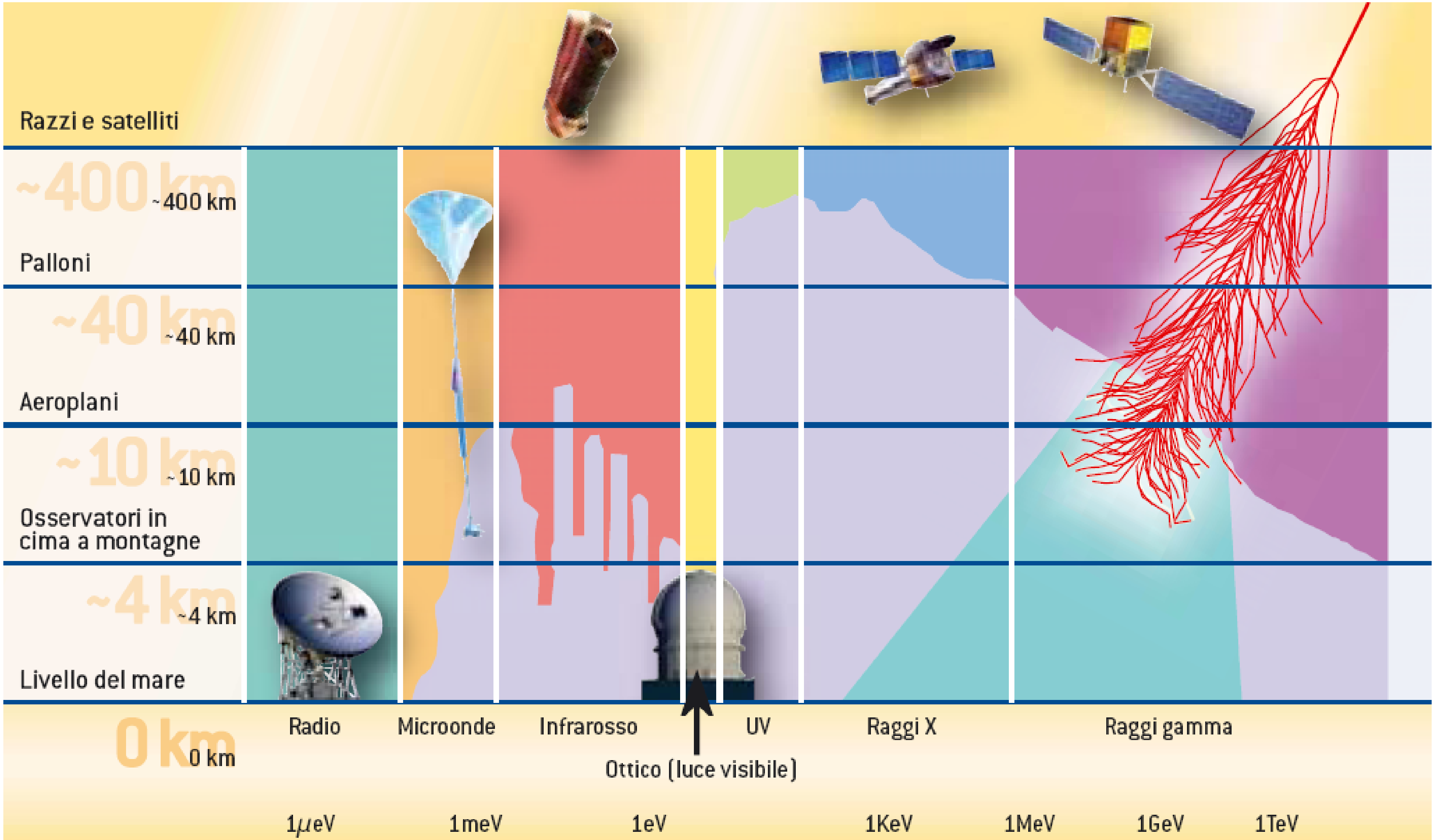
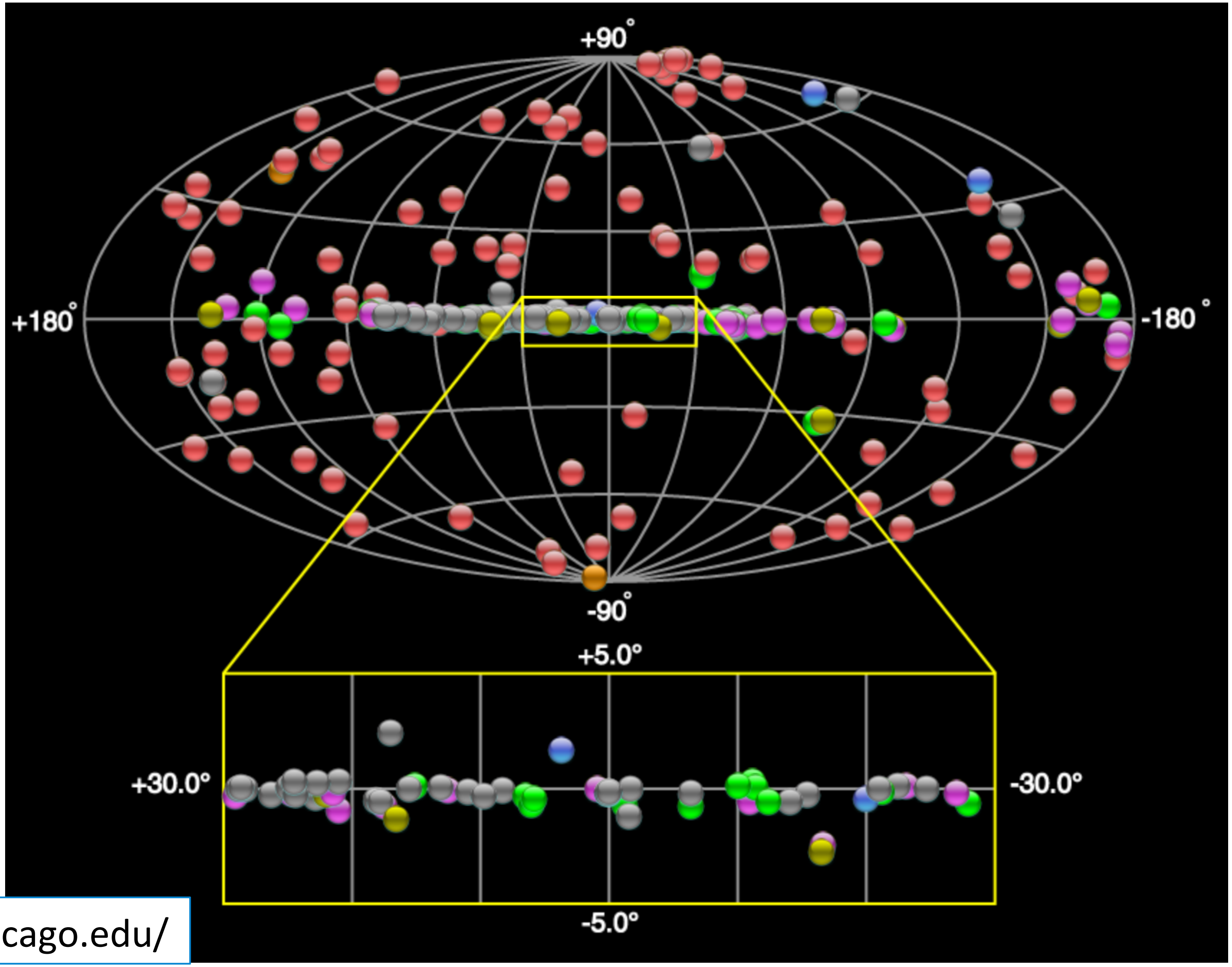
Astrofisica Nucleare e Subnucleare

TeV Astrophysics II

The opacity of the atmosphere



The TeV Catalog 2021

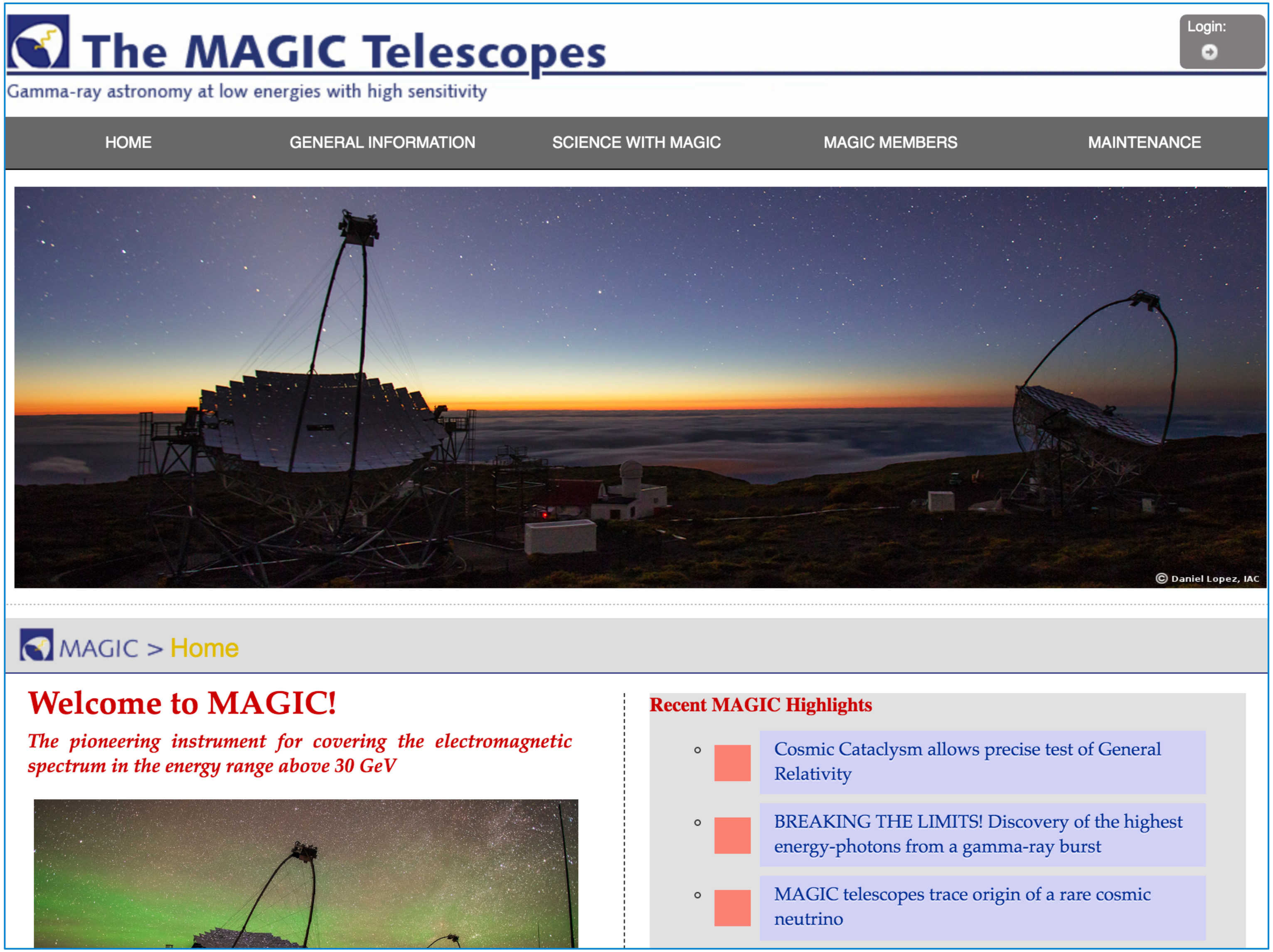


http://tevcat.uchicago.edu/

Exercise #5

- Find the information about the 3 major currently operating IACT telescopes
- Find information on the “HESS” source of the month
- Visit the web site of CTA

MAGIC



https://magic.mpp.mpg.de/

VERITAS

Search ...

VERITAS

Very Energetic Radiation Imaging Telescope Array System

Home | Contact | News (most recent: 2021-Feb-02) | Whipple | Internal

Home

Welcome to VERITAS

Published: 01 January 2004

Quick link to our results pages (one page per paper, with descriptive text and all figures).

VERITAS (Very Energetic Radiation Imaging Telescope Array System) is a ground-based gamma-ray instrument operating at the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona, USA. It is an array of four 12m optical reflectors for gamma-ray astronomy in the GeV - TeV energy range. These imaging Cherenkov telescopes are deployed such that they have the highest sensitivity in the VHE energy band (50 GeV - 50 TeV), with maximum sensitivity from 100 GeV to 10 TeV. This VHE observatory effectively complements the NASA Fermi mission.

Main Menu

- Home
- About VERITAS
  - Atmospheric Cherenkov Technique and VERITAS
  - Technologies
  - VERITAS Specifications
  - People
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  - VERITAS Governance
  - History & Timeline
  - Funding
  - Schedule
- The Science of VERITAS
  - Introduction to VHE Gamma-Ray Astrophysics
  - VERITAS Results
  - VERITAS Blazar Spectral Information & Light Curves
  - VERITAS Blazar Long-term Monitoring
  - Mrk 421 Long-term Light Curve
  - Publications
    - Theses & dissertations
- Visiting VERITAS
  - Directions & Maps
  - FLWO Visitor's Information
  - Information for Mountain Users
  - Current Weather

https://veritas.sao.arizona.edu/

HESS

https://www.mpi-hd.mpg.de/hfm/HESS/

HESS source of the month

Home | About H.E.S.S. | Collaboration | Publications | Contact | Internal

H.E.S.S. Source of the Month

Each month a TeV gamma ray source investigated with the H.E.S.S. telescopes is featured. See also the pages on Astrophysics with H.E.S.S.: The Nonthermal Universe with an overview of the physics and the source types. Details about the H.E.S.S. telescopes can be found here.

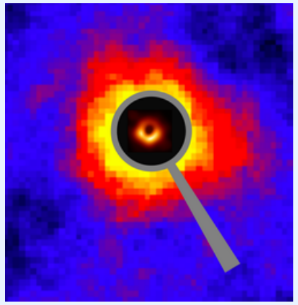
2021

- May 2021: A large armada targets famous M87
- April 2021: Mini Black Holes in the Atmosphere?
- March 2021: 30 Doradus C - The high-energy supershell
- February 2021: Striking a jet - and pinpointing the flame
- January 2021: Dark matter search in the dwarf Irregular dalaxy "WLM"

2020

- December 2020: The bright extreme BL Lac object HESS J1958-301
- November 2020: The black hole in the Galactic Centre
- October 2020: A new camera on the large telescope of H.E.S.S.
- September 2020: 20th anniversary of H.E.S.S. groundbreaking

Source of the Month



May 2021 - A large armada targets famous M87

More Info | All Sources

Options for External Proposals for H.E.S.S. Observations

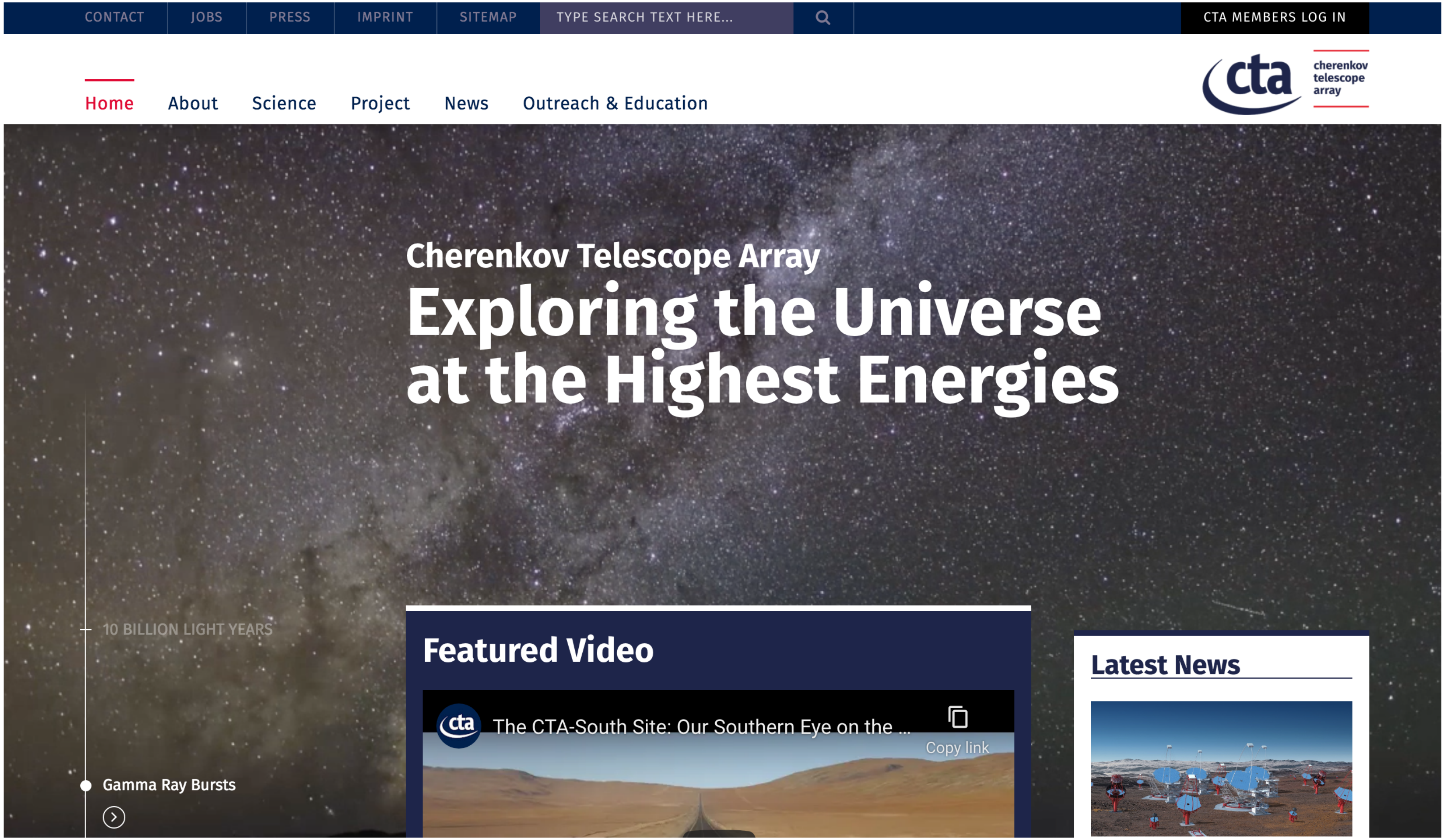
Requests for Follow-up Observations of TOOs

