cherenkov telescope array

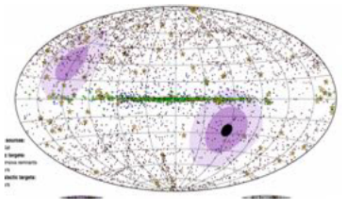
Introduction to the Science of KSPs

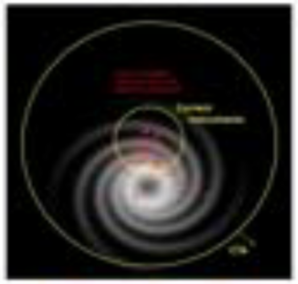
Francesco Longo – University of Trieste, INFN, CTAO

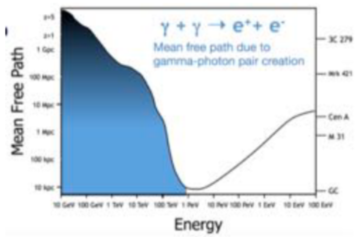
Summary

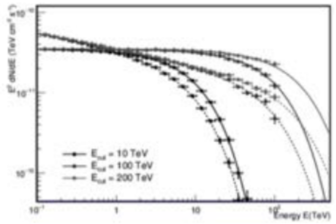
- The Cherenkov Telescope Array
- Key Science Topics
- Ongoing work to revise the KSPs

Design drivers







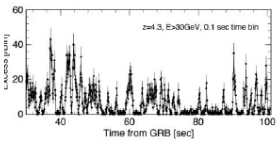


Full sky coverage

10 x sensitivity

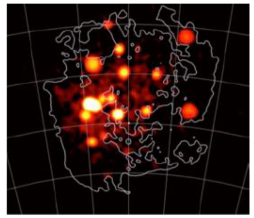
Energies down to 20 GeV

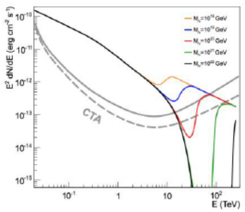
Energies up to 300 TeV



Rapid slewing 20 sec

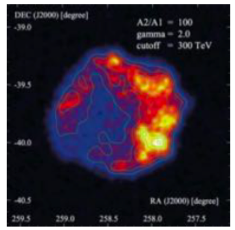
~ 10° FoV



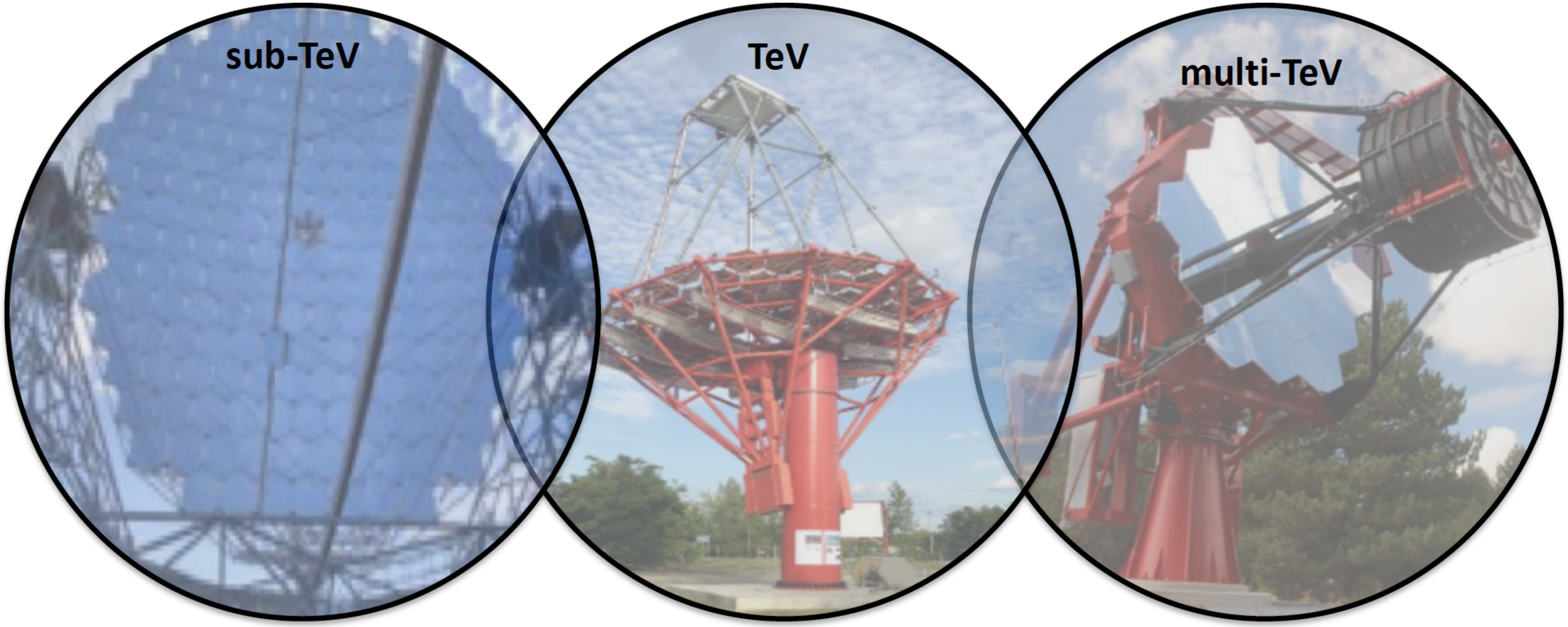


10% energy resolution

arcmin angular resolution



Science cases and design



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

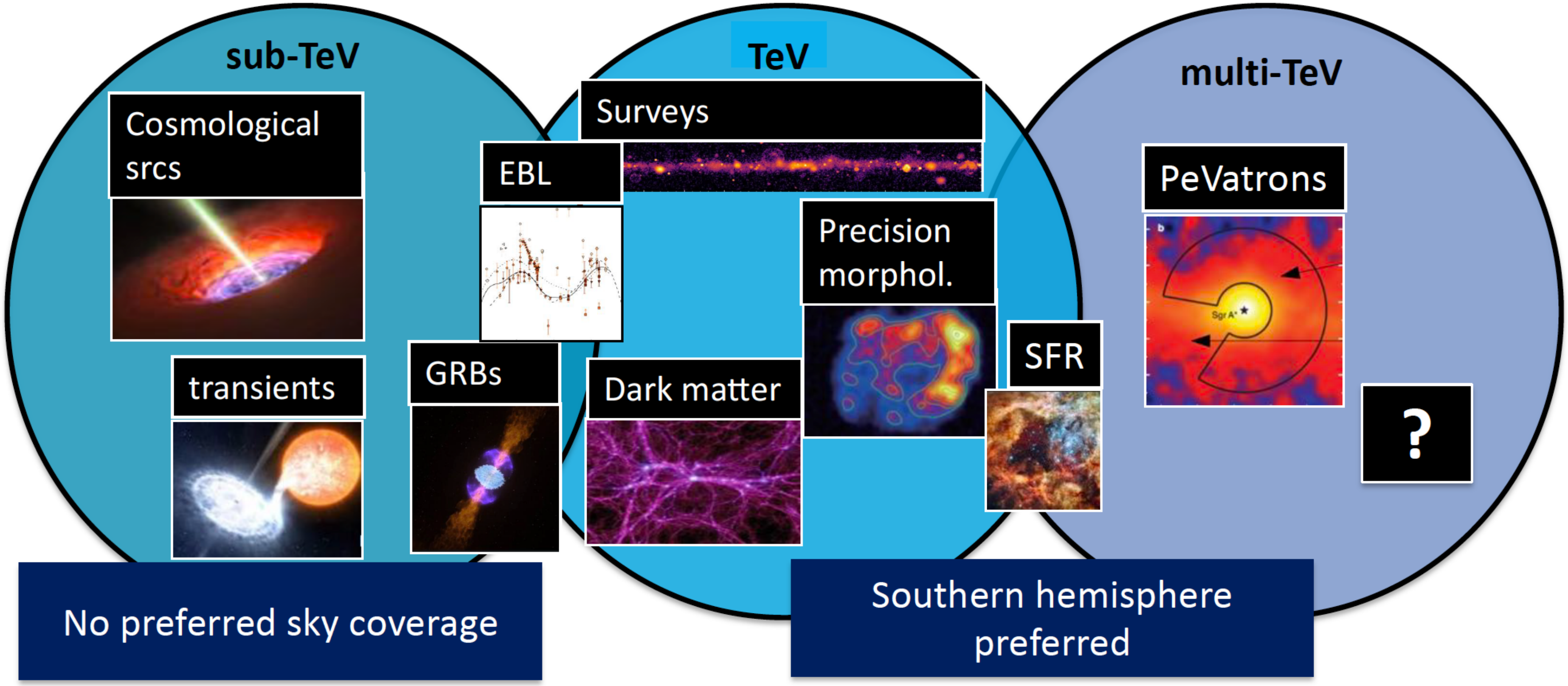
- deepest sensitivity ever
- arcmin angular resolution
- large FoV

- Surveys & precision studies

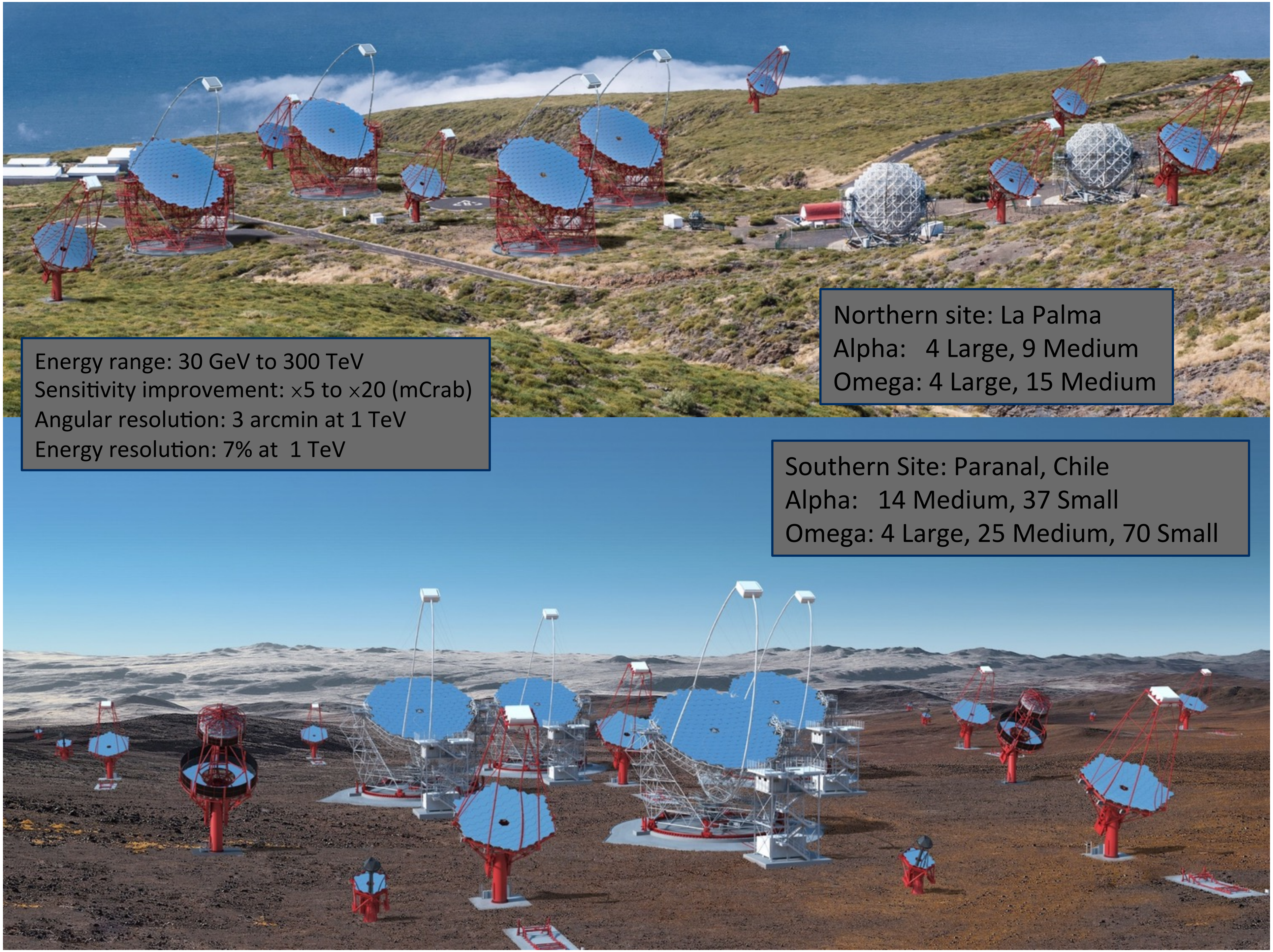
- Precision measurements in a still little explored energy range

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

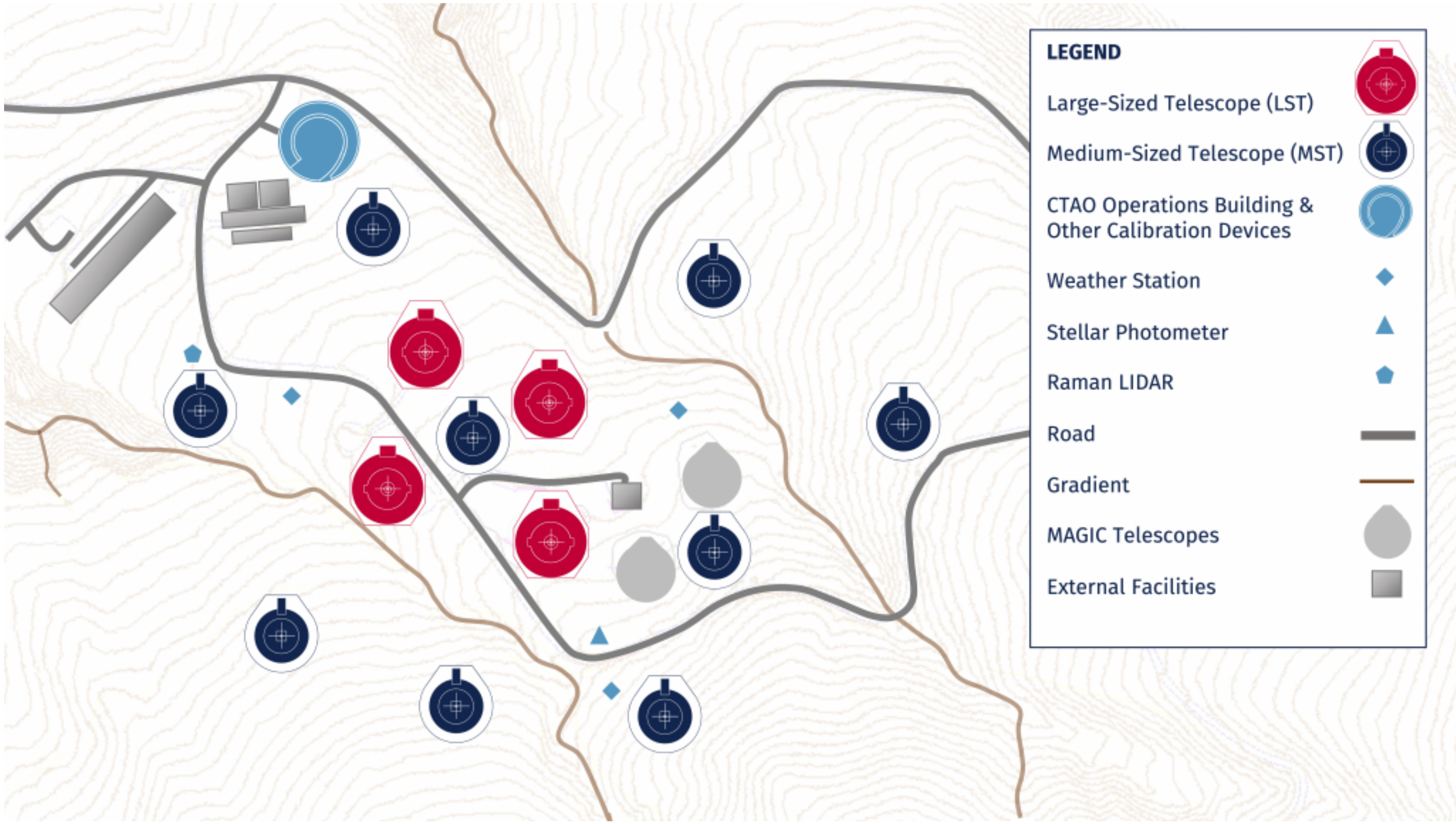
Science cases



- **Mainly CTA consortium involved in the definition of the science cases**
  (Science with CTA, CTA Consortium 2019 - https://doi.org/10.1142/10986)


