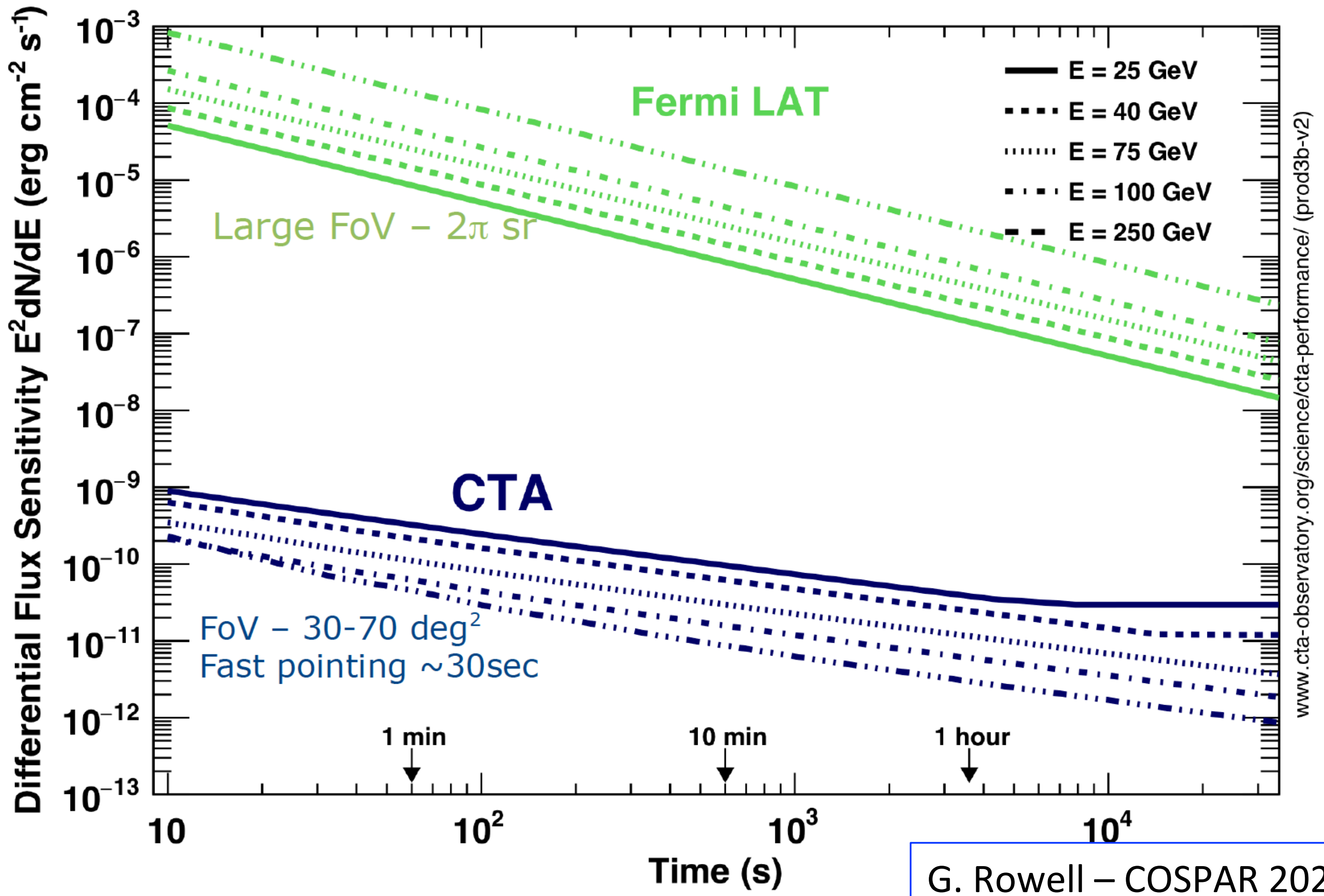
+ GRB 201216C (z = 1.1)

Strong MWL and MM synergies for spectral and variability studies

U.Barres – COSPAR 2020

Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)



G. Rowell – COSPAR 2020

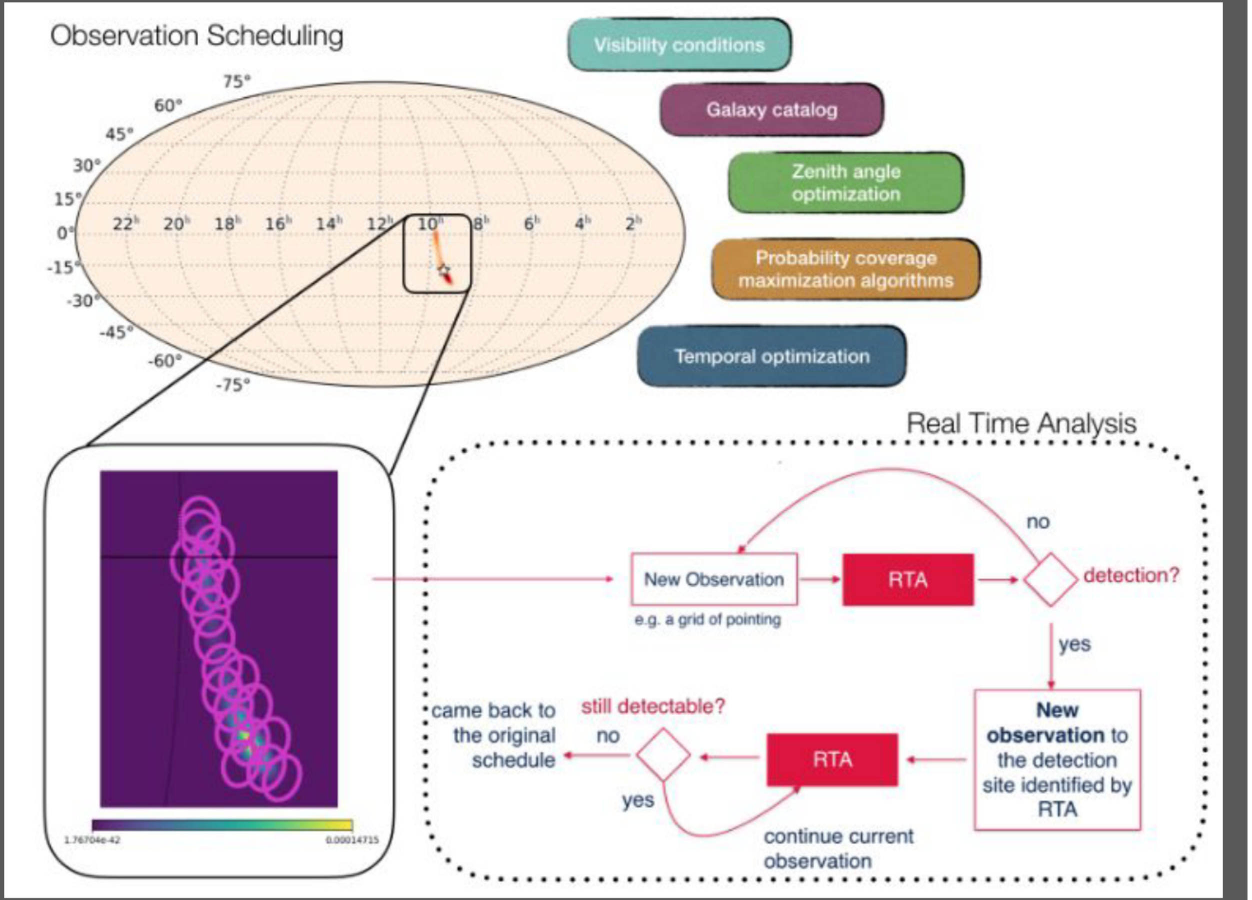
CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range

→ GRBs, AGN, giant pulses, FRBs, GW, SGR bursts......