The HESS Source Catalog

The HESS First Public Test Data Release

https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/

CTA

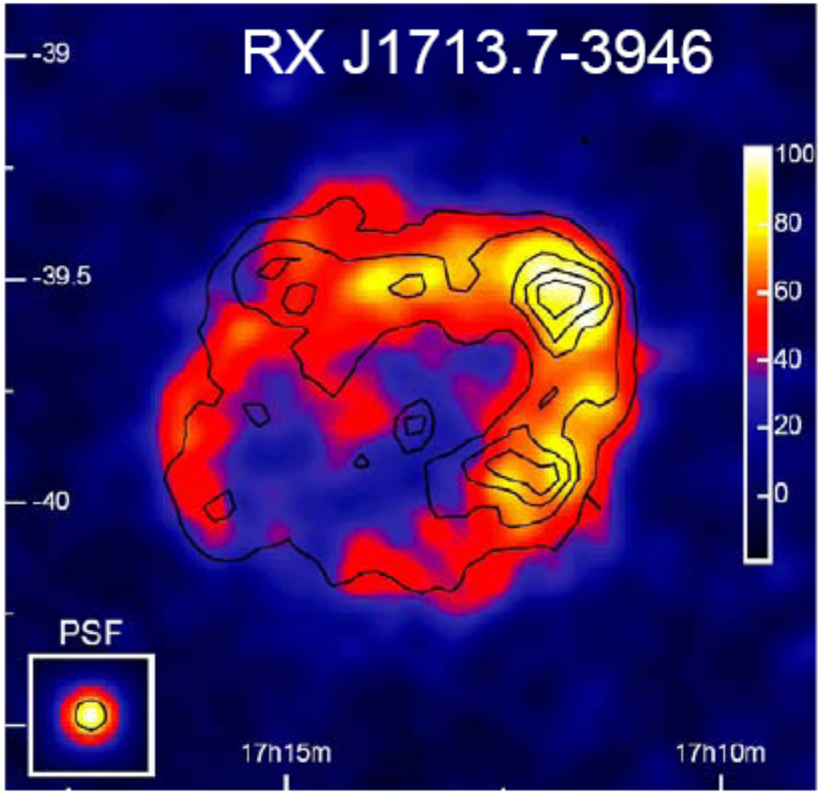


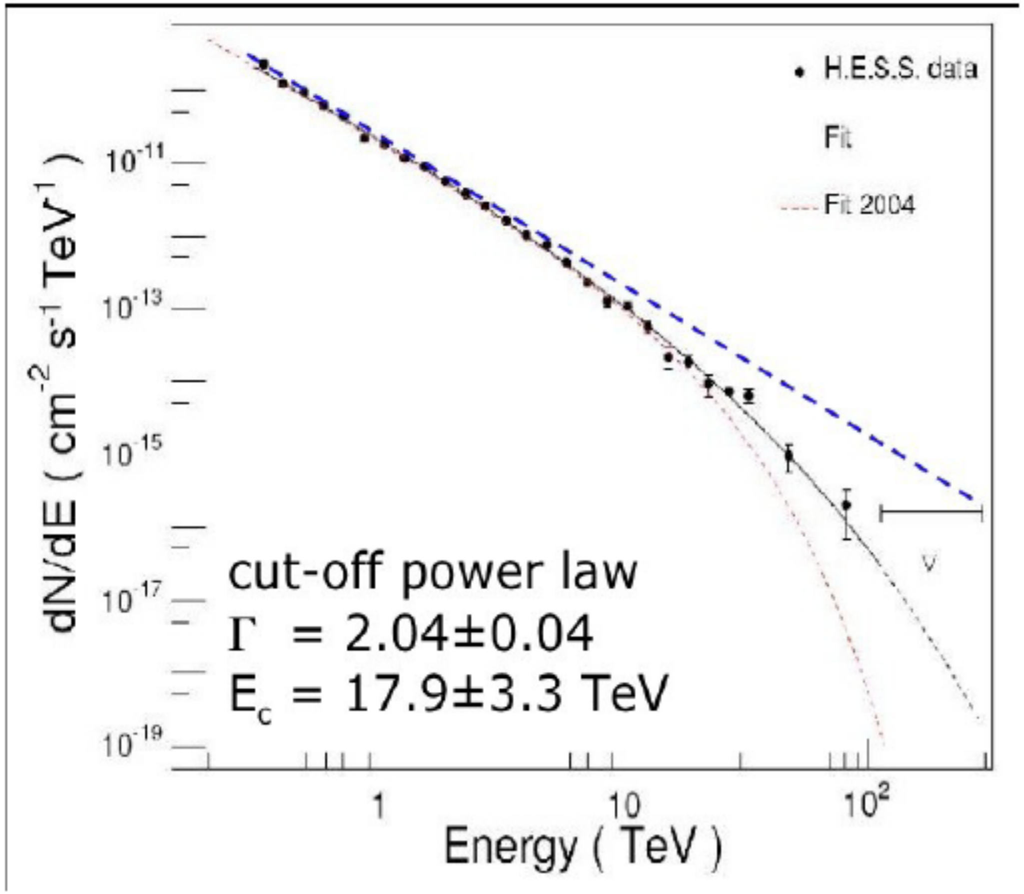
https://www.cta-observatory.org/

Astrofisica Nucleare e Subnucleare

VHE Galactic Sources

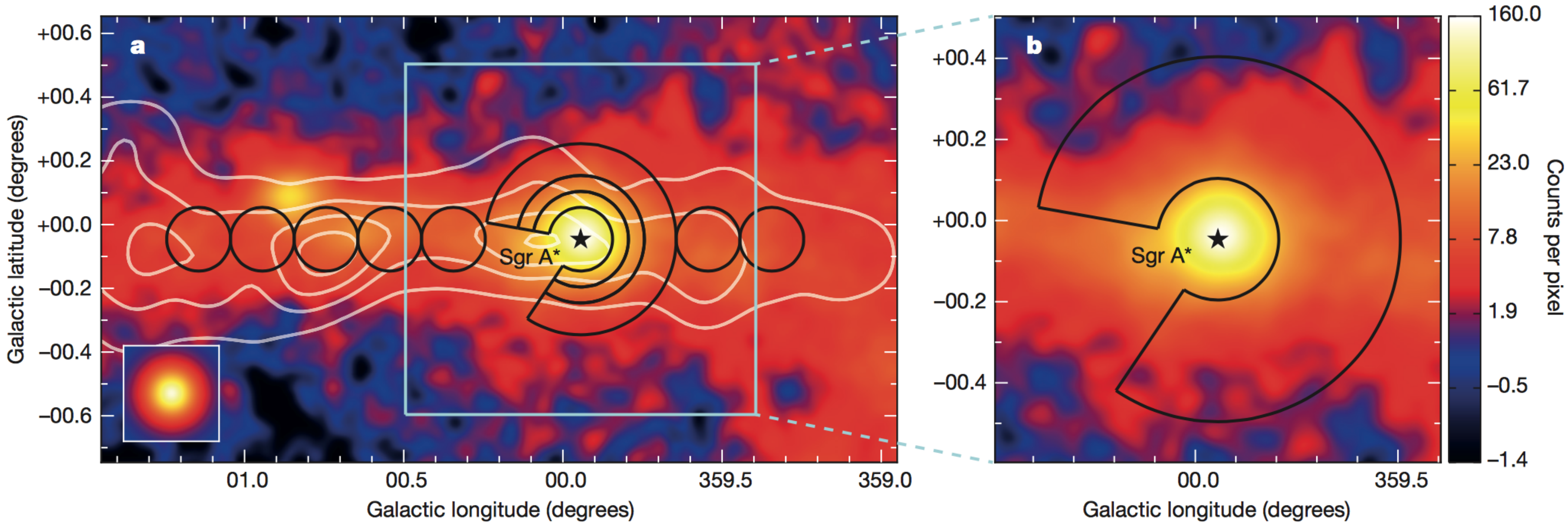
HESS – SNR in VHE gamma





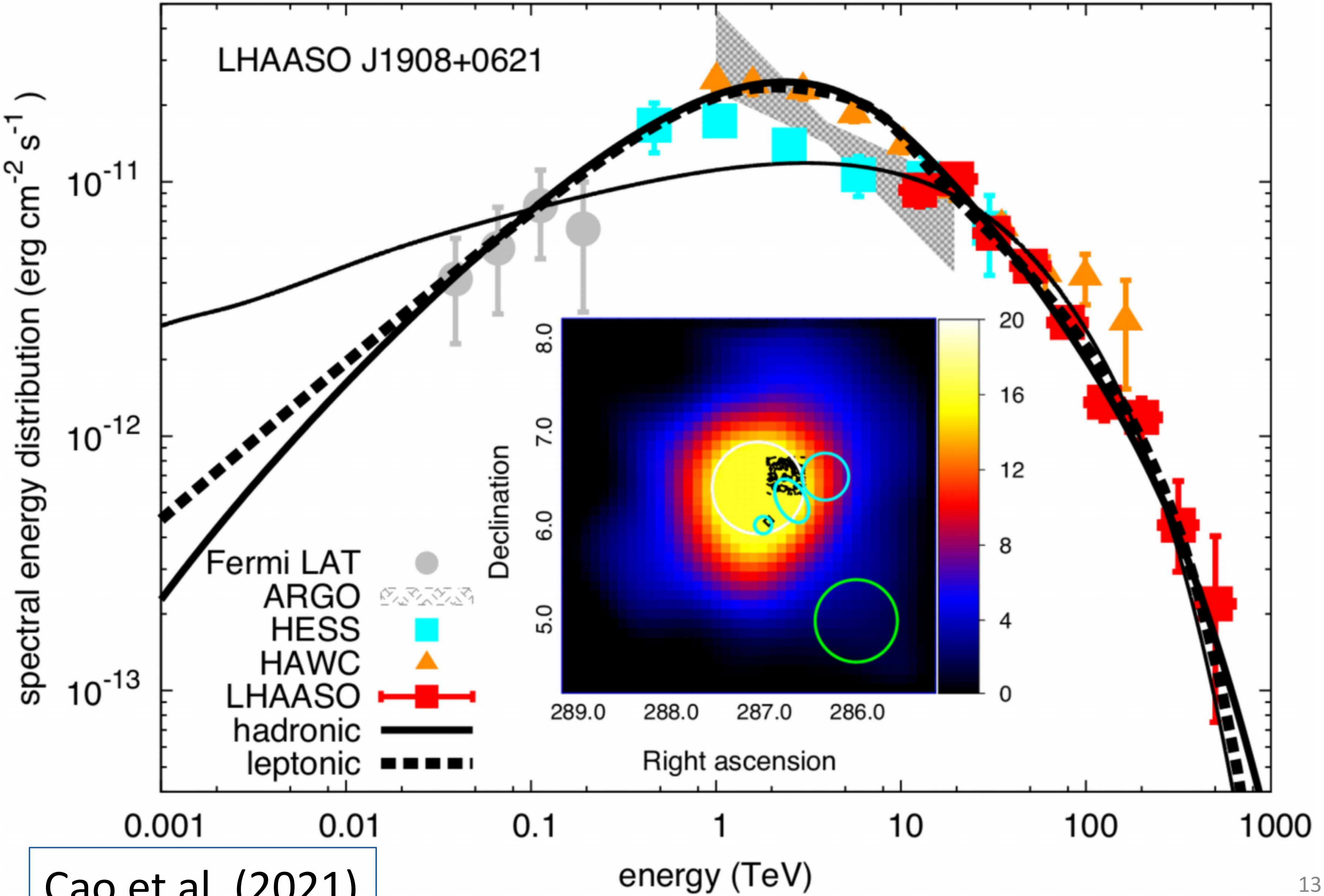
Aharonian et al. 2004

The "Pevatron"



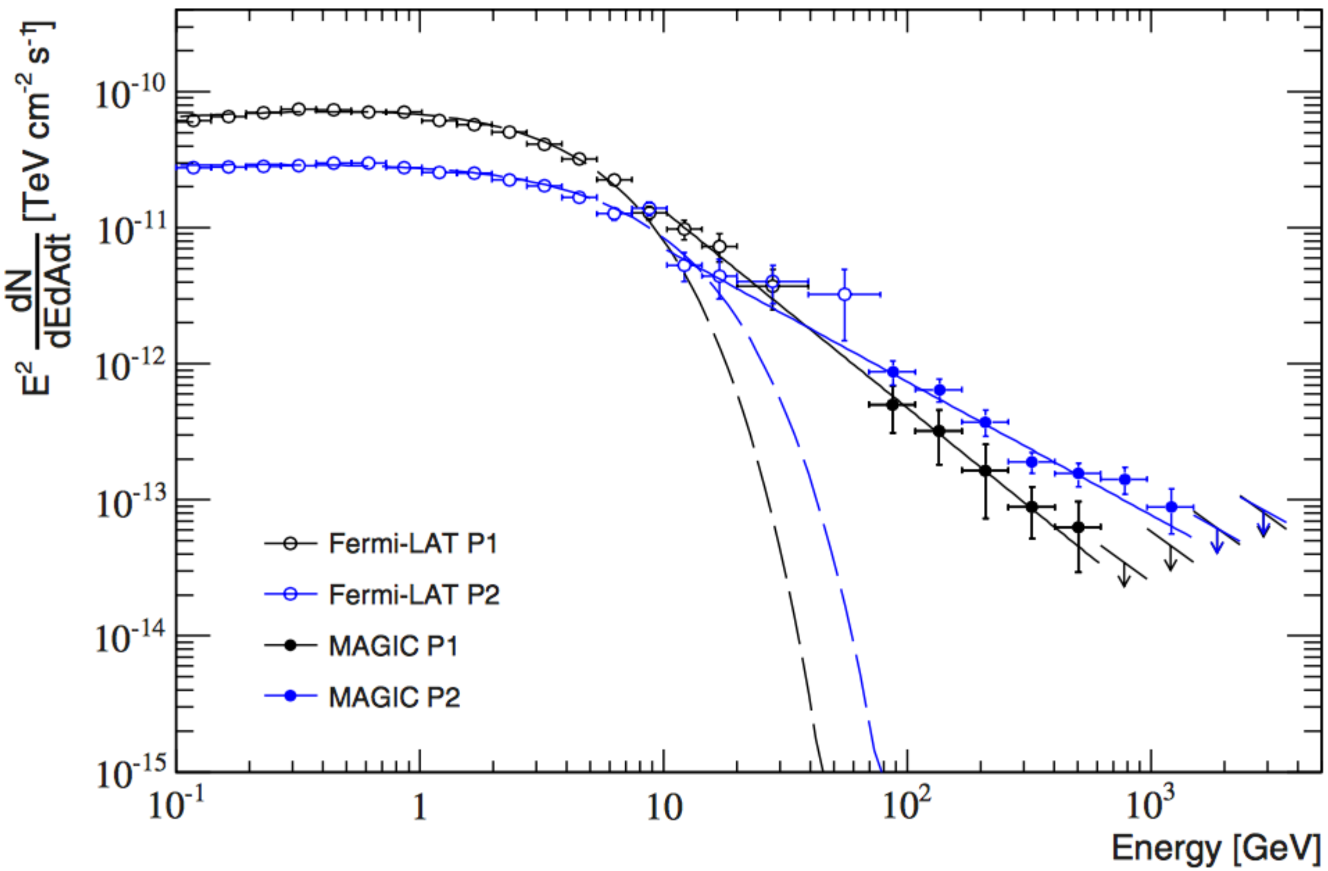
Abramovski et al. (2016)

LHAASO Pevatrons



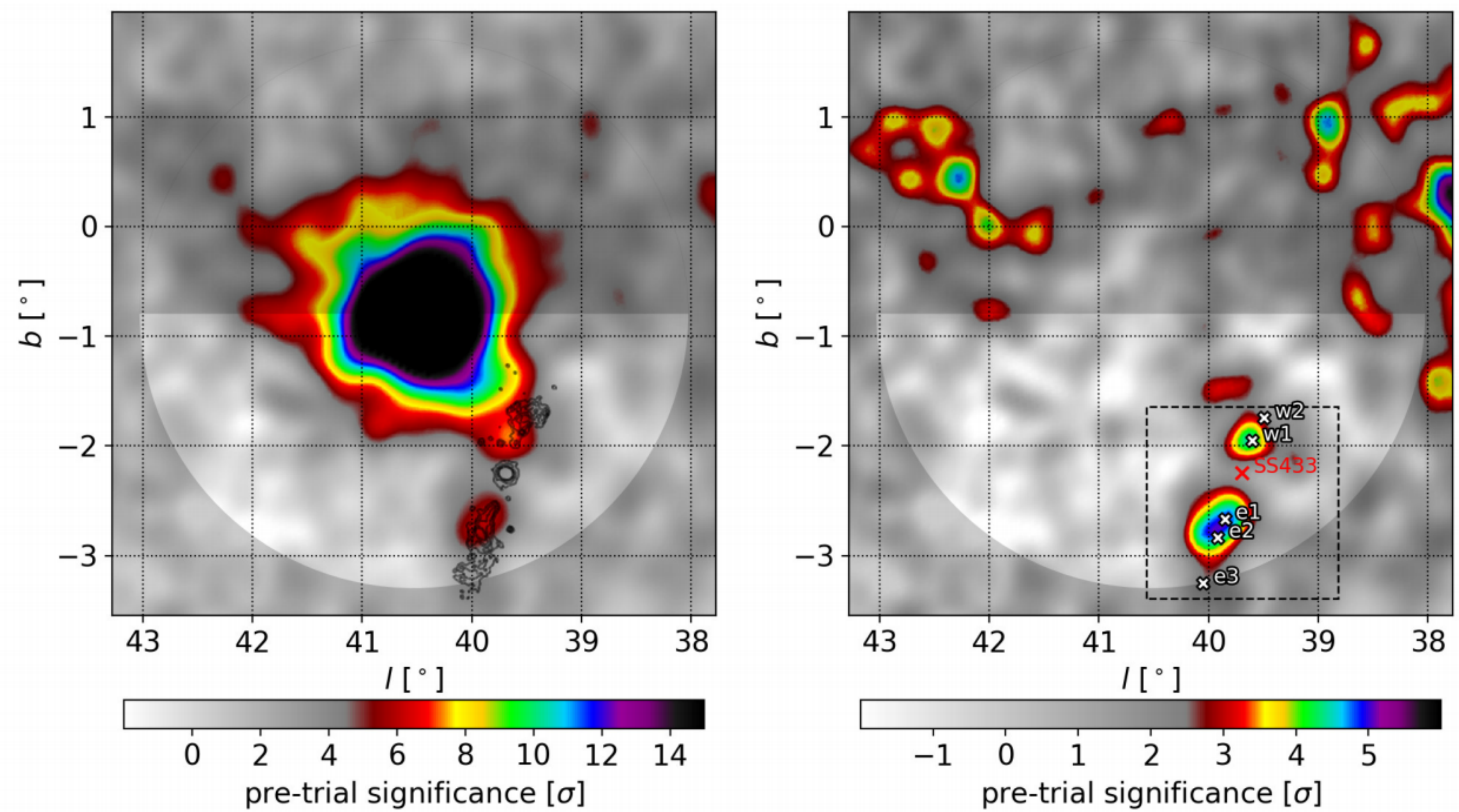
Cao et al. (2021)

Crab PSR



Ansoldi et al. (2016)