Northern site: La Palma
Alpha: 4 Large, 9 Medium
Omega: 4 Large, 15 Medium
Energy range: 30 GeV to 300 TeV
Sensitivity improvement: ×5 to ×20 (mCrab)
Angular resolution: 3 arcmin at 1 TeV
Energy resolution: 7% at 1 TeV
Southern Site: Paranal, Chile
Alpha: 14 Medium, 37 Small
Omega: 4 Large, 25 Medium, 70 Small

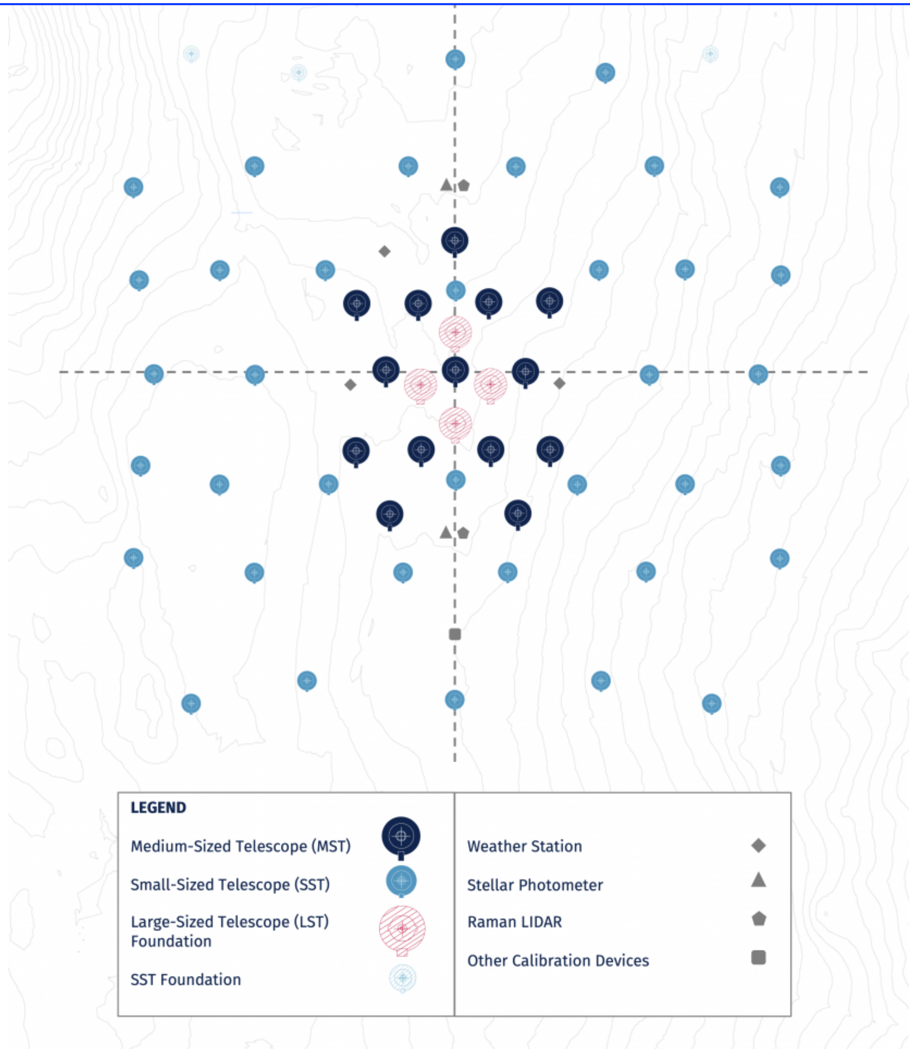
CTA Alpha Layout



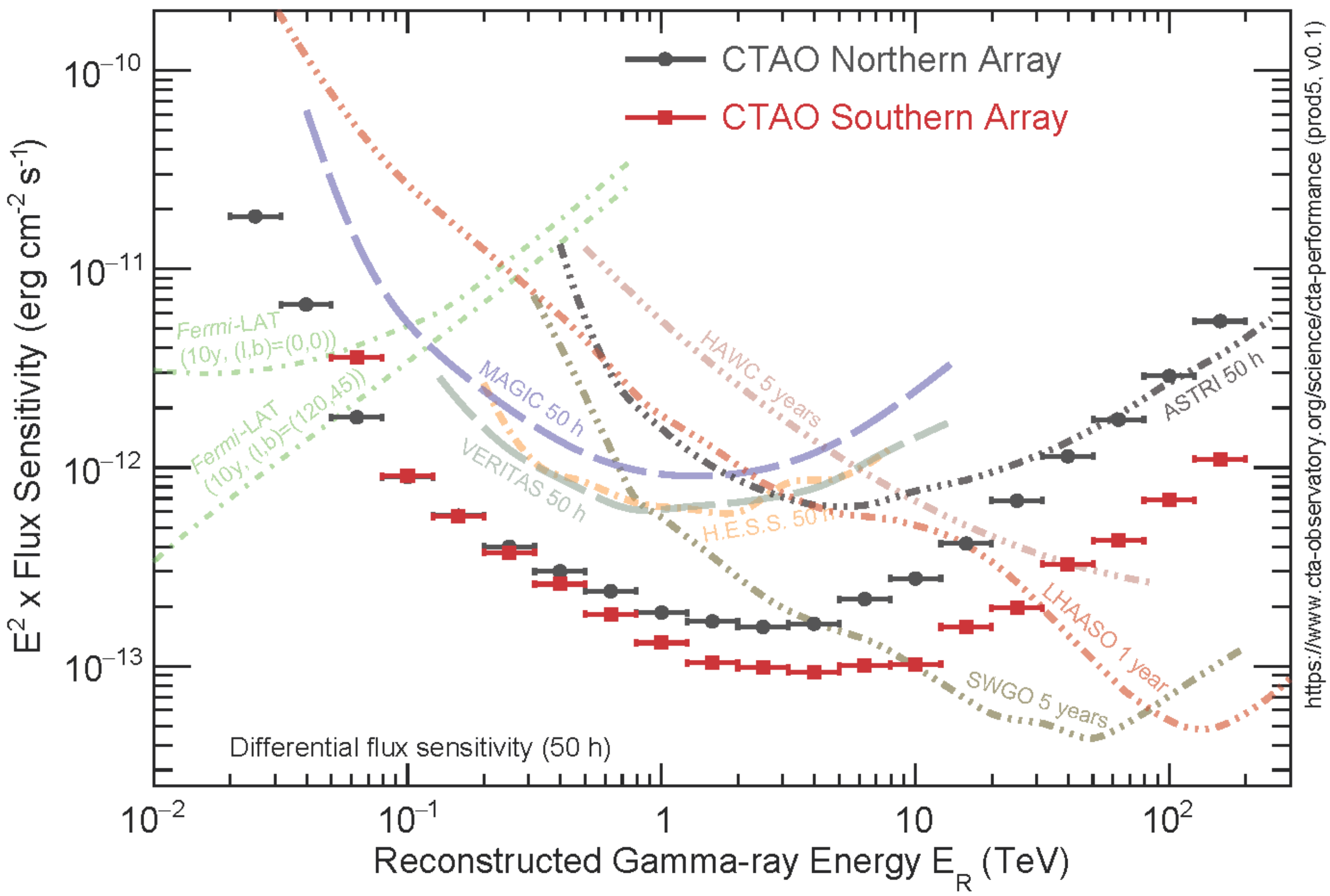
https://www.cta-observatory.org/ctao-releases-layouts-for-alpha-configuration/

CTA Alpha Layout

https://www.cta-observatory.org/ctao-releases-layouts-for-alpha-configuration/

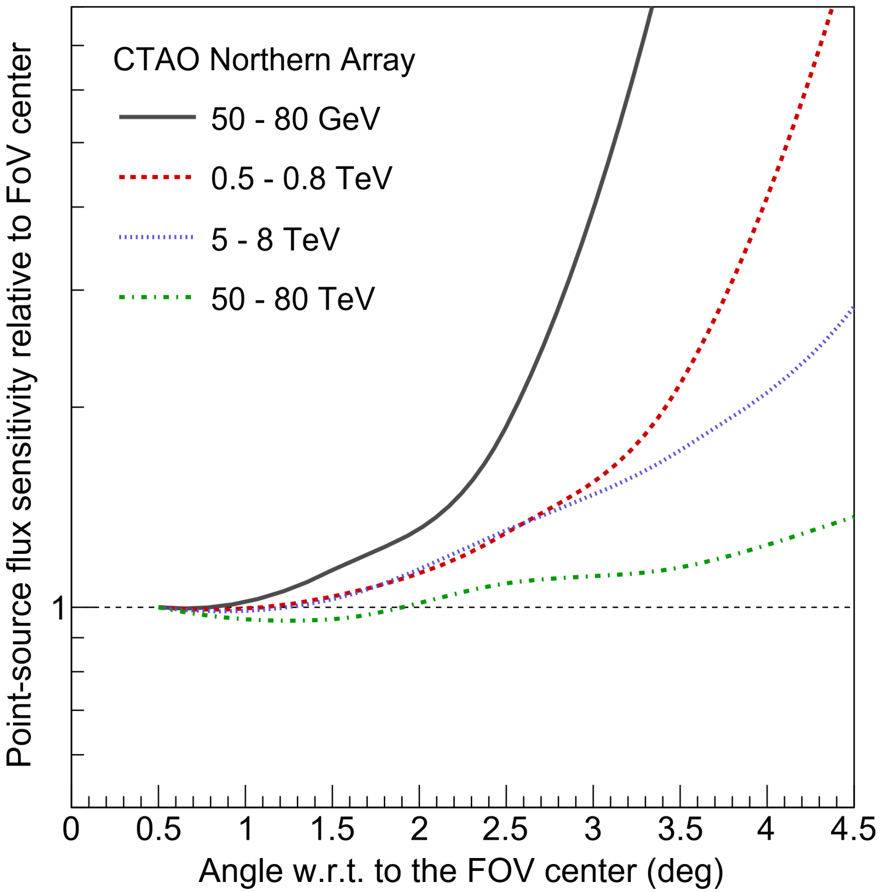


CTA performance



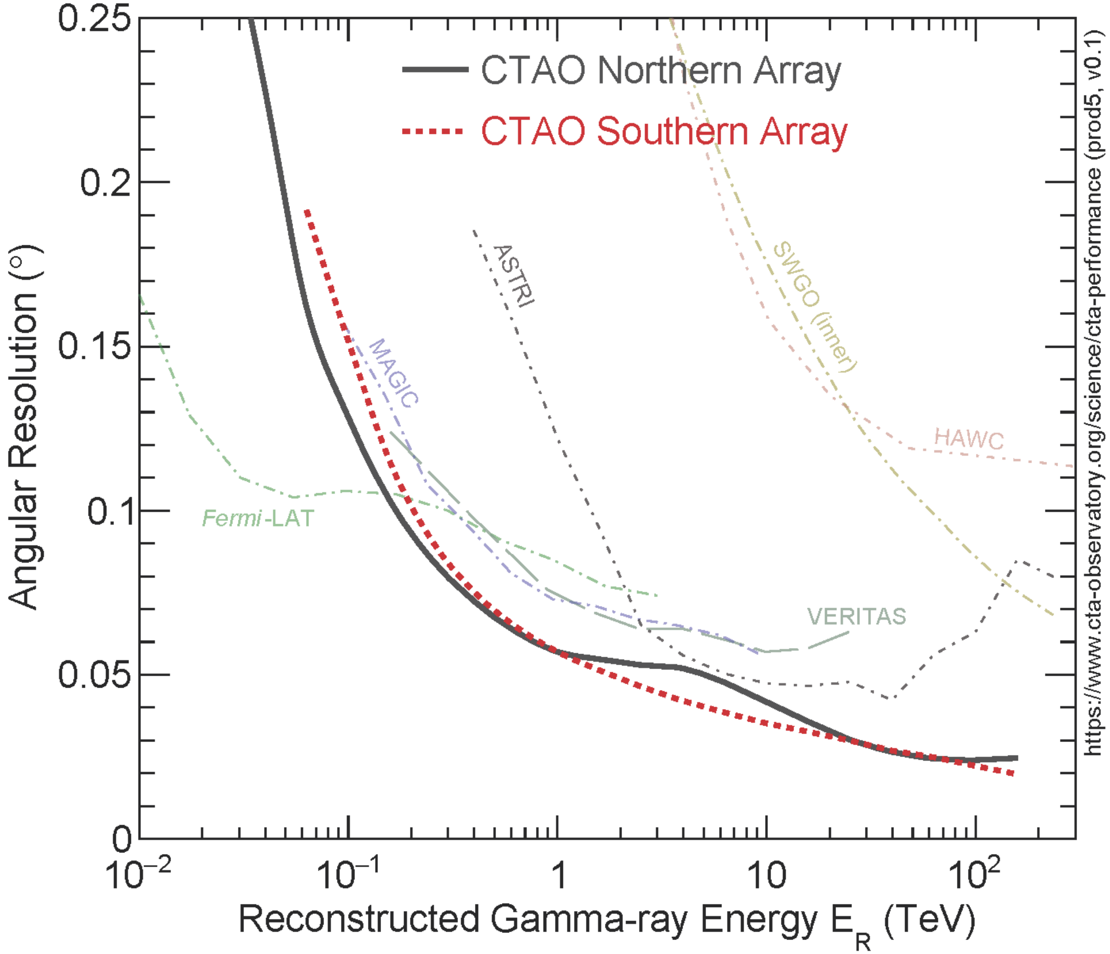
https://www.cta-observatory.org/science/cta-performance/