Gravitational wave follow-ups

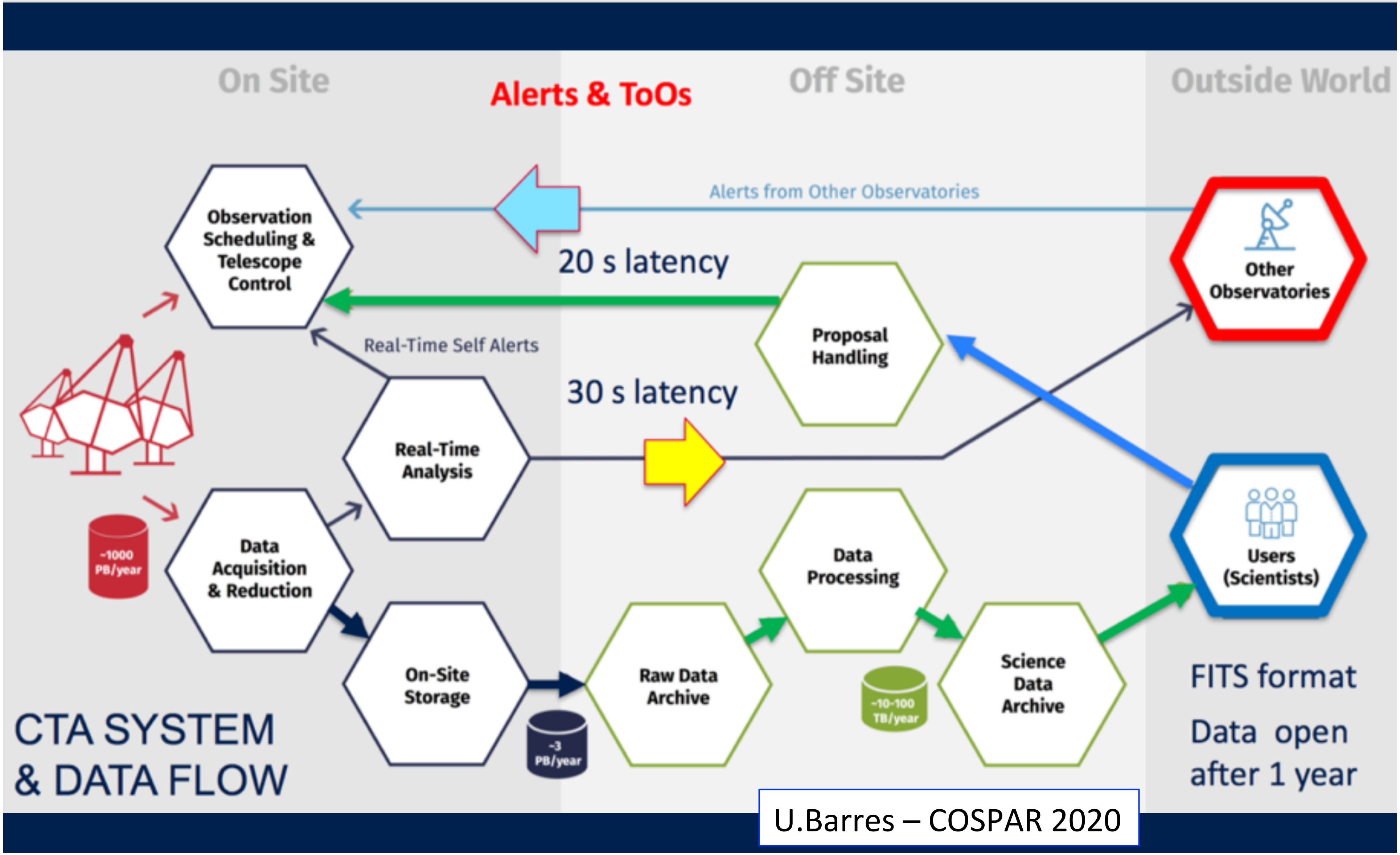
CTA will represent an important improvement on the follow-up of gravitational wave events

- Larger field of view of 5° - 7° means quicker scan of GW error regions
- An optimised pointing strategy will be used to efficiently cover the sky area of the GW signal