SS433 HAWC



b [°]
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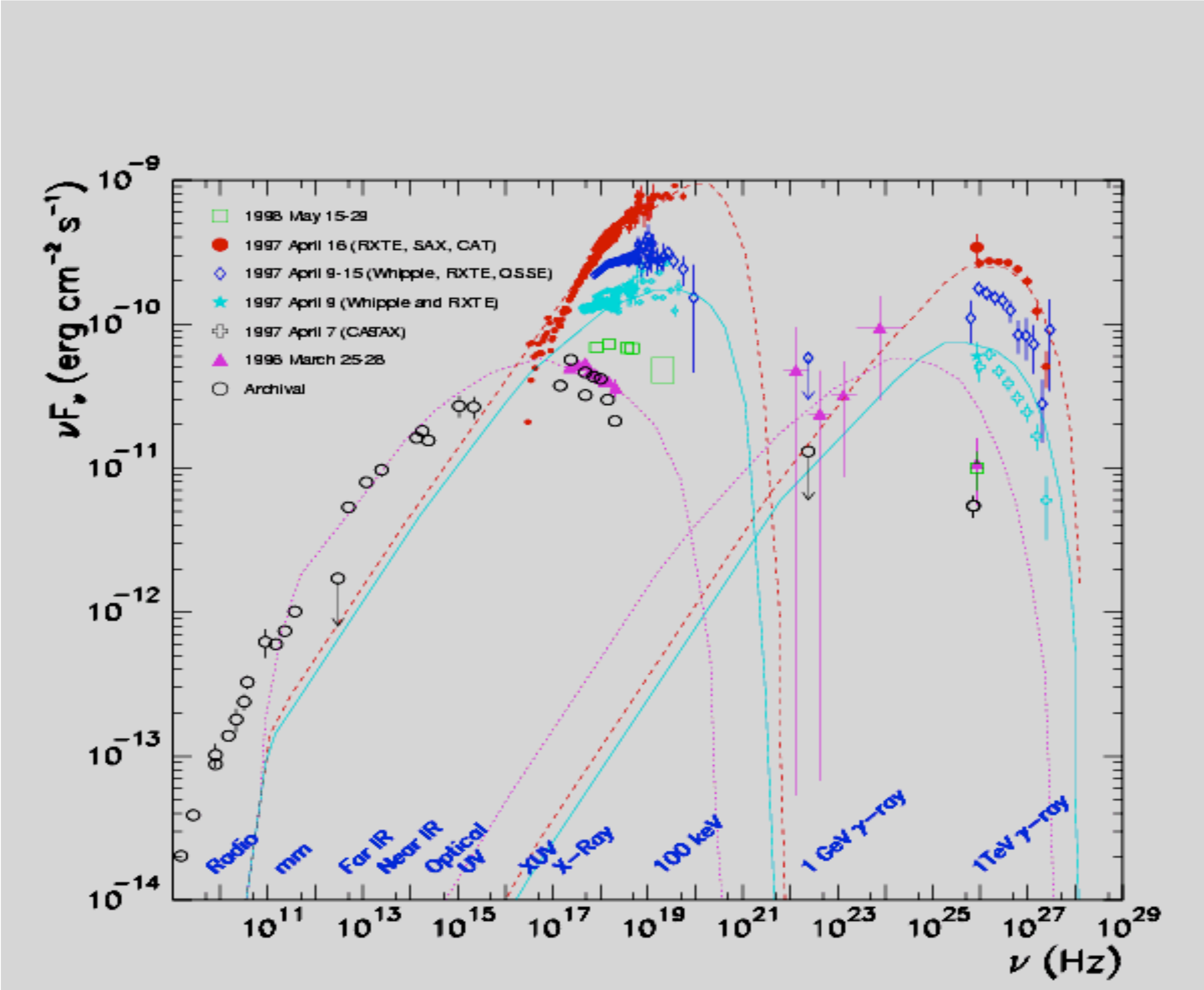
12
14
pre-trial significance [σ]
w2
w1
SS433
e1
e2
e3
−1
0
1
2
3
4
5
pre-trial significance [σ]