CTA performance



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

CTA performance



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

CTA telescopes – first LST ATEL

https://astronomerstelegram.org/?read=14783

Detection of very-high-energy gamma-ray emission from BL Lac with the LST-1

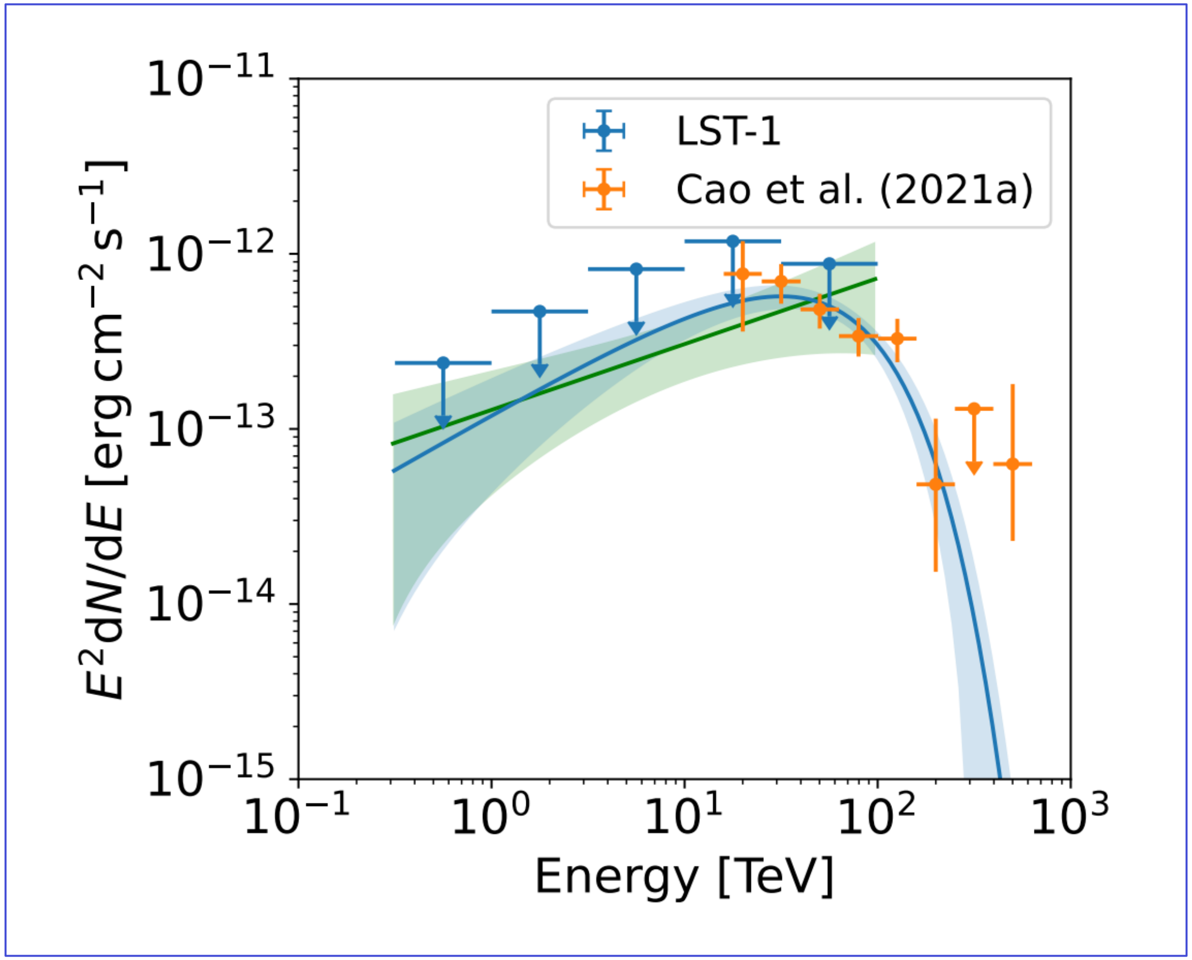
ATel #14783; ***Juan Cortina for the CTA LST collaboration***
*on **13 Jul 2021; 21:03 UT***
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

Subjects: TeV, VHE, Request for Observations, AGN, Blazar, Transient

Referred to by ATel #: 14820, 14826, 14839

The LST-1 telescope has observed an increase in the very-high-energy (VHE; >100 GeV) gamma-ray flux from BL Lacertae (RA=22:02:43.3, DEC=+42:16:40, J2000.0). The preliminary offline analysis of the LST-1 data taken on 2021/07/11 (MJD 59406), triggered by an increase of the optical flux (see ATEL #14773 and references therein), has been detected with a significance of 8 sigma with a differential flux of 1.3 +/- 0.2 10^-9 cm-2 s-1 TeV-1 (25% of the Crab Nebula) at 100 GeV. Note though that this is the result of a quick-look analysis and the data were taken under non-optimal weather conditions (atmospheric transmission at 9km of ~50-60%), hence this flux measurement is a lower bound on the true flux. The LST-1 observations were performed during commissioning which began in 2018. LST-1 is a prototype of the Large-Sized Telescope for the Cherenkov Telescope Array, and is located on the Canary island of La Palma, Spain. The LST-1 is designed to perform gamma-ray astronomy in the energy range from 20 GeV to 3 TeV. LST-1 observations on BL Lacertae will continue during the next few nights, multi-wavelength observations are encouraged. The preliminary offline analysis has been performed by Daniel Morcuende (dmorcuen@ucm.es) and Ruben Lopez-Coto (ruben.lopezcoto@pd.infn.it). The LST-1 contact persons for these observations are Masahiro Teshima (mteshima@mpp.mpg.de) and Juan Cortina (juan.cortina@ciemat.es).

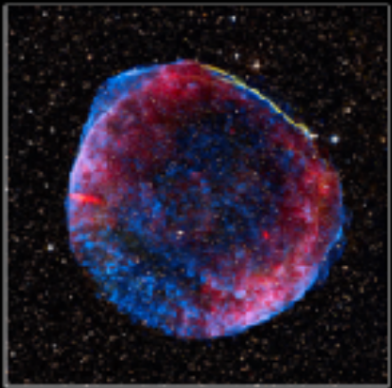
CTA telescopes – first LST paper

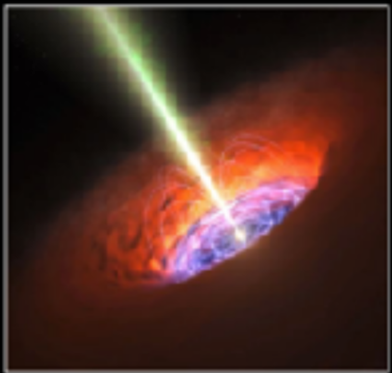


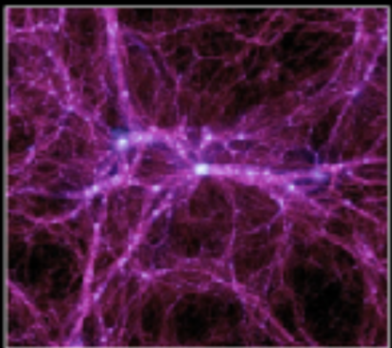
https://arxiv.org/pdf/2210.00775.pdf

https://www.cta-observatory.org/lst-collaboration-publishes-first-scientific-paper/

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

U.Barres – COSPAR 2020

The Science of CTA

cherenkov telescope array

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

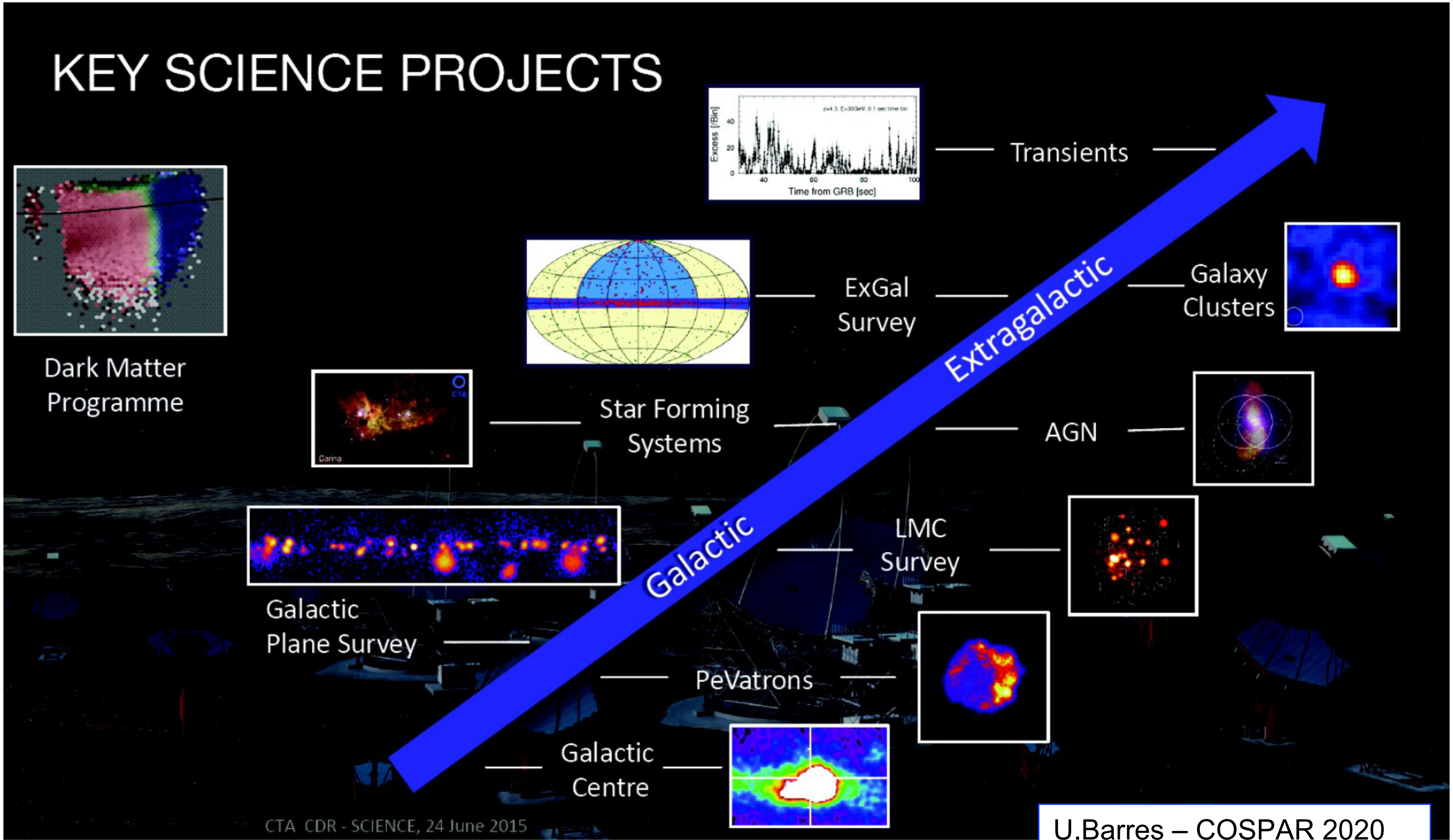
- PeVatrons
- Star-forming Systems
- Radio Galaxies & Clusters

Follow-ups of Transient and Multi-messenger events

Monitoring of Variability notably of AGN

U.Barres – COSPAR 2020

A Census of particle accelerators across all cosmic scales



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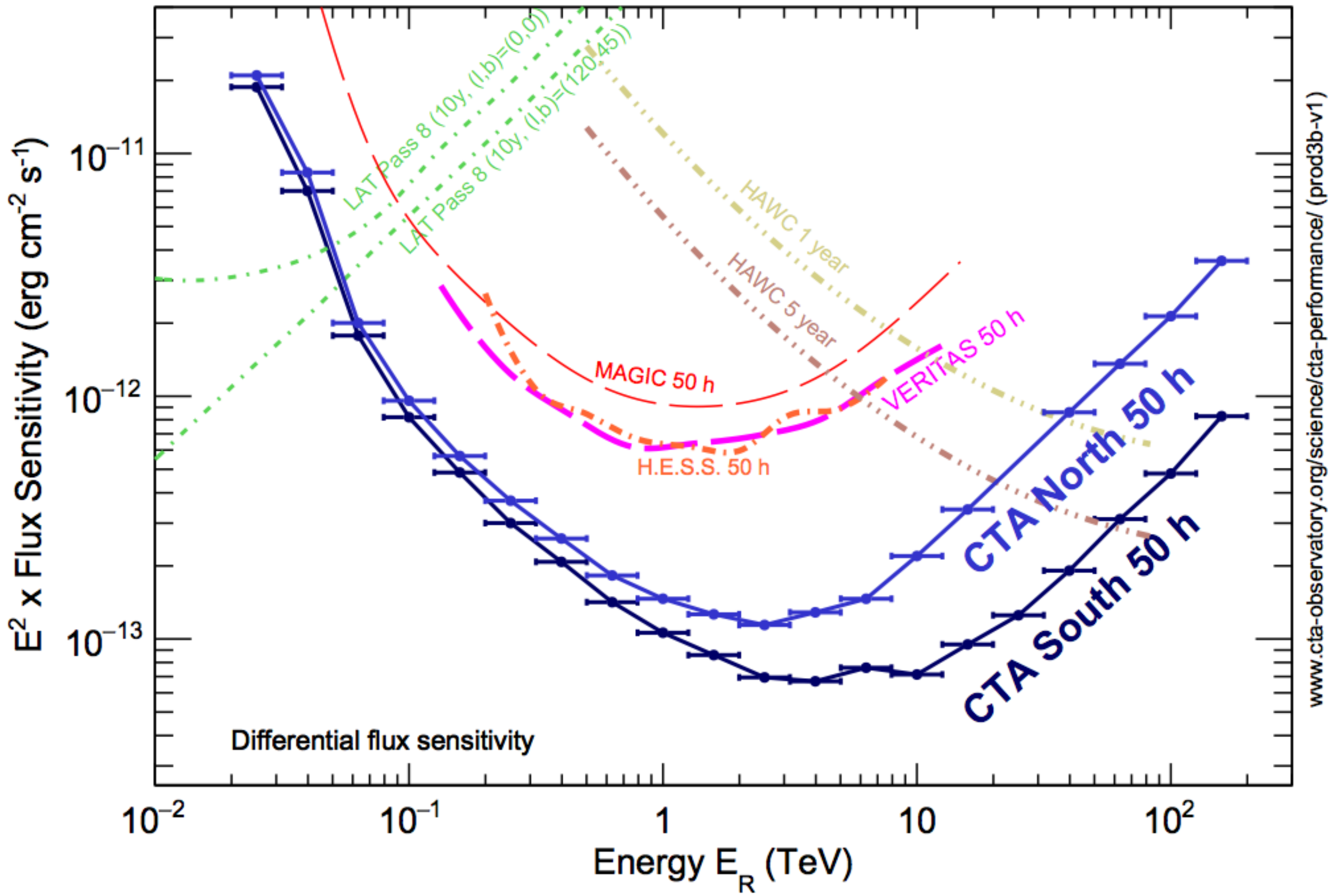
Science with CTA