U.Barres – COSPAR 2020

CTA Transients Science



U.Barres – COSPAR 2020

External Needs Matrix

cherenkov
telescope
array

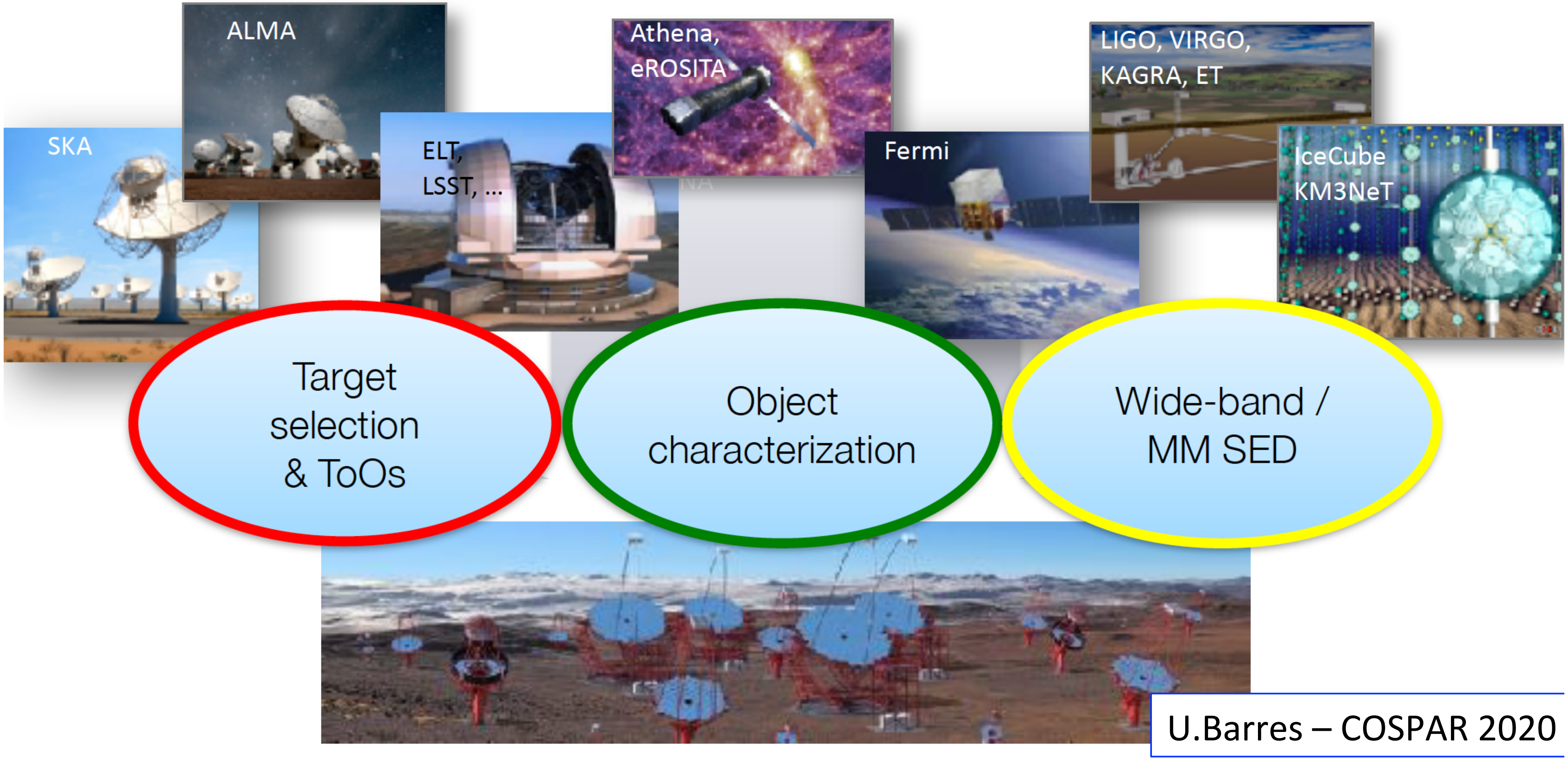
G. Rowell – COSPAR 2020

✓ = important ✔ = critical

Band or Messenger	Astrophysical Probes	Galactic Plane Survey	LMC & SFRs	CRs & Diffuse Emission	Galactic Transients	Starburst & Galaxy Clusters	GRBs	AGNs	Radio Galaxies	Redshifts	GWs & Neutrinos
Radio	Particle and magnetic-field density probe. Transients. Pulsar timing.	✔	✓	✔	✓	✓	✓	✔	✓		✓
(Sub)Millimetre	Interstellar gas mapping. Matter ionisation levels. High-res interferometry.	✔	✔	✔		✓		✓	✔		
IR/Optical	Thermal emission. Variable non-thermal emission. Polarisation.	✓	✔	✓	✔	✔		✔	✓	✔	
Transient Factories	Wide-field monitoring & transients detection. Multi-messenger follow-ups.						✓	✔			✓
X-rays	Accretion and outflows. Particle acceleration. Plasma properties.	✔	✔	✓	✔	✔	✔	✔	✔		✓
MeV-GeV Gamma-rays	High-energy transients. Pion-decay signature. Inverse-Compton process	✓	✓	✔	✓	✔	✔	✔			✔
Other VHE	Particle detectors for 100% duty cycle monitoring of TeV sky.	✓	✓	✓		✓		✓			
Neutrinos	Probe of cosmic-ray acceleration sites. Probe of PeV energy processes.			✓			✓	✔			✔
Gravitational Waves	Mergers of compact objects (Neutron Stars). Gamma-ray Bursts.						✔				✔