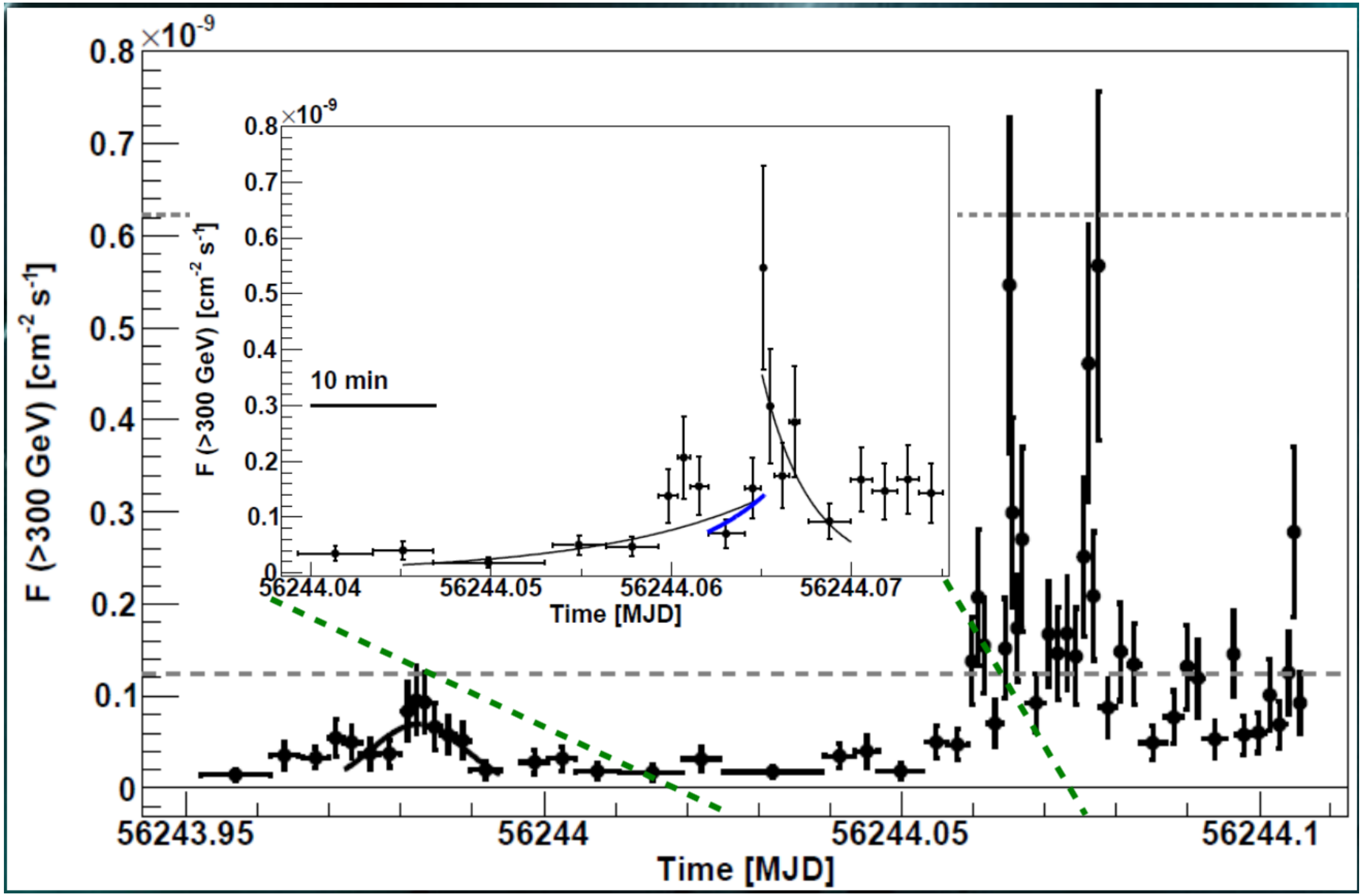
Astrofisica Nucleare e Subnucleare

VHE Extra Galactic Sources

Active Galactic Nuclei

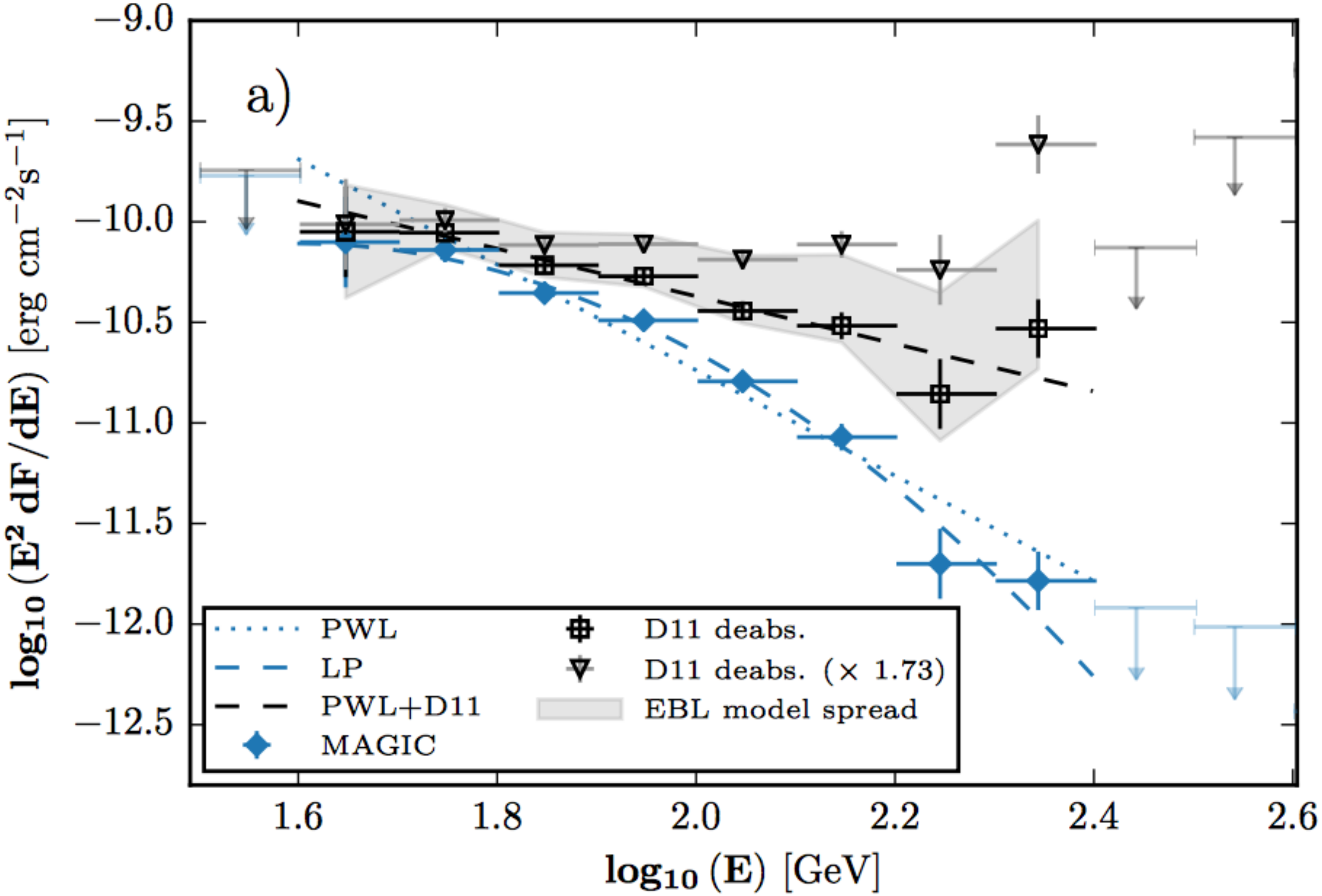


IC310



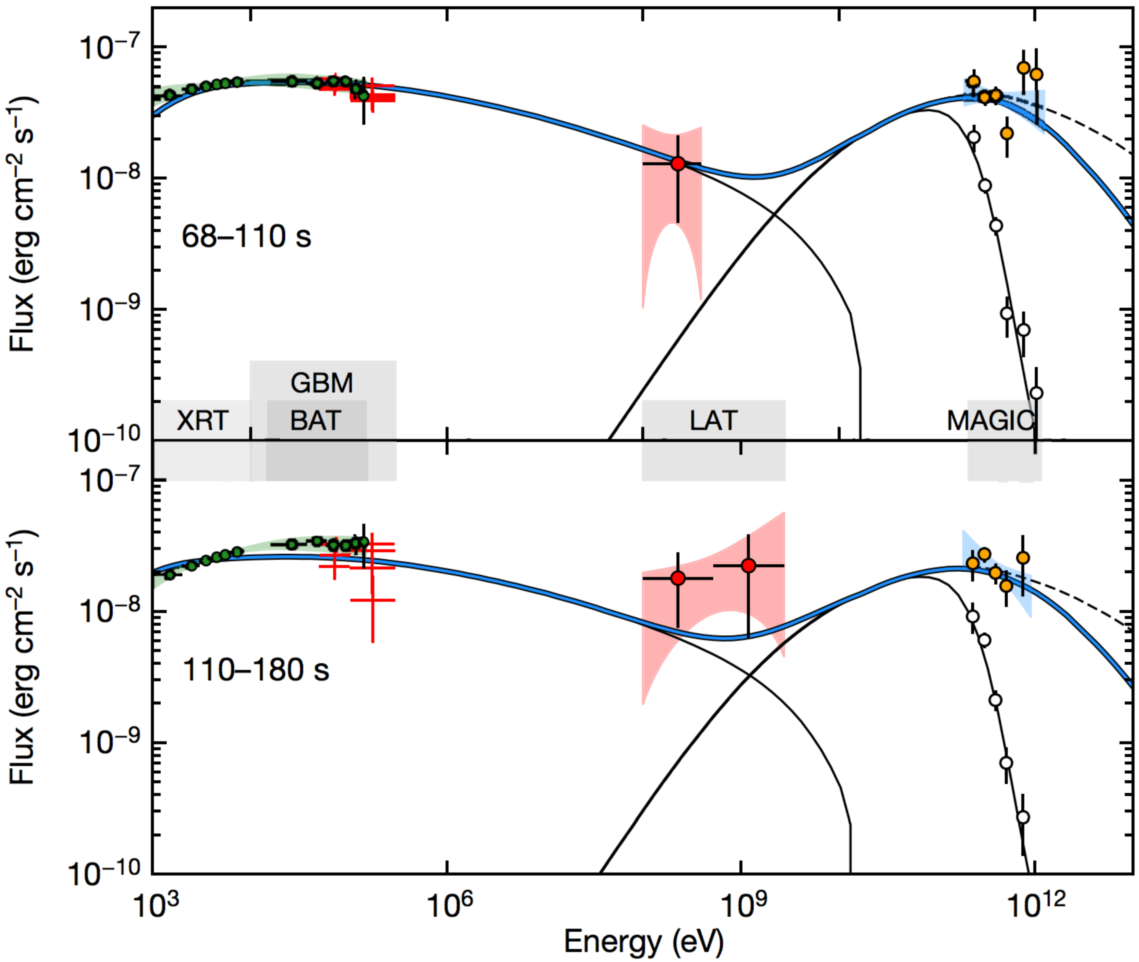
Aleksic et al 2015

PKS 1441+25
z=0.9397



Ahnen et al 2016

MAGIC detection



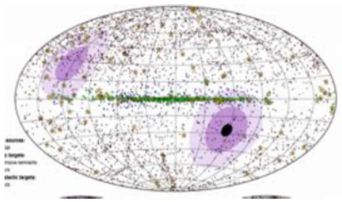
GRB 190114C

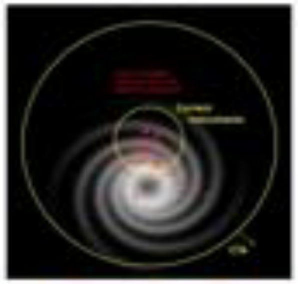
Acciari et al. 2019b

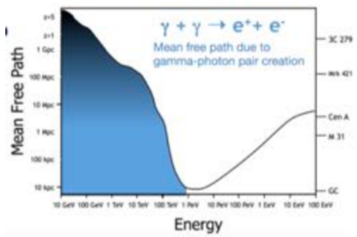
Astrofisica Nucleare e Subnucleare

Future detectors

Design drivers

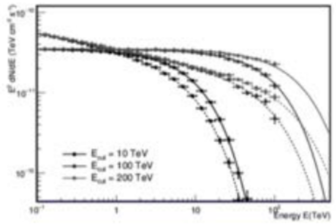






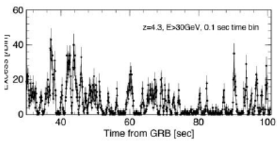
Full sky coverage

10 x sensitivity



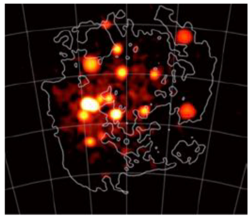
Energies down to 20 GeV

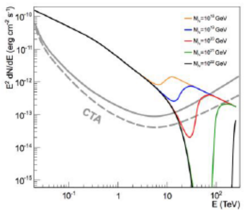
Energies up to 300 TeV



Rapid slewing 20 sec

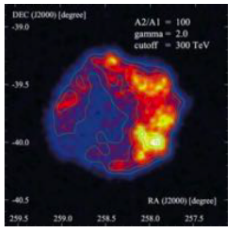
~ 10° FoV





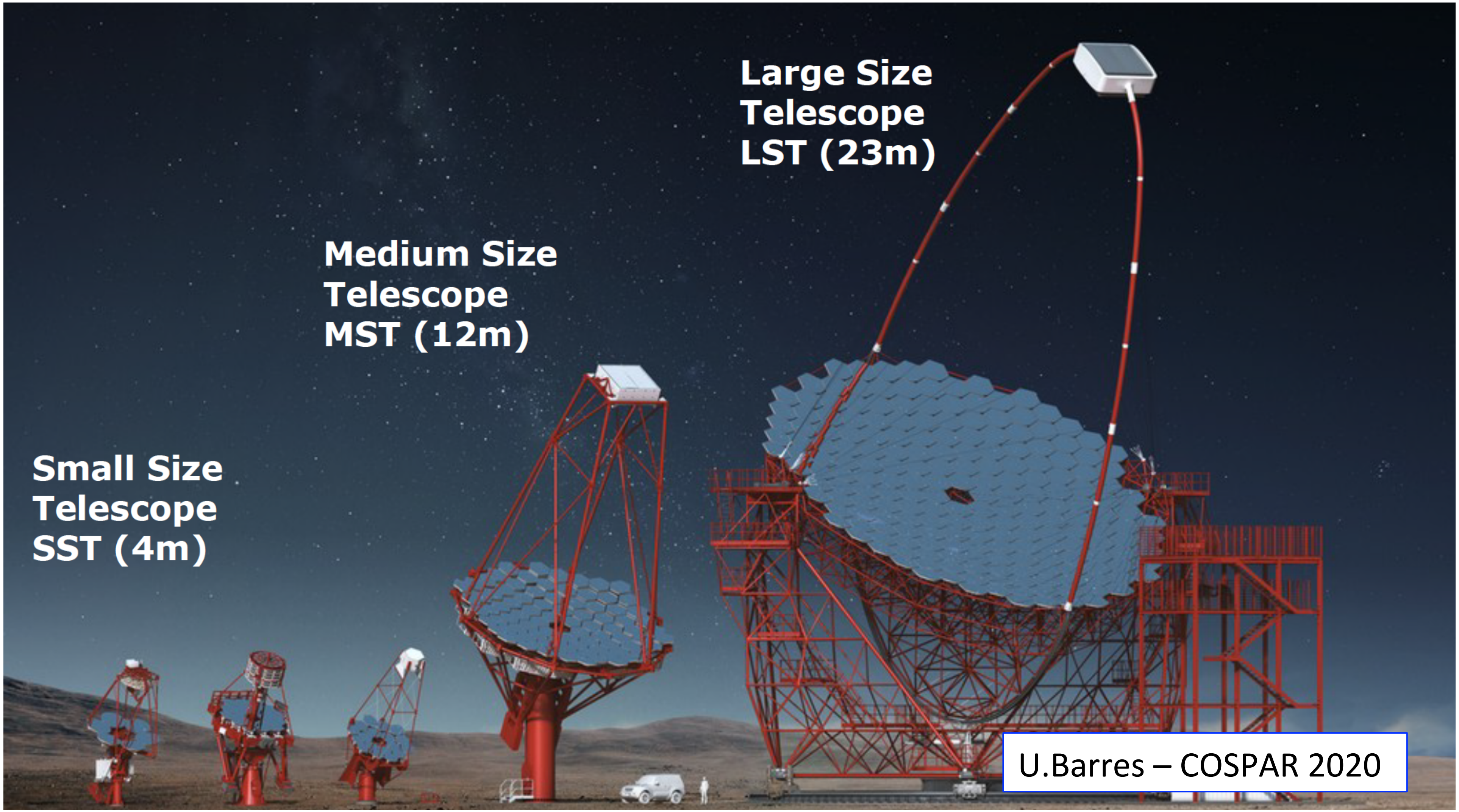
10% energy resolution

arcmin angular resolution

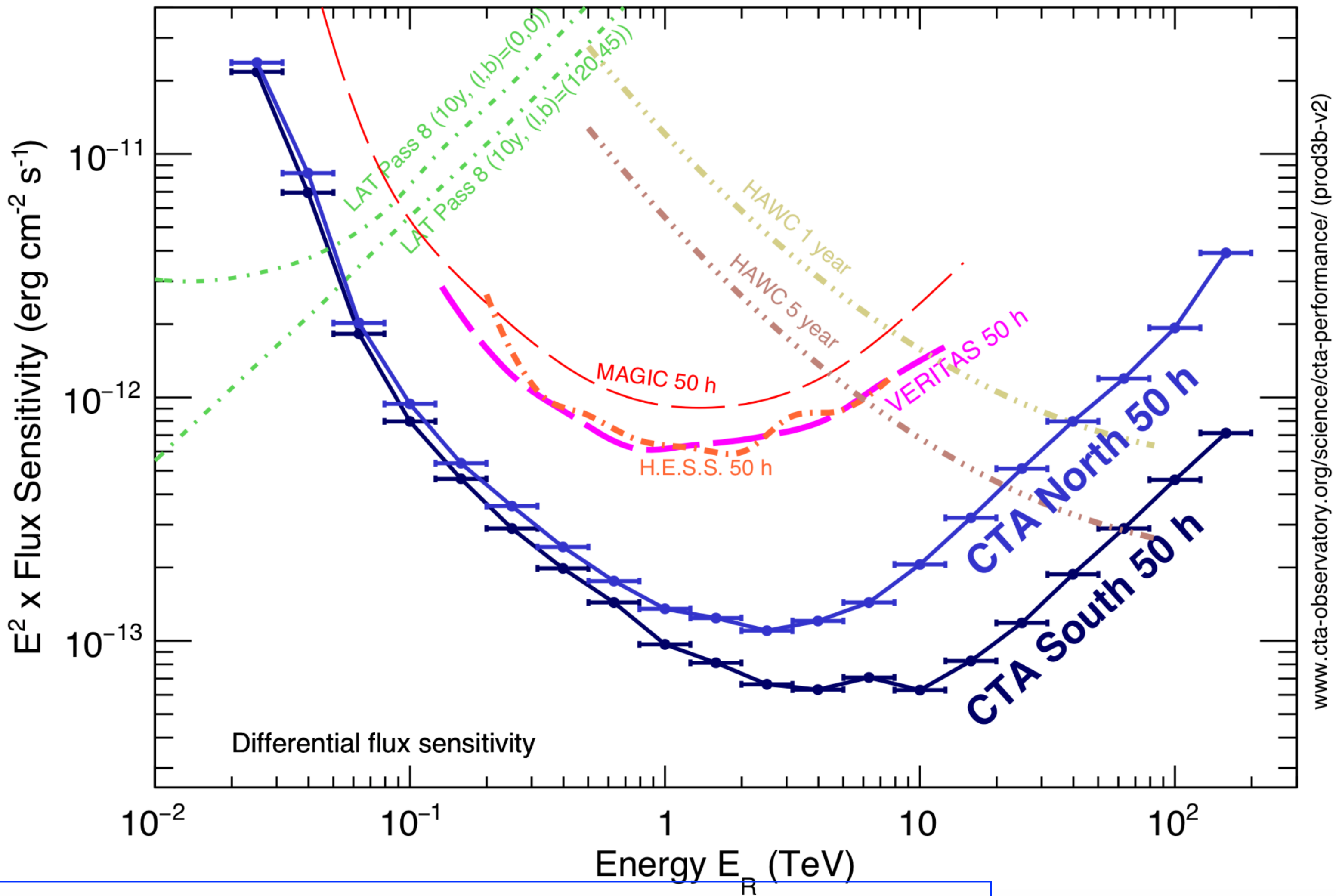


The CTA Telescopes

A Hybrid Observatory…

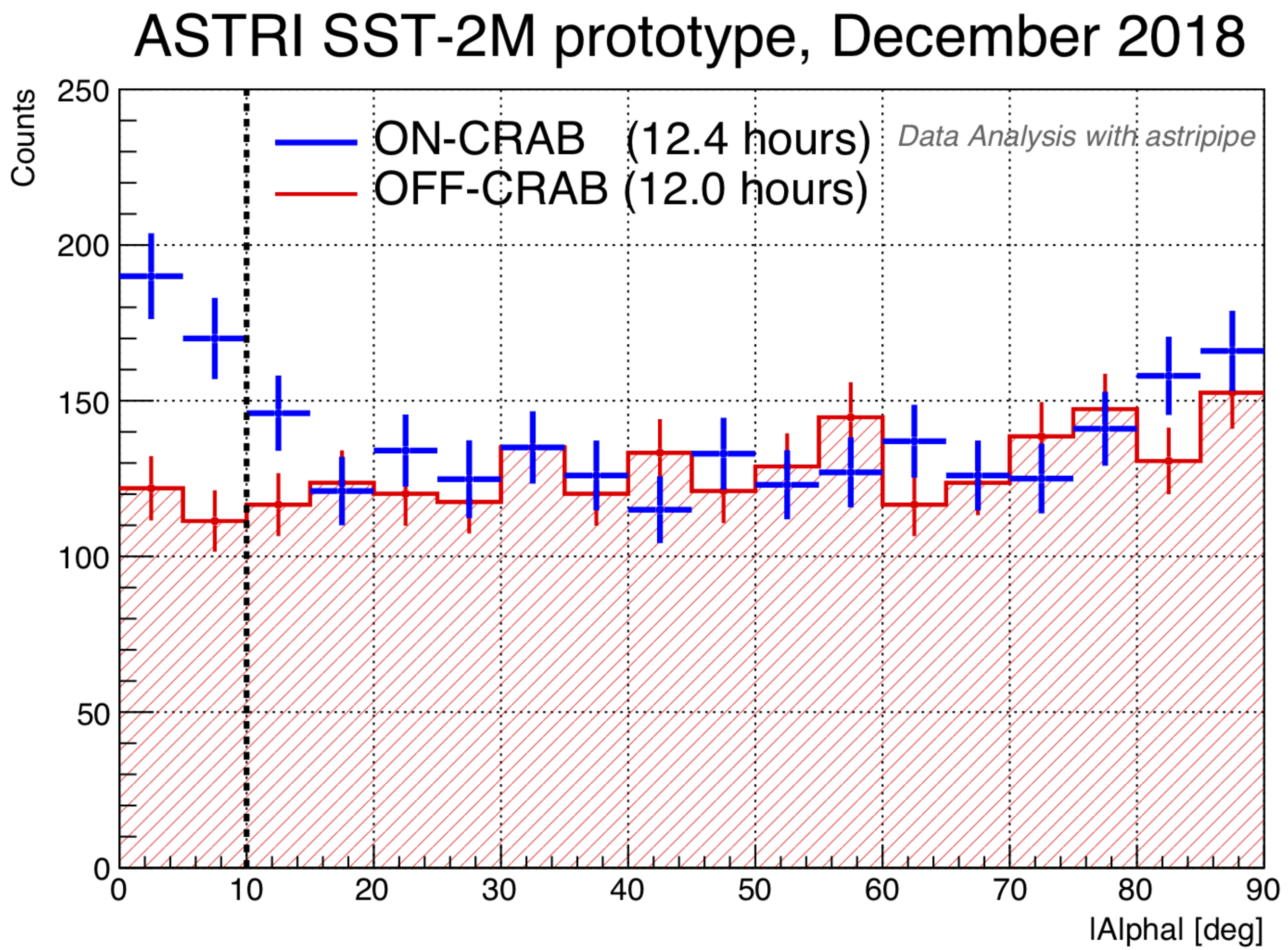


CTA performance



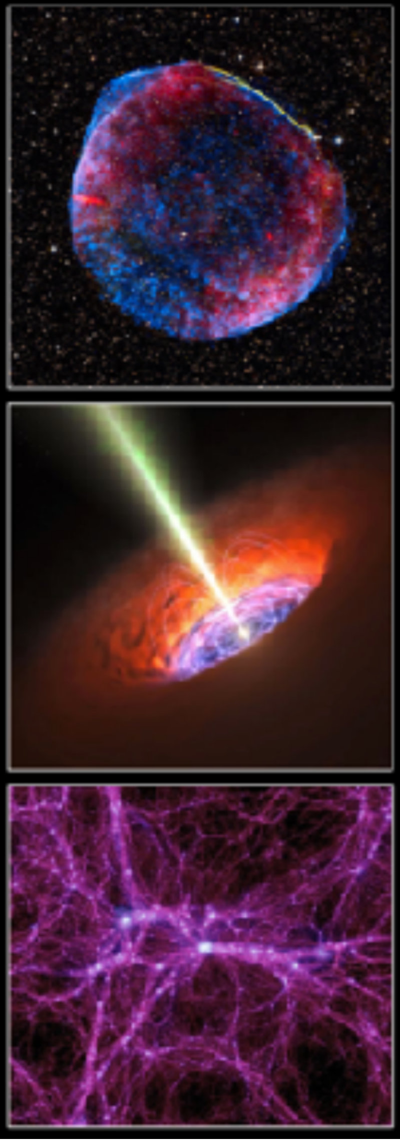
https://www.cta-observatory.org/science/cta-performance/

CTA telescopes – first results



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

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

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

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

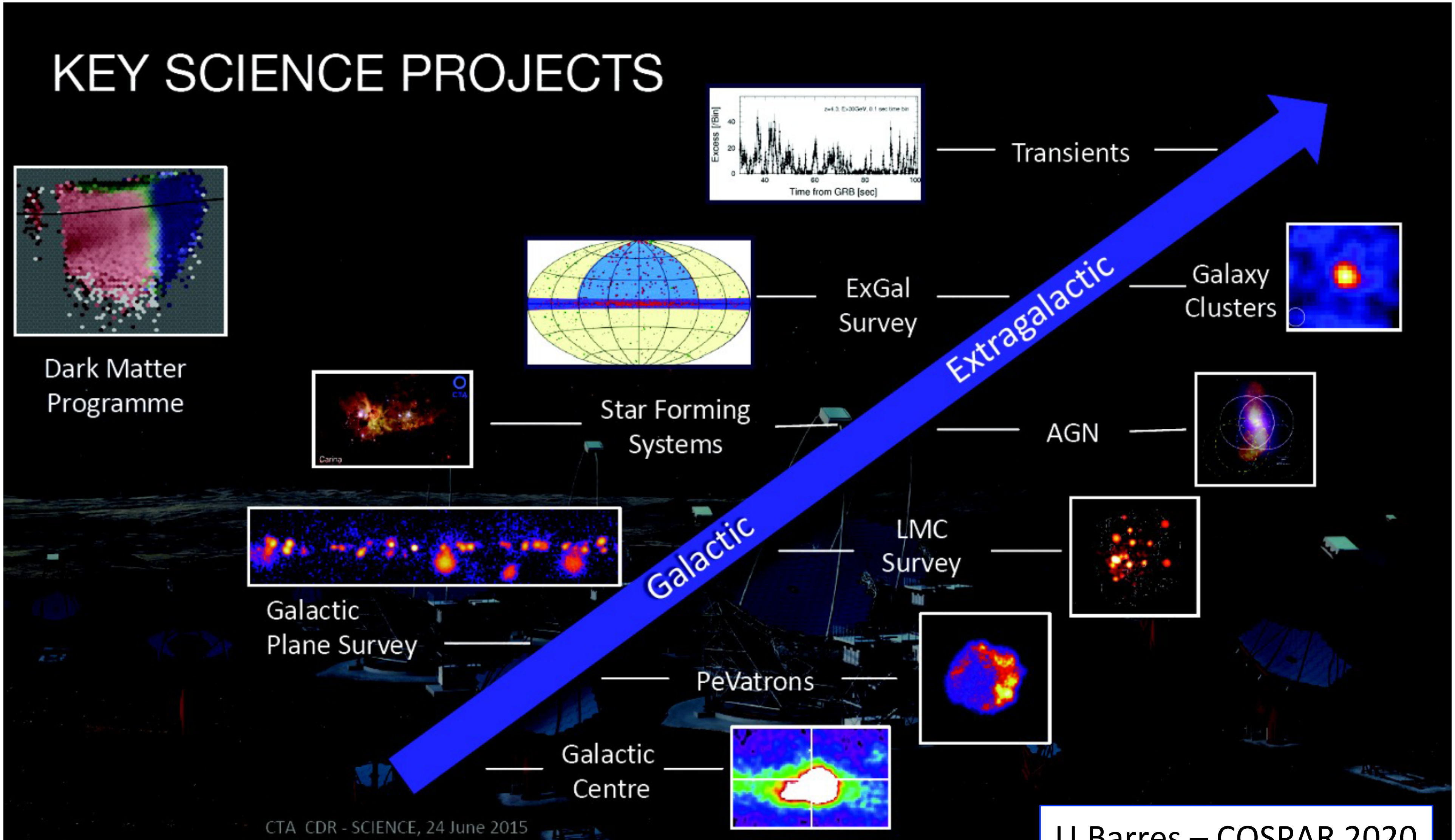
- PeVatrons
- Star-forming Systems
- Radio Galaxies & Clusters

Follow-ups of Transient and Multi-messenger events

Monitoring of Variability notably of AGN

U.Barres – COSPAR 2020

A Census of particle accelerators across all cosmic scales

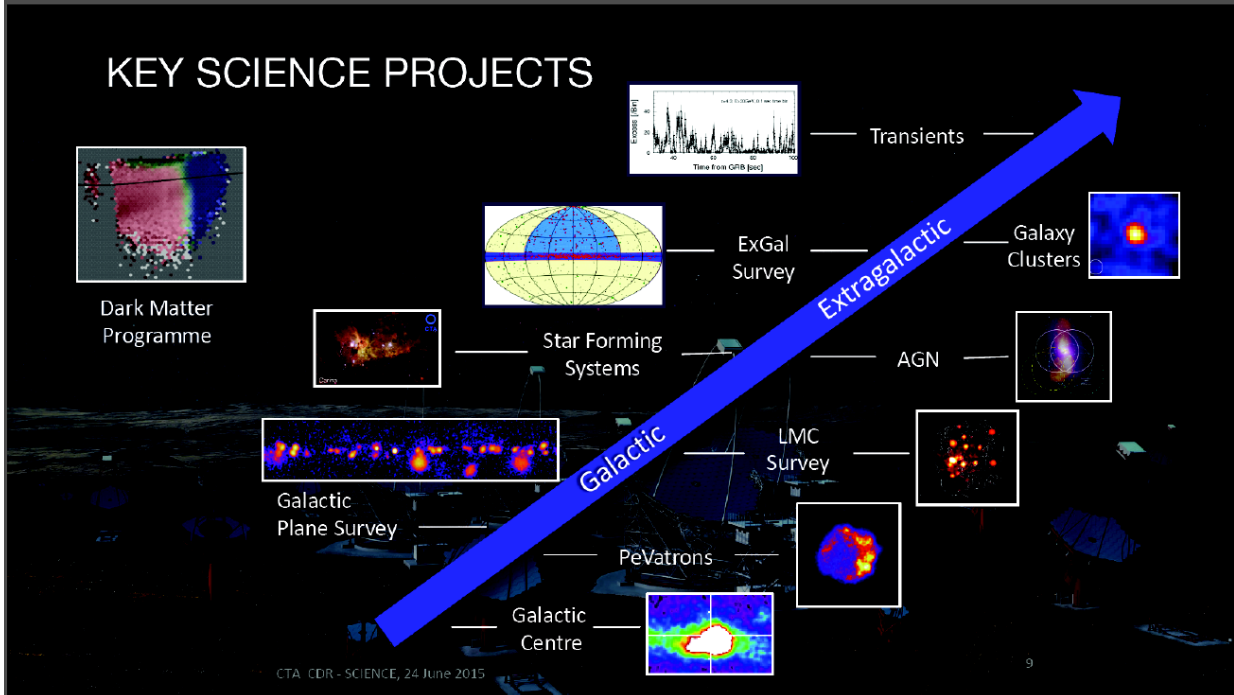


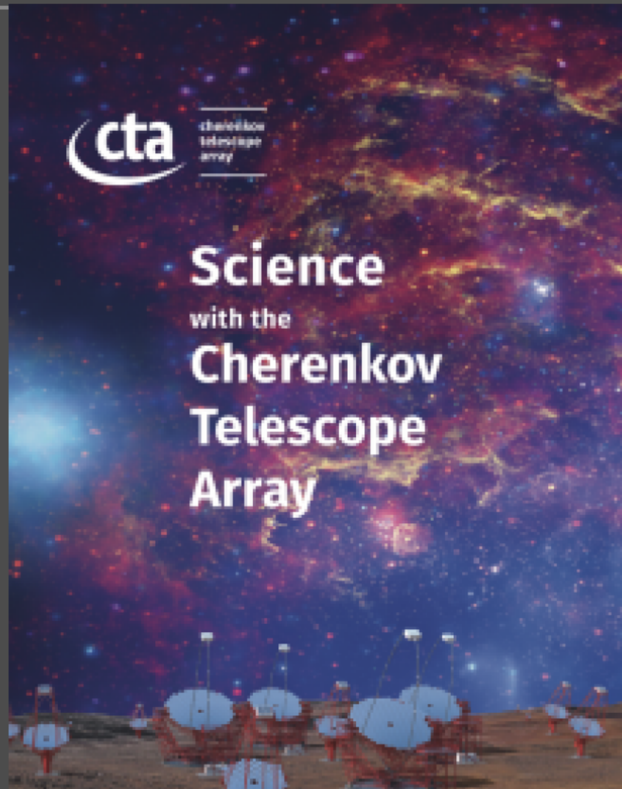
U.Barres – COSPAR 2020

CTA's Science

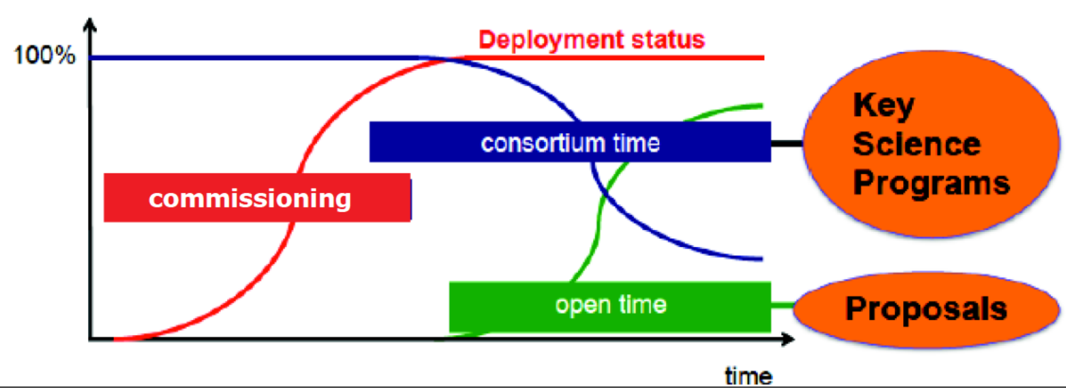
Key Science Projects: ~40% of observing time in first 10 yrs devoted to major projects.

