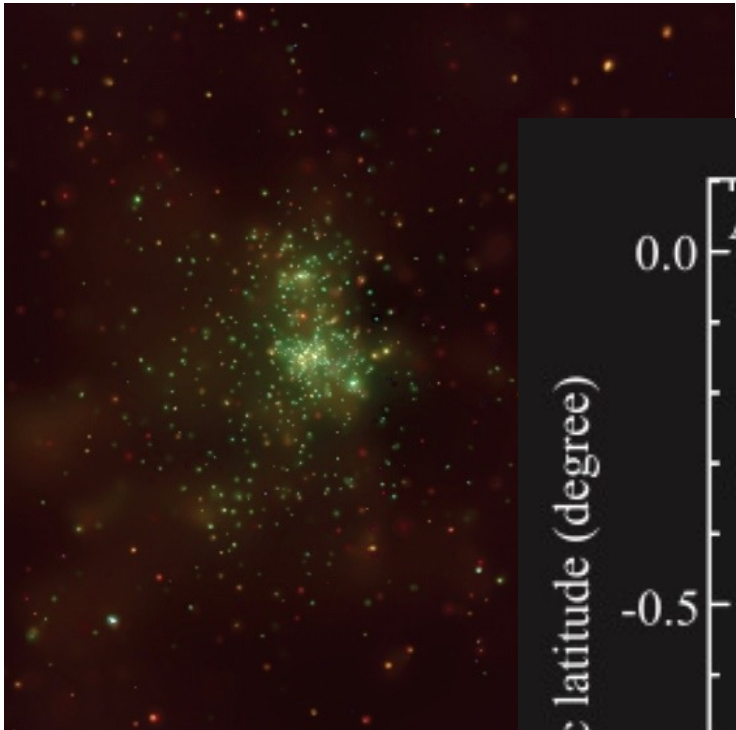
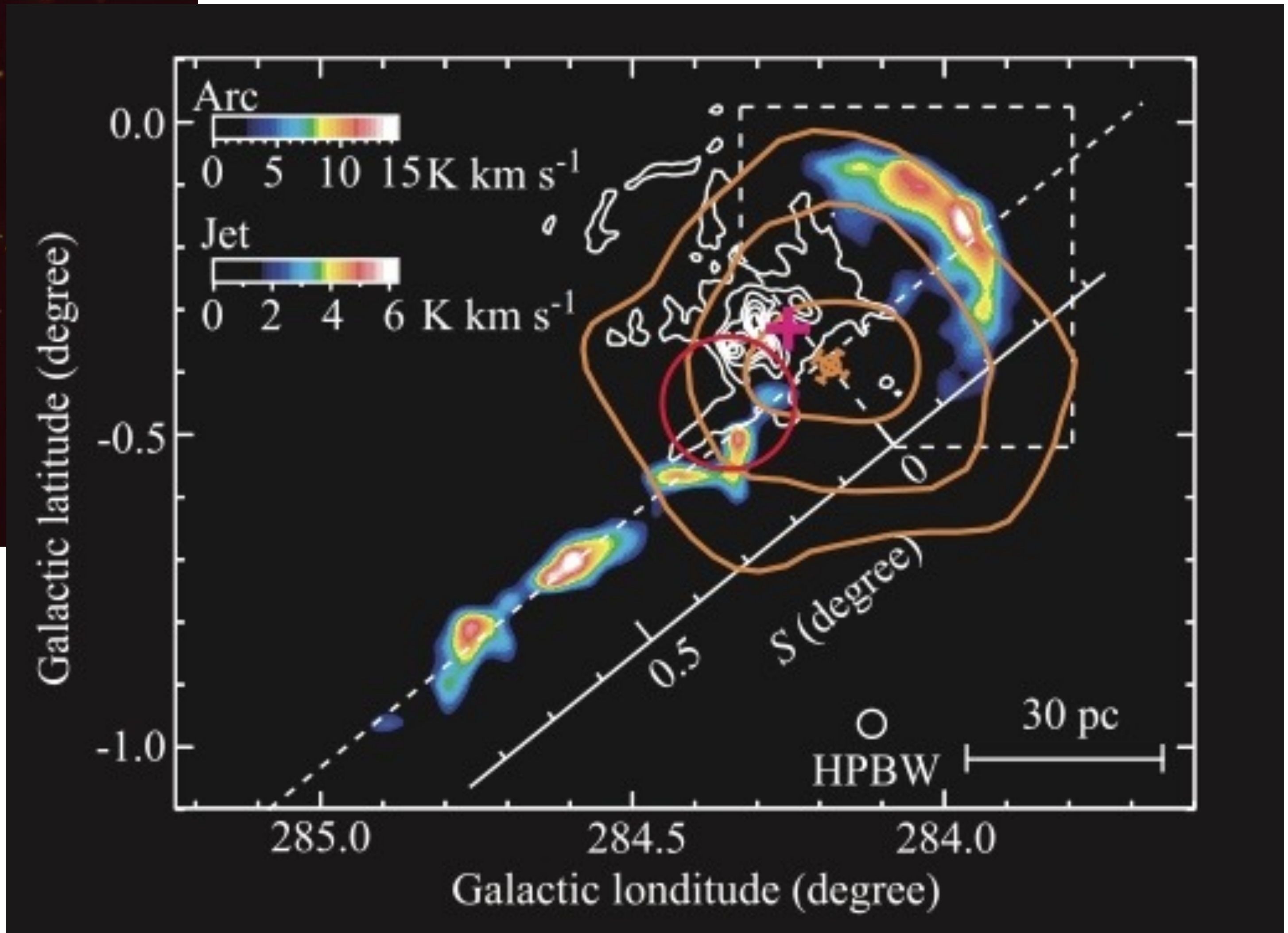
Astrofisica Nucleare e Subnucleare