MWL and Multi-Messenger Perspectives

Synergies with astrophysical facilities…



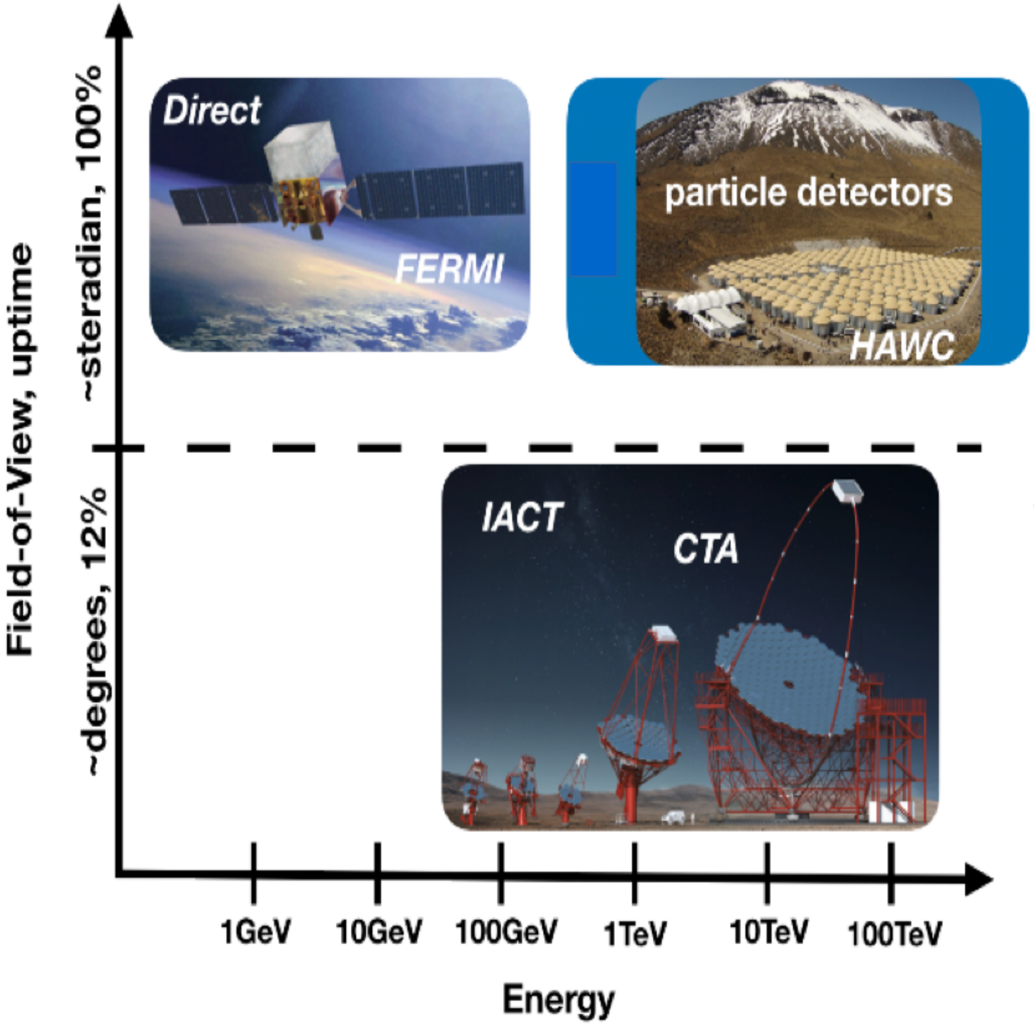
Target selection & ToOs

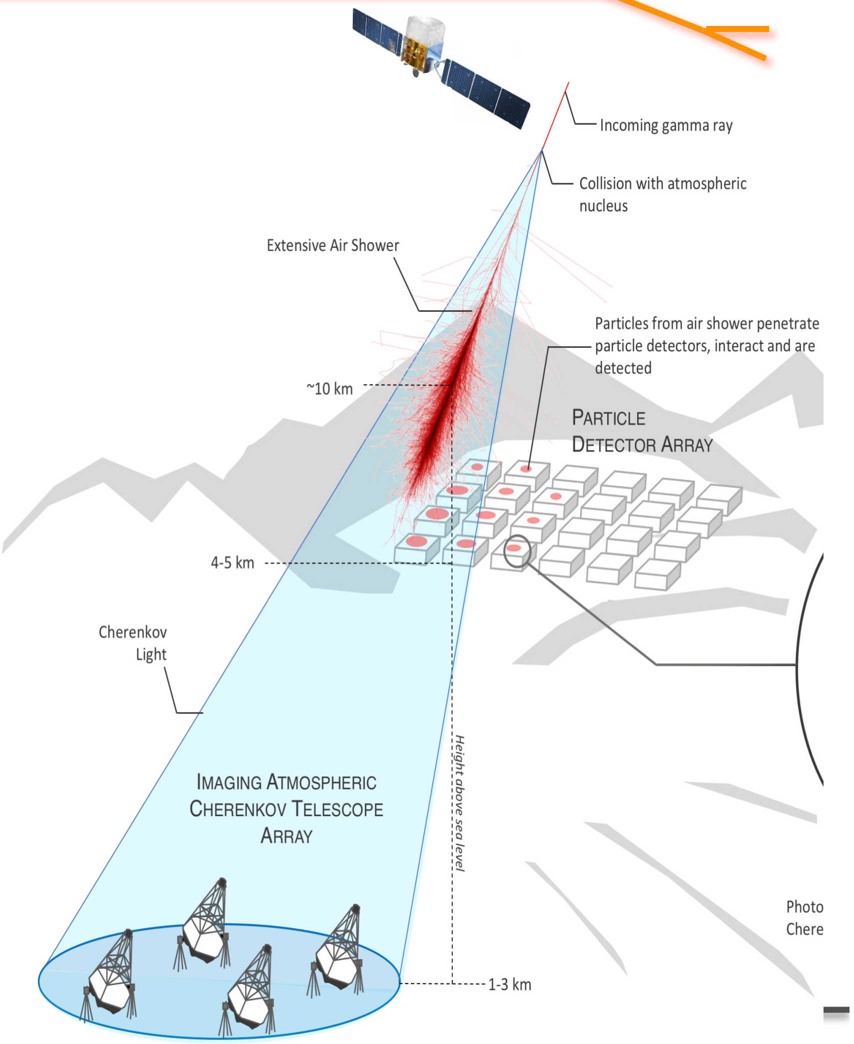
Object characterization

Wide-band / MM SED

SWGO
The Southern Wide-field
Gamma-ray Observatory

Gamma-ray Astronomy





Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

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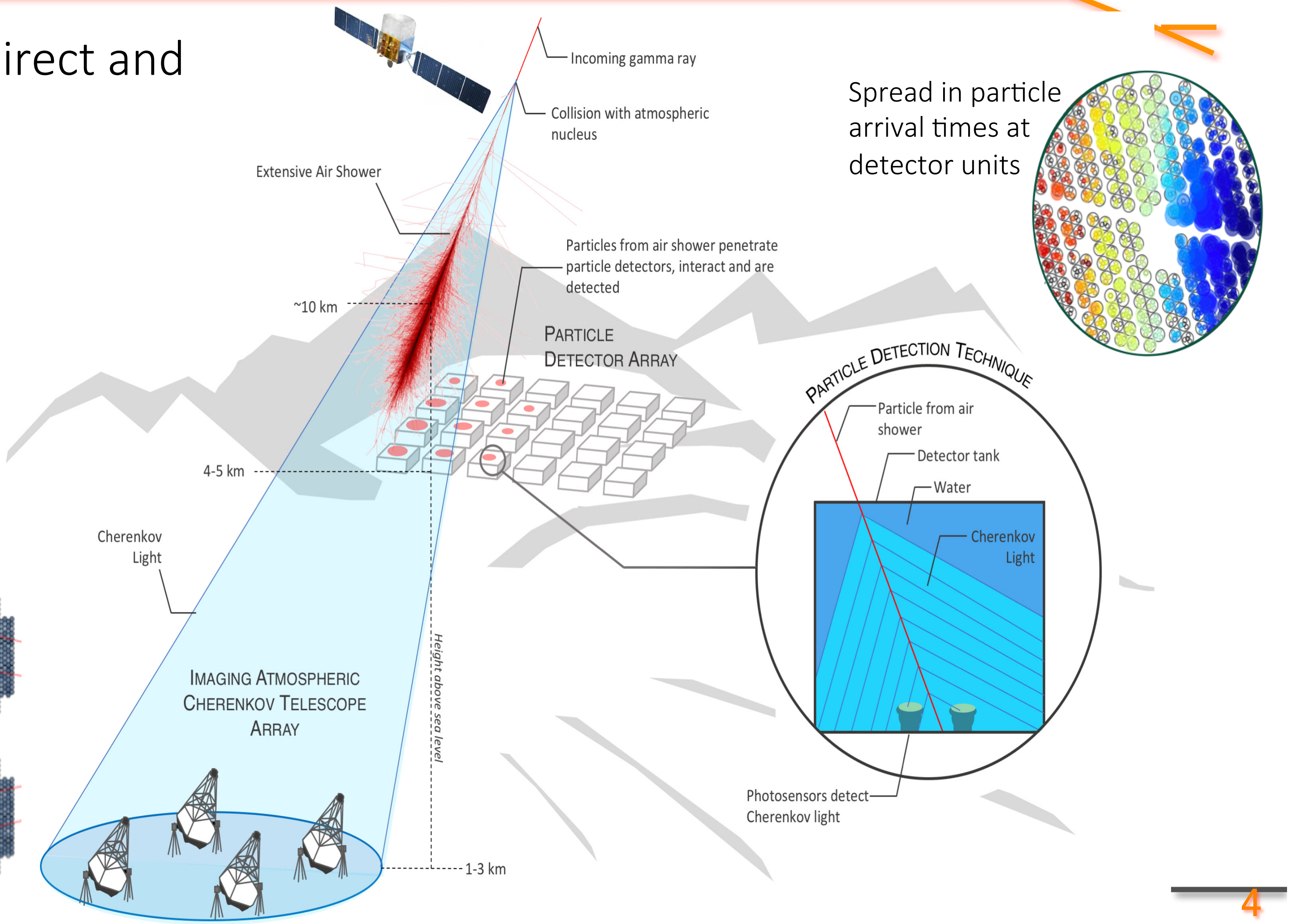
SWGO
The Southern Wide-field
Gamma-ray Observatory

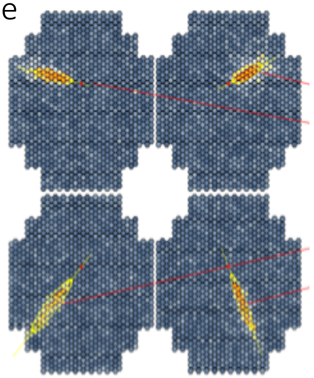
Gamma-ray Astronomy

Complementary direct and indirect detection techniques



Spread in particle arrival times at detector units

Atmospheric Cherenkov light image



Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

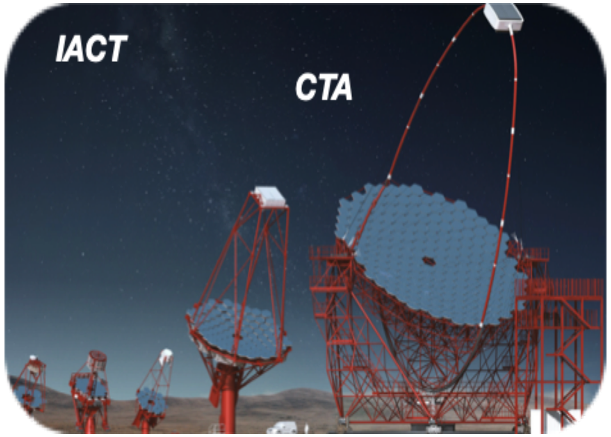
Not to scale

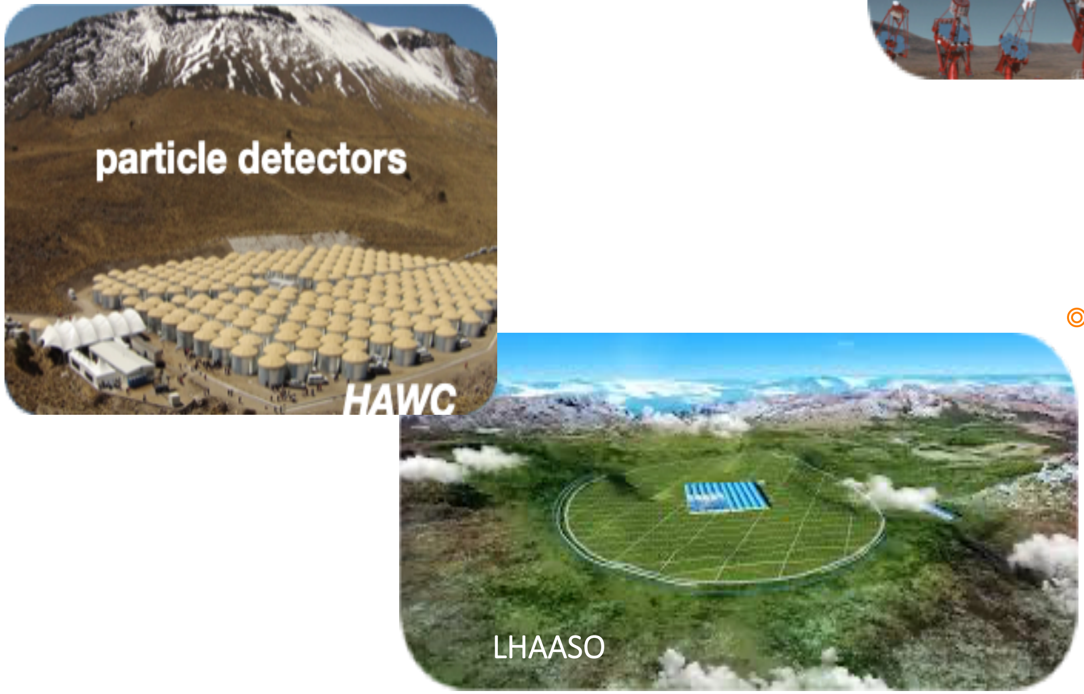
- Astonishing variety of TeV* emitters
  - Within the Milky Way
    - Supernova remnants
    - Bombarded molecular clouds
    - Stellar binaries - colliding wind & X-ray
    - Massive stellar clusters
    - Pulsars and pulsar wind nebulae
    - Supermassive black hole Sgr A*
  - Extragalactic
    - Starburst galaxies
    - MW satellites
    - Radio galaxies
    - Flat-spectrum radio quasars
    - ‘BL Lac’ objects
    - Gamma-ray bursts
- Acceleration to TeV energies is common, gamma-rays are an effective probe
  - Strongly complementary to sync. measurements