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





G. Rowell – COSPAR 2020

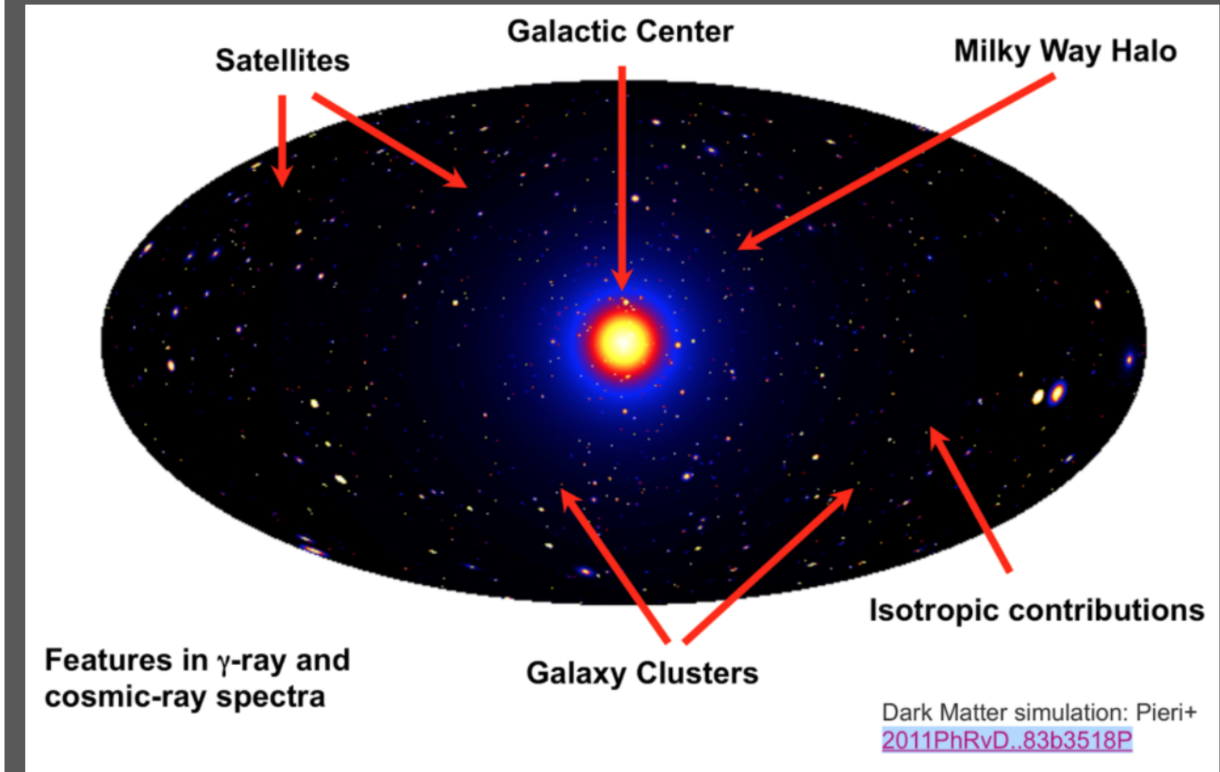


Signficant multi-wavelength support needed.

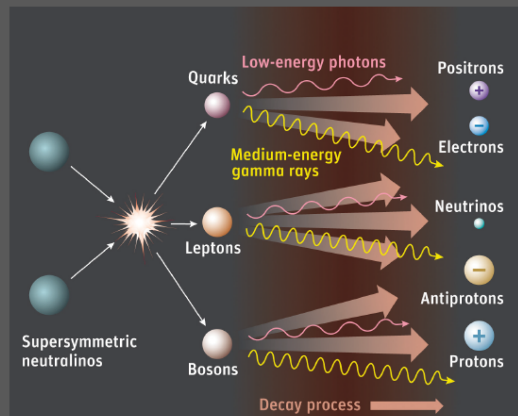
e.g optical/radio coverage > 500 hr/yr

The Dark Matter Programme

Gamma-rays trace annihilating Dark Matter



- 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



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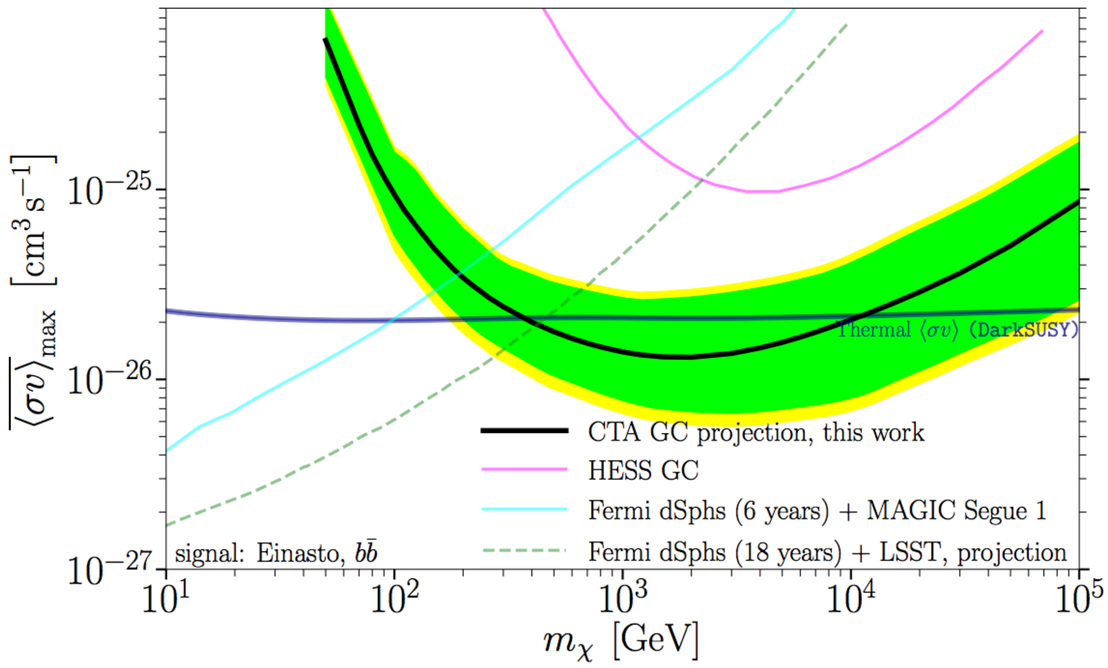
The Dark Matter Programme

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

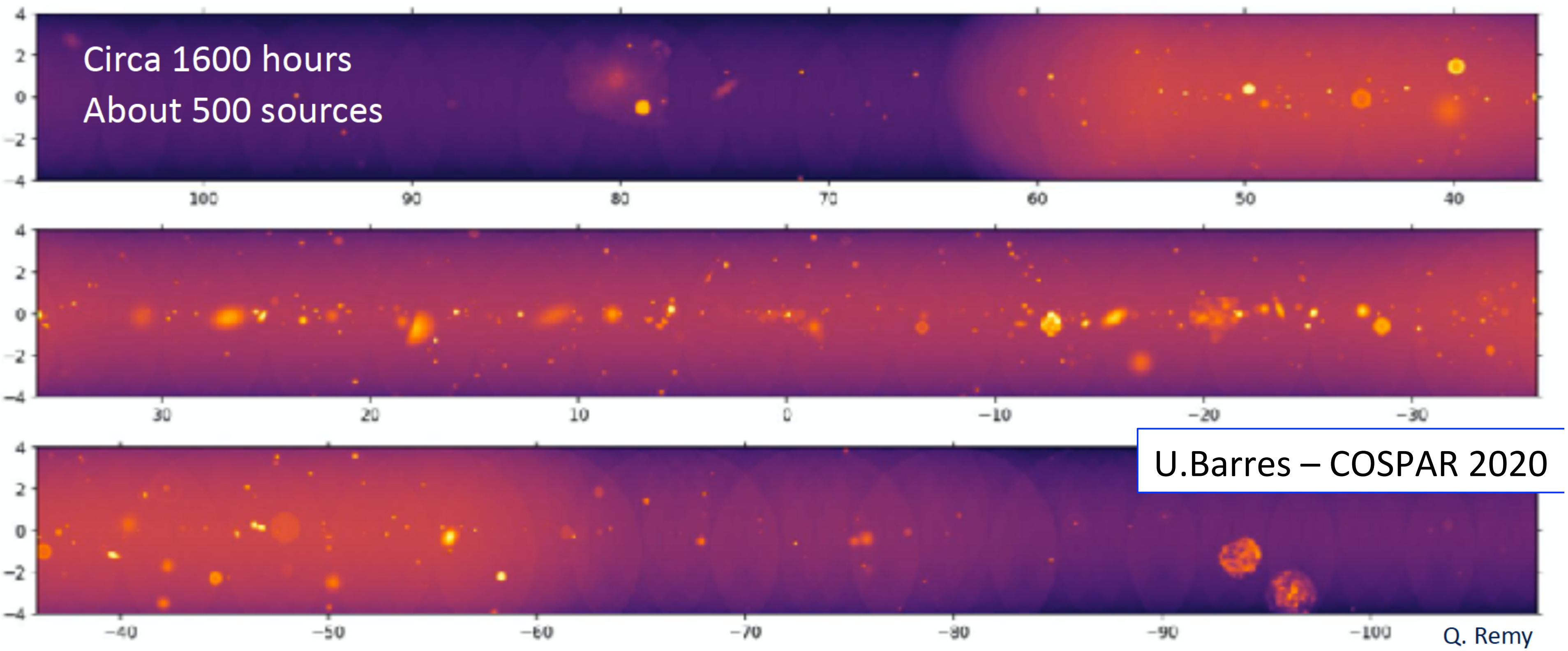
Sensitivity of the Cherenkov Telescope Array to a dark matter signal from the Galactic centre

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

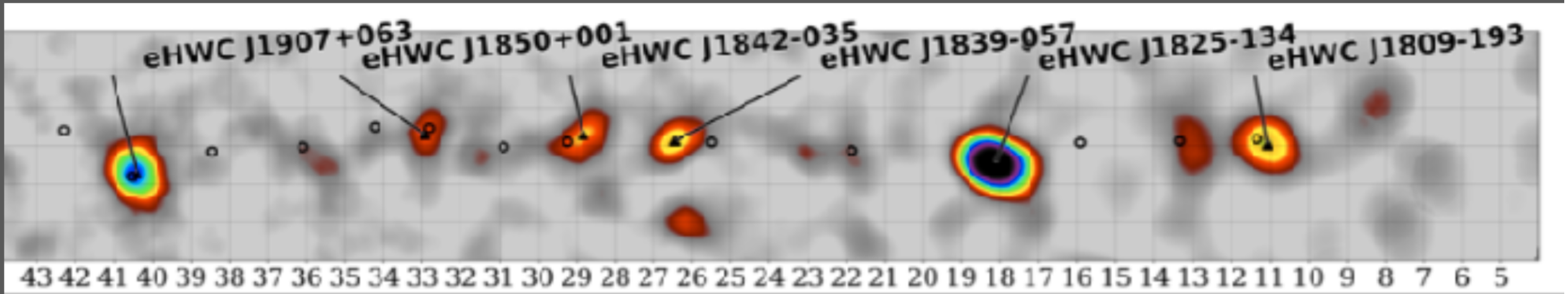
CTA Galactic Science

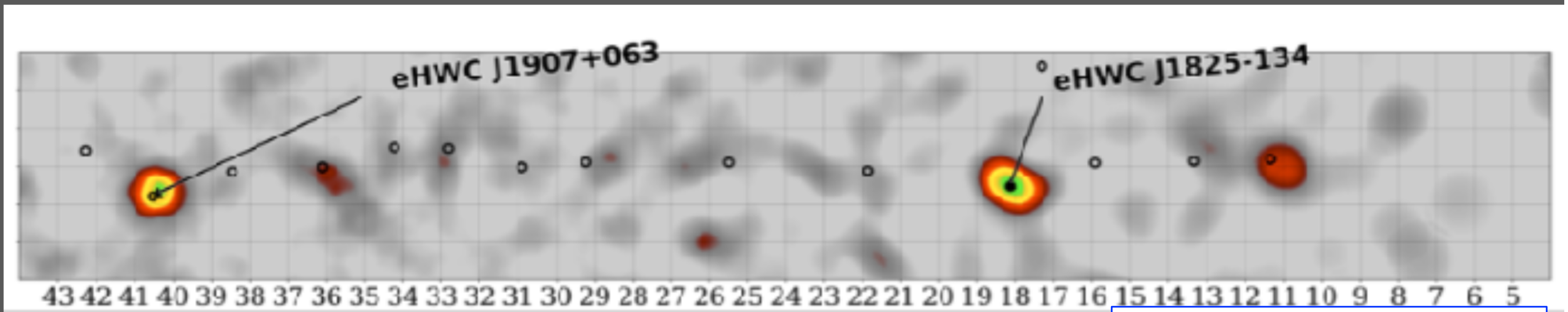
- Survey speed about 300x greater than H.E.S.S.
- Much deeper reach, to scan the entire galaxy for PWNe and SNRs, as opposed to the few-kpc reach of current instruments.



PeVatrons: the extreme energy frontier

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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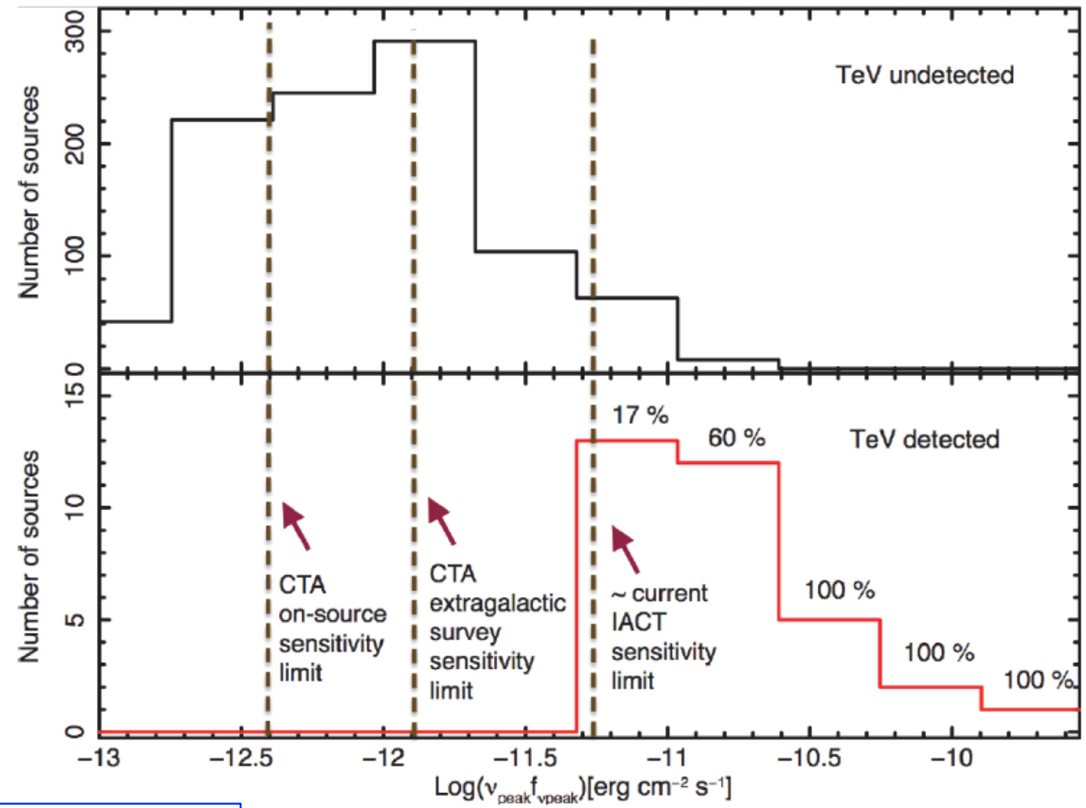
CTA's Prospects for AGN

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

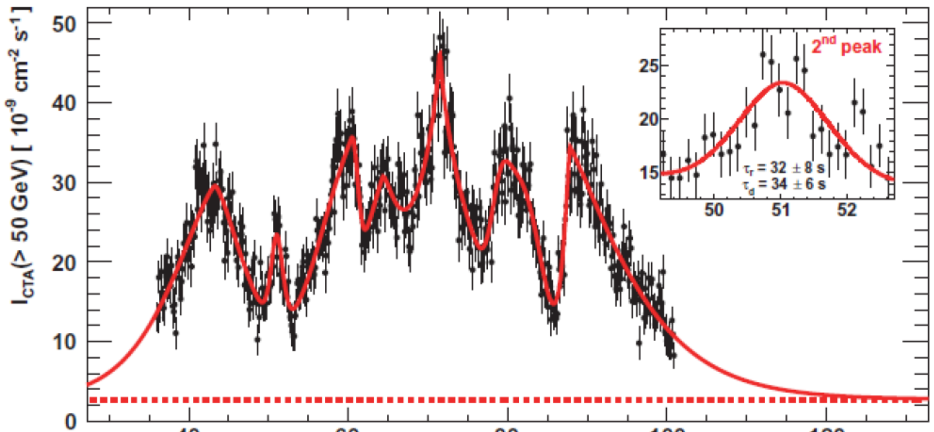
FoV up to 10 degrees → several AGN in FoV at same time.

Light curve details down to sub-minutes.

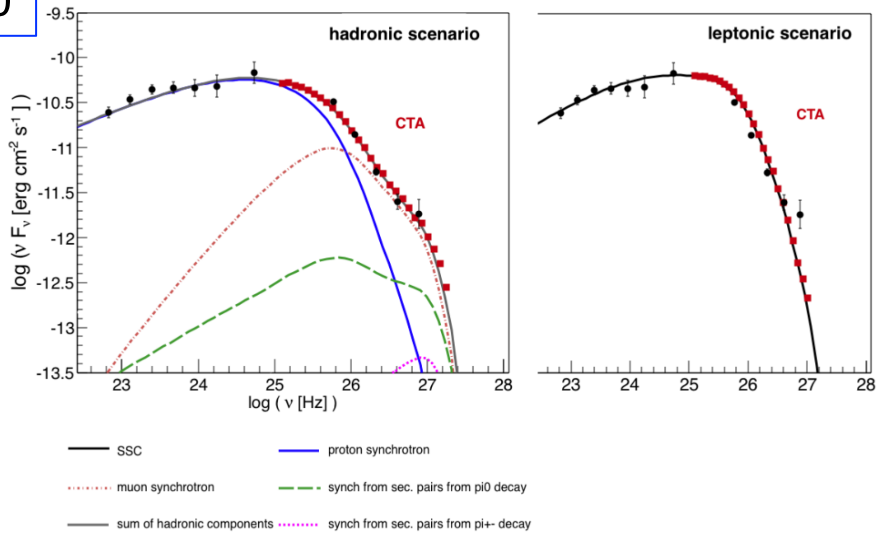
Spectral resolution to reveal sub-components:
- Hadronic (synchrotron from protons, muons, + secondaries)
- Leptonic (SSC)