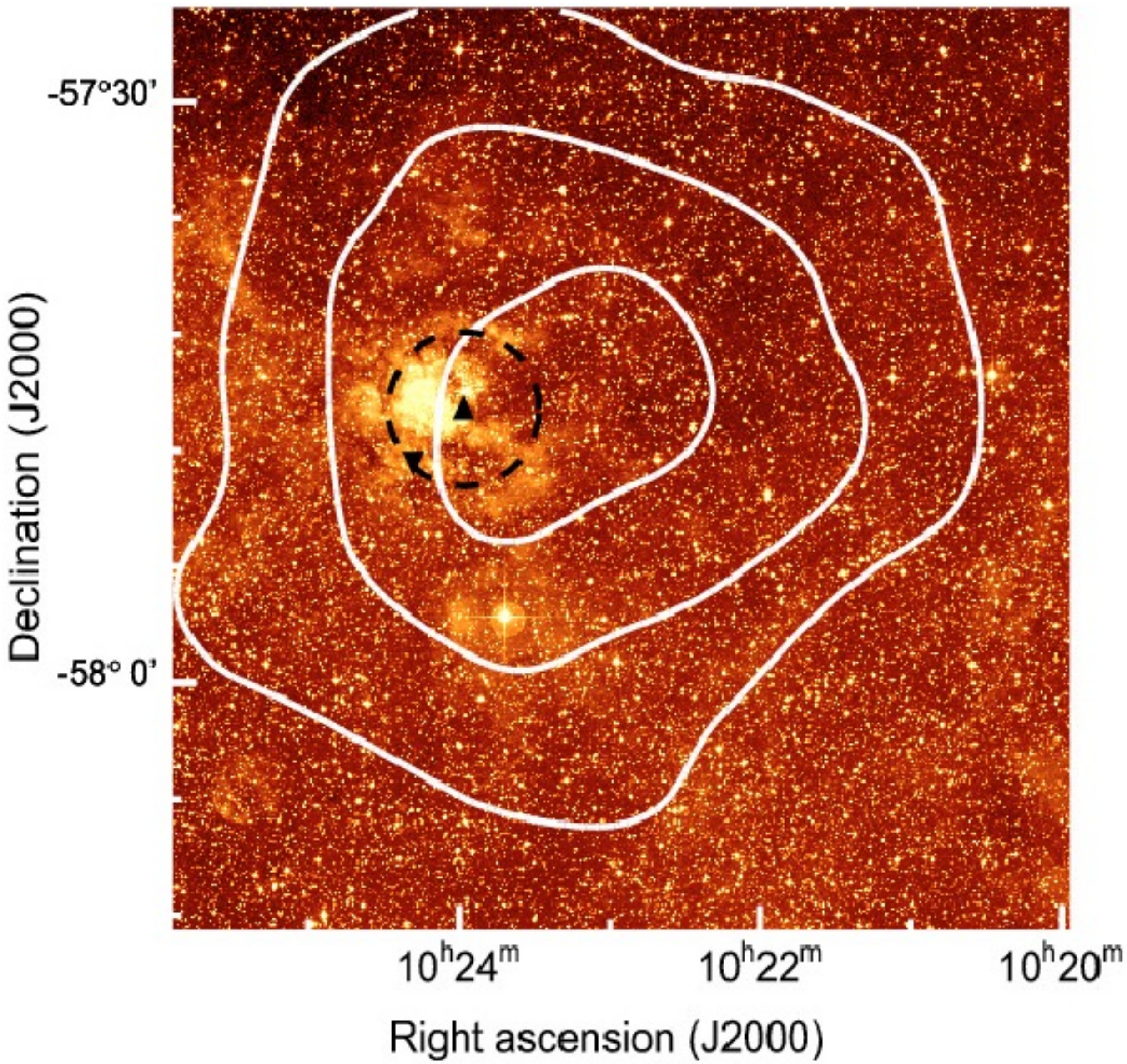
TeV Astrophysics

Star clusters

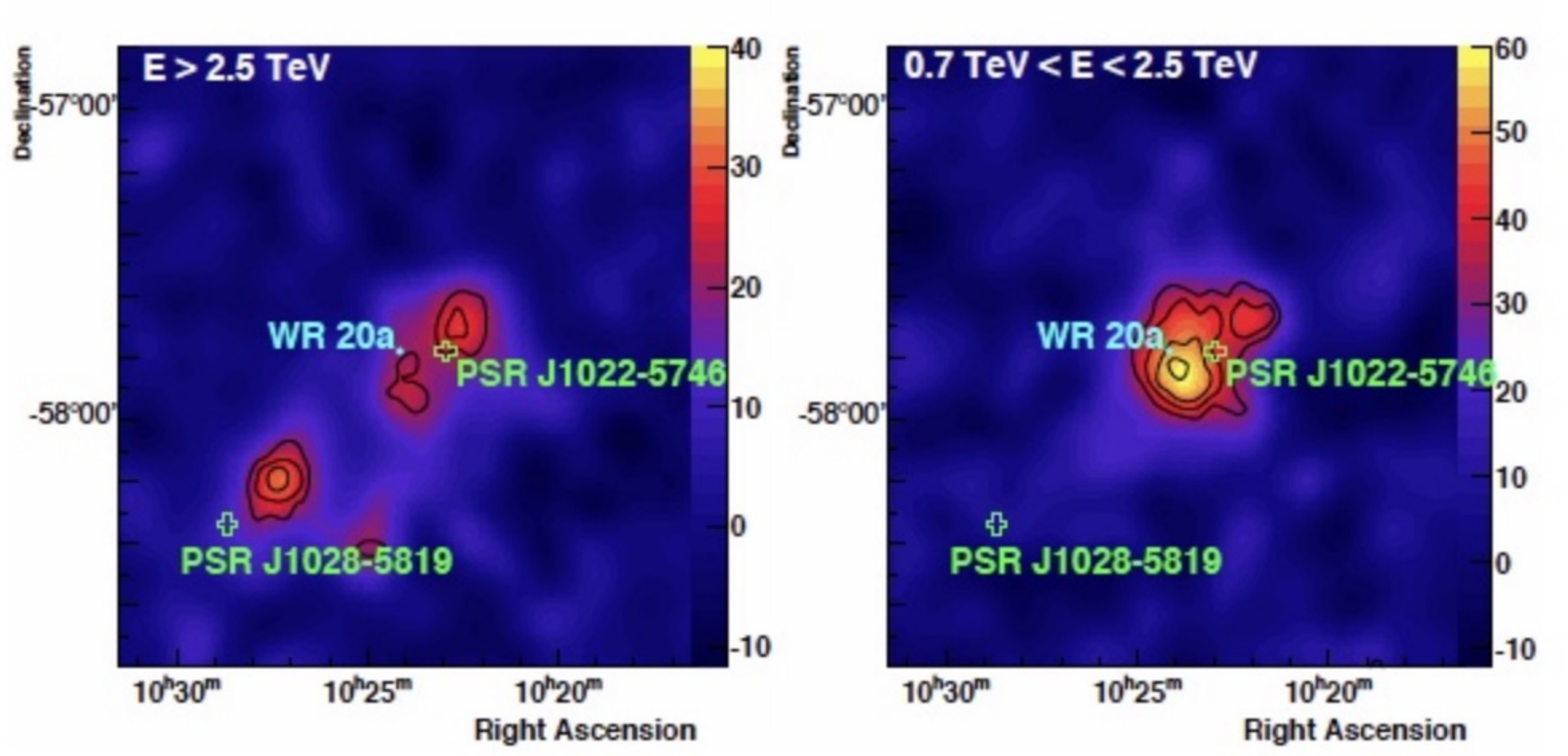




Star clusters

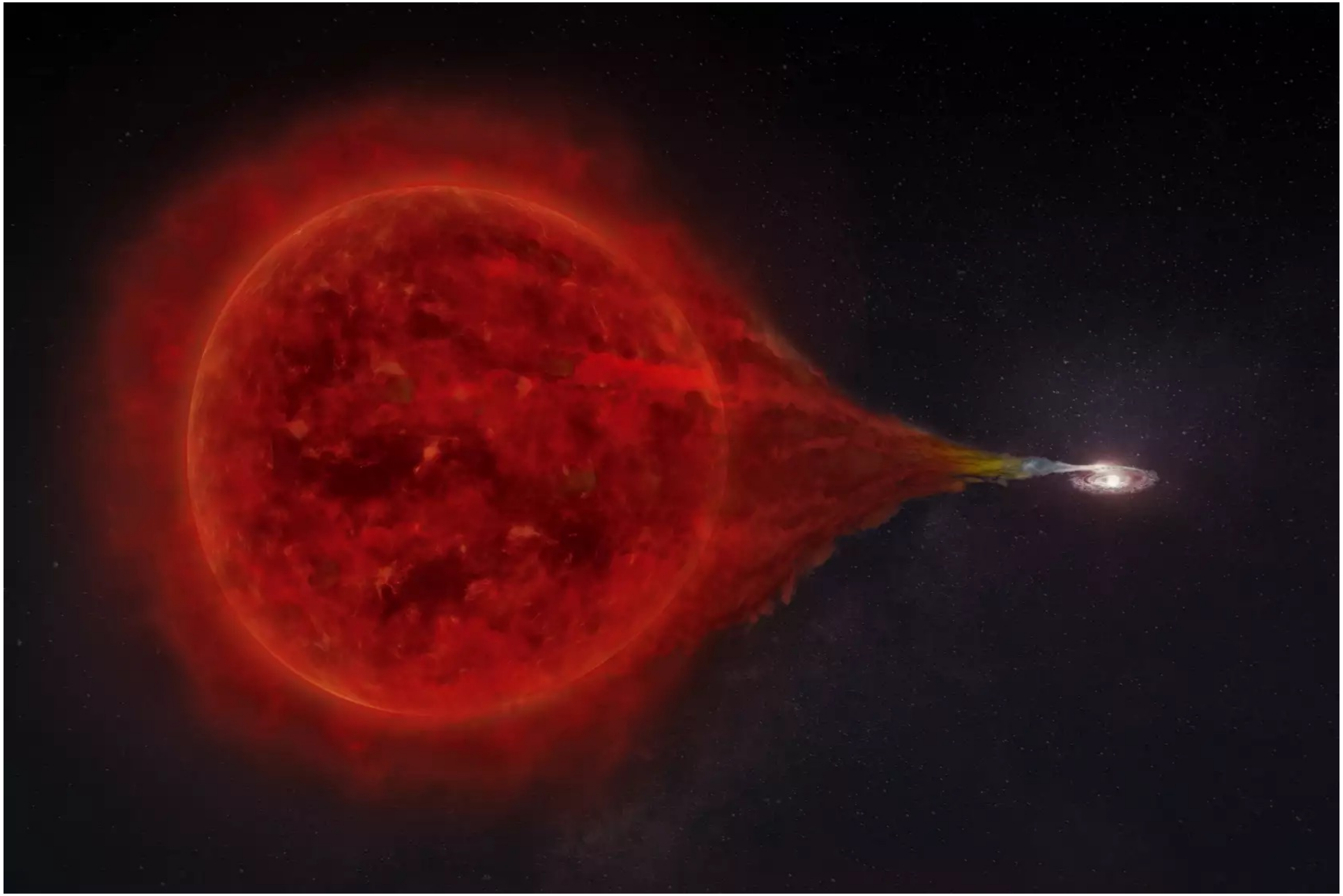


Star clusters

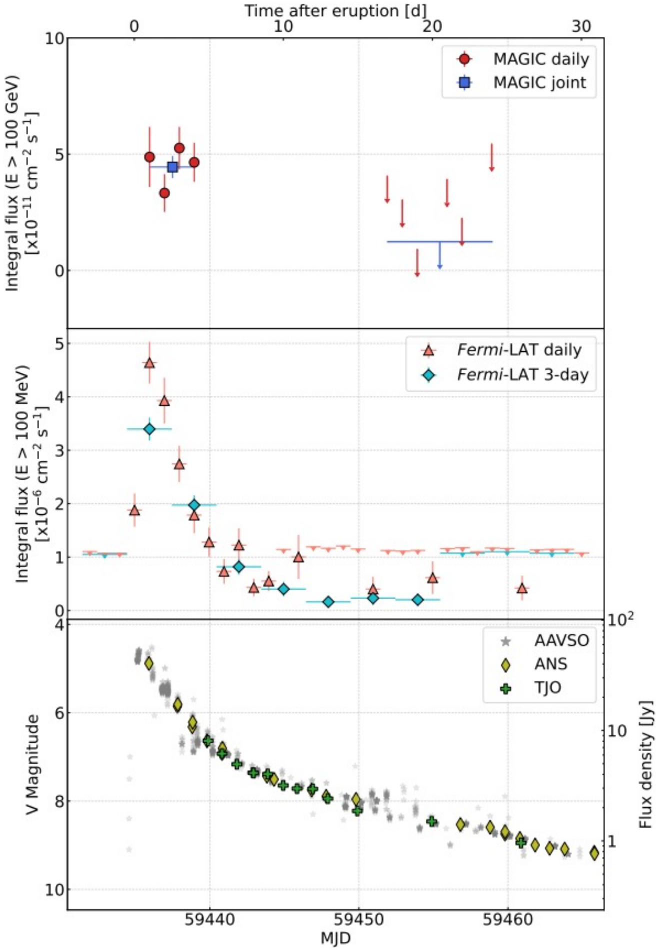


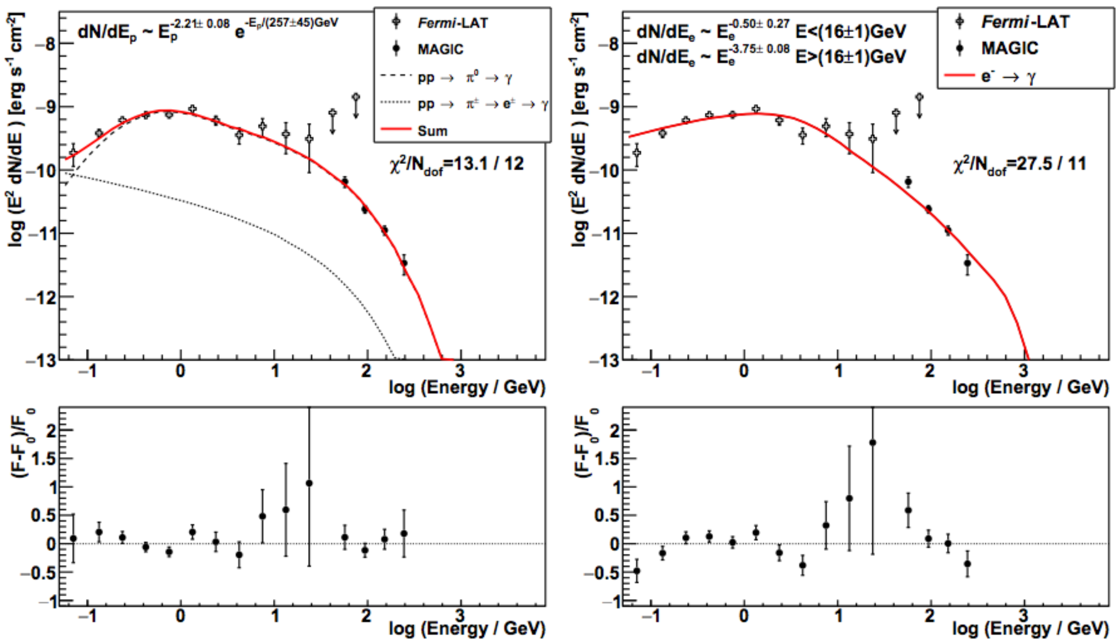
https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2010/04/

Novae



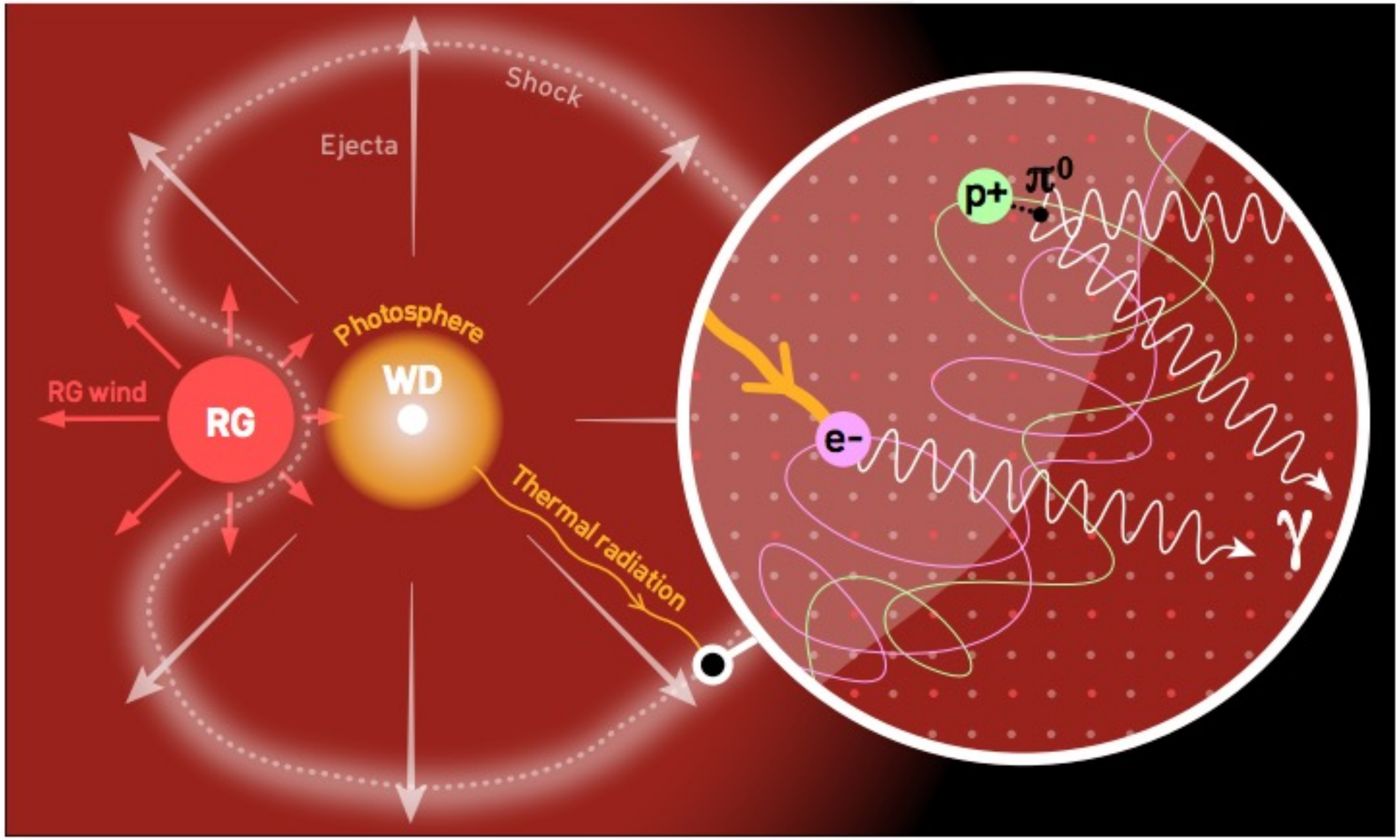
Novae





https://arxiv.org/pdf/2202.07681

Novae



https://arxiv.org/pdf/2202.07681

Astrofisica Nucleare e Subnucleare

VHE Extra Galactic Sources

The unexplored spectrum gap

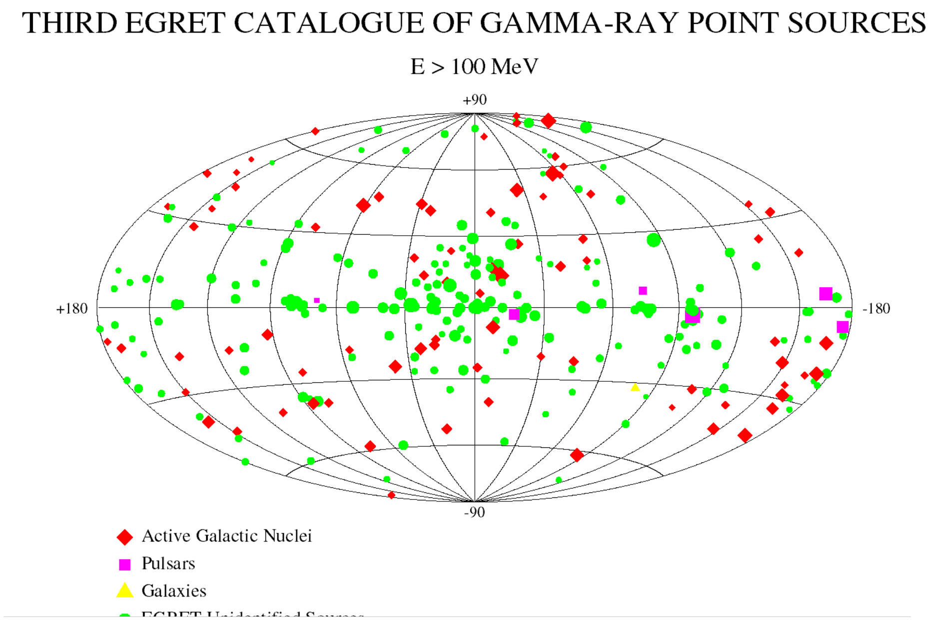
- γ-ray sources observed with EGRET satellite (E < 10 GeV)
- 271 sources (171 unidentified)