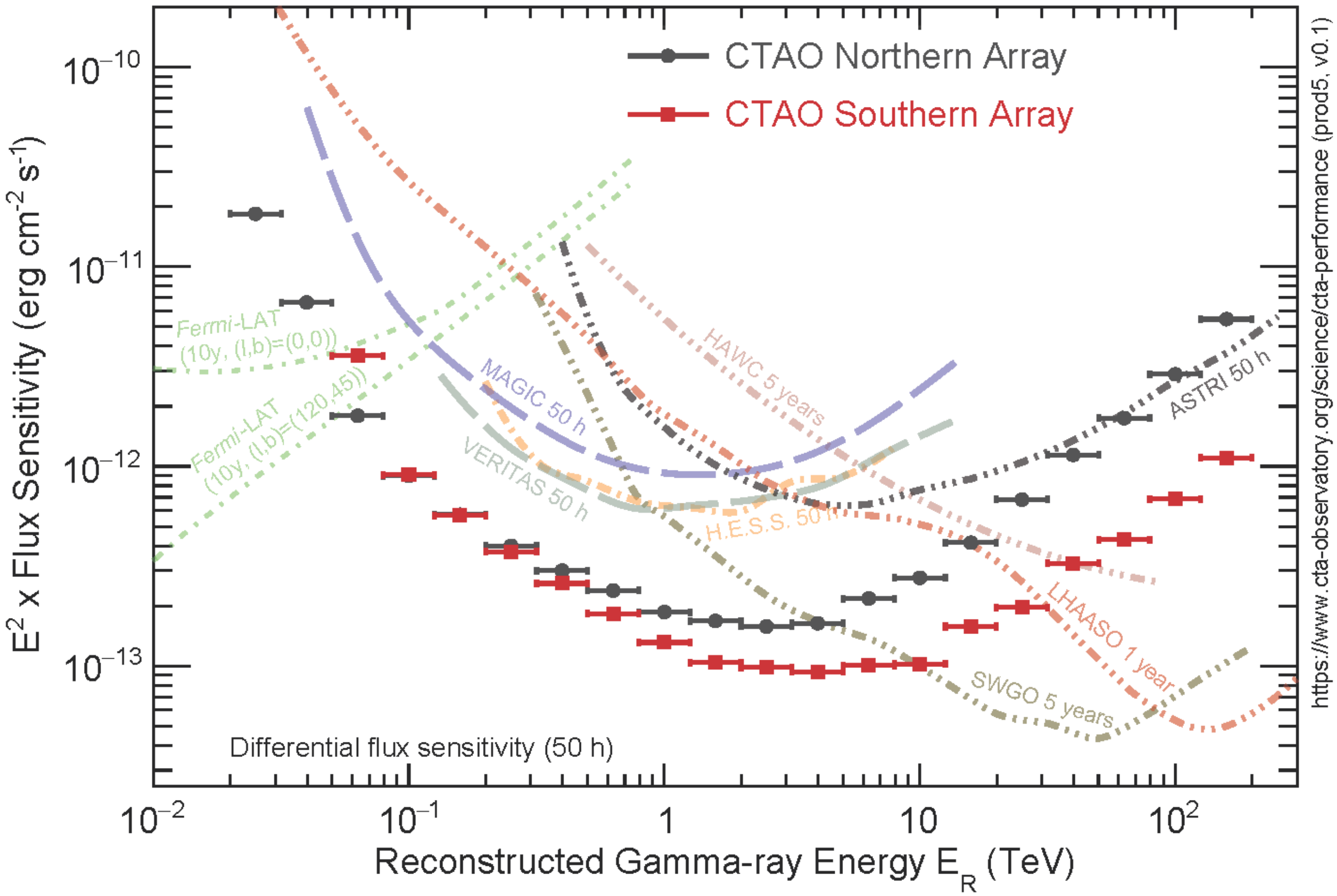
CTA will have important synergies with many of the new generation of major astronomical and astroparticle observatories. Multi-wavelength and multi-messenger approaches combining CTA data with those from other instruments will lead to a deeper understanding of the broad-band non-thermal properties of 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

CTA performance (around 2017)

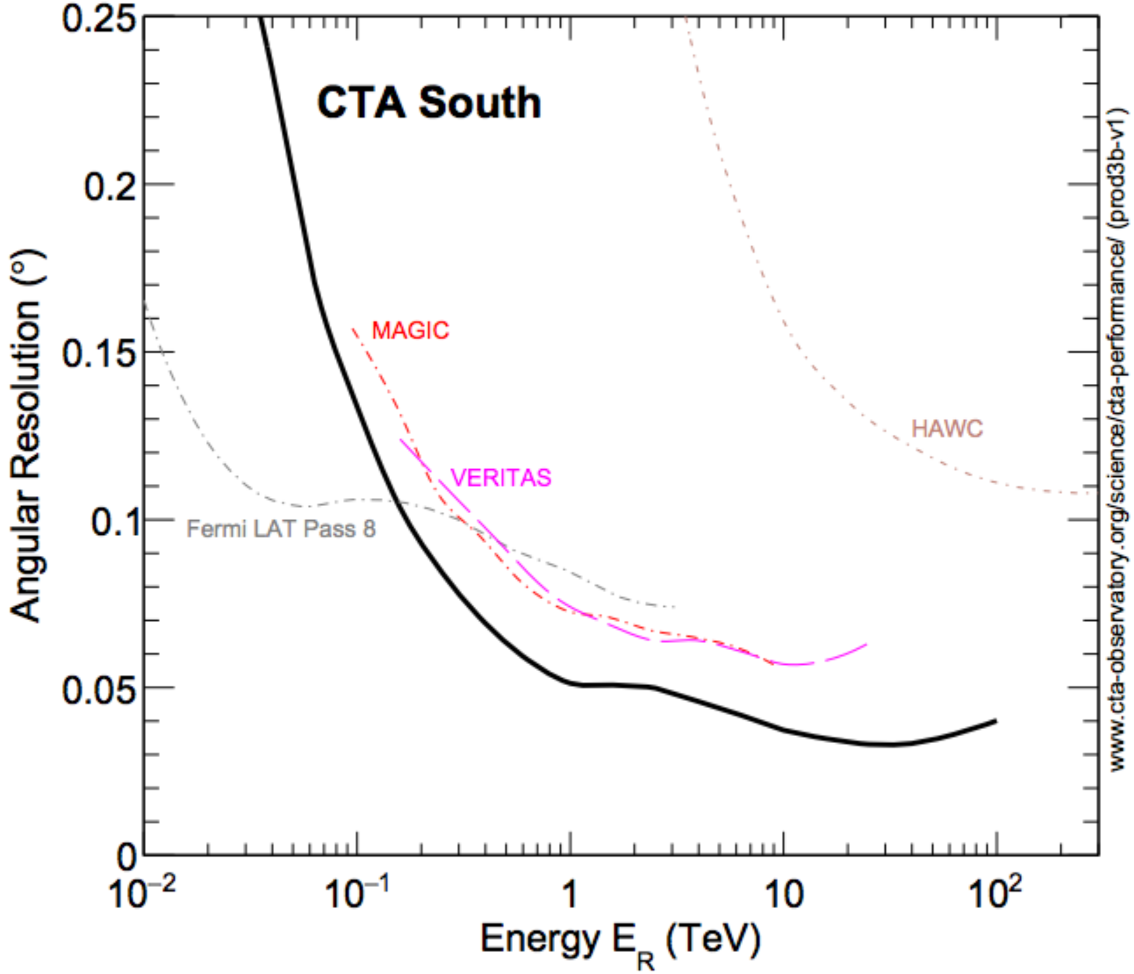


CTA performance (now)

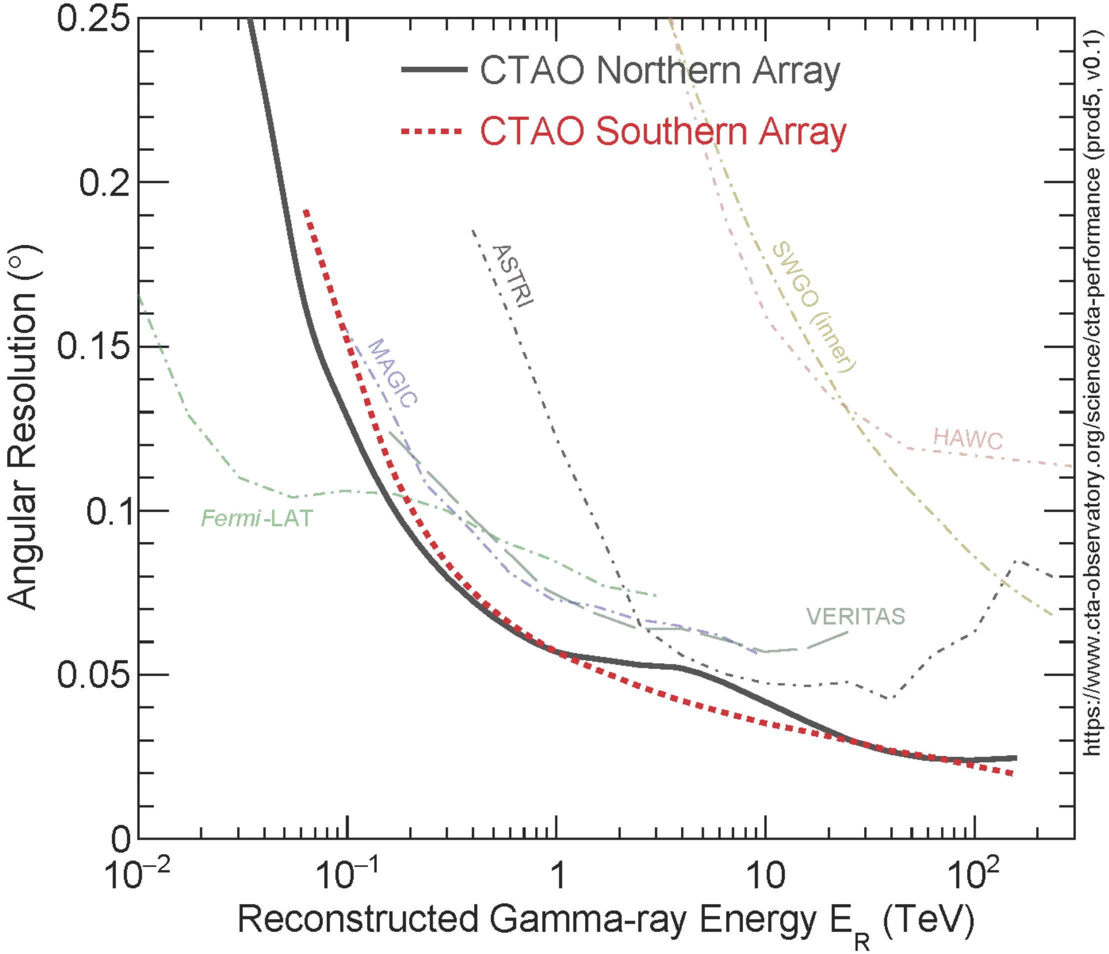


https://www.cta-observatory.org/science/cta-performance/

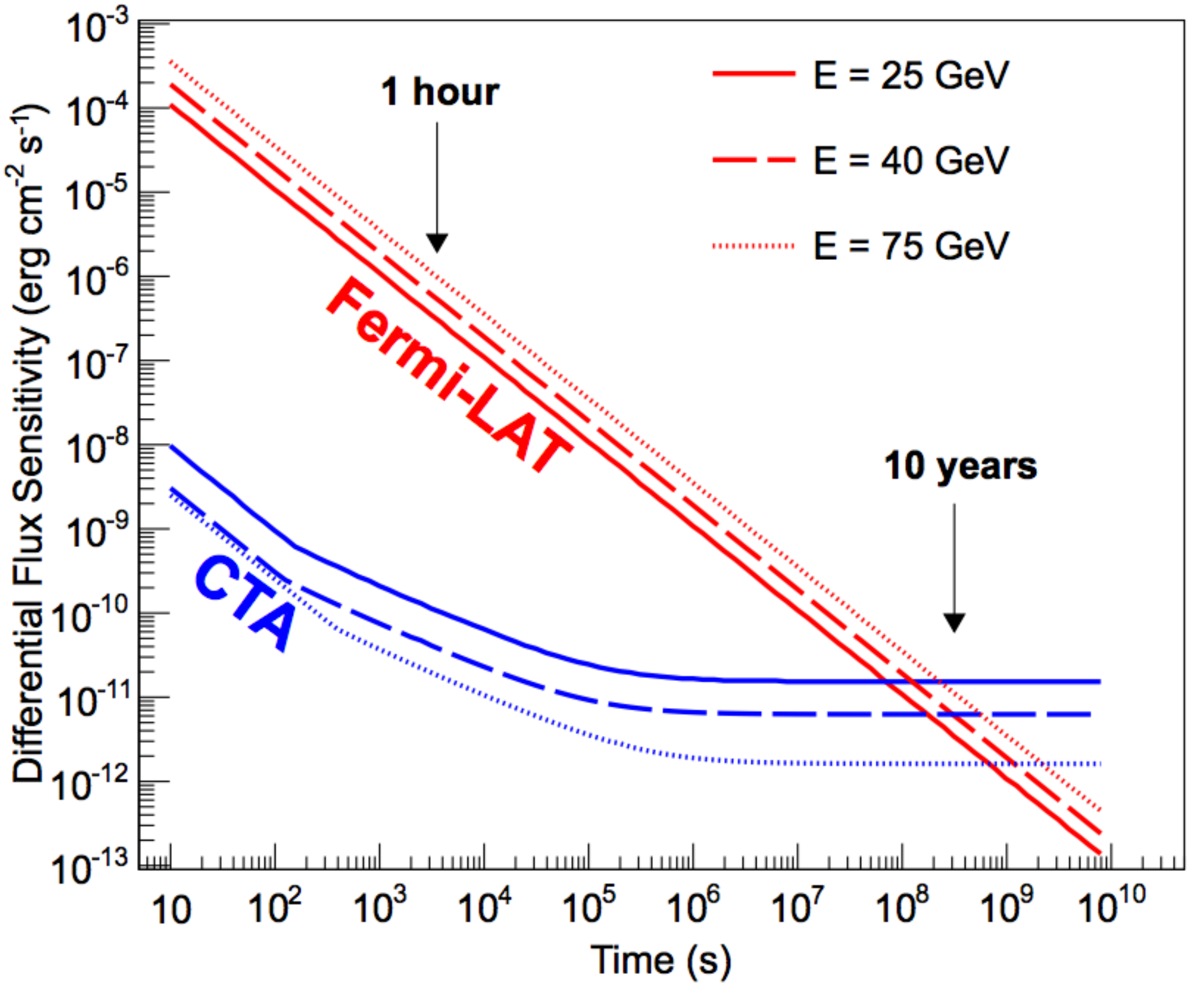
CTA performance (around 2017)