G. Rowell – COSPAR 2020



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



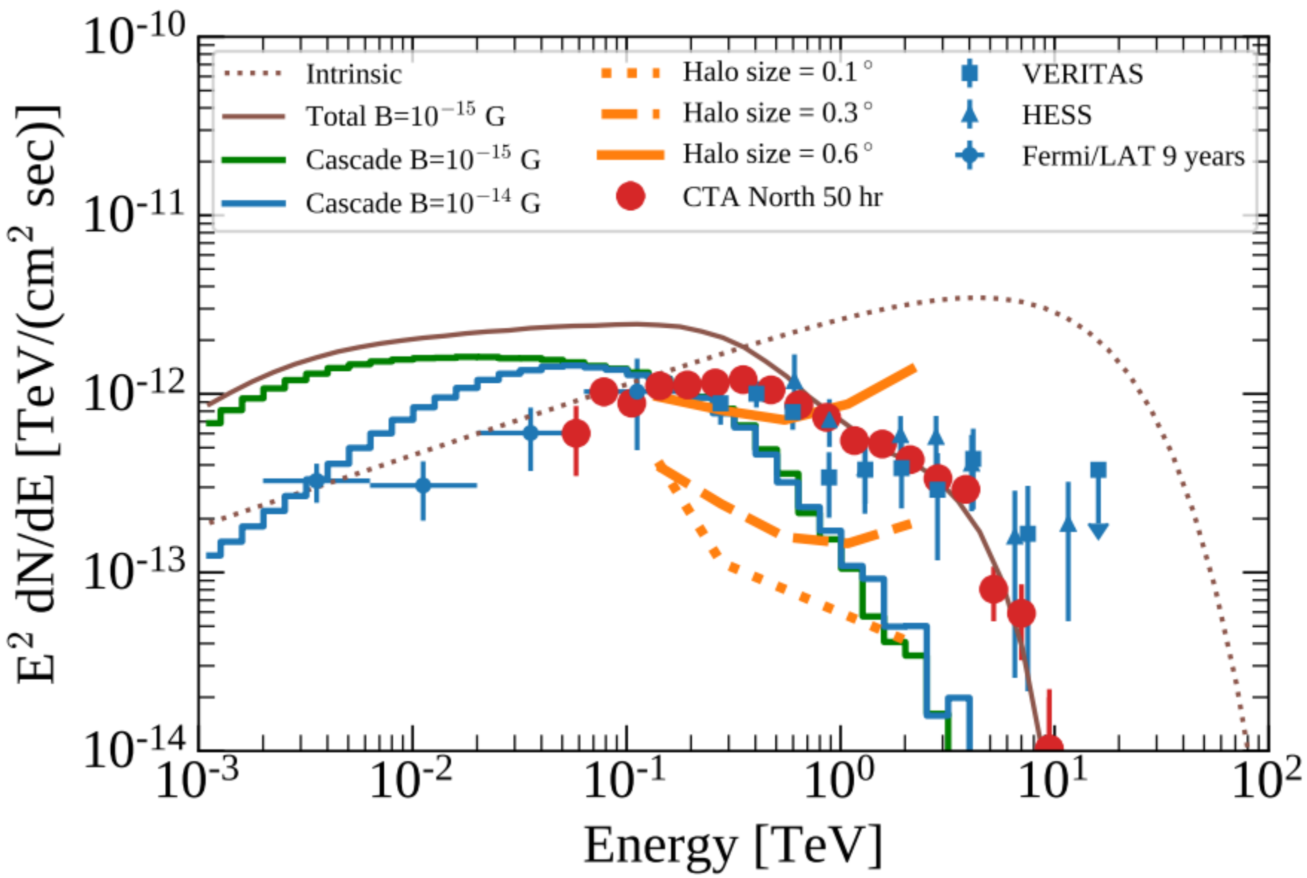
Cosmology and Fundamental Physics

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

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

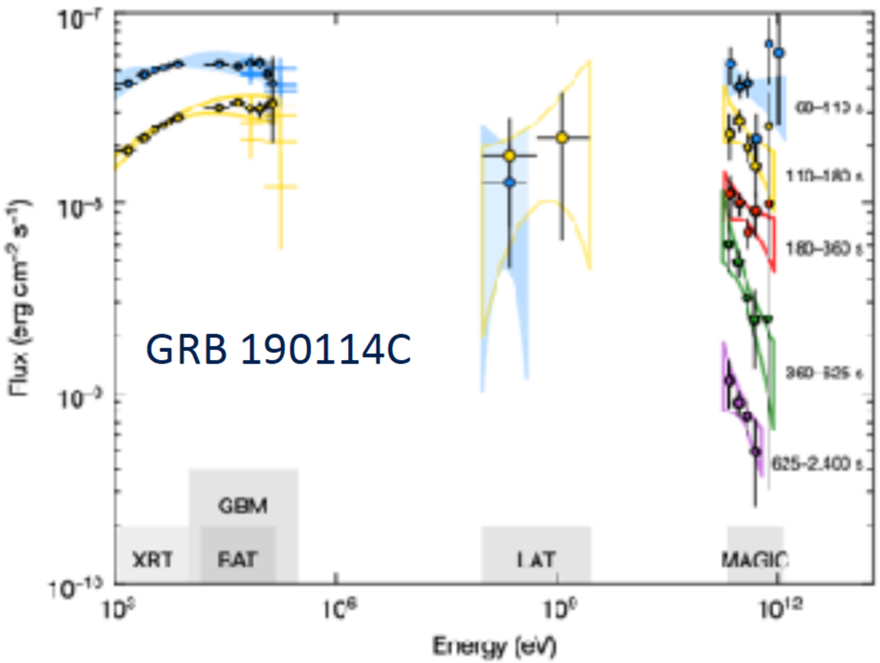
ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
on ***15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

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)

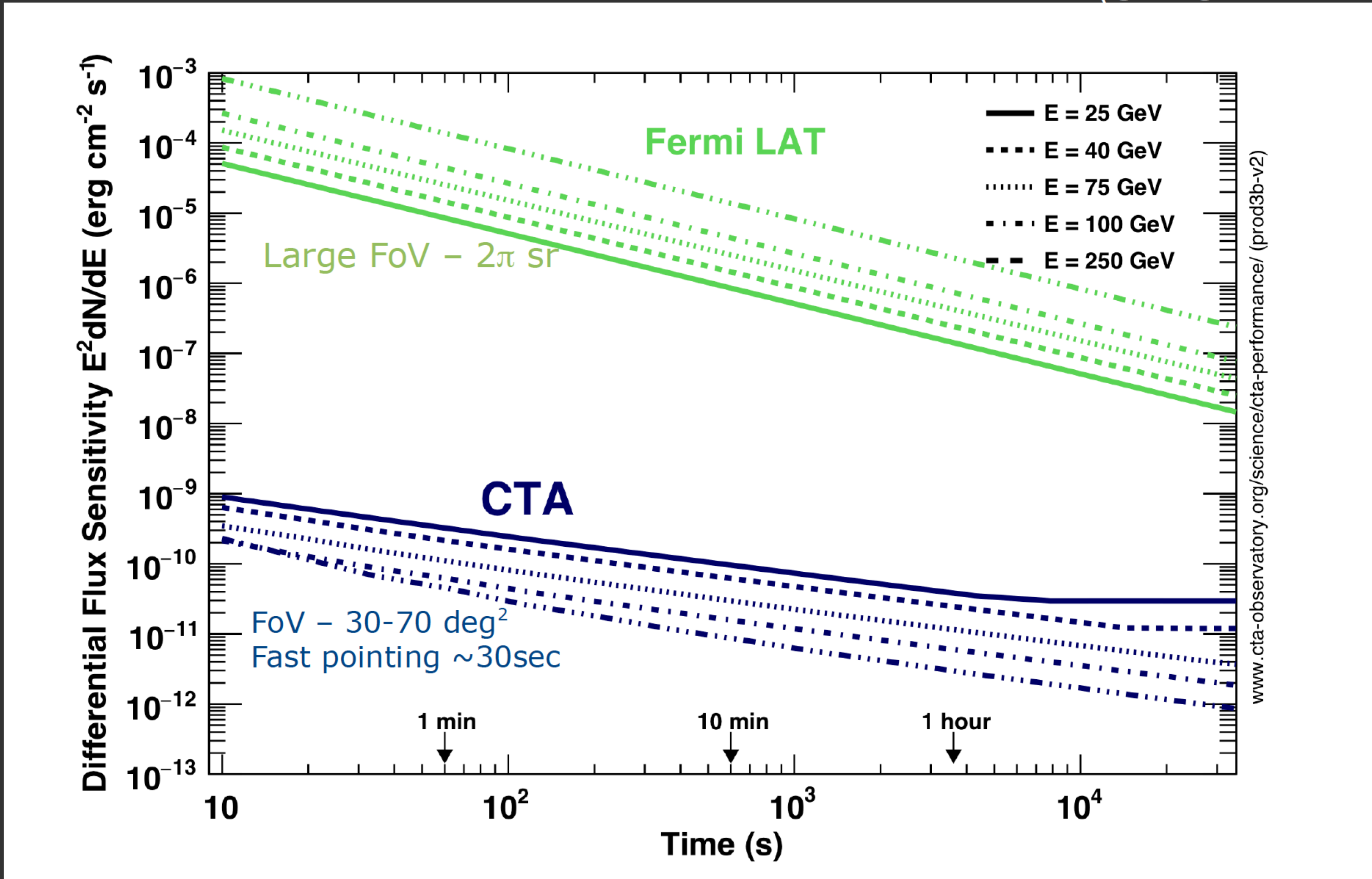
+ GRB 201216C (z = 1.1)

Strong MWL and MM synergies for spectral and variability studies

U.Barres – COSPAR 2020

Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)



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

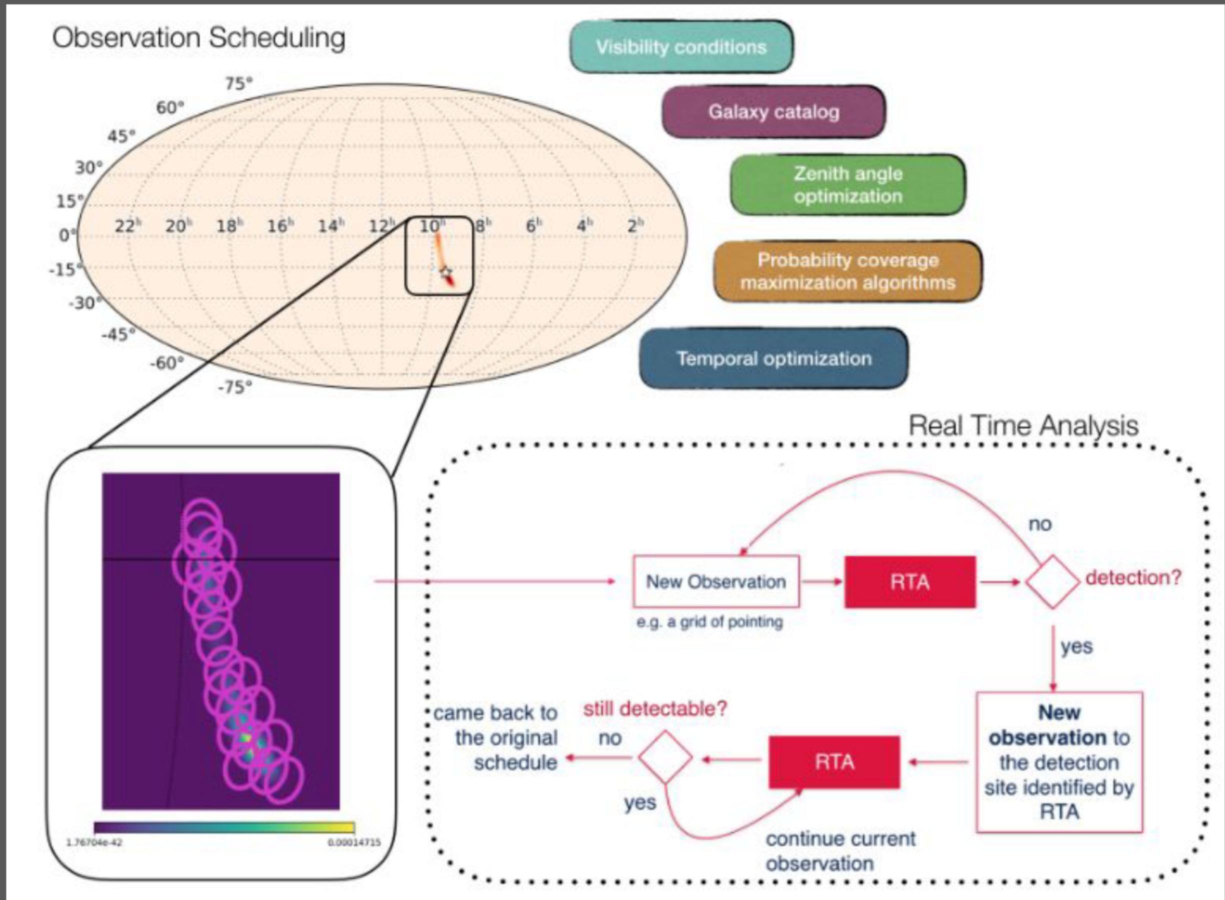
→ GRBs, AGN, giant pulses, FRBs, GW, SGR bursts...

G. Rowell – COSPAR 2020

Gravitational wave follow-ups

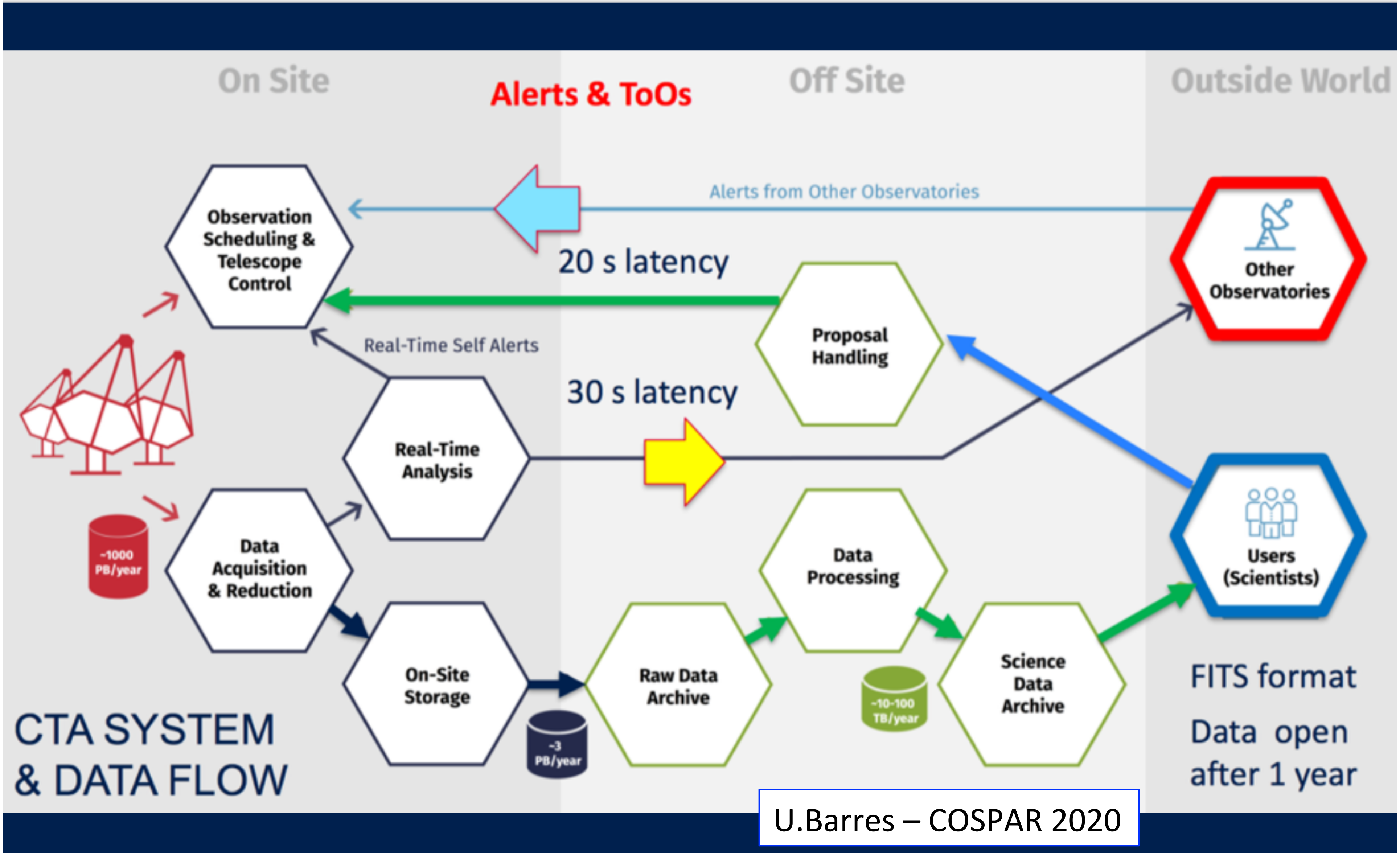
CTA will represent an important improvement on the follow-up of gravitational wave events

- 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

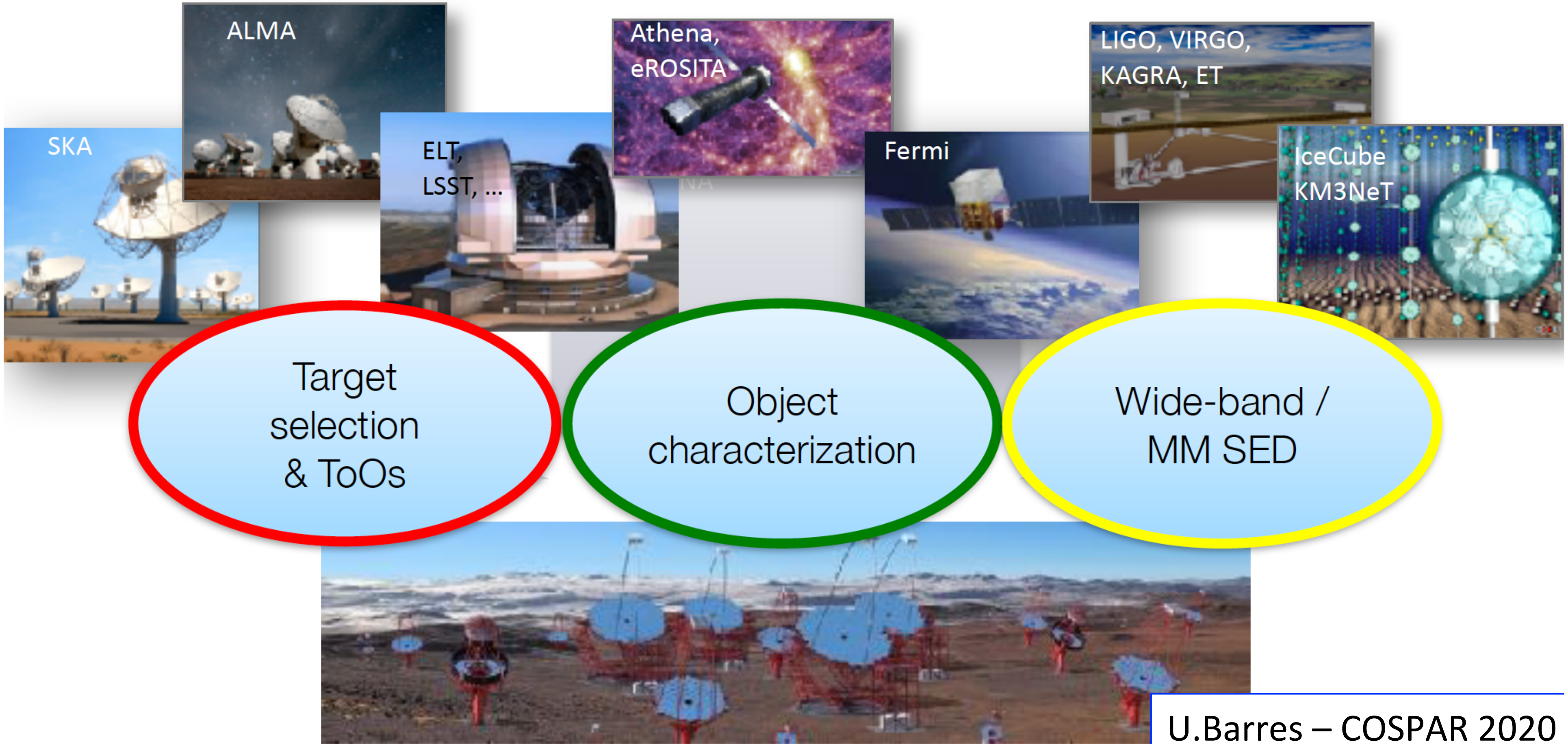
G. Rowell – COSPAR 2020

✓ = 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…



U.Barres – COSPAR 2020

ctools “user” Introduction

Francesco Longo
Universita’ di Trieste and INFN Trieste

Most of the material from J.Knödleseder

ctools introduction

CTA

Cherenkov Telescope Array Science Analysis Software

Home Get it

ctools

About

ctools is a software package developed for the scientific analysis of Cherenkov Telescope Array (CTA) data. Analysis of data from existing Imaging Air Cherenkov Telescopes (such as H.E.S.S., MAGIC or VERITAS) is also supported, provided that the data and response functions are available in the format defined for CTA.