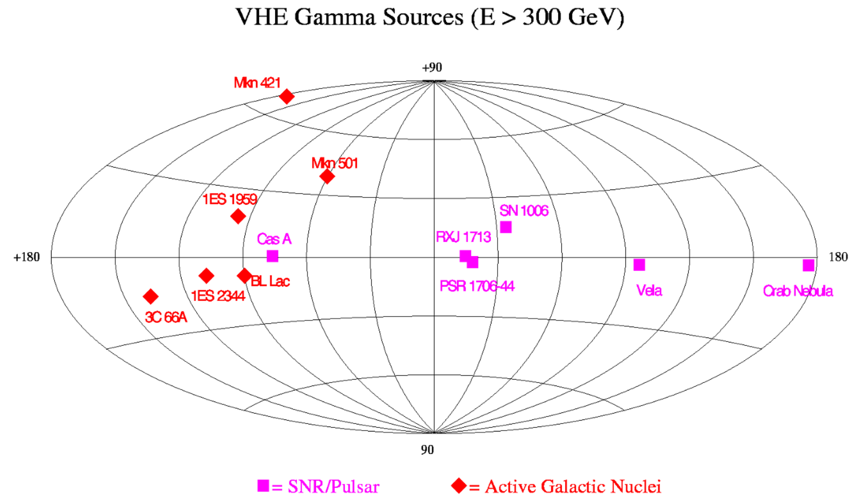
Satellite effective area < 1 m^2

- Old generation ground-based experiments observe few sources with E > 300 GeV.

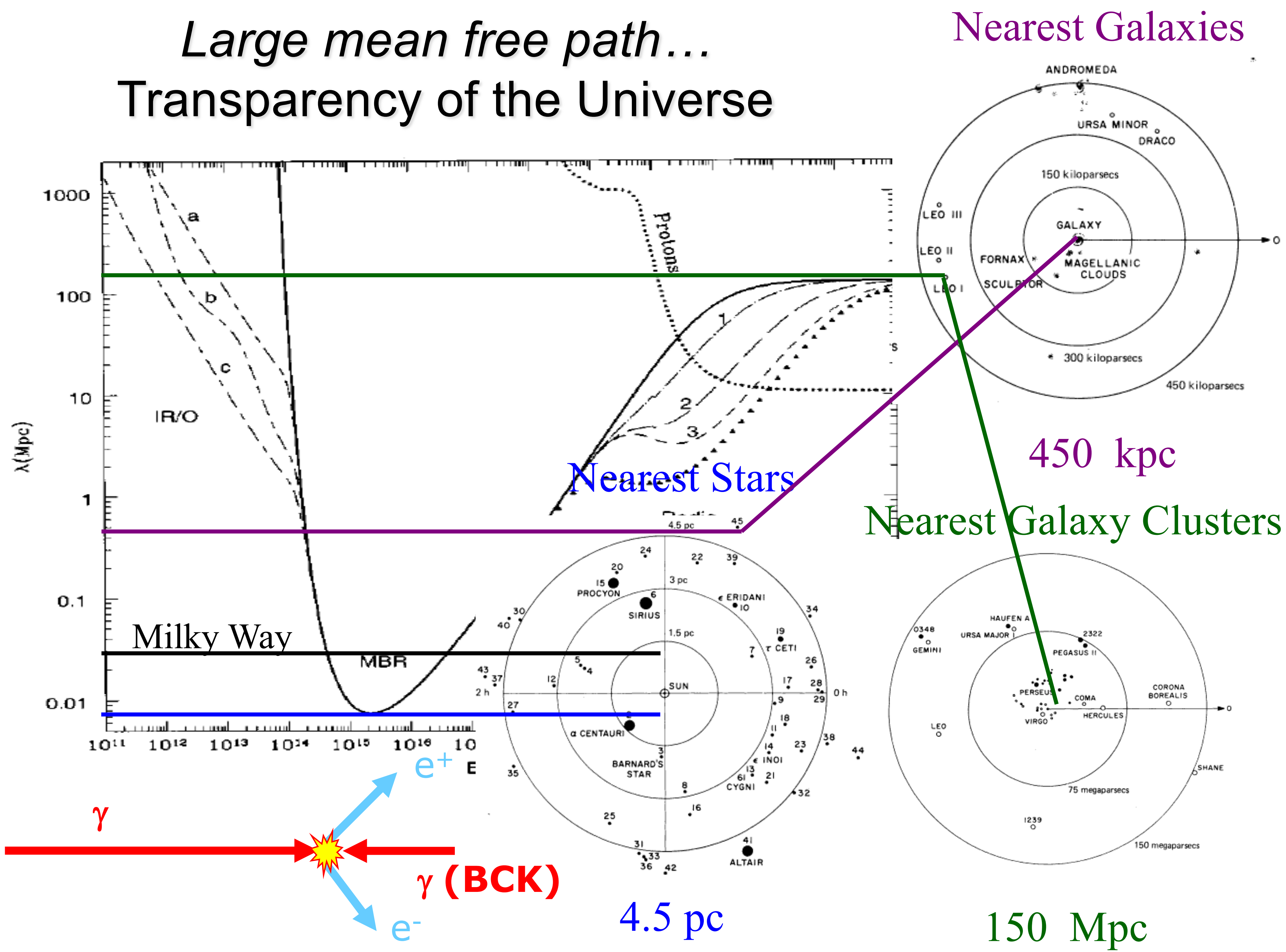
Effective area > 10^4 m^2

Strong cutoff in γ-spectrum for 30 Gev < E < 300 GeV
Explore energy gap with MAGIC

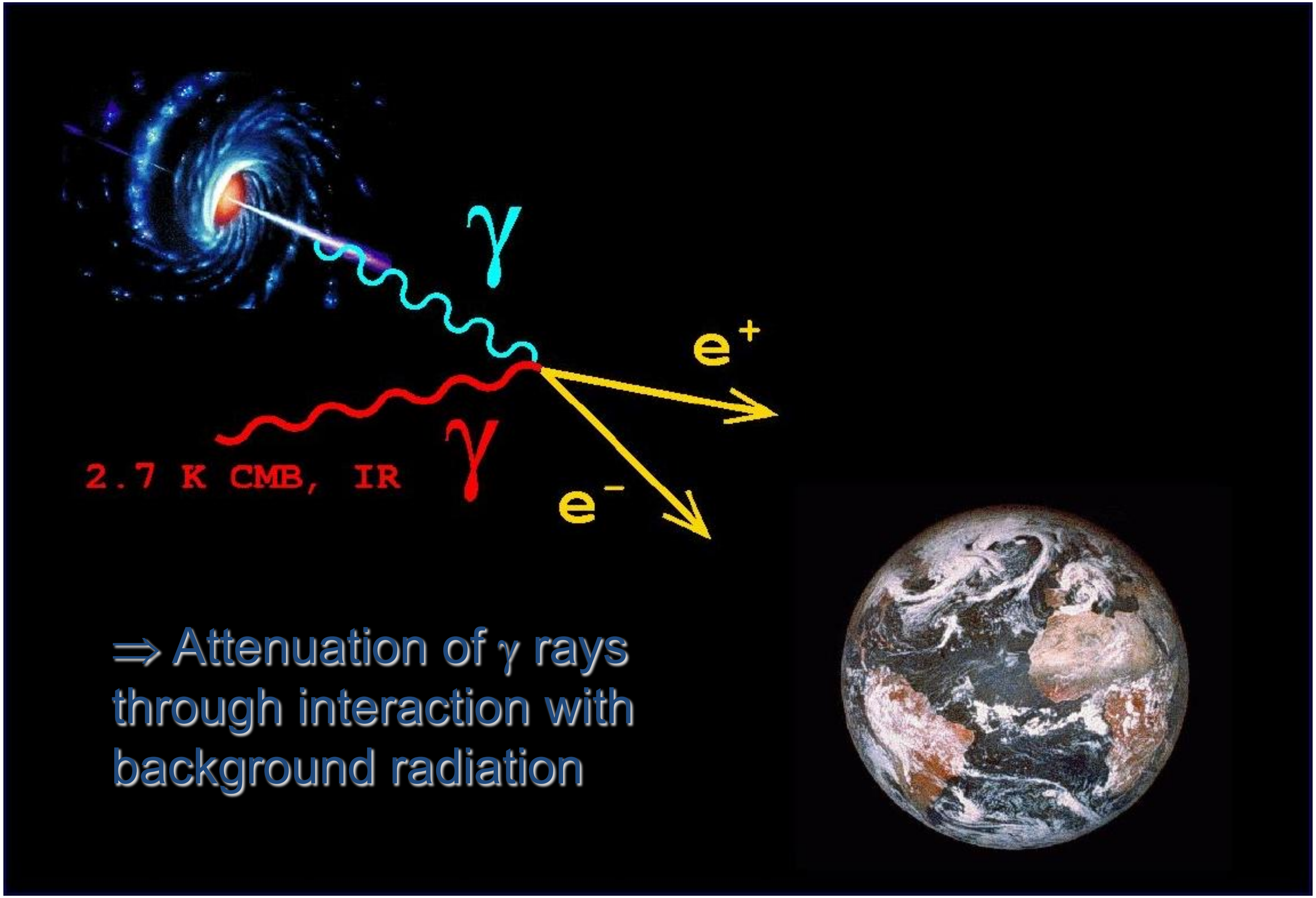




Large mean free path…
Transparency of the Universe



Photon Propagation Effects



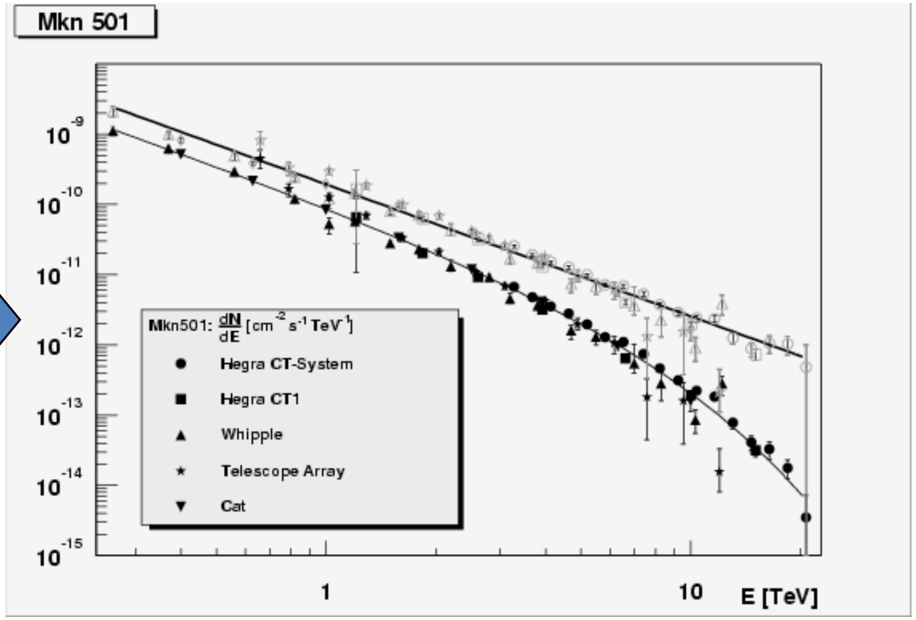
Gamma Ray Horizon

Any γ that crosses cosmological distances through the universe **interacts with the EBL**

$$\gamma_{HE}\,\gamma_{EBL} \rightarrow e^{+}\,e^{-} \quad \longrightarrow \quad E\varepsilon(1-\cos\theta) > 2\left(m_e c^2\right)^2$$

The absorption effect seen on a nearby blazar

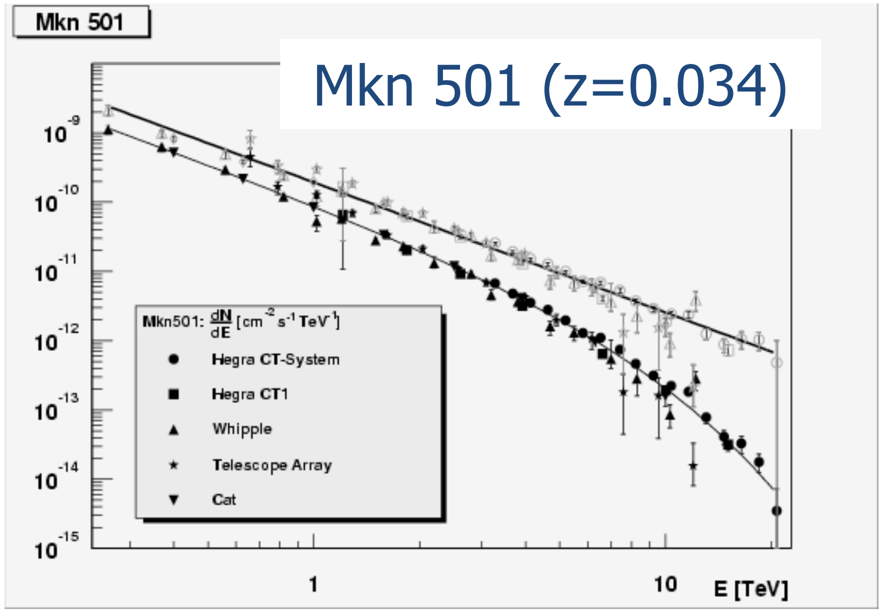
Mkn 501 (z=0.034)