*0.05-50 TeV

Observational Panorama

- Cherenkov Atmospheric Telescopes
  - 20% duty-cycle
  - Pointing (few degrees FoV)
  - Energy threshold down to 10s GeV
  - Good energy and angular resolution





- Particle Detector Arrays
  - → 100% duty-cycle
  - → Wide-field of View (~ steradian)
  - → Energy range 100s GeV up to 100s TeV
  - → Continual view and accurate background determination

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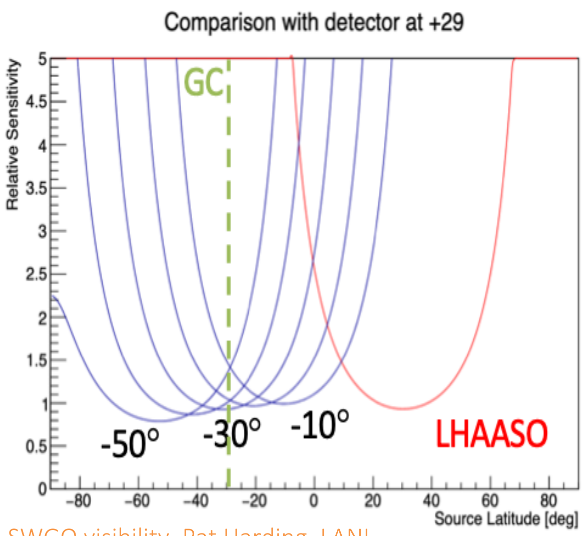
The Southern Wide-field
Gamma-ray Observatory

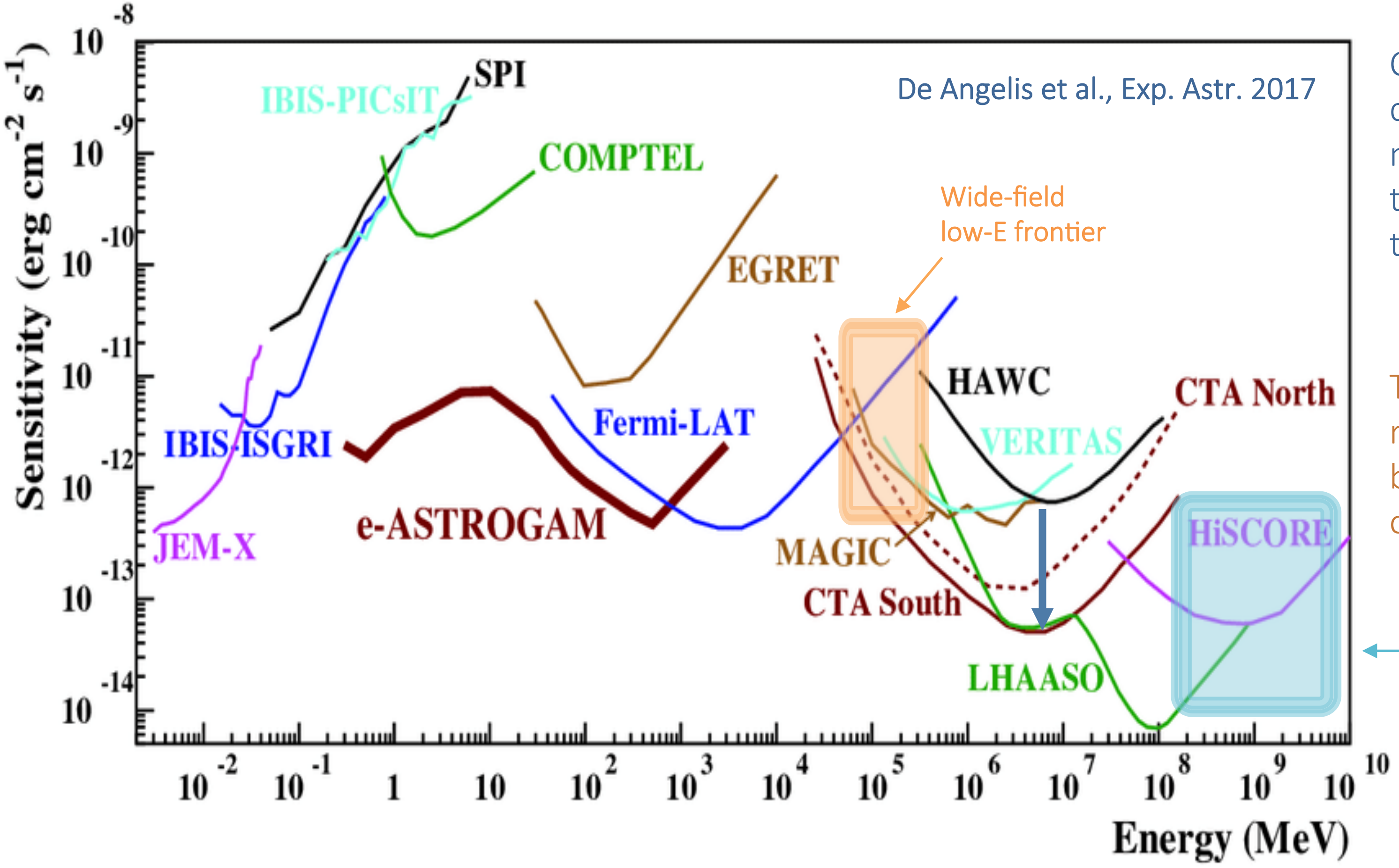
Geographic distribut



SWGO visibility, Pat Harding, LANL

Broadband panorama of high-energy Astrophysics

- Point source sensitivity for X- and gamma-ray instruments



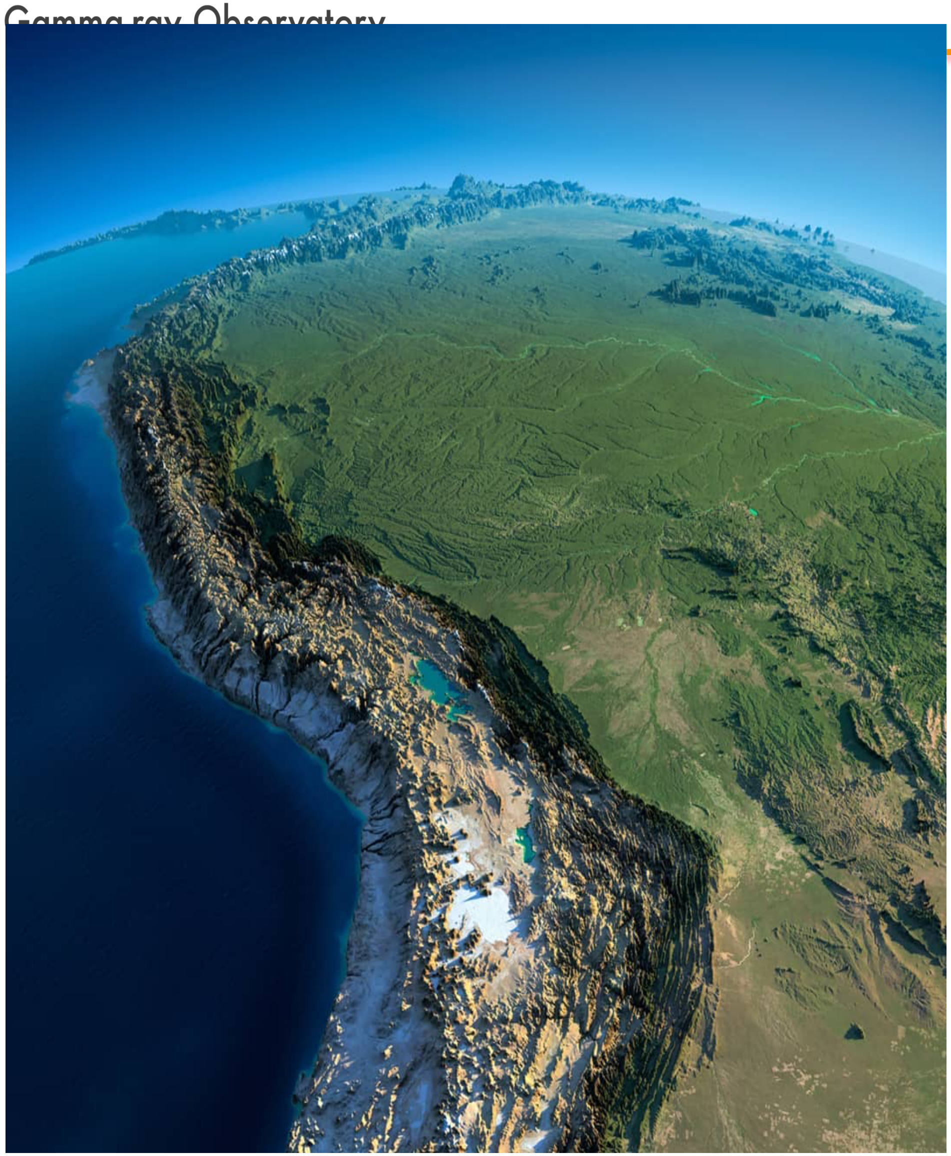
CTA and LHAASO will drive an order of magnitude increase in the TeV - PeV region in the next decade.