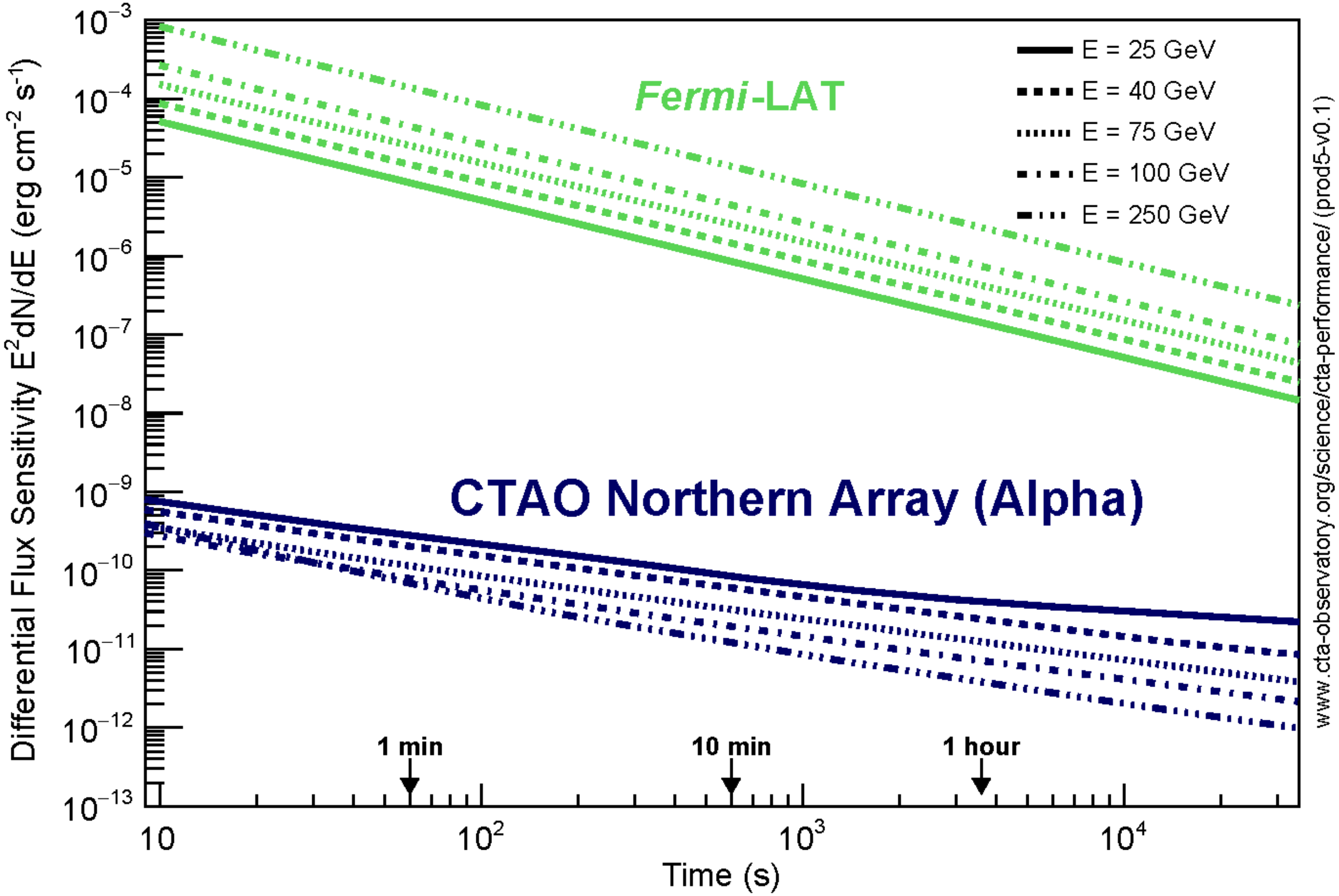
CTA performance (now)



CTA performance (around 2017)



CTA performance (now)



KSP/SWG	GAL	EGAL	CR	Trans	DMEP	II
GPS	GPS		*			
			Electrons			
GC survey	*		GC astro			
					GC DM	
AGN		AGN pop				
		gamma prop			*	
		AGN variability		*		
		*		extra-gal v sources		
DM					Gal. clusters	
					Dwarf gal.	
					DM Lines	
LMC survey	*		LMC survey		*	
Gal. clusters			Perseus cluster		*	
PeVatrons	PeVatrons		*			
SFS		*	CRs in SFS			
Transients				v transients		
				GRBs		
				GW		
			*	CC SNe		
	*			Gal. transients		
				Novae		*

STATUS at CTAO/CTAC meeting in NAPLES

published	submitted	SAPO review	advanced	in progress	starting	lack manpower

* Secondary SWG

KSP/SWG	GAL	EGAL	CR	Trans	DMEP	II
GPS	GPS		*			
			Electrons			
GC survey	*		GC astro			
					GC DM	
AGN		AGN pop				
		gamma prop			*	
		AGN variability		*		
		*		extra-gal ν sources		
DM					Gal. clusters	
					Dwarf gal.	
					DM Lines	
LMC survey	*		LMC survey		*	
Gal. clusters			Perseus cluster		*	
PeVatrons	PeVatrons		*			
SFS		*	CRs in SFS			
Transients				ν transients		
				GRBs		
				GW		
			*	CC SNe		
	*			Gal. transients		
				Novae		*

STATUS at CTAO/CTAC meeting in GRANADA

published	submitted	SAPO review	advanced	in progress	starting	lack manpower

* Secondary SWG

KSP/SWG	GAL	EGAL	CR	Trans	DMEP	II
GPS	GPS		*			
			Electrons			
GC survey	*		GC astro			
					GC DM	
AGN		AGN pop				
		gamma prop			*	
		AGN variability		*		
		*		extra-gal v sources		
DM					Gal. clusters	
					Dwarf gal.	
					DM Lines	
LMC survey	*		LMC survey		*	
Gal. clusters			Perseus cluster		*	
PeVatrons	PeVatrons		*			
SFS		*	CRs in SFS			
Transients				v transients		
				GRBs		
				GW		
			*	CC SNe		
	*			Gal. transients		
				Novae		*

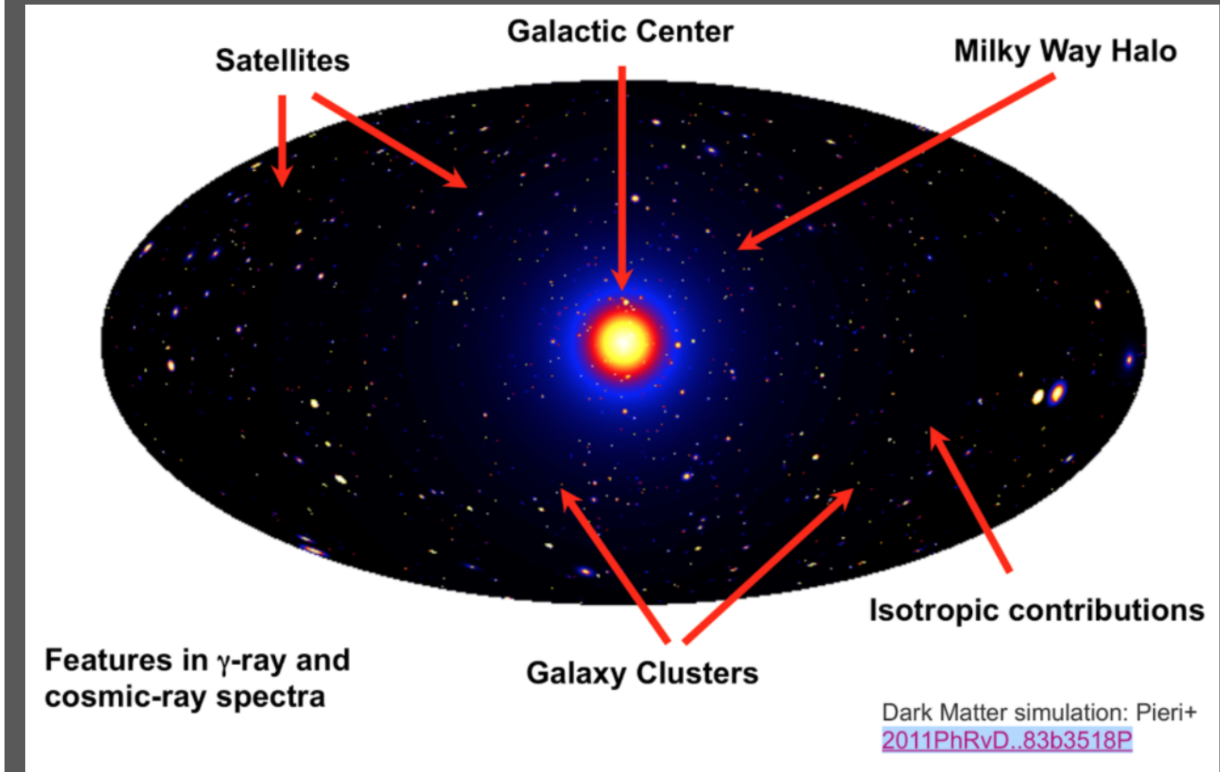
STATUS … now …

published	submitted	SAPO review	advanced	in progress	starting	lack manpower

* Secondary SWG

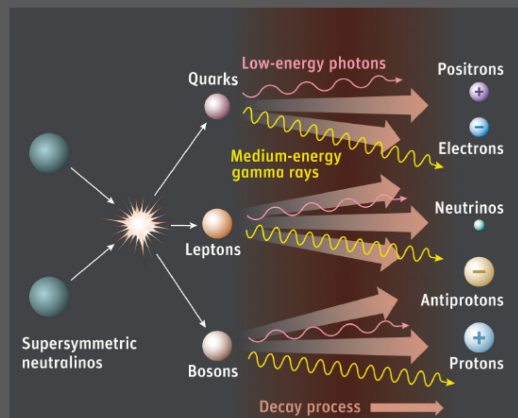
The Dark Matter Programme

Gamma-rays trace annihilating Dark Matter



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

- 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



U.Barres – COSPAR 2020

Dark Matter with CTA

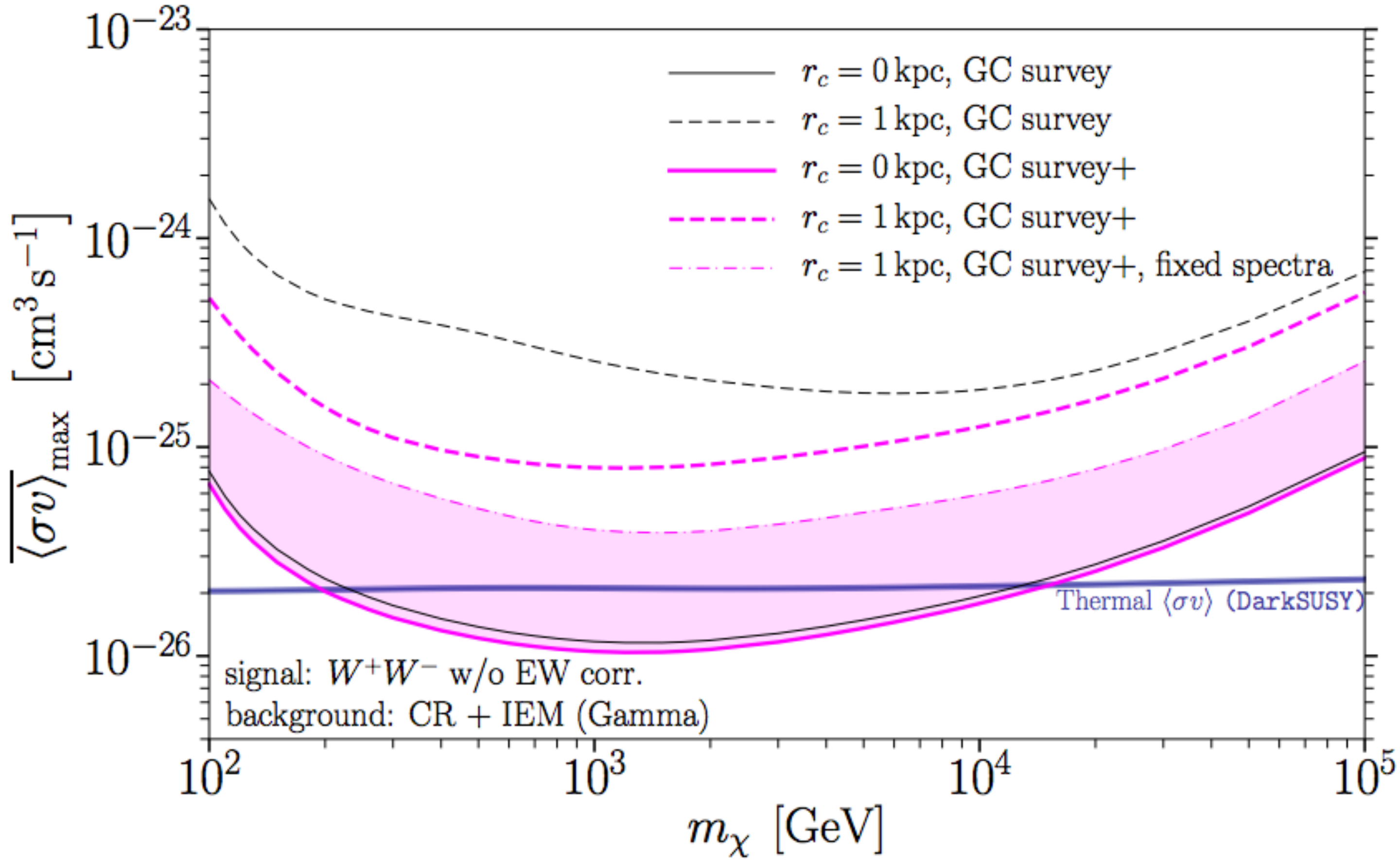
Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre