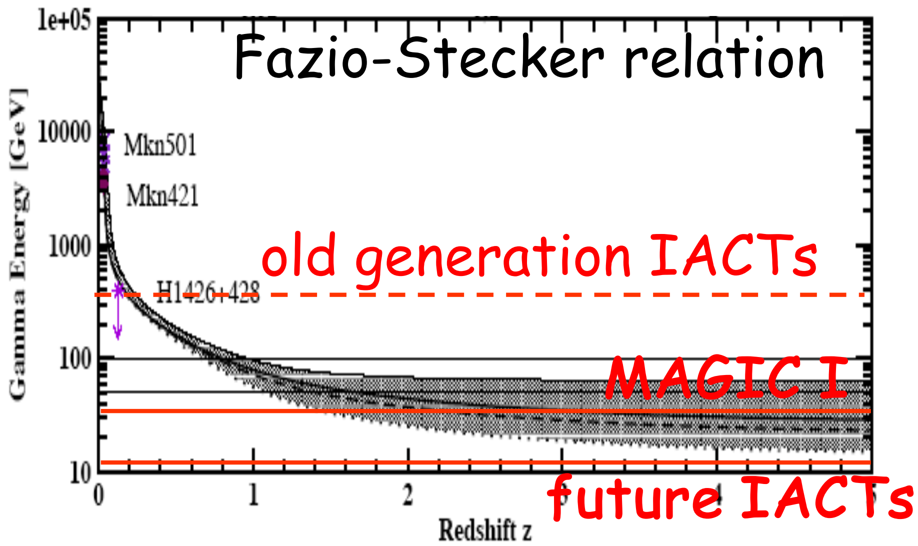


Gamma Ray Horizon

γ-rays traveling cosmological distances **interact** with **Extragalactic Background Light (EBL)**

$$\gamma_{HE}\,\gamma_{EBL} \rightarrow e^{+}\,e^{-}$$



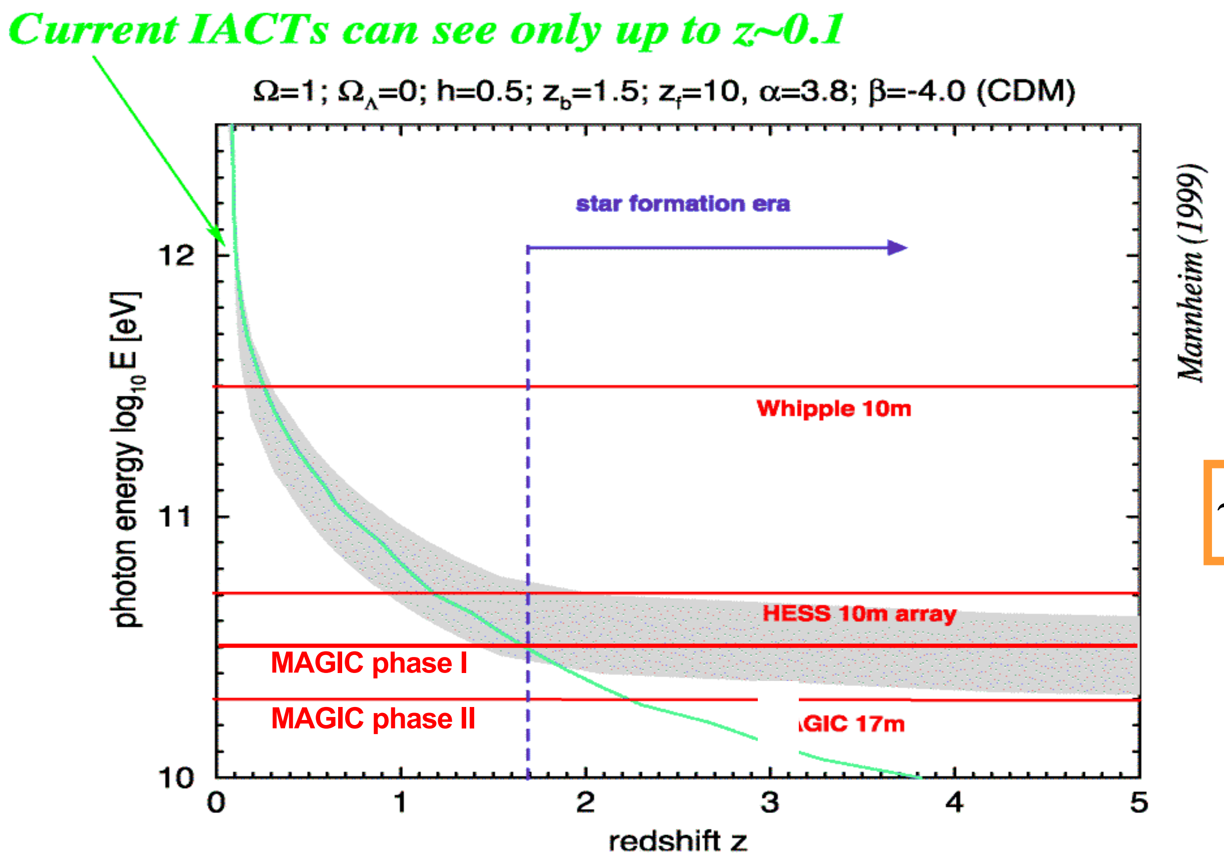


- lower energy threshold
  => observe more distant sources

- Absorption increases with energy of **γ-rays**
- Absorption leads to cutoff in AGN spectrum
- Measurement cutoff of several sources allows extraction of EBL

Gamma ray horizon (GRH)

Defined as the distance for which the optical depth for pair production process is τ = 1 (i.e. a reduction 1/e of the flux of the extragalactic source).



$$\tau(E, z) = 1$$

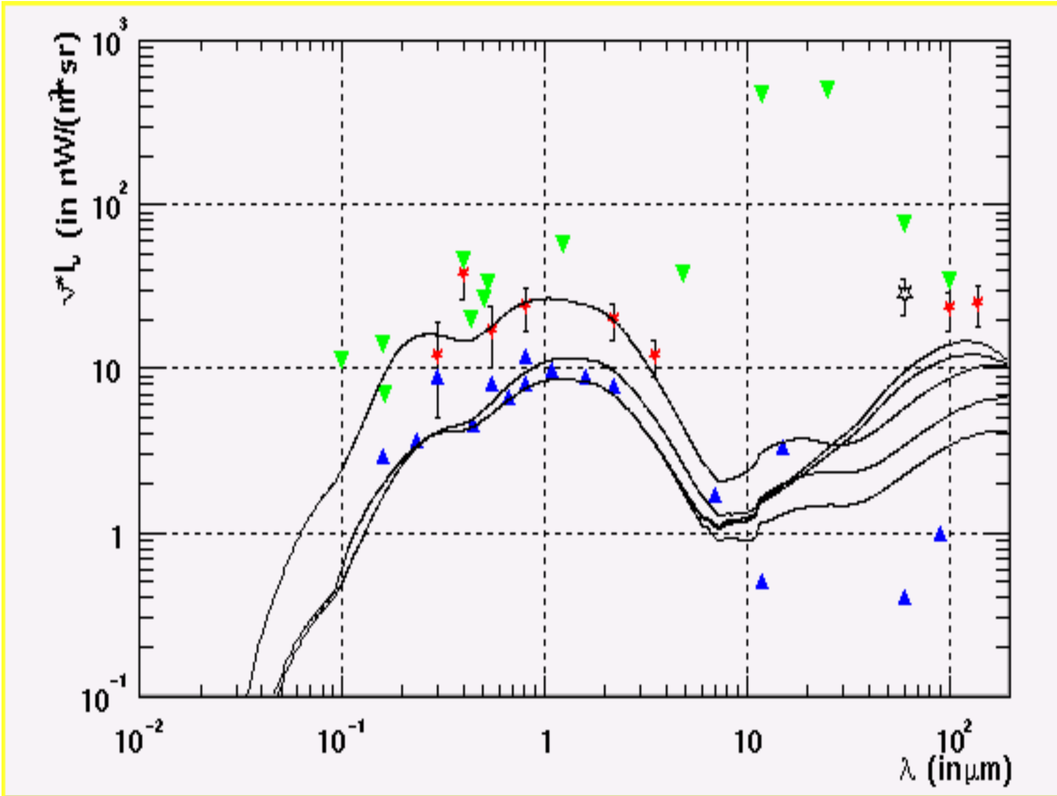
Extragalactic absorption

For the energy range of IACTs (10 GeV - 10 TeV), the interaction takes place with the **infrared** (0.01 eV - 3 eV , 100 μm - 1 μm).

Origin

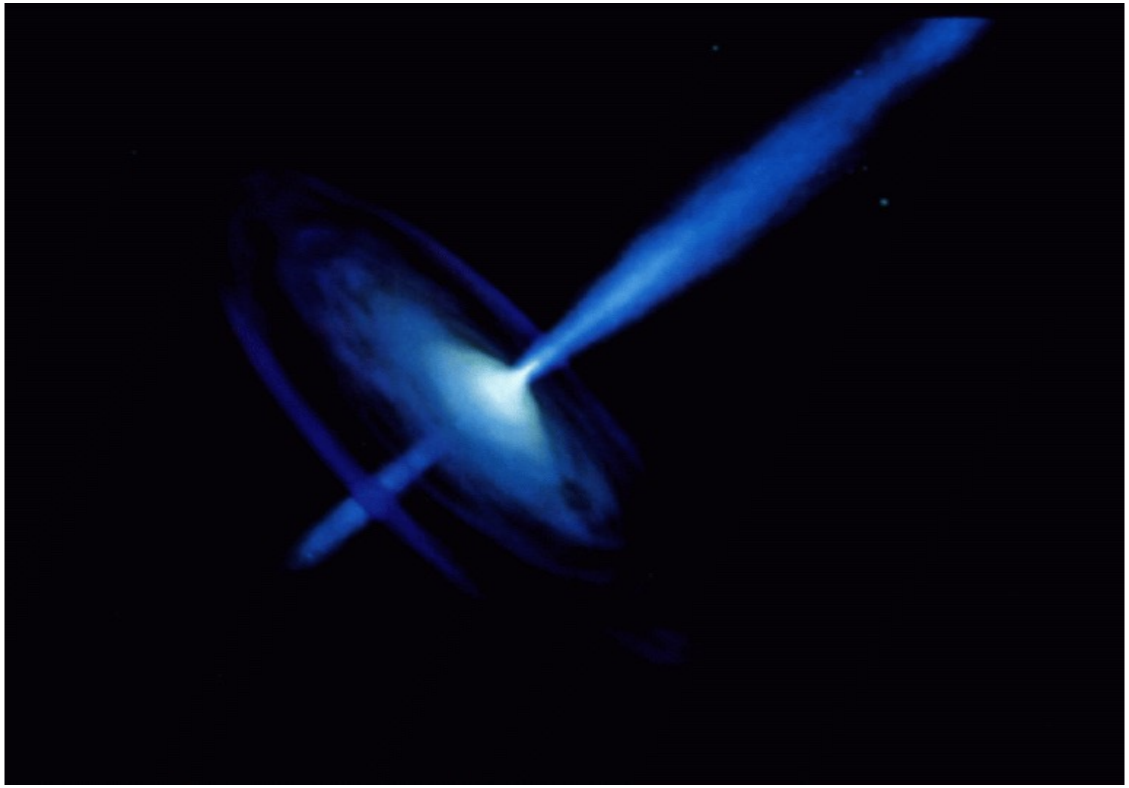
- Star formation
- Radiation of stars
- Absorption and reemission by ISM

By measuring the cutoffs in the spectra of AGNs within the, MAGIC can help in determining the IR background