The 100 GeV frontier remains to be explored by wide-field gamma observatories.

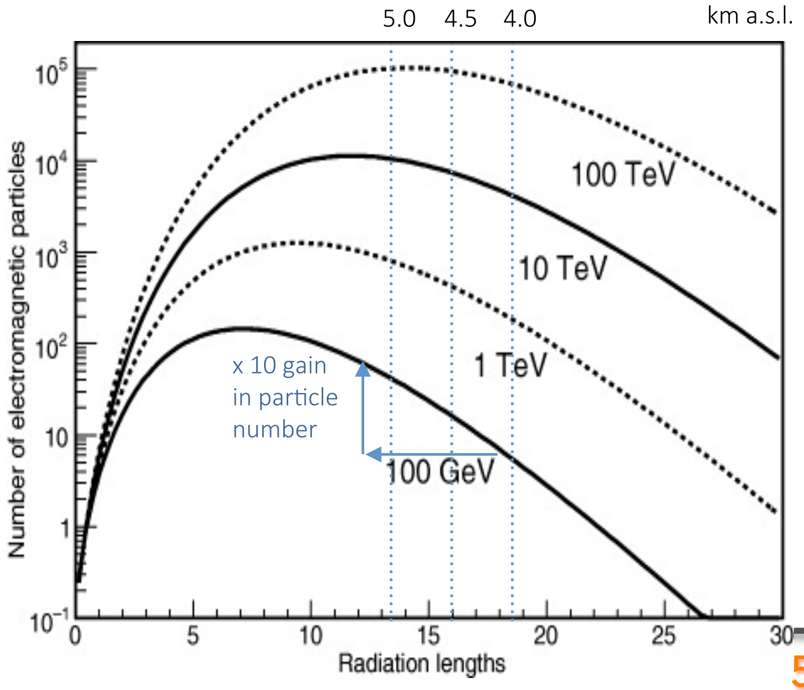
High-sensitivity TeV-PeV frontier

The Southern Wide-field
Gamma-ray Observatory

The high-altitude frontier



The Andes provides a number of high-altitude plateaus and high-altitude lakes that constitute suitable sites for a particle array aiming to extend the low-energy frontier for Wide-Field Observatories.



Adapted from G. Sinnis, NJPh, 2009

The Southern Wide-field
Gamma-ray Observatory

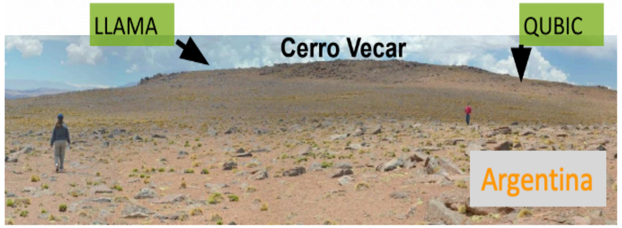
Candidate Sites

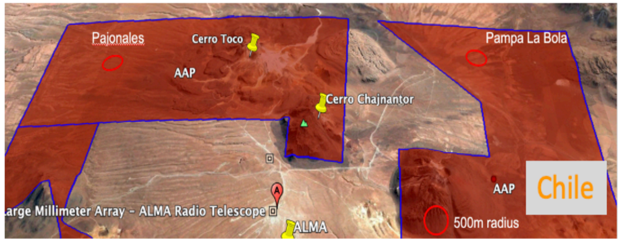
lat. 15 S

lat. 23 S

- Alto Tocomar (Argentina)
- Cerro Vecar (Argentina)
- Chacaltaya (Bolivia)
- AAP Pajonal (Chile)
- AAP Pampa La Bola (Chile)
- Lake Sibinacocha (Peru)
- Imata (Peru)
- Sumbay (Peru)
- Peru National Observatory
- Yanque (Peru)

The complete list of potential sites is still under investigation, aiming at an evaluation for site choice by 2022.

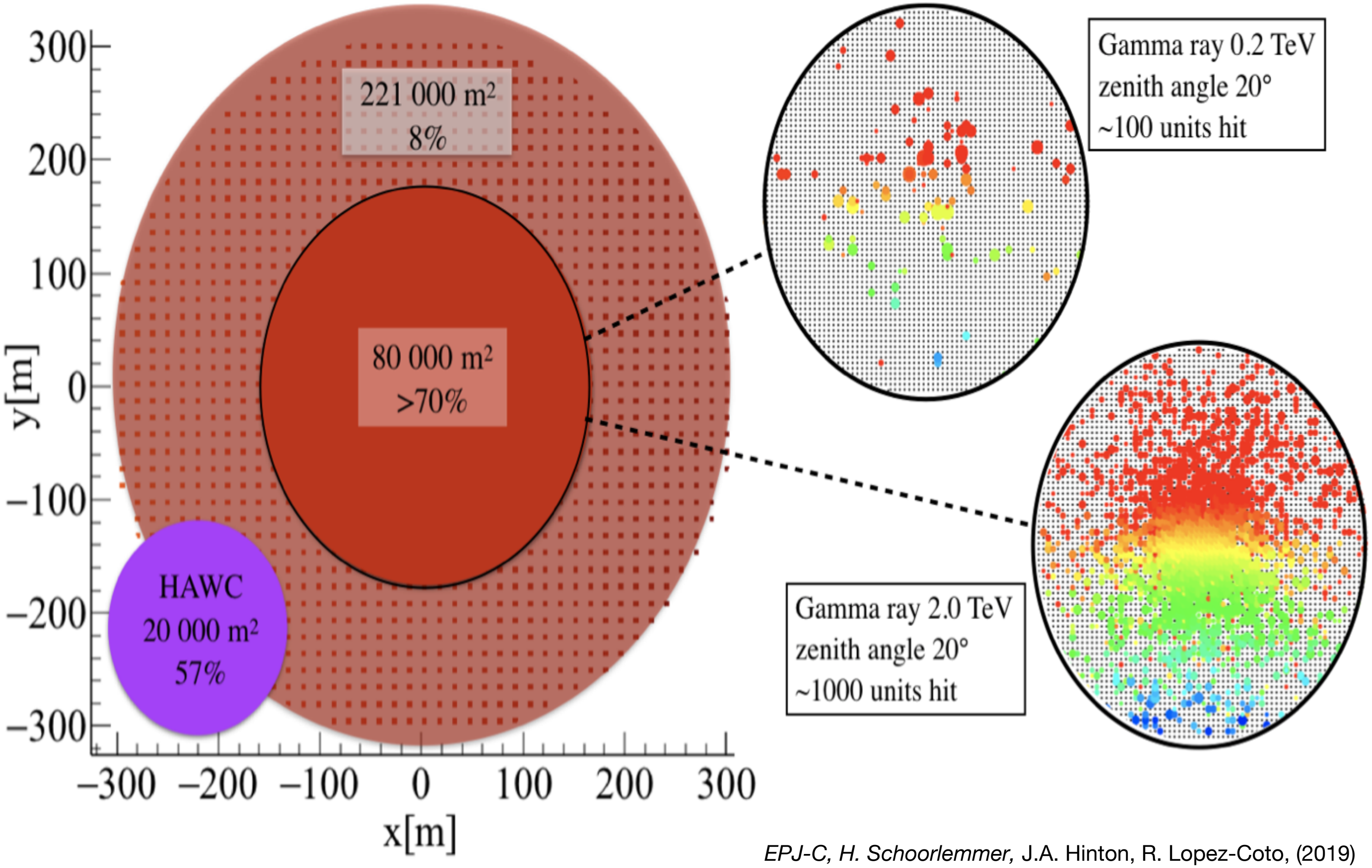




The SWGO Concept

Detector array

Large array for low-energy events
Compact core with large instrumented area



EPJ-C, H. Schoorlemmer, J.A. Hinton, R. Lopez-Coto, (2019)