ctools comprises a set of ftools-like binary executables with a command-line interface allowing for interactive step-wise data analysis. ctools comprises also a Python module allowing to control all executables. Creation of shell or Python scripts and pipelines is supported. ctools comprises also cscripts, which are Python scripts that behave like binary ftools executables. Extensions of the ctools package by user defined binary executable or Python scripts is supported.

ctools are based on GammaLib, a versatile toolbox for the high-level analysis of astronomical gamma-ray data. Besides CTA, GammaLib supports also the analysis of Fermi/LAT and COMPTEL data, and extensions to support further gamma-ray instruments are planned. An interface to virtual observatory ressources is also in preparation. By making use of the GammaLib multi-instrument capabilities, ctools supports the joint analysis of CTA (or any IACT providing data in the CTA format), Fermi/LAT and COMPTEL data.

ctools is free software distributed under the GNU GPL license version 3

http://cta.irap.omp.eu/ctools/

ctools

ctools

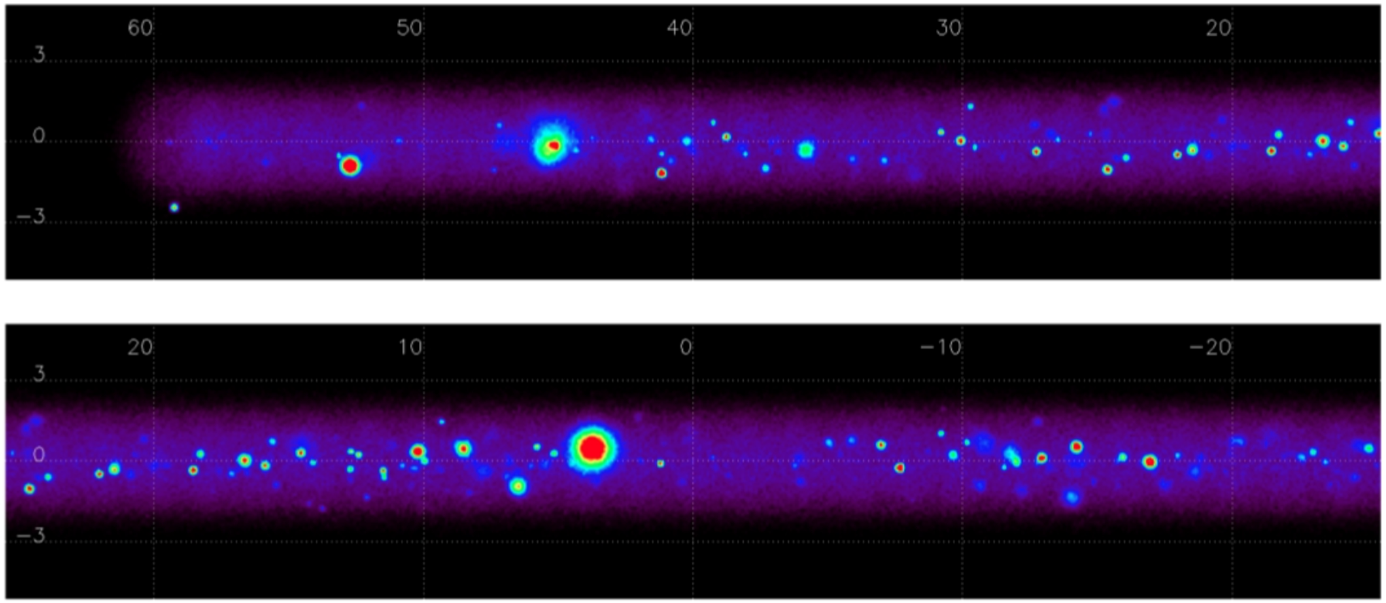
Overview
Activity
Roadmap
Issues
News
Documents
Wiki
Code status
Links
Forums
Files
Repository

ctools

ctools are a set of ftools-like executables needed for the scientific analysis of Cherenkov Telescope Array data. ctools is also a Python module that allows for interactive data analysis and building of analysis scripts and pipelines. ctools includes also an observation simulator to enable the scientific simulation of future CTA observations.

ctools are based on GammaLib, a versatile toolbox for the high-level analysis of astronomical gamma-ray data. Besides CTA, GammaLib supports also the analysis of Fermi-LAT data, and extensions to support further gamma-ray instruments are planned. This enables a simultaneous and coherent multi-instrument analysis of high-energy sources in the Universe.

ctools and GammaLib is free software distributed under the GPL license version 3.



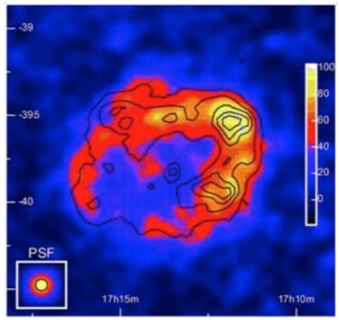
What are the ctools?

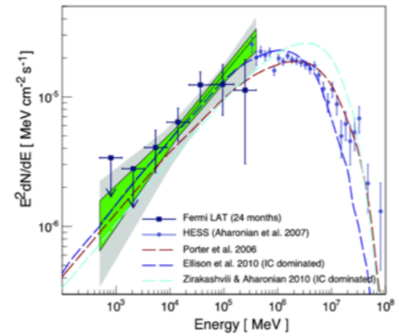
Tools for **end users** to extract science results from Cherenkov Telescope Array event lists and instrument response functions

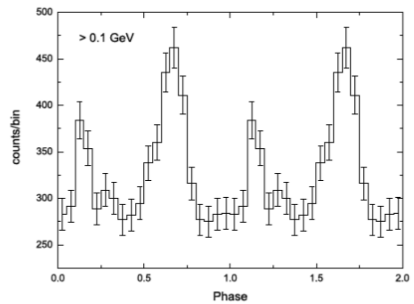
Background reduced event lists
Instrument response functions

Simulated event lists
Instrument response functions

ctools
cherenkov telescope array







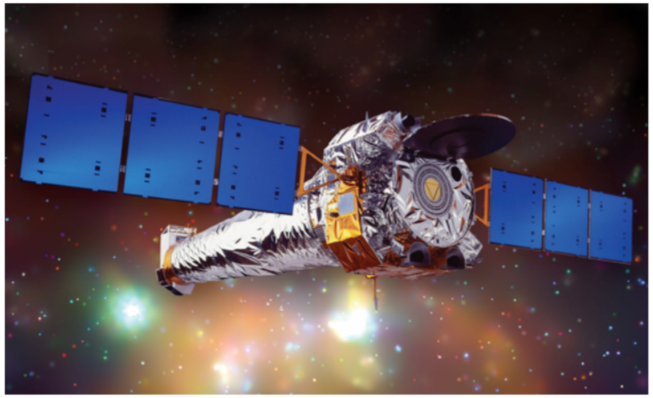
Where do the ctools come from?

- **FITS** format invented in 1980'ies for the interchange of astronomical images on magnetic tapes (Wells, Greisen, Harten, 1981, A&AS, 44, 363)
- **HEASARC** established in 1990 as NASA's archive for **high-energy observatories** (support ROSAT, CGRO, ASCA, RXTE and achieve cost savings by reusing software and archive resources, today supports 32 HE missions and 25 CMB experiments)
- **FTOOLS** developed by HEASARC since 1992 as a generic set of software utilities to manipulate FITS files (current release: 6.20, 18/1/2017)

Where do the ctools come from?

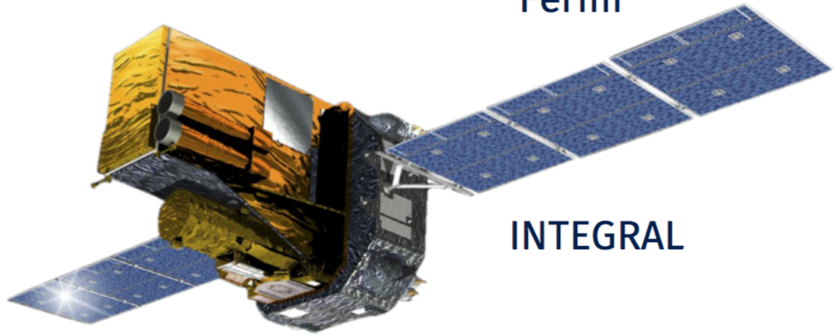
FTOOLS characteristics

- Modular workflow
- Use of IRAF parameter files

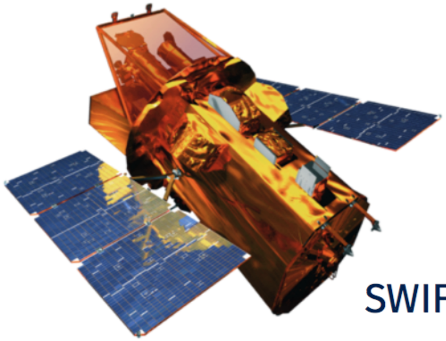


Chandra

Fermi



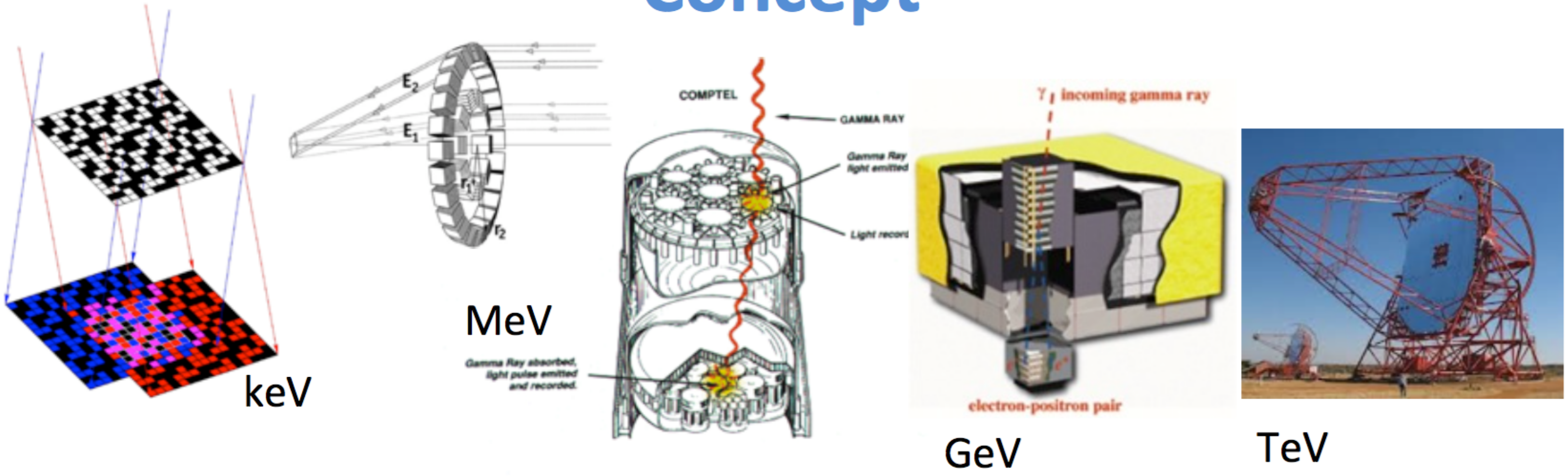
INTEGRAL



SWIFT

FTOOLS (like) analysis has become a **standard in high-energy astronomy**. Thousands of astronomers are today **familiar** with this standard.

Concept



All gamma-ray telescopes measure individual photons as events =>
Handle events from gamma-ray telescopes in an abstract and common software framework.
Existing high-energy analysis frameworks share a number of **common features** (FITS files, likelihood fitting, modular design).

ctools … is the client that uses the bricks provided by GammaLib

CTA specific *generic*

… to build a set of analysis executables for CTA (and alike)

Where do the ctools come from?

ctools are **intentionally** very similar to the Fermi/LAT Science Tools

- Fermi/LAT Science Tools proven successful
- Basically **no learning** curve for **Fermi/LAT users**
- **Low learning curve** for users of other **HE observatories**
- But admittedly **some learning curve** for people from the **VHE community**

ctools

ctools CTA

Cherenkov Telescope Array Science Analysis Software

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Introduction

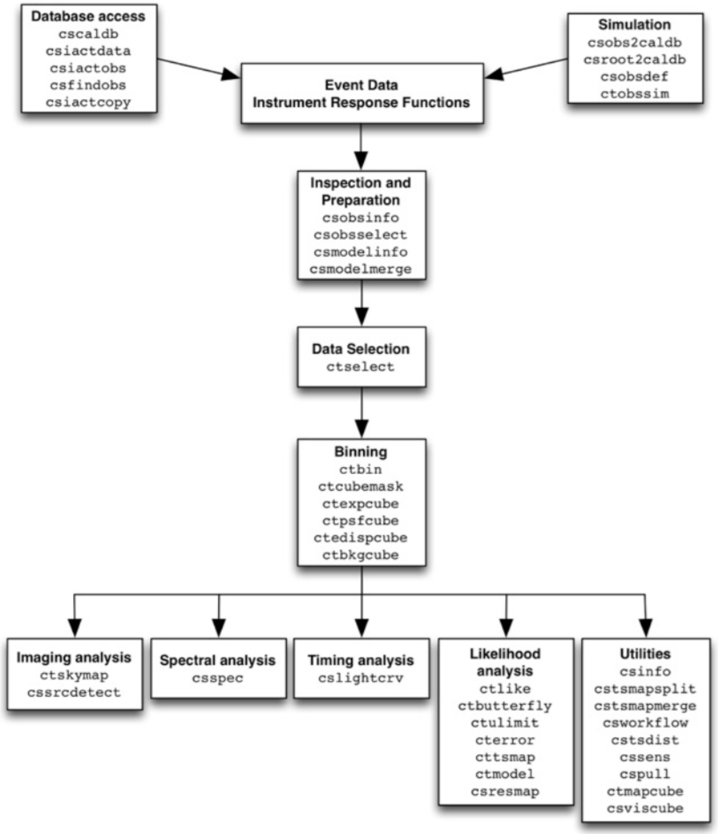
ctools is a highly modular collection of utilities for processing and analysing CTA reconstructed event data in the FITS (Flexible Image Transport System) data format. Each utility presents itself as a FTOOL (see http://heasarc.gsfc.nasa.gov/ftools/) and performs a single simple task such as event binning, event selection or model fitting. Individual utilities can easily be chained together in scripts to achieve more complex operations, either by using the command line interface, or by using the Python scripting language. The ctools user interface is controlled by standard IRAF-style parameter files. Software is written in C++ to provide portability across most computer systems. The data format dependencies between hardware platforms are isolated through the cfitsio library package from HEASARC (http://heasarc.gsfc.nasa.gov/fitsio/).

This User Manual describes the use of the ctools software.

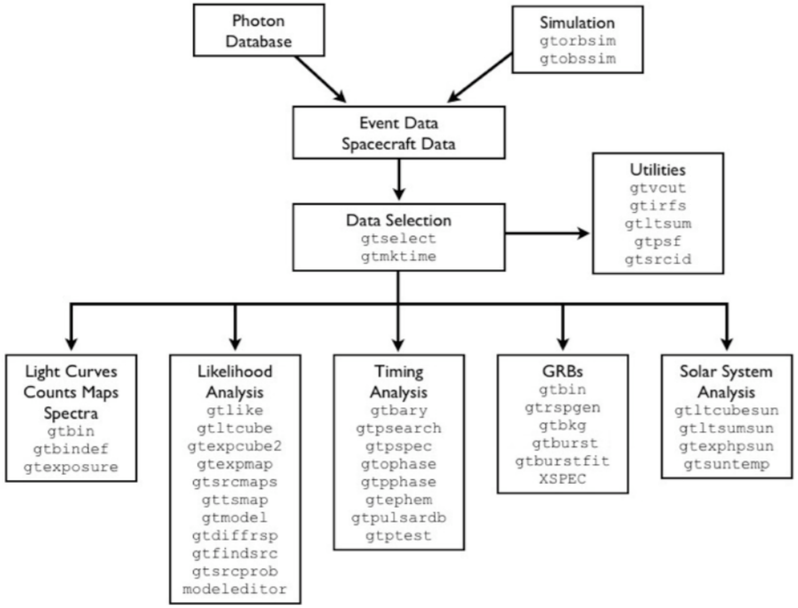
http://cta.irap.omp.eu/ctools/

Status of ctools

ctools



Fermi/LAT Science Tools



- In terms of functionality and number of tools equivalent to the Fermi/LAT Science Tools
- More models
- Fitting of spatial and temporal parameters possible

ctools paper

arXiv.org > astro-ph > arXiv:1606.00393

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Astrophysics > Instrumentation and Methods for Astrophysics

GammaLib and ctools: A software framework for the analysis of astronomical gamma-ray data

J. Knödlseder, M. Mayer, C. Deil, J.-B. Cayrou, E. Owen, N. Kelley-Hoskins, C.-C. Lu, R. Buehler, F. Forest, T. Louge, H. Siejkowski, K. Kosack, L. Gerard, A. Schulz, P. Martin, D. Sanchez, S. Ohm, T. Hassan, S. Brau-Nogué

(Submitted on 1 Jun 2016 (v1), last revised 22 Jul 2016 (this version, v2))

The field of gamma-ray astronomy has seen important progress during the last decade, yet there exists so far no common software framework for the scientific analysis of gamma-ray telescope data. We propose to fill this gap by means of the GammaLib software, a generic library that we have developed to support the analysis of gamma-ray event data. GammaLib has been written in C++ and all functionality is available in Python through an extension module. On top of this framework we have developed the ctools software package, a suite of software tools that enables building of flexible workflows for the analysis of Imaging Air Cherenkov Telescope event data. The ctools are inspired by science analysis software available for existing high-energy astronomy instruments, and they follow the modular ftools model developed by the High Energy Astrophysics Science Archive Research Center. The ctools have been written in Python and C++, and can be either used from the command line, via shell scripts, or directly from Python. In this paper we present the GammaLib and ctools software versions 1.0 that have been released end of 2015. GammaLib and ctools are ready for the science analysis of Imaging Air Cherenkov Telescope event data, and also support the analysis of Fermi-LAT data and the exploitation of the COMPTEL legacy data archive. We propose to use ctools as the Science Tools software for the Cherenkov Telescope Array Observatory.

Comments:	19 pages, 10 figures, accepted for publication in A&A, corrected X axis units in Figure 10
Subjects:	**Instrumentation and Methods for Astrophysics (astro-ph.IM)**; High Energy Astrophysical Phenomena (astro-ph.HE)
Journal reference:	A&A 593, A1 (2016)
DOI:	10.1051/0004-6361/201628822
Cite as:	**arXiv:1606.00393 [astro-ph.IM]**
	(or **arXiv:1606.00393v2 [astro-ph.IM]** for this version)

Installation

CTA
Cherenkov Telescope Array Science Analysis Software

About | Getting ctools | For Users

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Installing via Anaconda

Anaconda (you can also use Miniconda for a smaller footprint) is a scientific Python installation shipping with essentially all needed packages. Install it according to the instructions on their homepage. You can use any Anaconda Python version. An Anaconda Python installation is completely separate from any existing system wide or user space Python installation, so Anaconda can be tested without the fear of breaking an existing installation.

Anaconda ctools packages exist for Mac OS X and Linux distributions. Windows is not supported.

Installing

- Install Anaconda following the instructions on their site
- Add the `conda-forge` and `cta-observatory` channels to your Anaconda configuration

```
$ conda config --append channels conda-forge
$ conda config --append channels cta-observatory
```

http://cta.irap.omp.eu/ctools/admin/install_conda.html

ctools developers

CTA

Cherenkov Telescope Array Science Analysis Software

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Develop

ctools is an open source projet and you are highly welcome to contribute to the development. Contributions can come in any areas: writing C++ code, contributing Python scripts, writing documentation, testing code, etc.

The ctools development is managed by a development platform that is accessible at https://cta-redmine.irap.omp.eu/projects/ctools/. Please check out the Wiki on that platform that contains information on how to contribute to the ctools development.