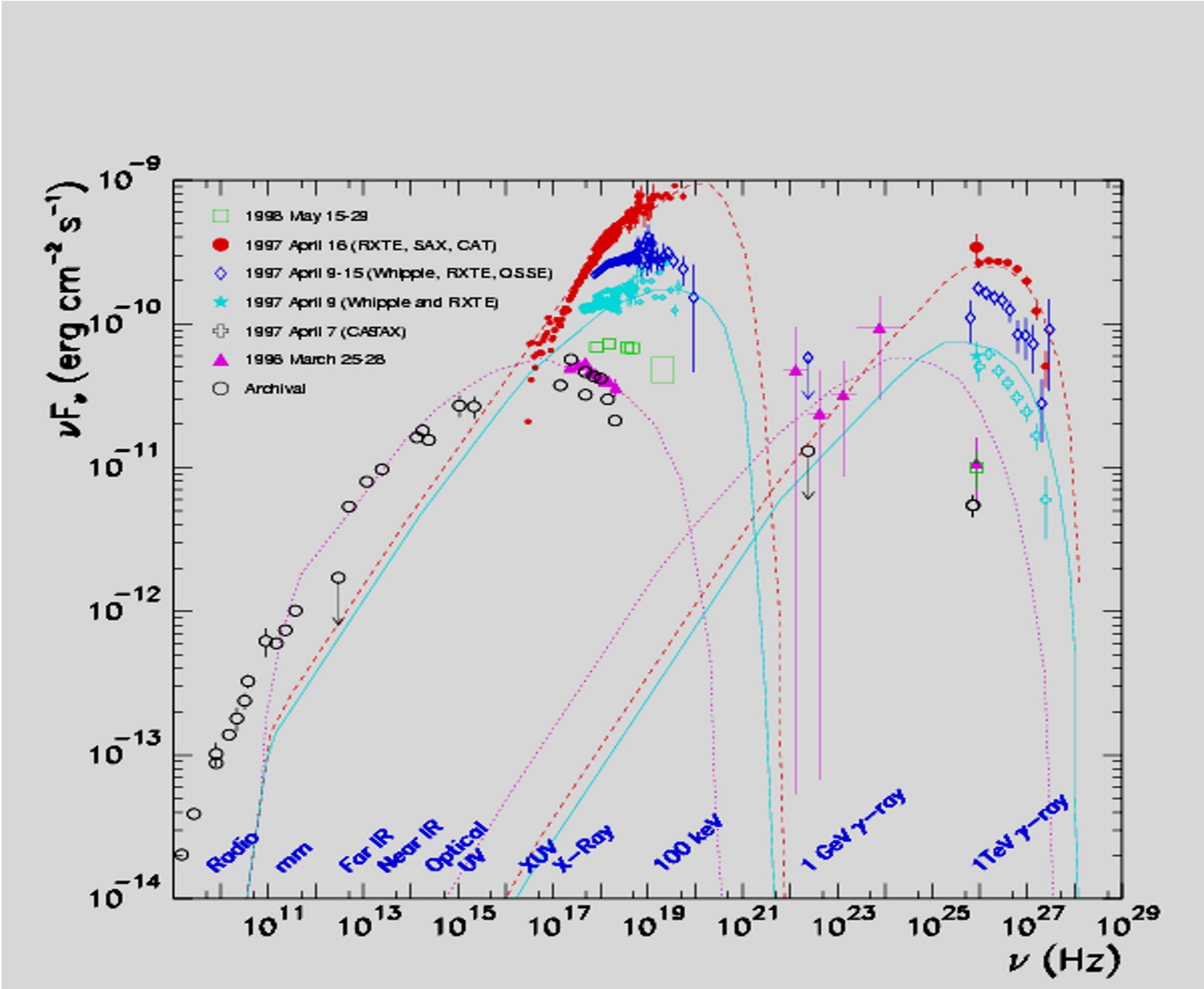


Extragalactic Sources

- Physics of AGN jets
- Cosmological extragalactic background light (EBL)



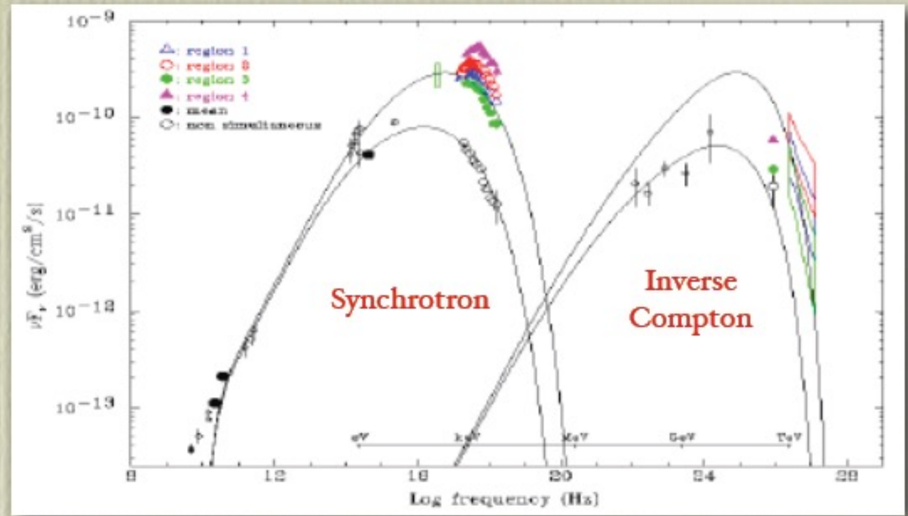
Active Galactic Nuclei



γ-ray Astronomy and Cosmic Rays

- Search for the sources of Cosmic Rays
- Investigate acceleration mechanisms
- γ-rays can be traced back to the origin

<u>Spectral Energy Distribution (SED)</u>
- characteristic two-peak structure
- competing leptonic and hadronic acceleration models.



Hadron acceleration

proton-proton interaction
p+ (TeV) + matter → π^{o}... → γ γ (GeV)

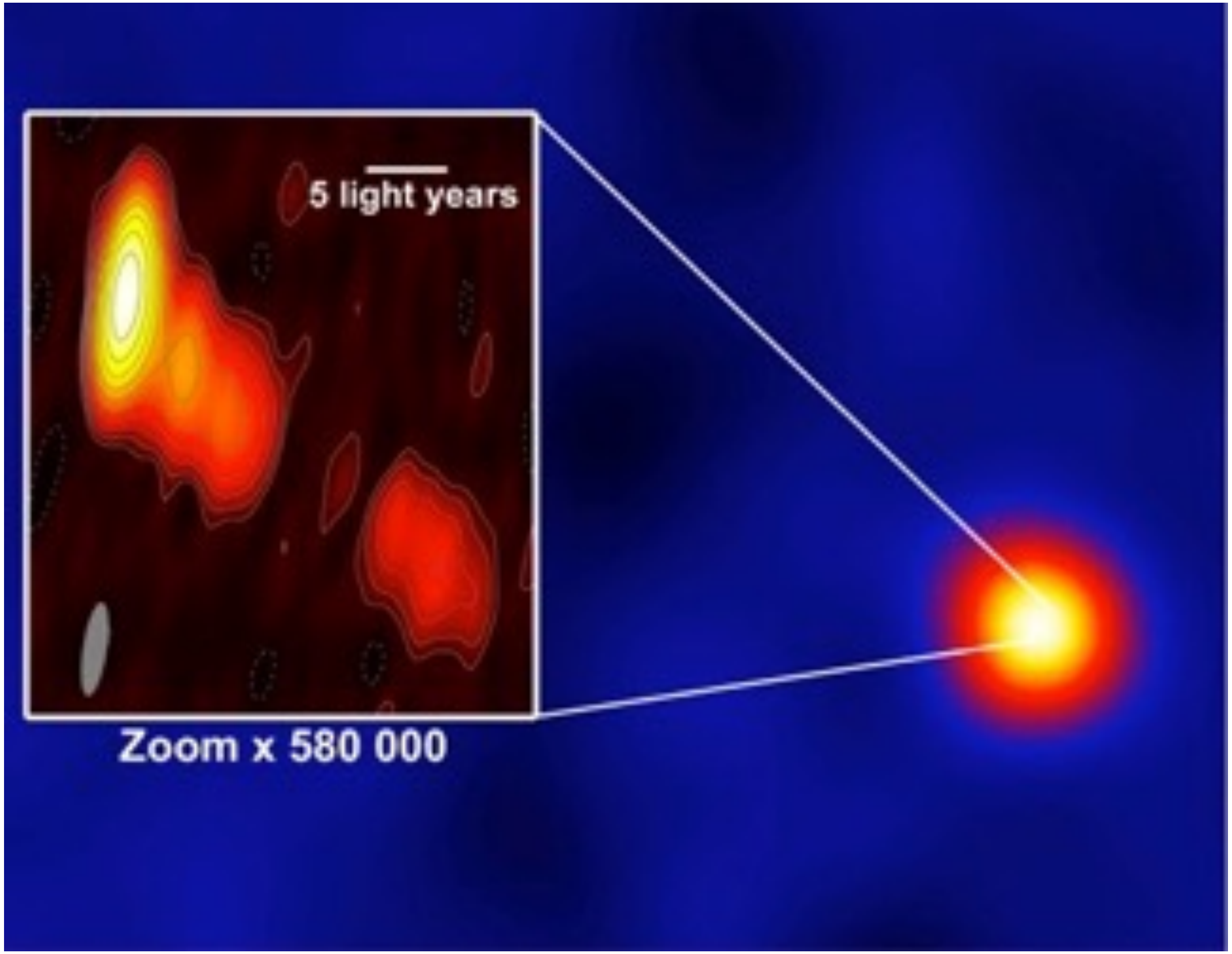
photo-hadron interaction
p+ (TeV) + γ (eV) → π^{o}... → γ γ (GeV)

Electron acceleration

Synchrotron Radiation
e^- + B → e^- + γ (eV-keV)

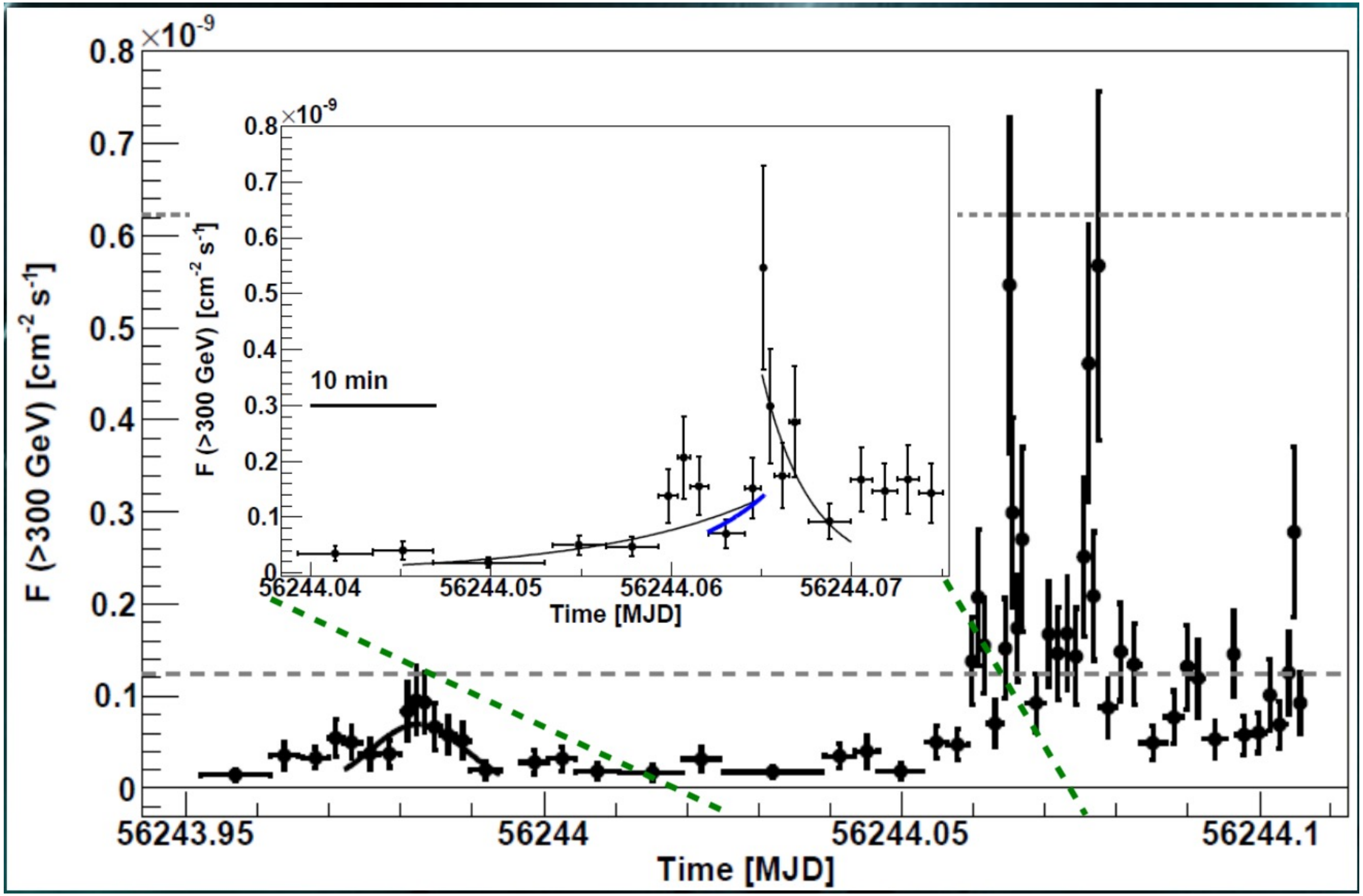
Inverse Compton Scattering
e^- (GeV) + γ (eV) → e^- + γ (GeV)