- ‘Strawman’ - reference detector layout

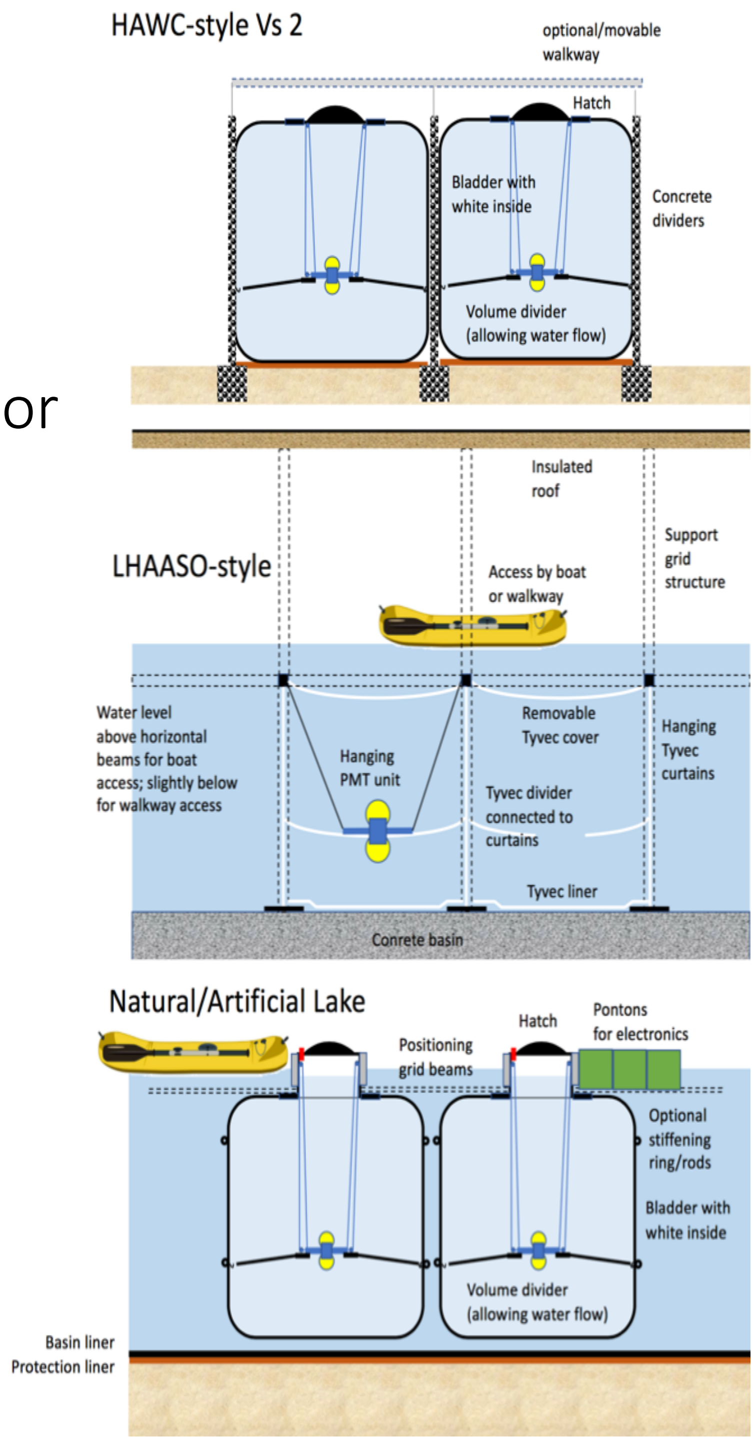
The Southern Wide-field Gamma-ray Observatory

The SWGO Concept

Multiple detector options to be investigated

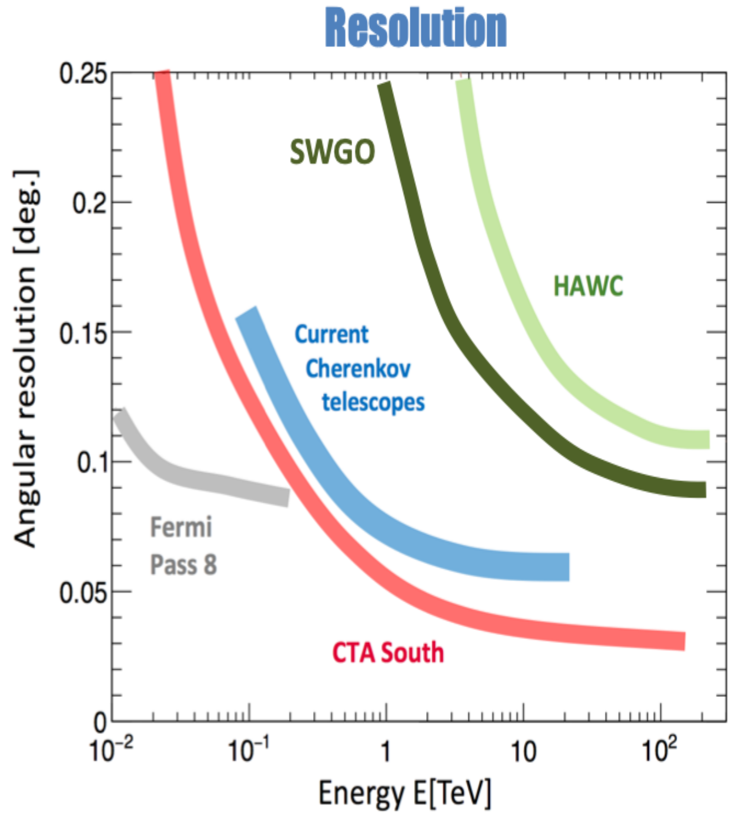
Detector units

- Core unit is a water-Cherenkov Detector
  - Options being investigated based on tanks (HAWC-like), ponds (Milagro-like) and lake-base (test pool under construction at MPIK-Heidelberg)
- Simulations currently ongoing to constrain all aspects of the detectors
- Design strongly dependent on site choice
  - Water access, construction costs, infrastructure feasibility, compatibility with scientific driven main design goals…