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

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

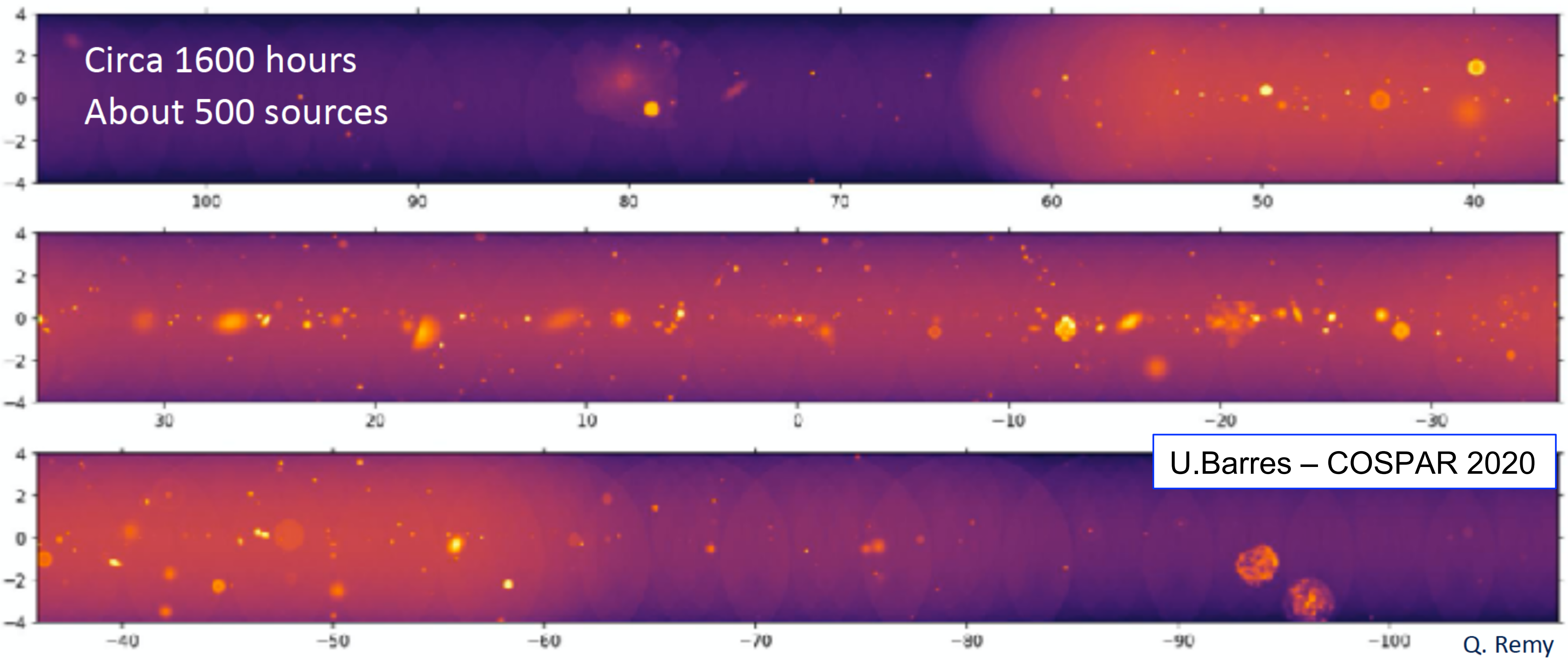
Dark Matter with CTA



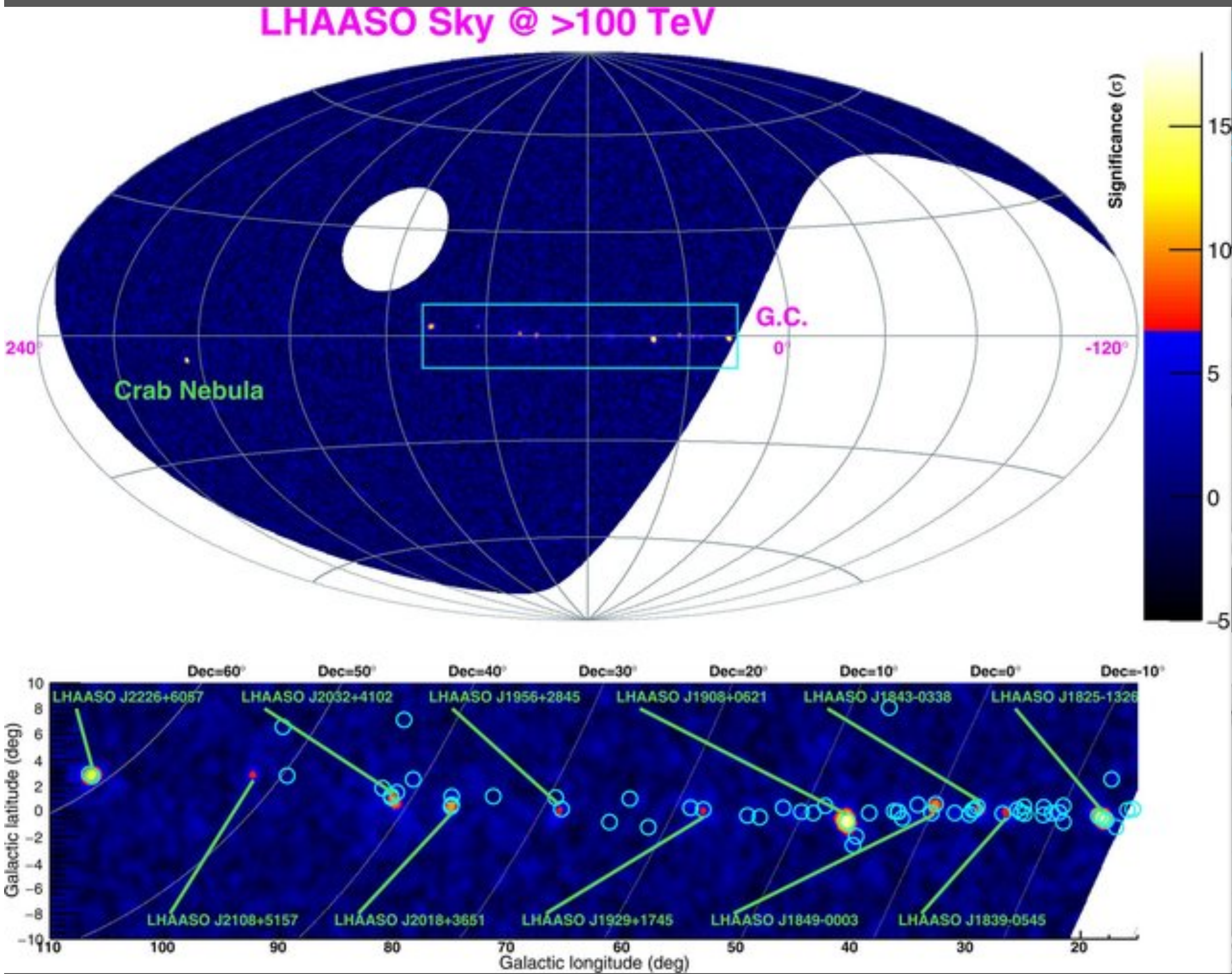
https://arxiv.org/abs/2007.16129

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.



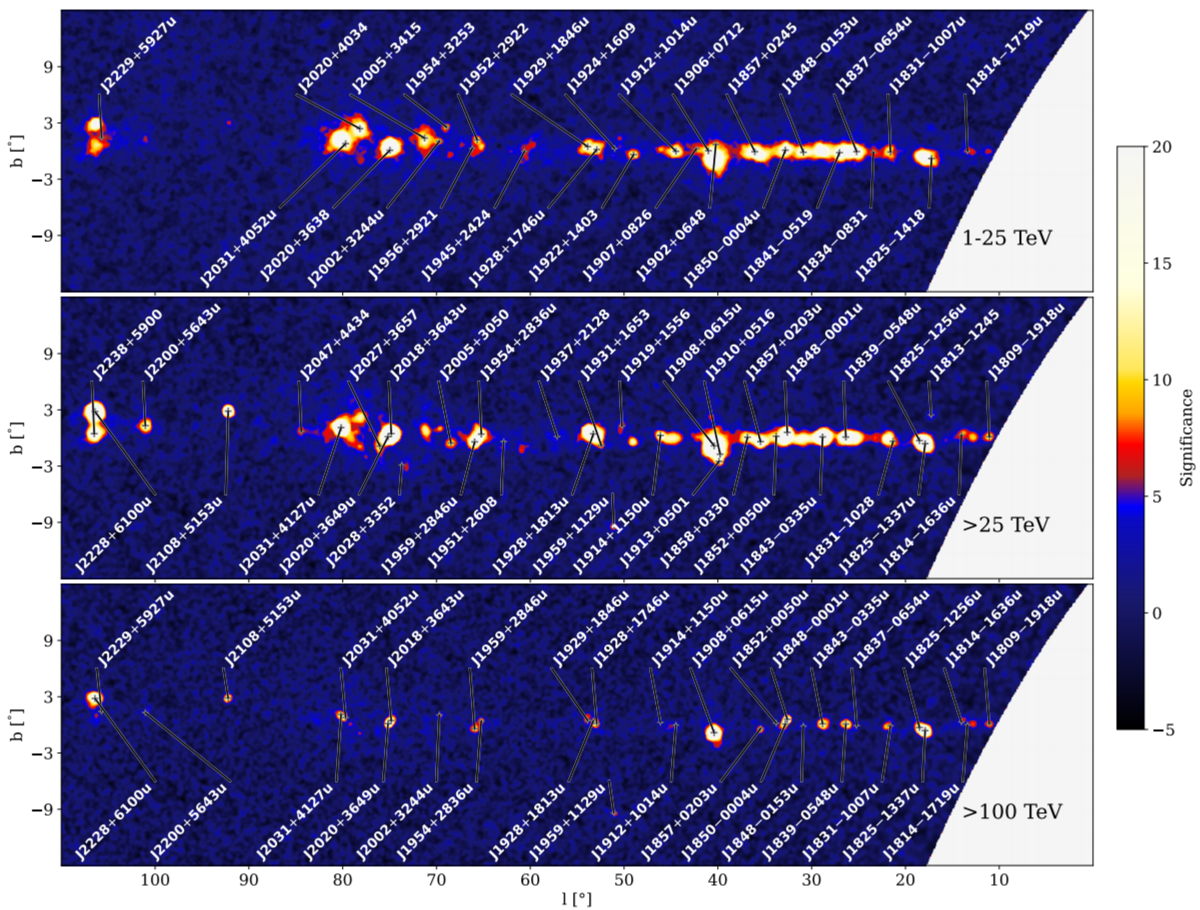
PeVatrons: the extreme energy frontier



Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

LHAASO
(Nature 2021)

The 1st LHAASO catalog



https://arxiv.org/pdf/2305.17030.pdf

CTA Pevatrons KSP

Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants

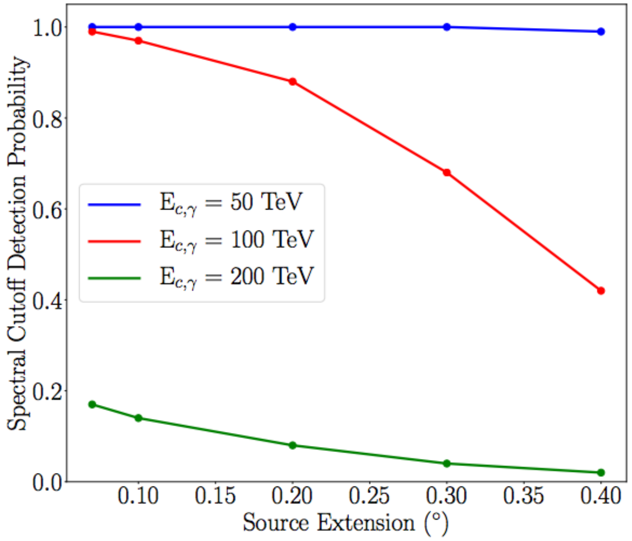
Abstract

The local Cosmic Ray (CR) energy spectrum exhibits a spectral softening at energies around 3 PeV. Sources which are capable of accelerating hadrons to such energies are called hadronic PeVatrons. However, hadronic PeVatrons have not yet been firmly identified within the Galaxy. Several source classes, including Galactic Supernova Remnants (SNRs), have been proposed as PeVatron candidates. The potential to search for hadronic PeVatrons with the Cherenkov Telescope Array (CTA) is assessed. The focus is on the usage of very high energy γ-ray spectral signatures for the identification of PeVatrons. Assuming that SNRs can accelerate CRs up to knee energies, the number of Galactic SNRs which can be identified as PeVatrons with CTA is estimated within a model for the evolution of SNRs. Additionally, the potential of a follow-up observation strategy under moonlight conditions for PeVatron searches is investigated. Statistical methods for the identification of PeVatrons are introduced, and realistic Monte–Carlo simulations of the response of the CTA observatory to the emission spectra from hadronic PeVatrons are performed. Based on simulations of a simplified model for the evolution for SNRs, the detection of a γ-ray signal from in average 9 Galactic PeVatron SNRs is expected to result from the scan of the Galactic plane with CTA after 10 hours of exposure. CTA is also shown to have excellent potential to confirm these sources as PeVatrons in deep observations with $\mathcal{O}(100)$ hours of exposure per source.

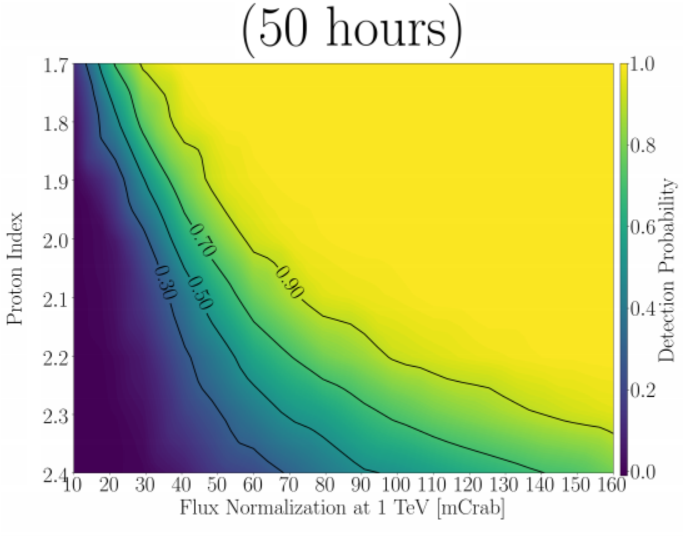
Keywords: Gamma rays: general, Cosmic rays, Galactic PeVatrons, (Stars:) supernovae: general, Methods: data analysis, Methods: statistical