IC 310



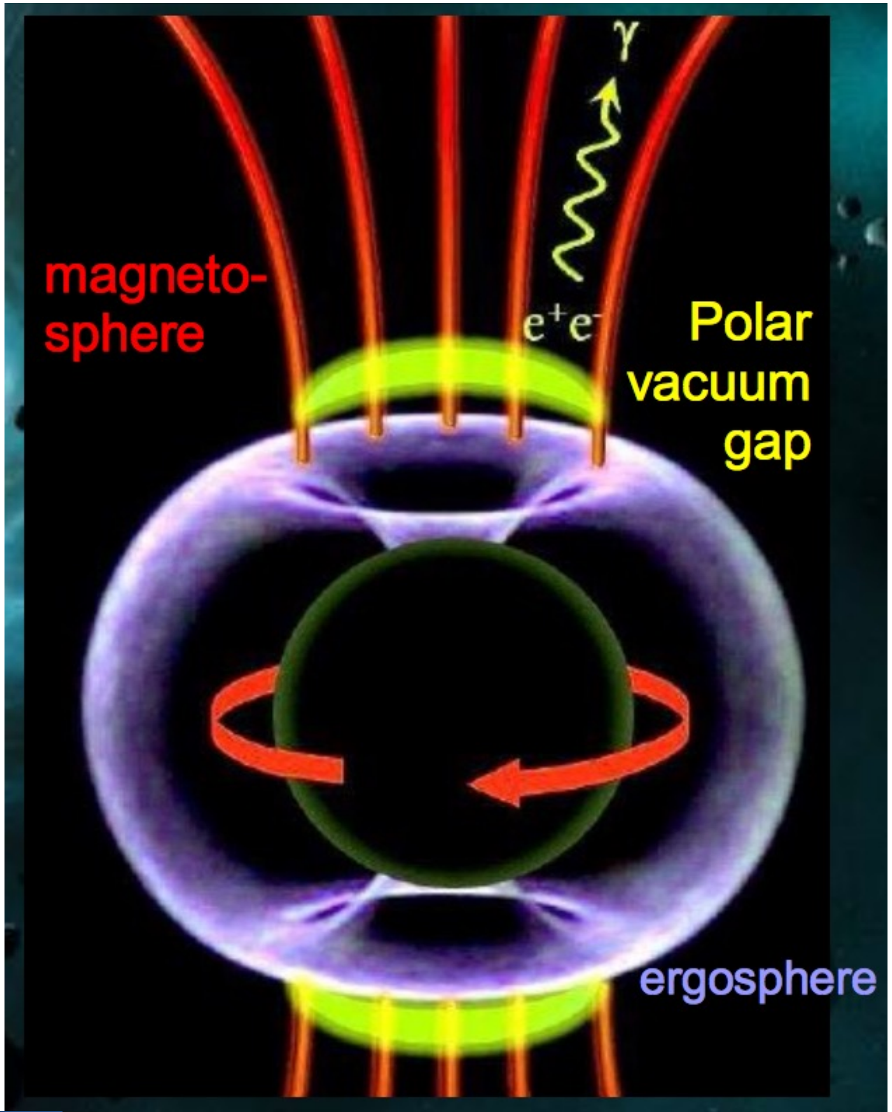
Aleksic et al 2015

IC310



Aleksic et al 2015

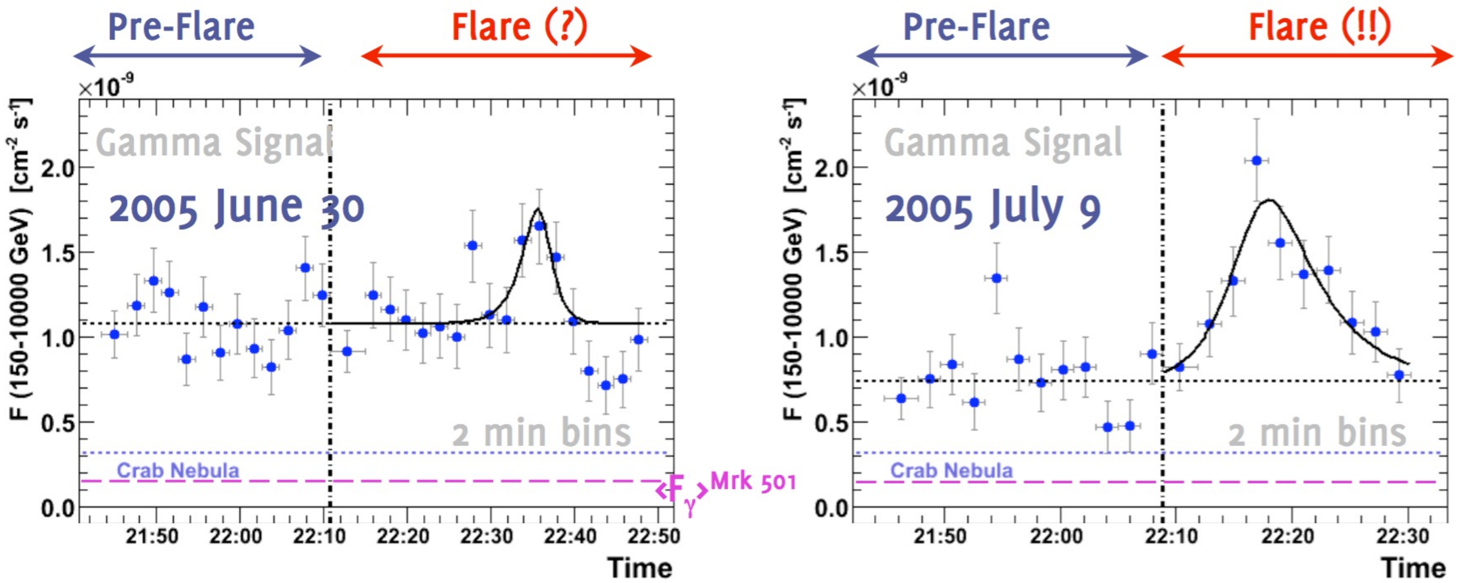
IC310



Aleksic et al 2015

Previous results

The Fastest Variability Observed So Far



Assumption: Flux variation (flare) on the top of a stable emission

b $\left(\frac{10^{-10}\ ph}{cm^2 \cdot s}\right)$	c (s)	d (s)	χ^2/NDF[d]	P [e] (%)
13.2±4.7	81±41	50±23	20.0/15	17.3[f]
20.3±3.3	95±24	185±40	4.2/7	75.8

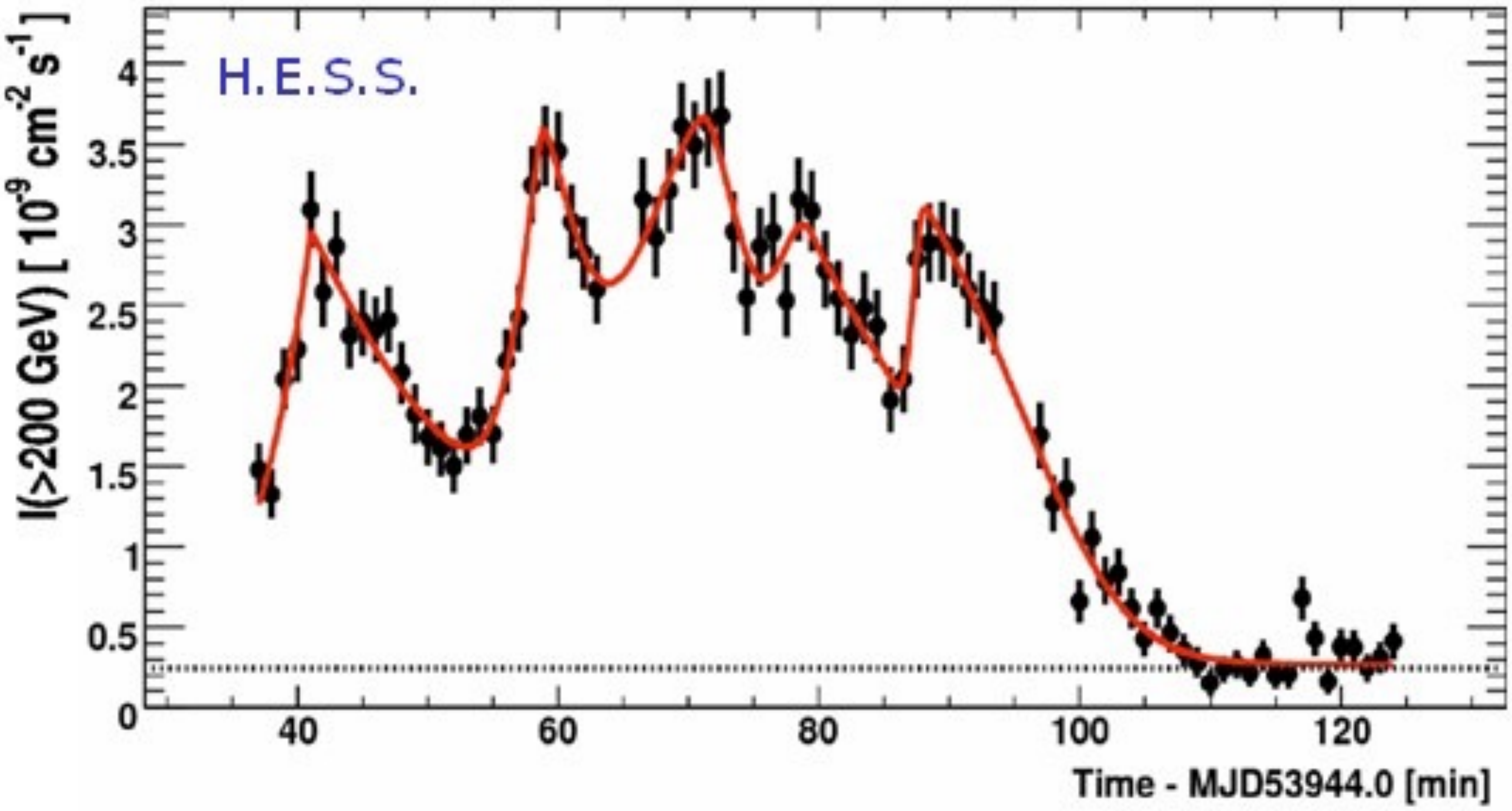
a: pedestal (not fit)

b: amplitude of flux variation

t_0: ~ peak position (not fit)