You may also want to get in the ctools information flow by subscribing to the ctools@irap.omp.eu mailing list. To subscribe simply send an e-mail to ctools-subscribe@irap.omp.eu.

We are organising regular Coding sprints to allow newcomers to get familiar with the code base and the coding practices. You are highly invited to join one of the next coding sprints.

You can also follow @gammalib on twitter to get informed about new release of GammaLib and ctools.

ctools paper

arXiv.org > astro-ph > arXiv:1606.00393

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Astrophysics > Instrumentation and Methods for Astrophysics

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Journal reference:	A&A 593, A1 (2016)
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Cite as:	**arXiv:1606.00393 [astro-ph.IM]**
	(or **arXiv:1606.00393v2 [astro-ph.IM]** for this version)

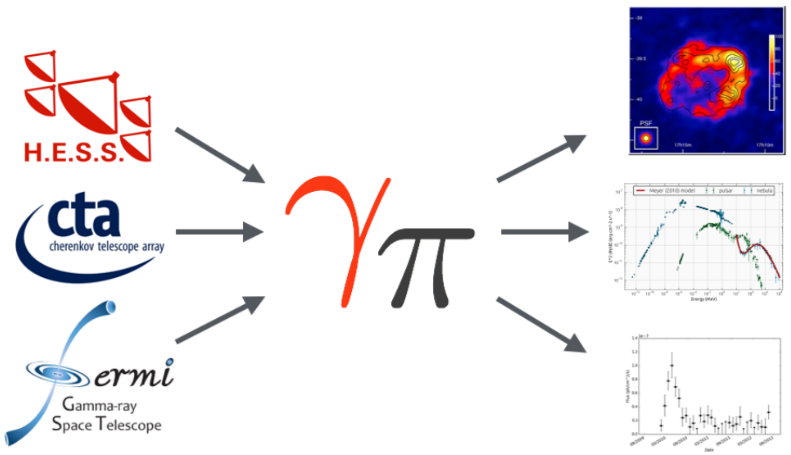
Gammapy "user" Introduction

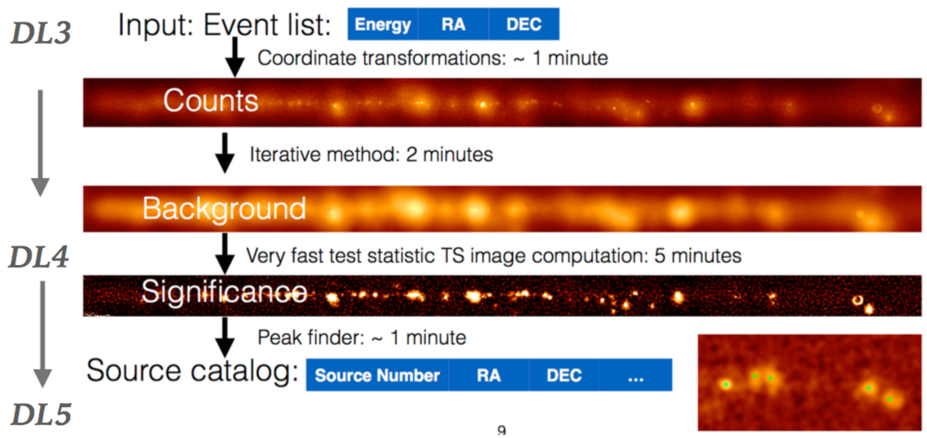
Francesco Longo
Universita' di Trieste and INFN Trieste

Most of the material from C.Deil and J.Lefaucheur

What is Gammapy?

- Gammapy is a Python package for gamma-ray astronomy
- Open source, open development (on Github)
- Officially proposed as CTA science tool prototype at the Kashiwa meeting in May 2016
- Currently used for H.E.S.S., CTA prototyping and Fermi-LAT
- Used for upcoming H.E.S.S. Galactic plane survey paper





Gammapy references

A **Python** package for **gamma-ray** astronomy

- Code: https://github.com/gammapy/gammapy
- Docs: http://docs.gammapy.org

To get started, click here!

- Tutorials: https://nbviewer.jupyter.org/github/gammapy/gammapy-extra/blob/master/index.ipynb

Questions, comments, requests?

- Mailing list: http://groups.google.com/group/gammapy
- Me: Christoph.Deil@mpi-hd.mpg.de

Gammapy references

A **Python** package for **gamma-ray** astronomy

- ICRC 2015 paper: 2015arXiv150907408D
- Code: https://github.com/gammapy/gammapy
- Docs: http://docs.gammapy.org
- Mailing list: http://groups.google.com/group/gammapy
- License: BSD-3 (same as Numpy, Scipy, Astropy, ...)

Gammapy paper

arXiv.org > astro-ph > arXiv:1509.07408

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Astrophysics > Instrumentation and Methods for Astrophysics

Gammapy - A Python package for γ-ray astronomy

Axel Donath, Christoph Deil, Manuel Paz Arribas, Johannes King, Ellis Owen, Régis Terrier, Ignasi Reichardt, Jon Harris, Rolf Bühler, Stefan Klepser

(Submitted on 24 Sep 2015 (v1), last revised 6 Oct 2015 (this version, v2))

In the past decade imaging atmospheric Cherenkov telescope arrays such as H.E.S.S., MAGIC, VERITAS, as well as the Fermi-LAT space telescope have provided us with detailed images and spectra of the gamma-ray universe for the first time. Currently the gamma-ray community is preparing to build the next-generation Cherenkov Telecope Array (CTA), which will be operated as an open observatory. Gammapy (available at this https URL under the open-source BSD license) is a new in-development Astropy affiliated package for high-level analysis and simulation of astronomical gamma-ray data. It is built on the scientific Python stack (Numpy, Scipy, matplotlib and scikit-image) and makes use of other open-source astronomy packages such as Astropy, Sherpa and Naima to provide a flexible set of tools for gamma-ray astronomers. We present an overview of the current Gammapy features and example analyses on real as well as simulated gamma-ray datasets. We would like Gammapy to become a community-developed project and a place of collaboration between scientists interested in gamma-ray astronomy with Python. Contributions welcome!

Comments: For more information about Gammapy visit this https URL, corrected typo in author list, removed latex commands in abstract
Subjects: **Instrumentation and Methods for Astrophysics (astro-ph.IM)**
Cite as: **arXiv:1509.07408 [astro-ph.IM]**
(or **arXiv:1509.07408v2 [astro-ph.IM]** for this version)

Software use in Astronomy — An informal survey

- Not everyone is using FTOOLs!
- Python has replaced IDL as #1 language in Astronomy
- The Astropy project started in 2011 and has become the standard core package for thousands of users (Hubble, JWST, Chandra, …)
- I have personally met several users that are comfortable using Python functions and classes.
- :-)

2015arXiv150703989M

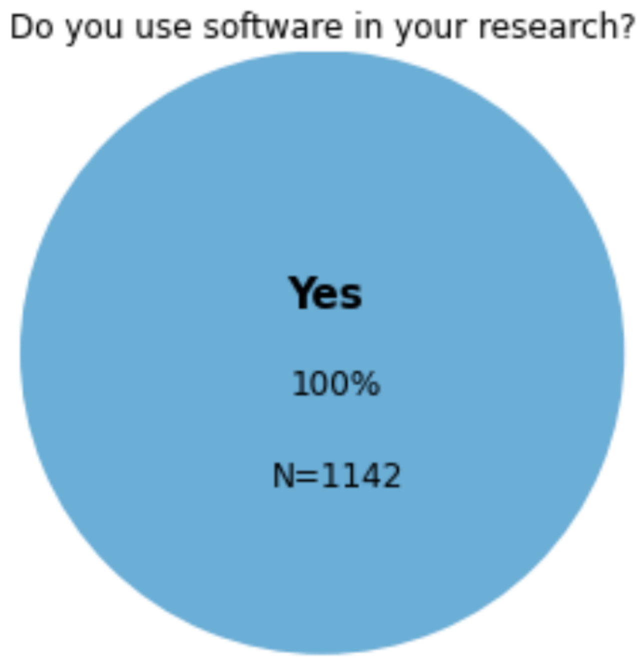
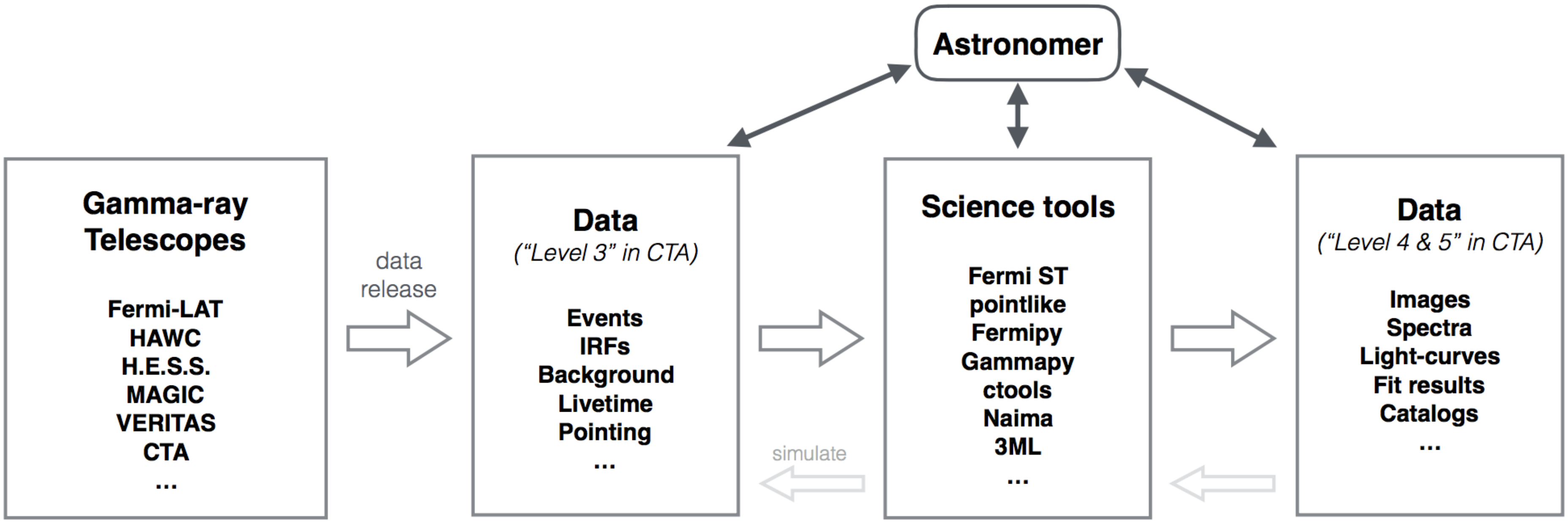


FIG. 2.— Responses to the question "Do you use software in your research?". 100% of survey participants answered in the affirmative.

Gammapy context

Several instruments producing high-level FITS data.
Always very similar, but different in detail.



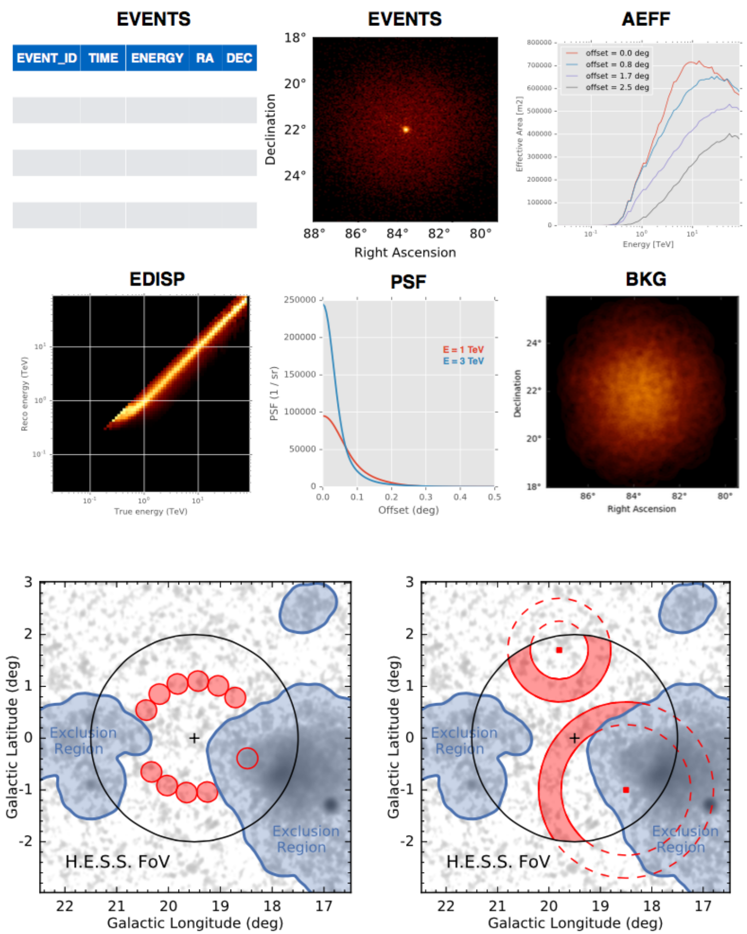
Open and reproducible science a big topic now.
Many projects and people develop their tools as open source.

Gammapy

- A prototype for the CTA science tools (proposed in Kashiwa)
- A Python package for gamma-ray astronomy, built on Python, Numpy, Scipy, Astropy
- 27k lines of code, 21 contributors
- So far mostly used for H.E.S.S. (e.g. Galactic plane survey)
- Now with the first data challenge, focus is moving more to CTA

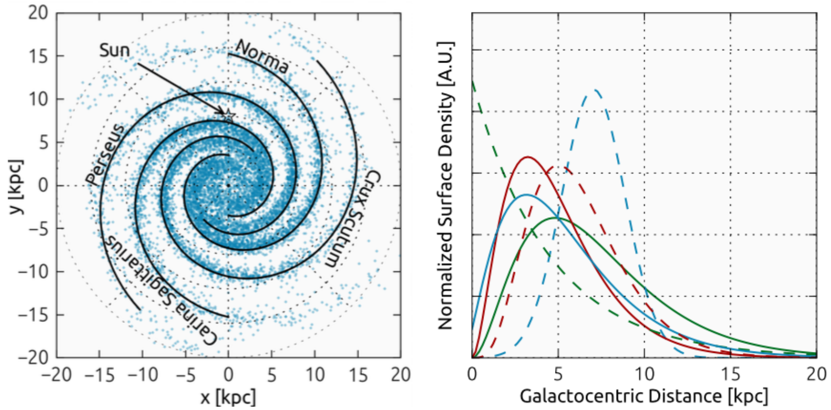
Gammapy features

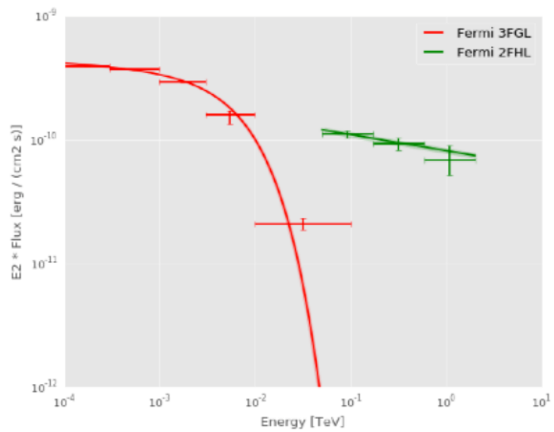
- **gammapy.data & gammapy.irf**
  IACT DL3 data handling
- **gammapy.image**
  2-dim image analysis
- **gammapy.spectrum**
  1-dim region spectral analysis
- **gammapy.background**
  Background modeling methods
  (might merge in image, spectrum cube)
- **gammapy.cube**
  3-dim cube analysis (work in progress)
- **gammapy.detect**
  Source detection (image-based for now)



Gammapy features

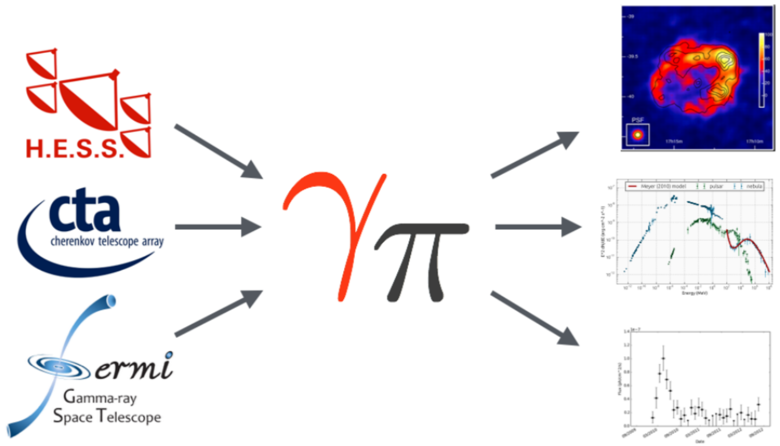
- **gammapy.stats**
  Statistics methods
- **gammapy.time**
  Time analysis (not much available yet)
- **gammapy.catalog**
  - Fermi-LAT spectra, lightcurves
  - Next: TeV data (gamma-cat)
- **gammapy.astro**
  Some simple models for Galactic sources and source populations
  (could go in separate higher-level science package)
- **gammapy.scripts**
  Command line interface (CLI) tools for common operations
  (not much available yet, see comments on science too user interface in backup slides)

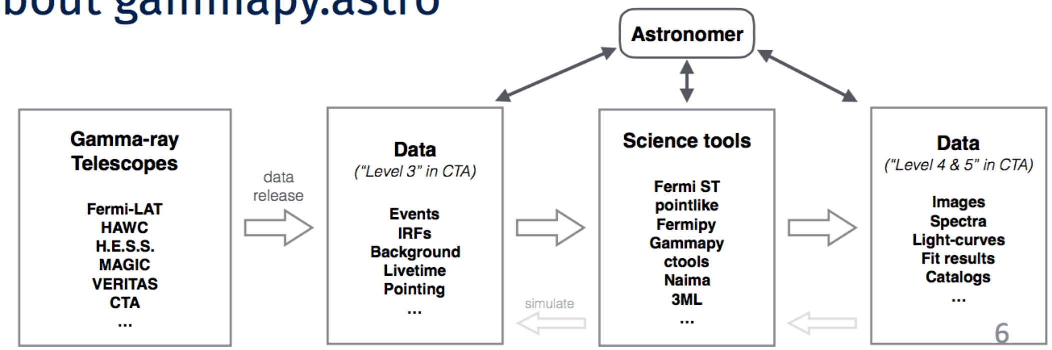




Gammapy scope & other projects

- Gammapy scope not set in stone
  Driven by users and contributions
- So far mostly prototyping of IACT DL3 FITS data formats and “classical TeV analysis” applied to H.E.S.S.
- Now project is expanding
  CTA use cases and data challenge
- Started collaborating with Fermipy
  Gammapy is the base package
  Move HEALPix, SED to Gammapy
- Astro model efforts are currently scattered (Naima, Gamera, …)
  Will have to see what to do about gammapy.astro





Gammapy approach

- Gammapy is written in Python, using Numpy, Scipy, Astropy
- For modeling / fitting, we currently use Sherpa
- A few stable, well-maintained, widely used dependencies
- Data in Gammapy objects *(EventList, SkyImage, ...)* or Astropy objects *(Time, SkyCoord, WCS, ...)* is stored as Numpy arrays

Gammapy approach benefits

- *"Standing on the shoulders of giants ..."*
- Gammapy codebase is small and focused on gamma-ray astronomy
- Single high-level language codebase that's easy to use, read and extend
- Interoperable (Numpy arrays) with larger scientific Python ecosystem: iminuit, emcee, Fermipy, naima, pint, ...
- Connected to the large scientific and specifically astronomy Python community