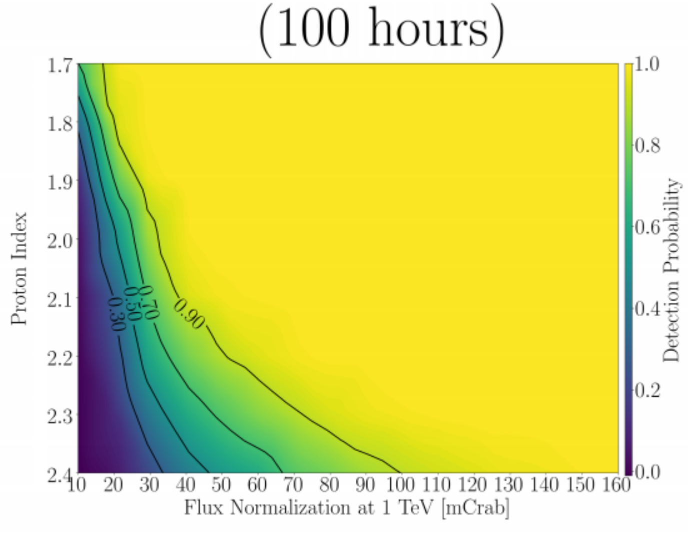
https://arxiv.org/pdf/2303.15007.pdf

CTA Pevatrons KSP



https://arxiv.org/pdf/2303.15007.pdf





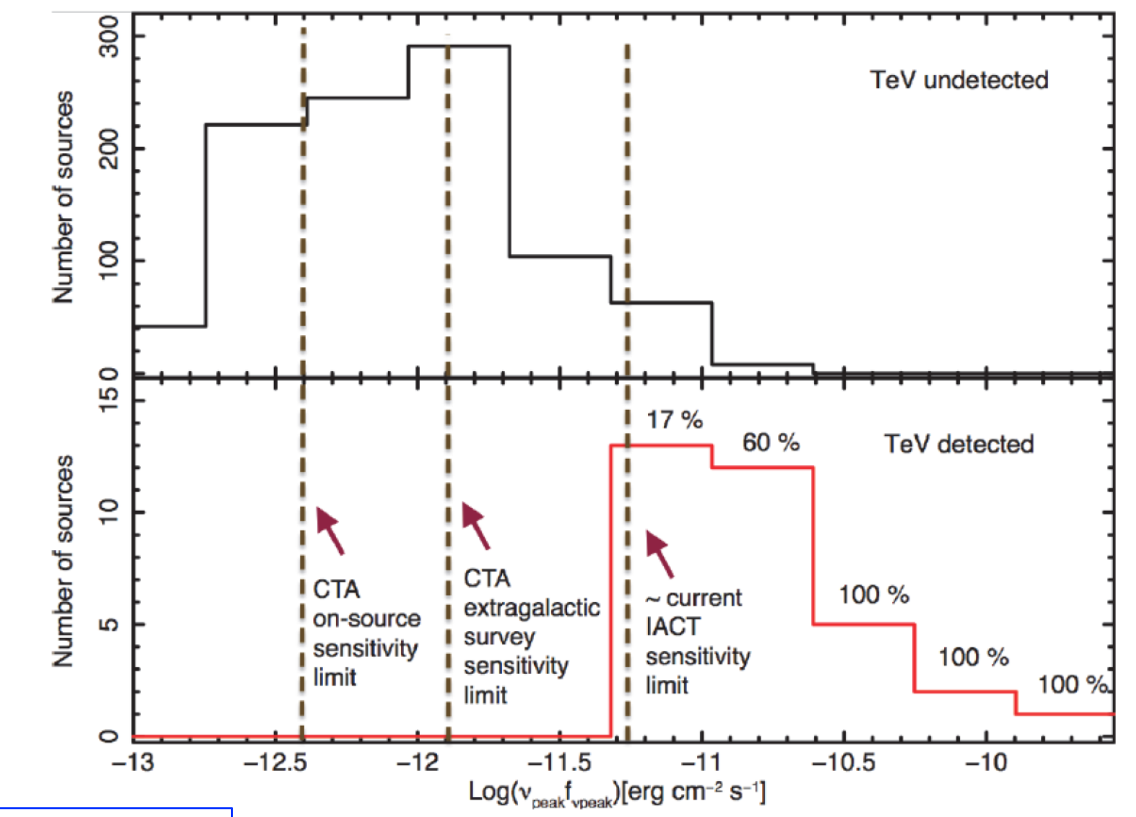
CTA's Prospects for AGN

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

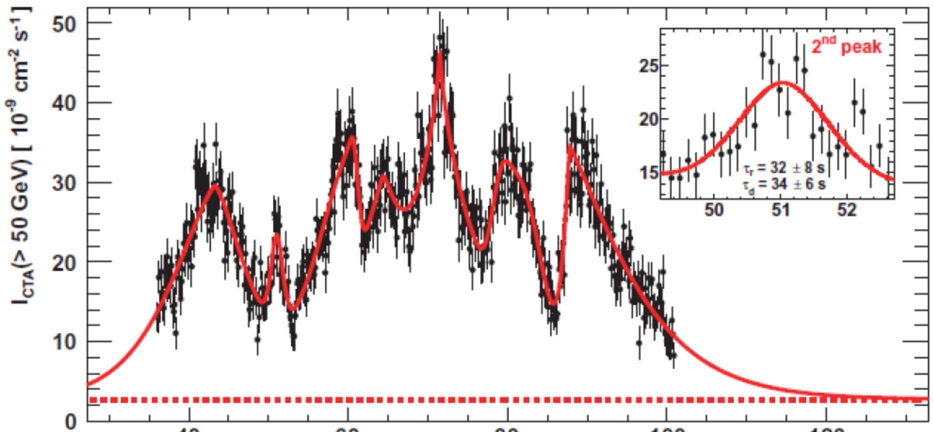
FoV up to 10 degrees → several AGN in FoV at same time.

Light curve details down to sub-minutes.

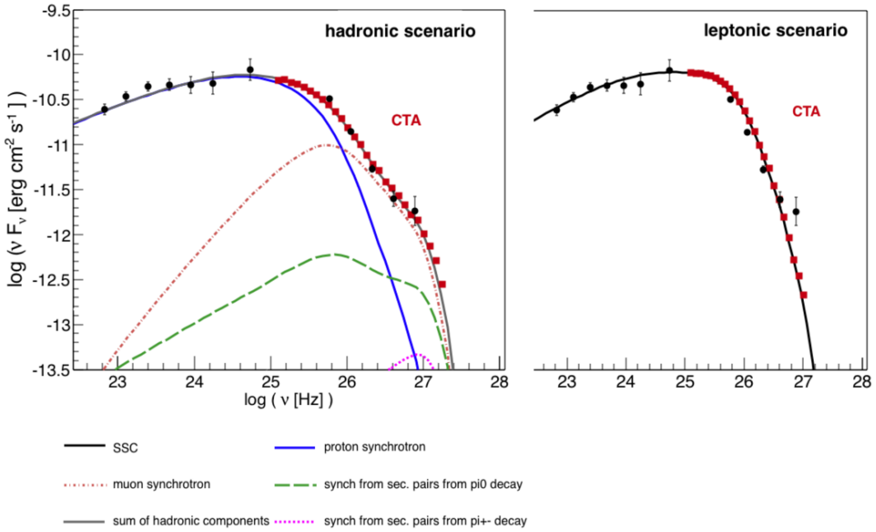
Spectral resolution to reveal sub-components:
- Hadronic (synchrotron from protons, muons, + secondaries)
- Leptonic (SSC)



G. Rowell – COSPAR 2020



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



Extragalactic SWG

Four task forces

- AGN variability: consortium paper in prep
  The **goal** is to test the CTA's potential to discriminate between different particle acceleration and emission scenarios
  - Theoretical models
  - AGN long-term monitoring
  - How many flares CTA will see?
  - MWL support data
- AGN Population: consortium paper in prep
  The **goal** is to quantify CTA’s ability to conduct source population studies of gamma-ray emitting, jetted AGNs

Extragalactic SWG

- Gamma-ray propagation: consortium paper published

Journal of Cosmology and Astroparticle Physics

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

H. Abdalla[1], H. Abe[2], F. Acero[3], A. Acharyya[4], R. Adam[5], I. Agudo[6], A. Aguirre-Santaella[7], R. Alfaro[8], J. Alfaro[9], C. Alispach[10] + Show full author list

Published 23 February 2021 • © 2021 IOP Publishing Ltd and Sissa Medialab

Journal of Cosmology and Astroparticle Physics, Volume 2021, February 2021

Citation H. Abdalla *et al* JCAP02(2021)048

DOI 10.1088/1475-7516/2021/02/048

- AGN Redshift determination:
  2 non-consortium papers (spectroscopy, imaging)
  The **goal** is to measure the redshift of blazars taking advantage of large and small worldwide facilities
  - Preparing a database

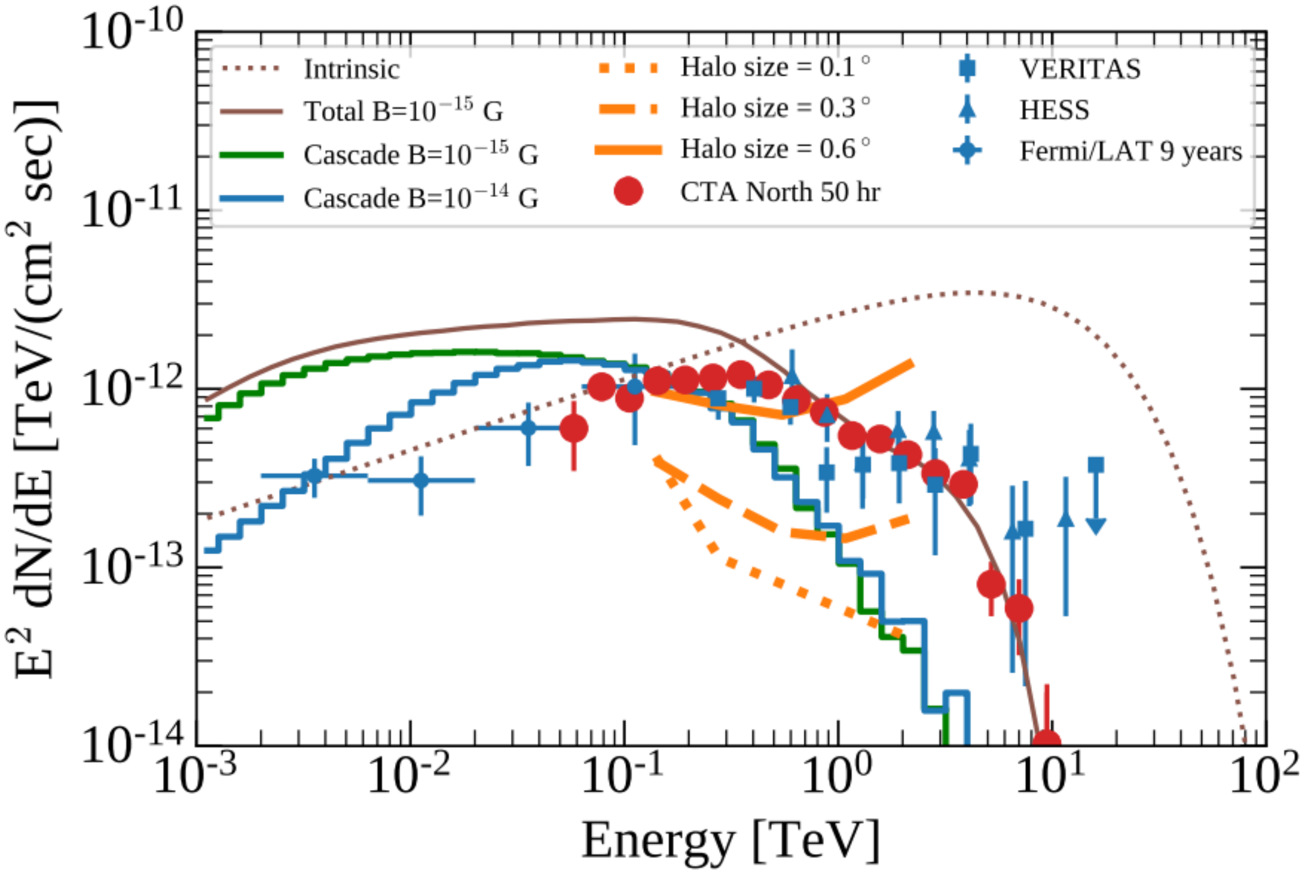
Cosmology and Fundamental Physics

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

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



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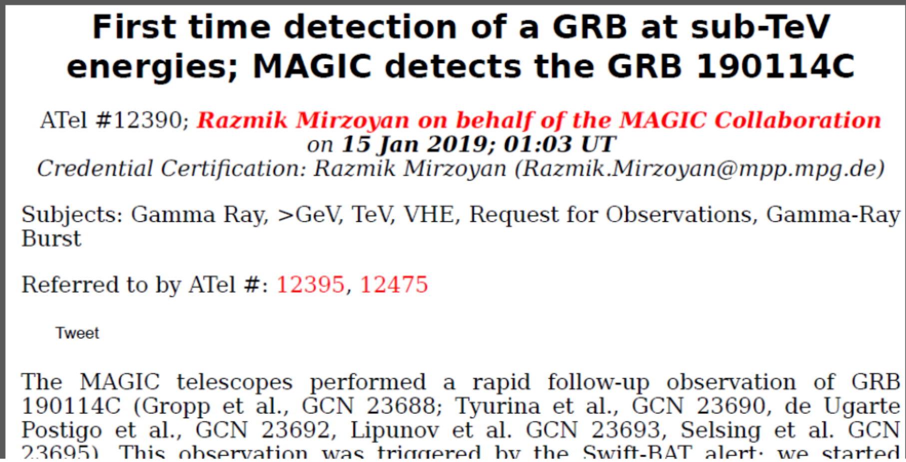
The new window of VHE Gamma-ray Bursts



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

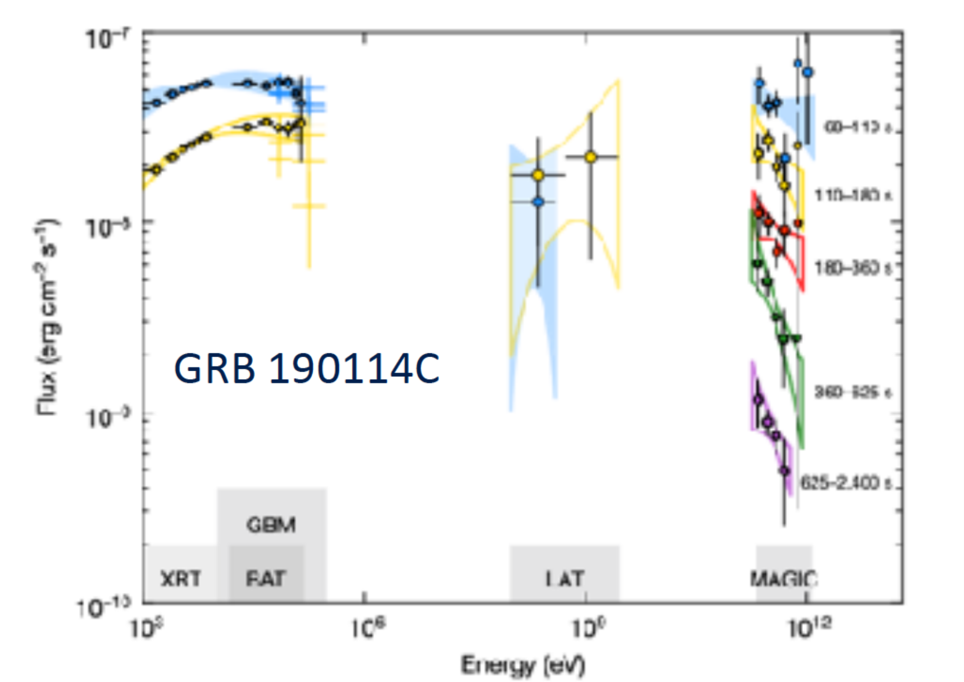
ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
on ***15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

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)

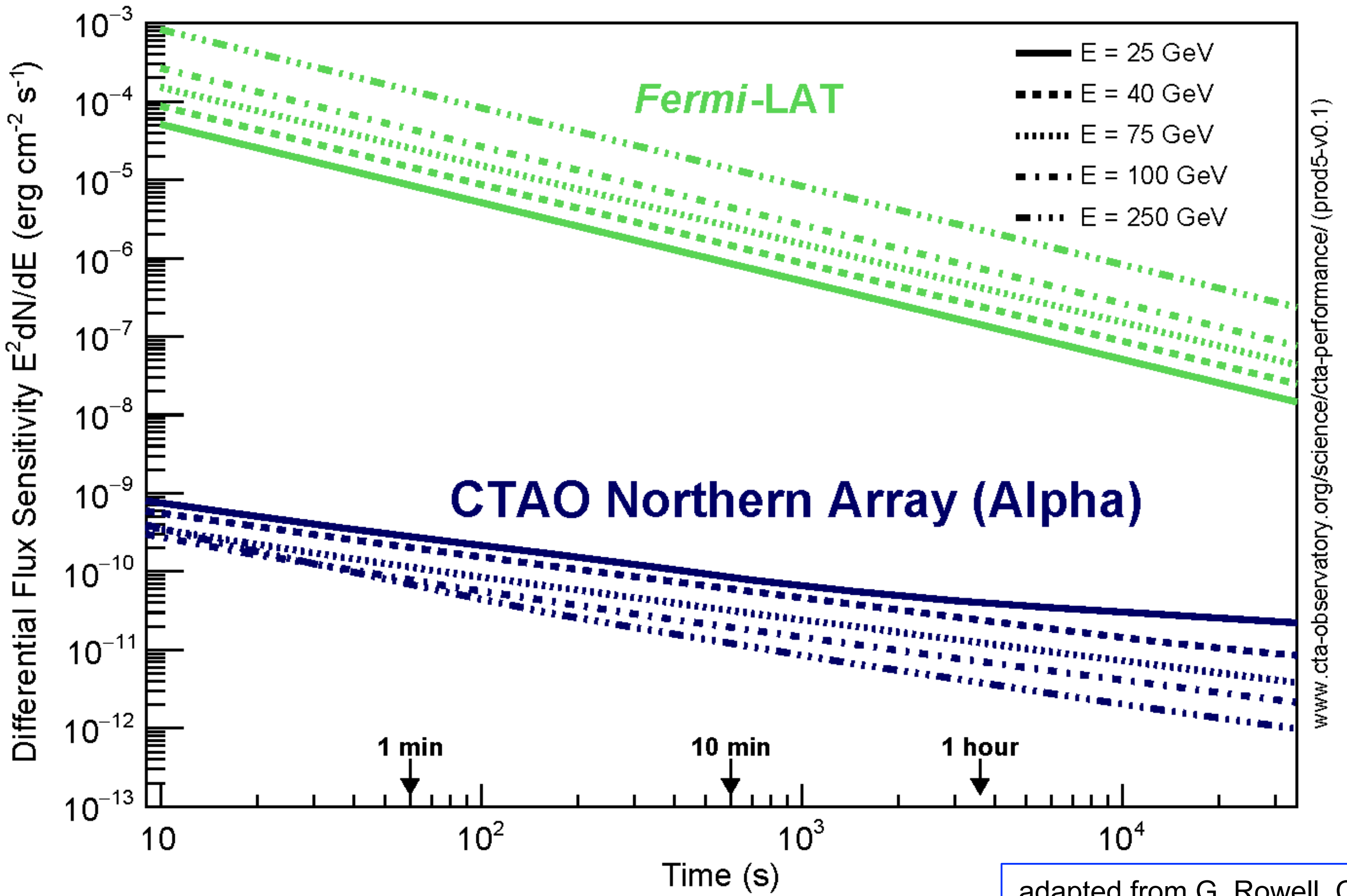
+ GRB 201216C (z = 1.1)