c, *d*: flux-doubling times

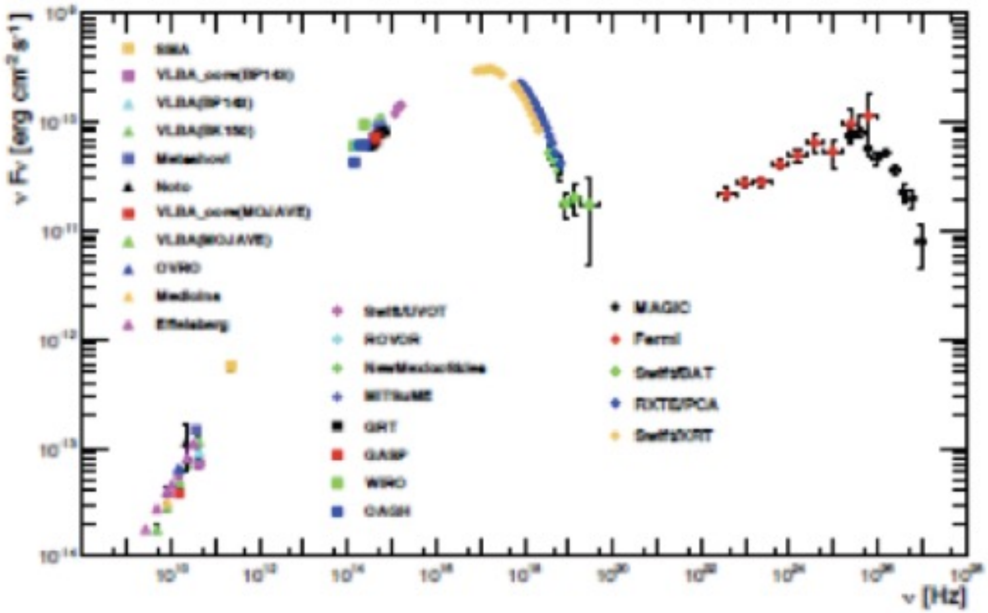
PKS 2155 -304



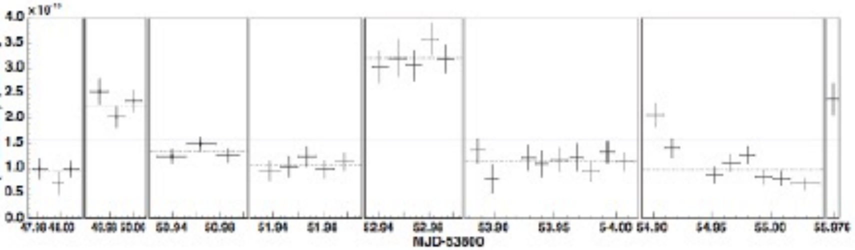
Aharonian et al 2007

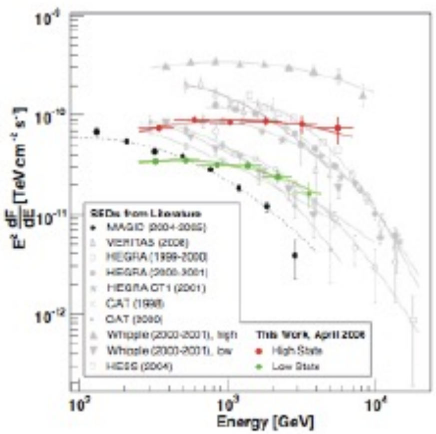
Contact with Fermi

+ Broadband radio-TeV Mrk421

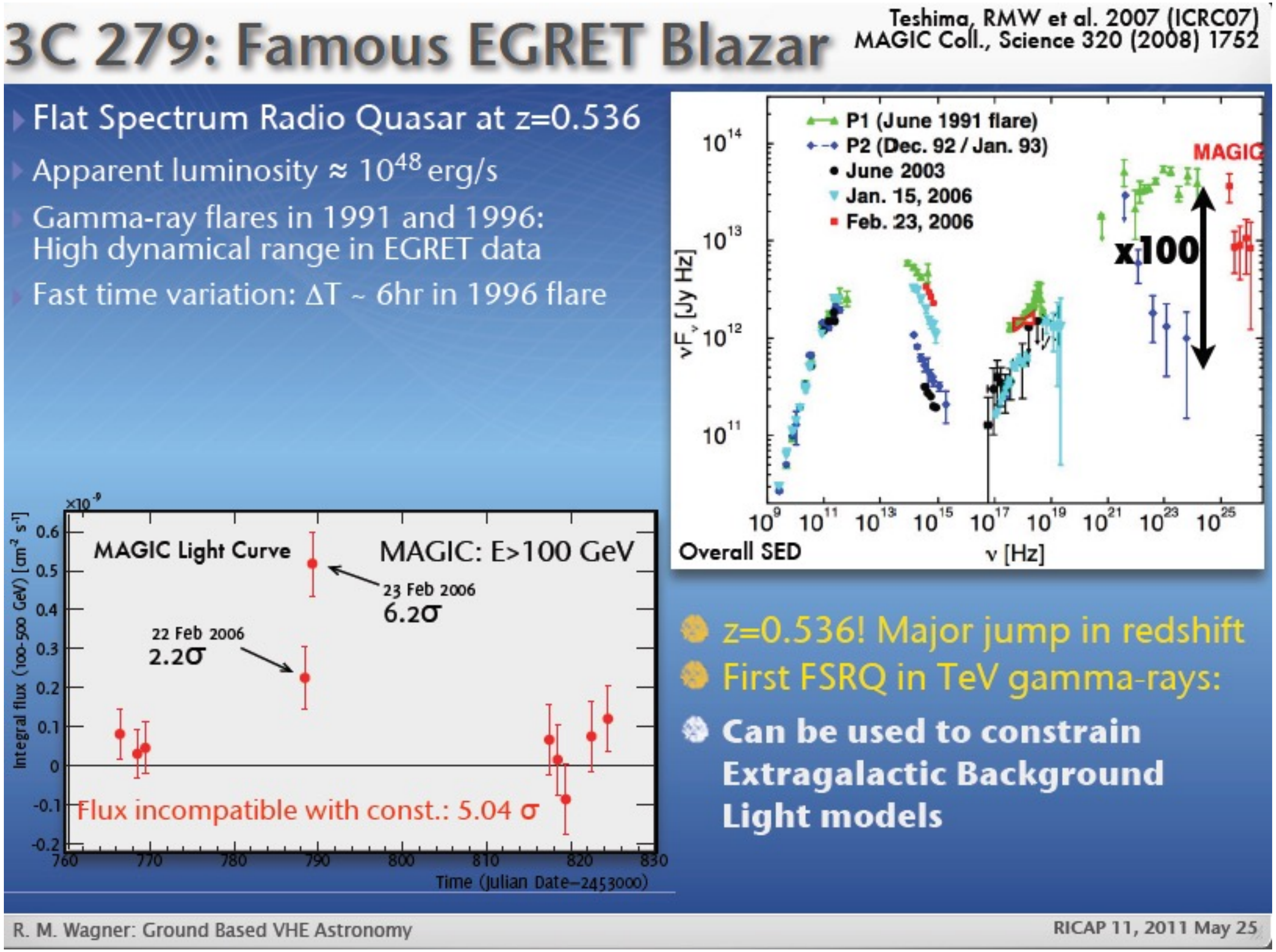


- 4.5 months campaign
- Most complete SED ever collected for Mrk421
- Total Fermi-MAGIC overlap over 5 decades in energy!
- HE-VHE connection!





3c279


3C 279: Famous EGRET Blazar
Teshima, RMW et al. 2007 (ICRC07)
MAGIC Coll., Science 320 (2008) 1752
Flat Spectrum Radio Quasar at z=0.536
Apparent luminosity ≈ 10^48 erg/s
Gamma-ray flares in 1991 and 1996: High dynamical range in EGRET data
Fast time variation: ΔT ~ 6hr in 1996 flare
P1 (June 1991 flare)
P2 (Dec. 92 / Jan. 93)
June 2003
Jan. 15, 2006
Feb. 23, 2006
MAGIC
x100
Overall SED
ν [Hz]
MAGIC Light Curve
MAGIC: E>100 GeV
23 Feb 2006
6.2σ
22 Feb 2006
2.2σ
Flux incompatible with const.: 5.04 σ
Integral flux (100-500 GeV) [cm^-2 s^-1]
Time (Julian Date−2453000)
z=0.536! Major jump in redshift
First FSRQ in TeV gamma-rays:
Can be used to constrain Extragalactic Background Light models
R. M. Wagner: Ground Based VHE Astronomy
RICAP 11, 2011 May 25

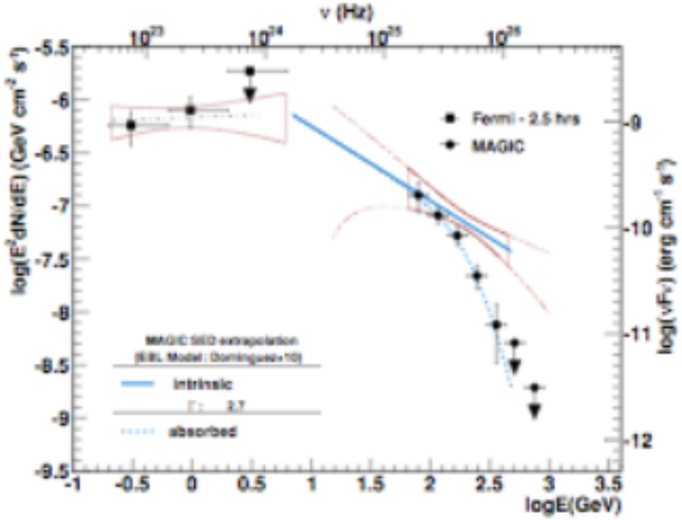
AGN

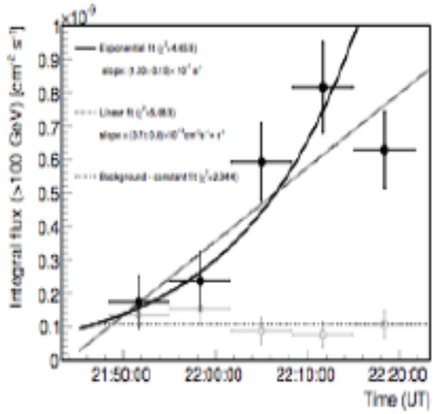
+ FSRQ PKS 1222+21 (4C21.35)

- Very good example of collaboration Fermi-IACTs (hard sources)
- Fermi Atel 2584 triggers MAGIC: 10.2 sigma detection in 0.5 h (1 Crab)
- 2nd farthest VHE source: z=0.432

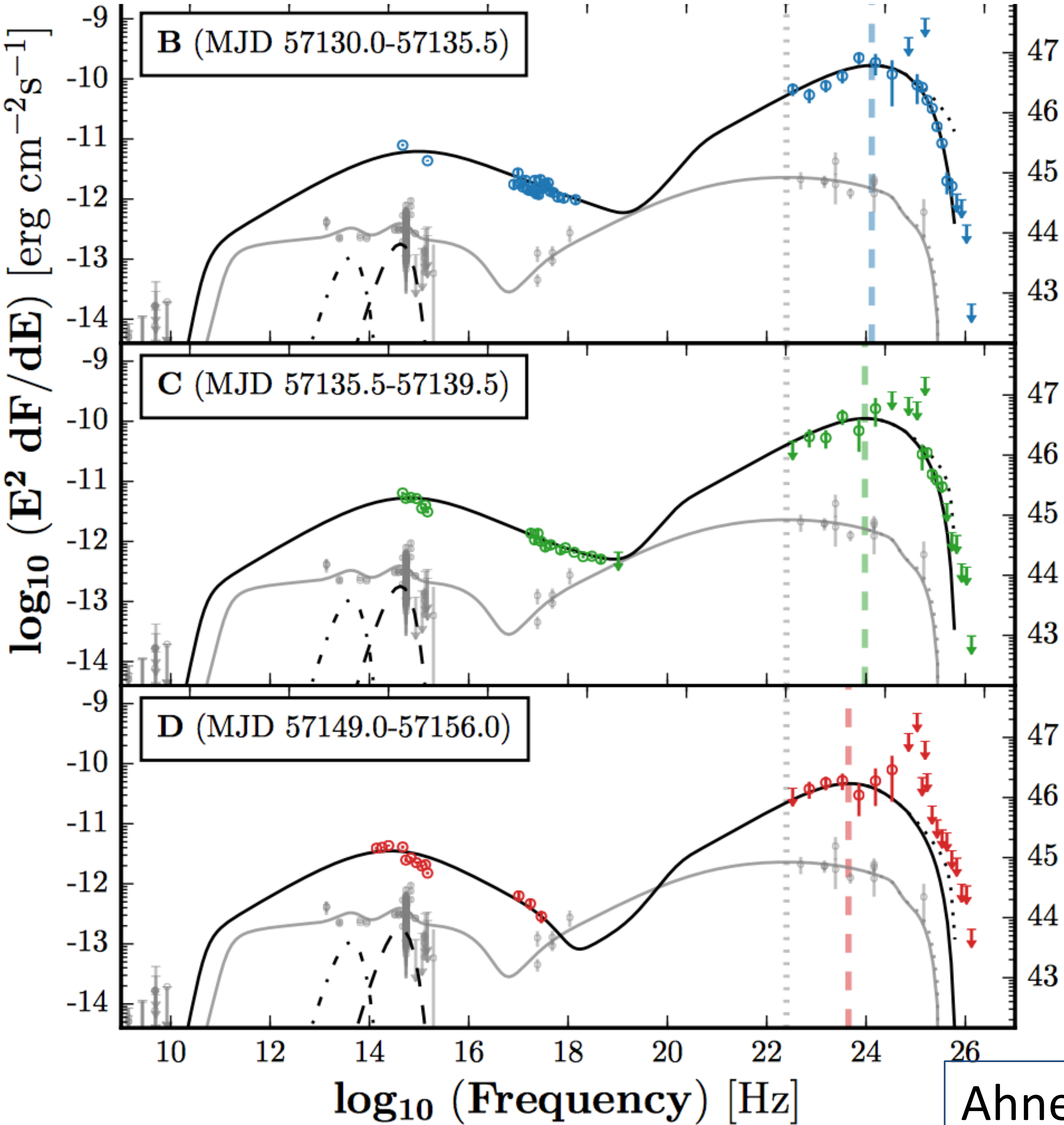
- MAGIC+Fermi: can fit to single power-law -2.7(0.3) between 3 and 400 GeV
- No-sign of any cutoff
- Most rapid variation ever observed at VHE: Flux doubling-time 8.6min!

- Single spectrum → emission due to unique component
- No GeV cutoff → emission outside the BLR region, in the relativistic jet?
- Flux rapid variability→compact emission
- CHALLENGE TO EMISSION MODELS!





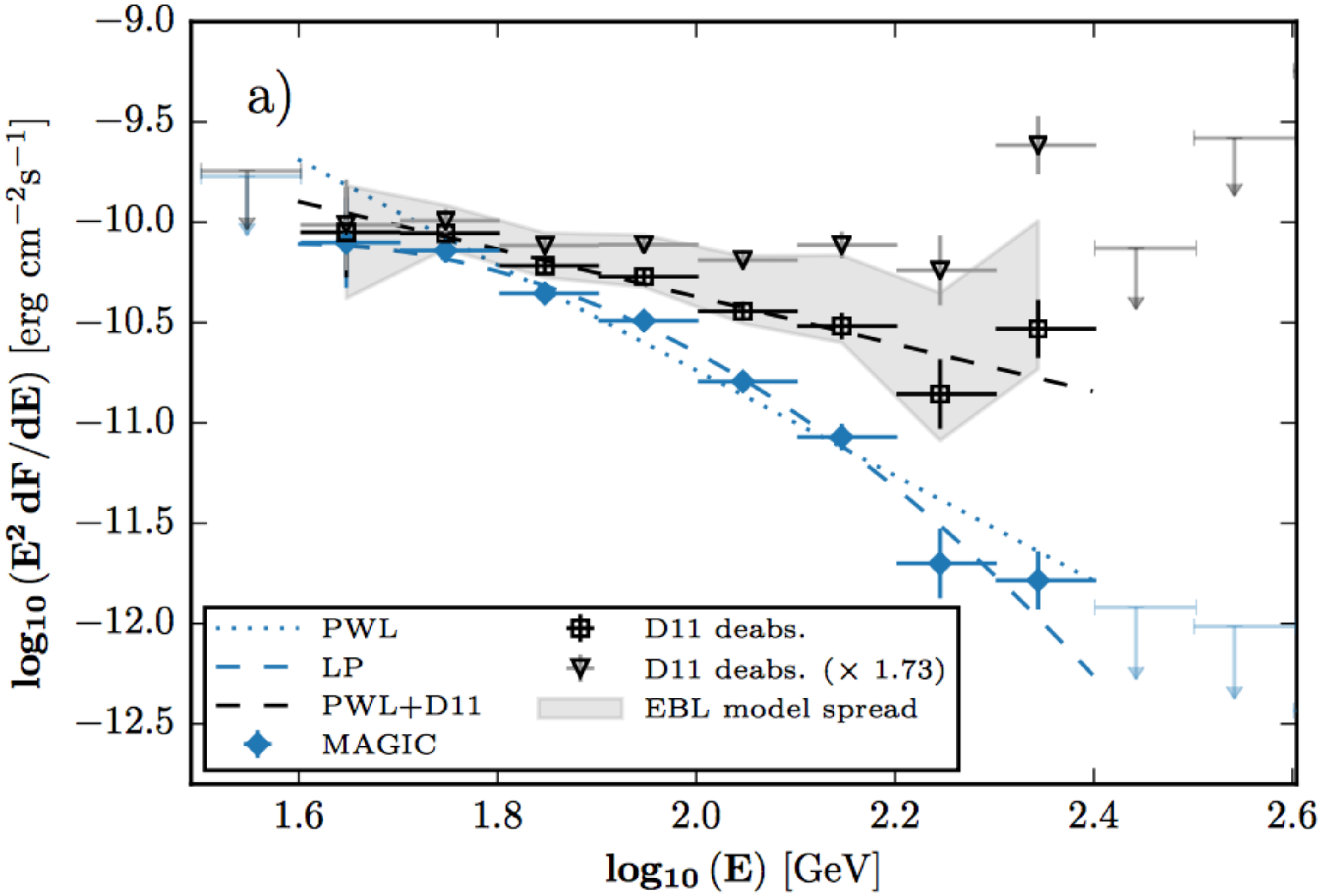
ApJL 730:L8 2011



PKS 1441+25
z=0.9397!