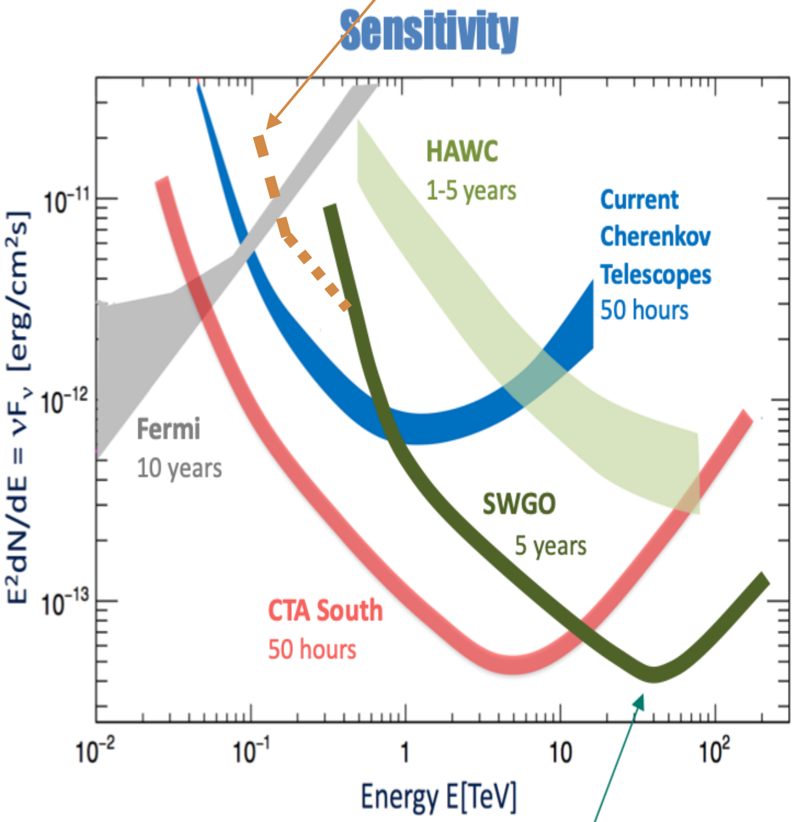


The Southern Wide-field Gamma-ray Observatory

Performance goals



Low-energy enhancement

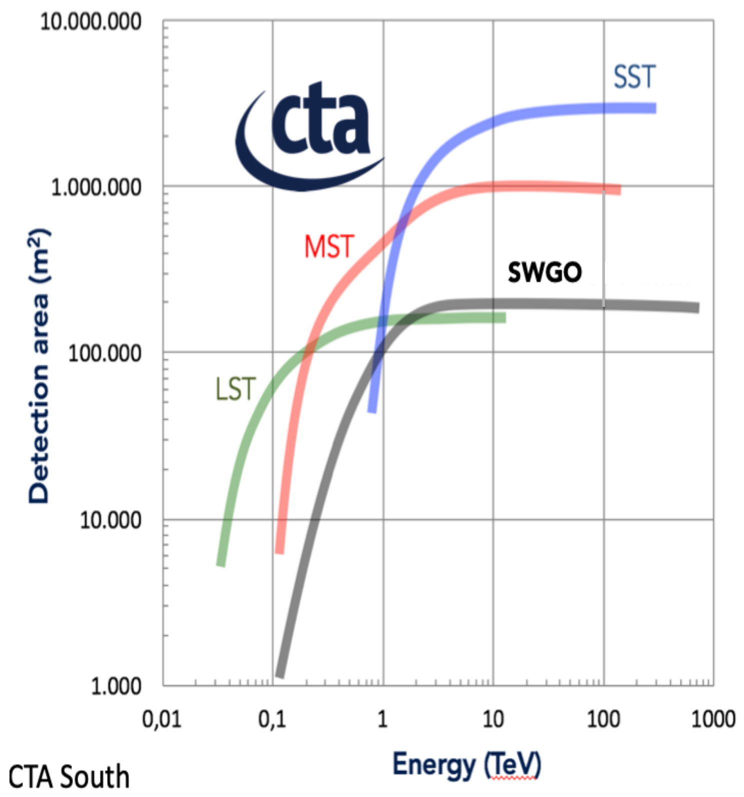


www.cta-observatory.org

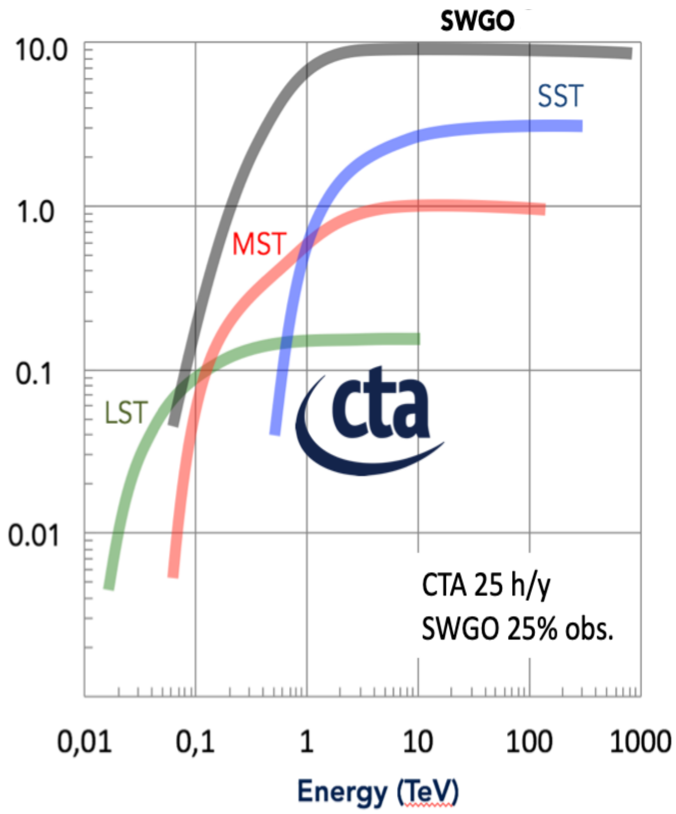
www.swgo.org

Background free above about 30 TeV for point-like sources, even after 5 years

Performance goals



Detection Area



Annual Exposure

Potentially more sensitive than CTA over several years integration
time provided good background suppression is achieved.

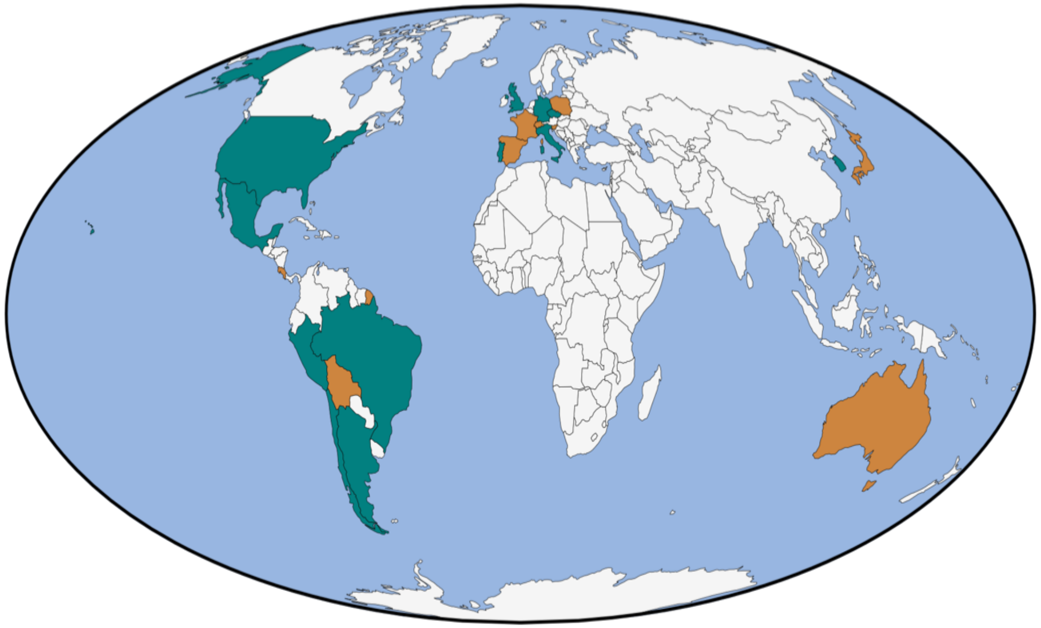
The Collaboration

- Southern Wide-Field Gamma-ray Observatory
  - + higher altitude (4400+ m asl) and larger area
  - + more efficient detector units + muon tagging capability

→ improved sensitivity and lower E threshold

Established in July 2019
3 year R&D Programme

www.swgo.org



Institutes

Argentina*, Brazil, Chile, Czech Republic, Germany*, Italy, Mexico, Peru, Portugal, South Korea, United Kingdom, United States*

Member institutes signed the SoI.

Supporting scientists

Australia, Bolivia, Costa Rica, France, Japan, Poland, Slovenia, Spain, Switzerland

**also supporting scientists*

Any interested individual can become supporting scientist.