Strong MWL and MM synergies for spectral and variability studies

U.Barres – COSPAR 2020

Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)



adapted from G. Rowell COSPAR2020

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

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

Transients CP

Coordinators: Thierry Stolarczyk and Elisabetta Bissaldi

Neutrino paper:
• under SWG review, implementing comments

Galactic transients:
• draft under final revision by authors, to be circulated in the SWG soon

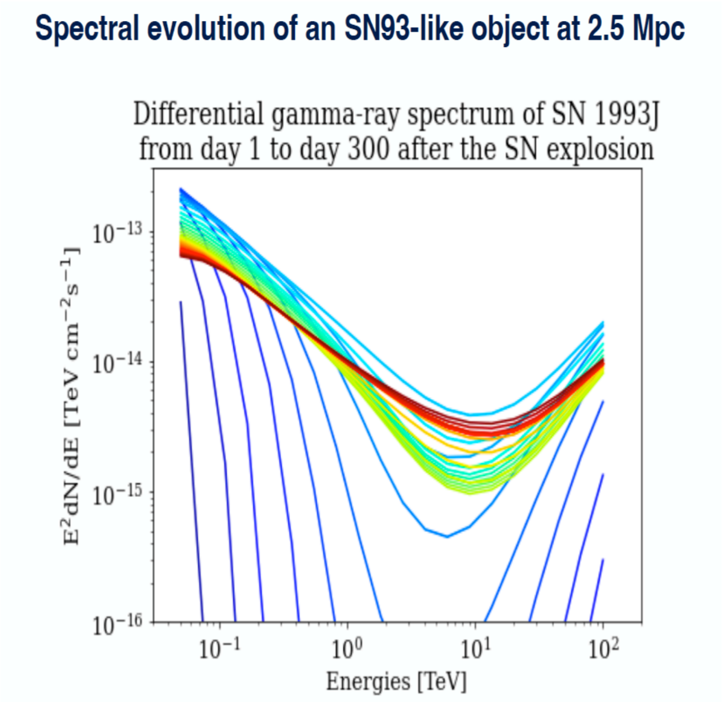
GRB
• paper to be drafted soon with preliminary results – large simulation starting

GW
• results almost final + cross check on few events

CCSNe (TRANS+CRs)
• Discussions on-going with CRs SWG

Transients – CCSNe

Coordinators: Thierry Stolarczyk and Elisabetta Bissaldi



P.Cristofari and F.Acero

- An **SN93J-like @ 2 Mpc** SN can be detected in the first weeks after the explosion both with CTA-N & CTA-S.
- However deep exposures (50 h over ~2 weeks) are needed.
- For this specific case best observation window is : 5-20 days

- **Type IIn : monsters like SN201jl (~1-2 evt/year R< 200 Mpc)**
  - High kinetic energy & velocity but high absorption
  - At 50 Mpc (1 evt/decade ?) : > 10σ every night for 6 months

- **Complex** modeling depending on system geometry, progenitor, photosphere T° time evolution, etc
- Lowest energies < 100 GeV seem to be key in detection

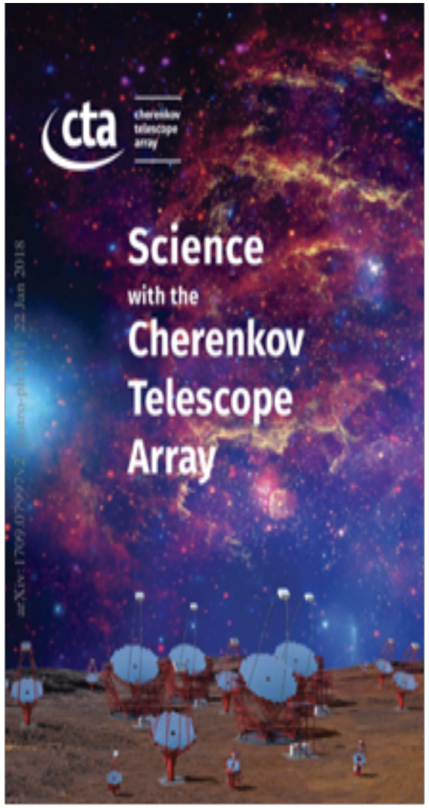
- CTA-North/South complementarity for follow-up at early/late times

Updates on Scientific Cases

- Critical check of assumptions on Science topics
  - Check with updated physics cases
  - Check with alpha configuration characteristics
  - Consider also Beta configuration → Omega

- Planned strategies:
  - Creation of task forces inside each SWG:
    - Contact people involved in the "Science with CTA"
    - Those currently working on the topic
  - Dedicated calls to review & update topics

- Discussion in SWGs on-going
  - Goal: Update scientific cases by fall General Meeting
  - Preparation of an internal document



CTA Consortium, 2018
arXiv:1709.07997

Updates on Scientific Cases - Transients

Some topics for the future studies

- Arrays
  - Address the various increments (Alpha, Beta, and +SCT)
  - Usage of sub-arrays; Divergent pointing (Serendipitous sources)
- First data – which (early) Science can enter KSPs ?
- Sinergy/complementarity with HAWC and LHASSO (+IACTs)
- External alerts
  - Triggers from Swift/GBM/SVOM and later (Theseus)
  - What can be expected from LIGO/VIRGO O4 (Should start soon ? link)
- High luminosity events : Real-time analysis – High frequency time analysis (variabilty)
- Other WG
  - Moonlight versus SII: conflicts?
  - DMEP: Cosmic voids (EBL, IGMF) and Cosmology (high z values)
  - GAL / EGAL transients
- Note: The Consortium science return is not only KSPs : We should be prepared to Open Time observations

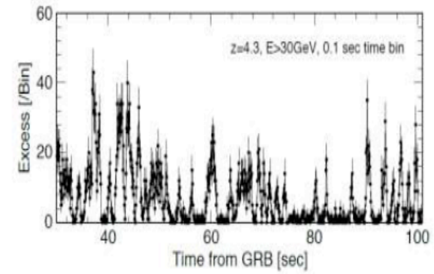
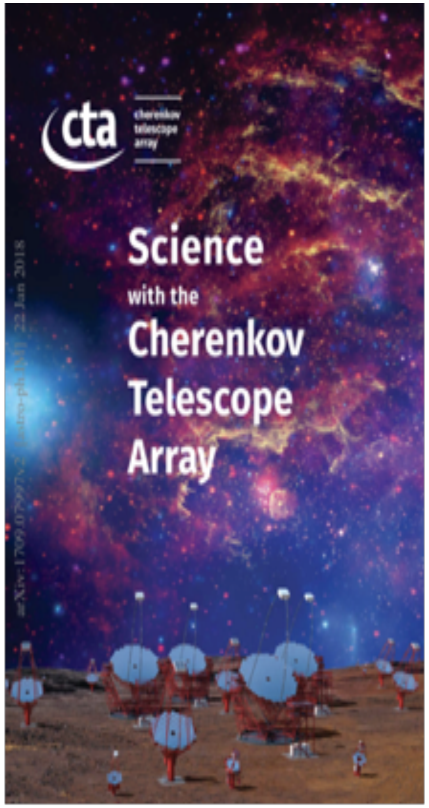


Figure 1.5 – Simulated CTA gamma-ray burst light curve, based on the Fermi-LAT-detected GRB 080916C at $z = 4.3$. See Figure 9.1 for more details.

Thierry Stolarczyk



CTA Consortium, 2018
arXiv:1709.07997

Updates on Scientific Cases - EGAL

Science perspectives: discussion

Contents

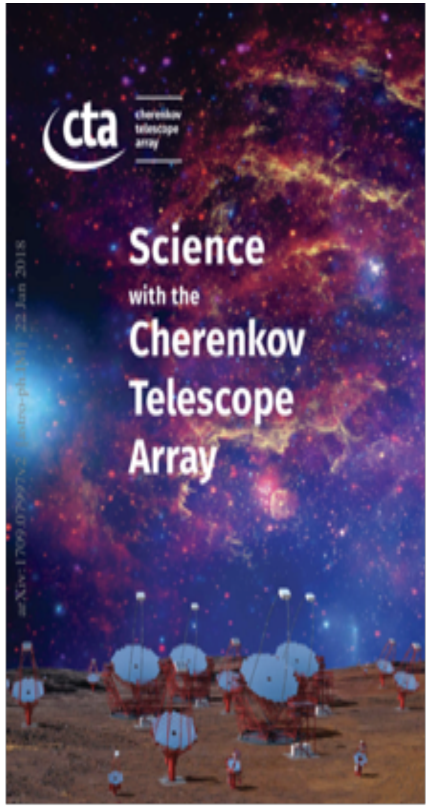
Chapters and corresponding authors:

Time has passed since the Science with CTA book.

We have been asked by the Science coordinators to start a discussion on the science perspectives with the goal of making an updated statement about science prospectives for CTA compared to what is in the CTA science book.

To be considered:

- Alpha configuration
- New information since the publication of the science book (e.g. new *Fermi* catalogs, enw detections…)
  - Comments in today's TF reports
  - Discussion in the Science session at 6 PM
  - Dedicated EGAL call



CTA Consortium, 2018
arXiv:1709.07997

Elisa Prandini & Elisa Pueschel

Updates on Scientific Cases - GAL/CR

Science with CTA

Joint CR/GAL/DMEP

Joint CR/GAL

CR/DMEP

3

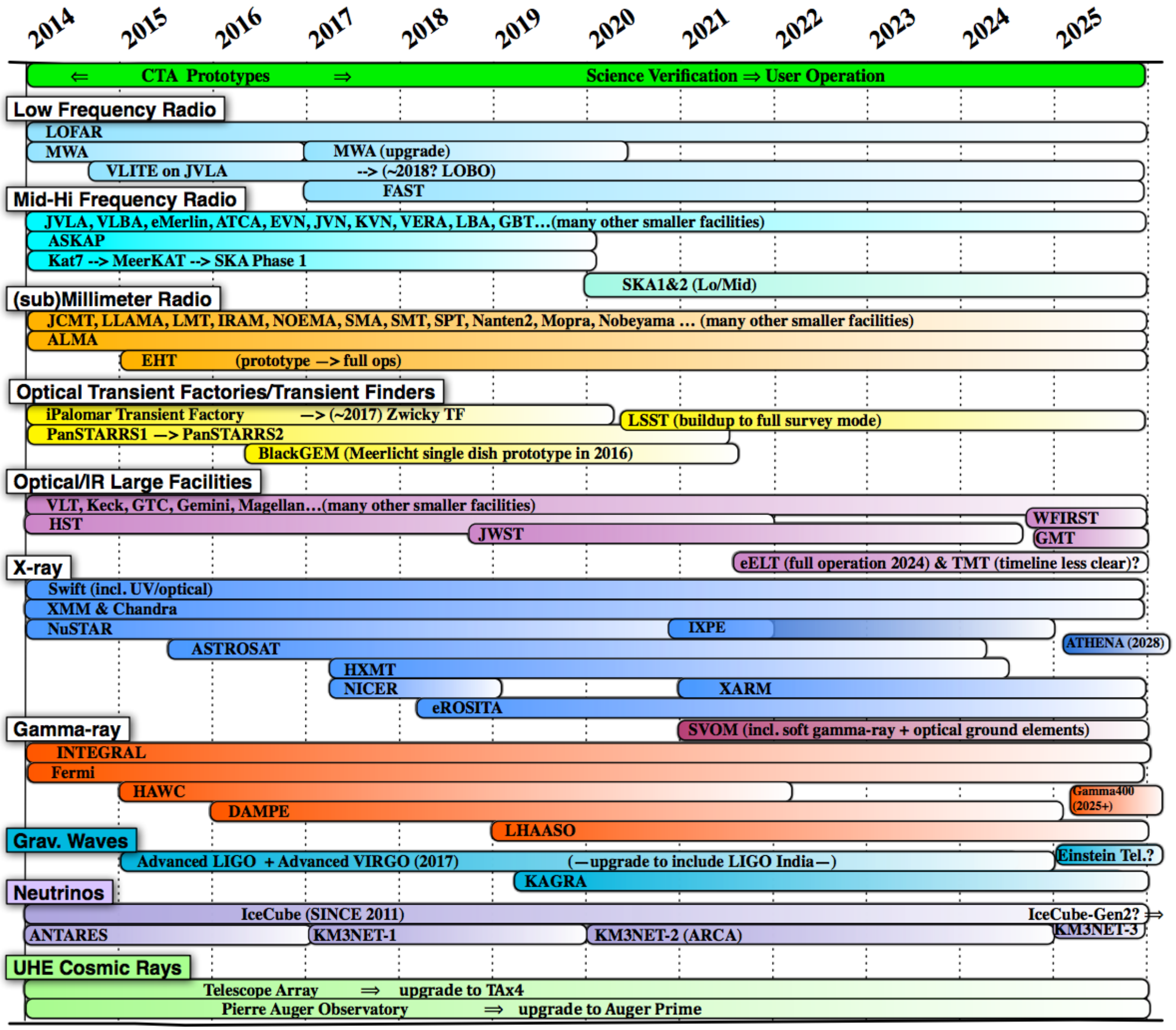
- Shown examples: GC, GPS, PeVatrons...
- Contacted some people involved in Science with CTA
- Dedicated meetings for each KSP

Heide Costantini and Quentin Remy
Kathrin Egberts and Pierre Cristofari

Updates on Scientific Cases - DMEP

- Updated Science cases: Consortium publications submitted/ under SAPO review & many non-consortium publications
- Starting point for document

MWL synergies (~2017)



Conclusions

- CTA will open a new era in VHE astrophysics
  - A rich science program to answer key scientific questions
  - A VHE observatory !
- Clear MM and MWL synergies
  - Fermi is crucial !