Ahnen et al 2016

PKS 1441+25
z=0.9397



Ahnen et al 2016

Lensed Blazar

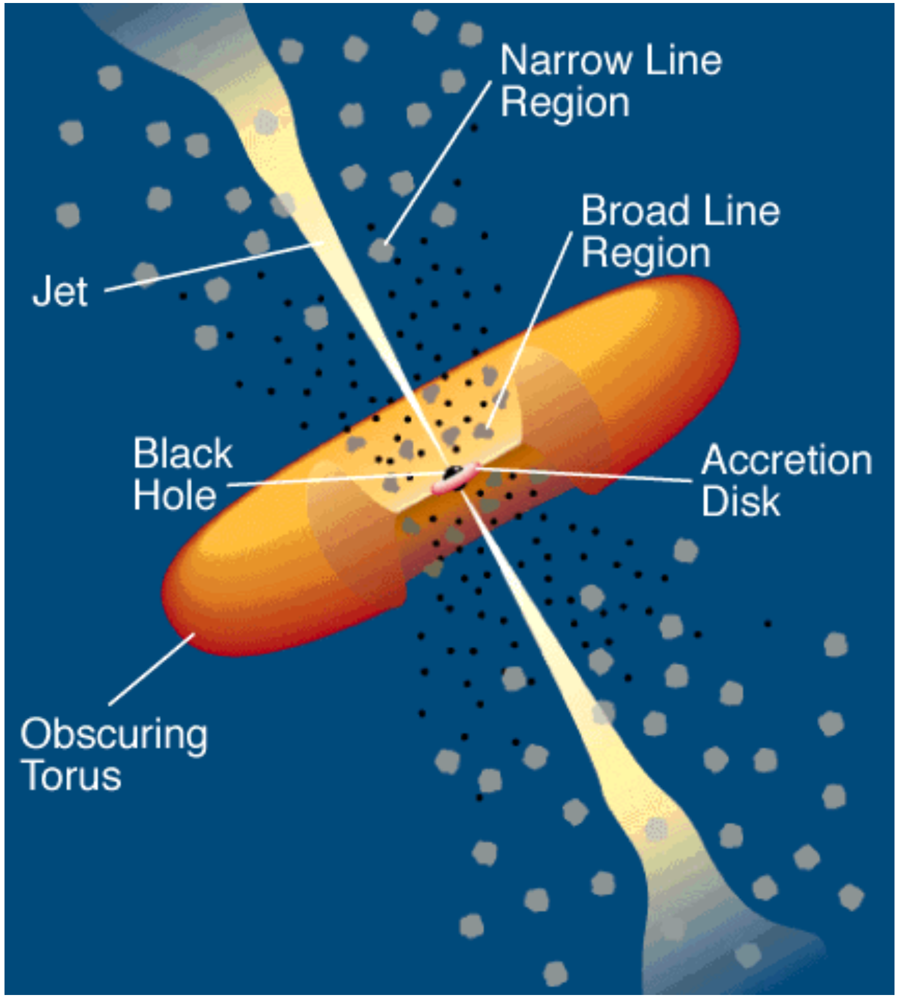
Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; *Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration*
*on **28 Jul 2014; 14:20 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

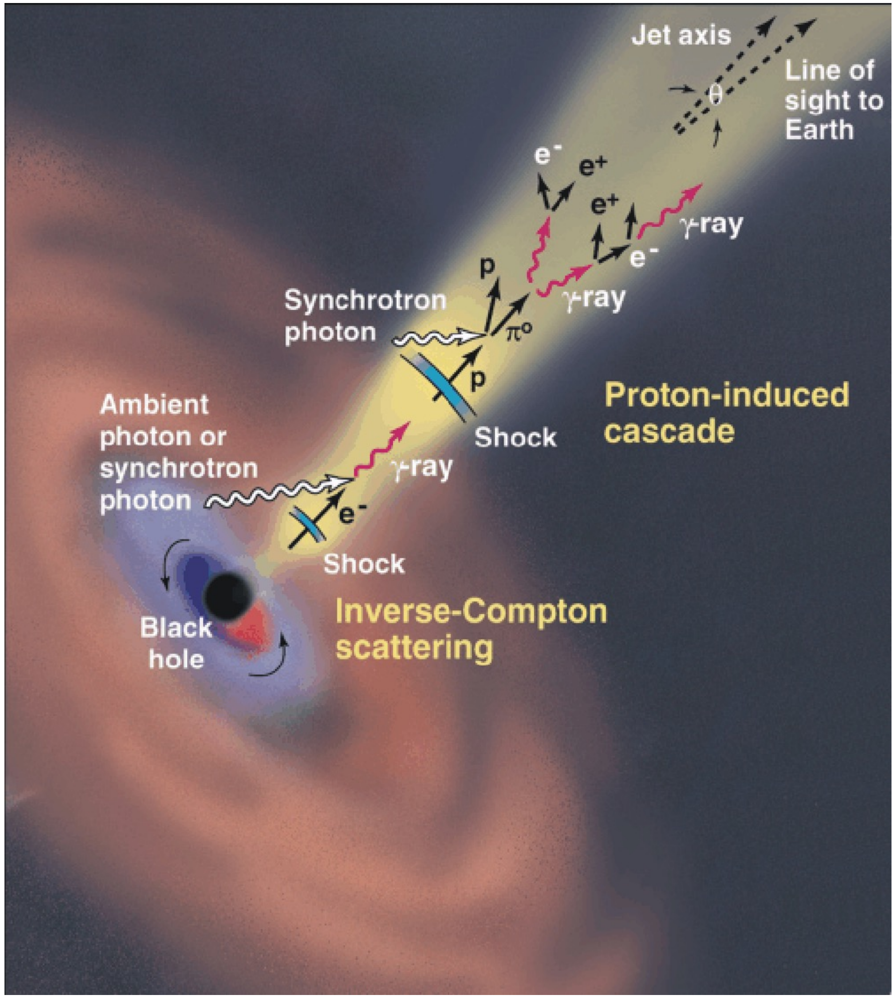
Subjects: Gamma Ray, >GeV, TeV, VHE, UHE, AGN, Blazar, Cosmic Rays, Microlensing Event

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from S3 0218+357 (RA=02h21m05.5s, DEC=+35d56m14s, J2000.0). The object was observed with the MAGIC telescopes for a total of 3.5 hours from 2014/07/23 to 2014/07/26. The preliminary analysis of these data resulted in the detection of S3 0218+357 with a statistical significance of more than 5 standard deviations. From the preliminary analysis, we estimate the VHE flux of this detection to be about 15% of the flux from the Crab Nebula in the energy range 100-200 GeV. S3 0218+357 is a gravitationally lensed blazar located at the redshift of 0.944+/-0.002 (Cohen et al., 2003, ApJ, 583, 67). Fermi-LAT observations during the flaring state of S3 0218+357 in 2012 revealed a series of flares with their counterparts after 11.46+/-0.16 days delay, interpreted as due to the gravitational lensing effect (Cheung et al. 2014, ApJ, 782, L14). On 2014 July 13 and 14 Fermi-LAT detected another flaring episode (ATel #6316). Due to the full-moon time, the MAGIC telescopes were not operational and could not observe S3 0218+357 after the original alert. However, observations scheduled at the expected time of arrival of the gravitationally lensed component led to the first significant detection of a gravitationally lensed blazar and the most distant source detected at VHE with Cherenkov telescopes to date. MAGIC observations on S3 0218+357 will continue during the next days and multiwavelength observations are encouraged. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and J. Sitarek (jsitarek@ifae.es). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Canary island of La Palma, Spain, and designed to perform gamma-ray astrophysics in the energy range from 50 GeV to greater than 50 TeV.

AGN model

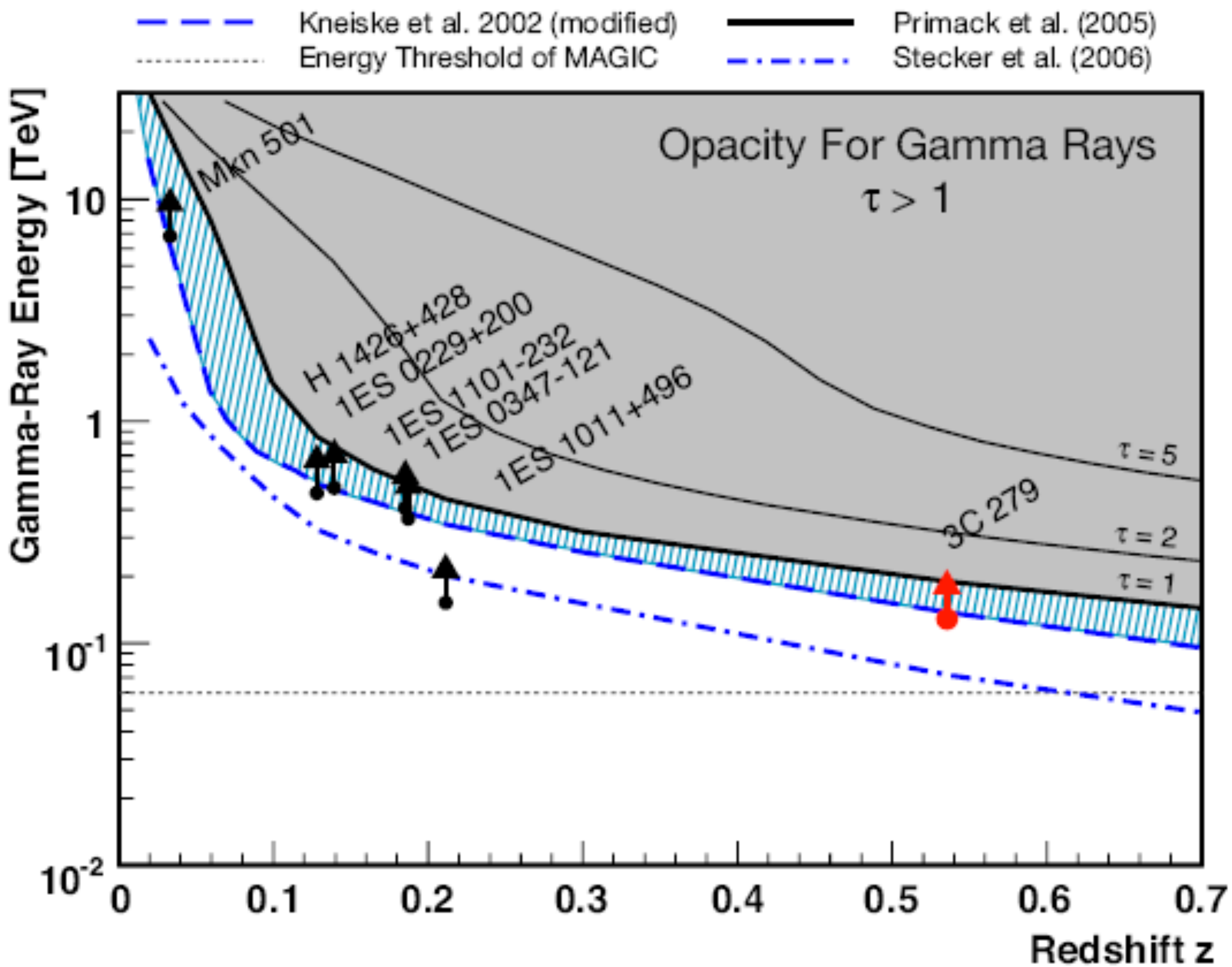


Narrow Line Region
Broad Line Region
Jet
Black Hole
Accretion Disk
Obscuring Torus



Jet axis
Line of sight to Earth
θ
e⁻
e+
e+
γ-ray
e⁻
p
γ-ray
Synchrotron photon
π°
p
Proton-induced cascade
Shock
Ambient photon or synchrotron photon
γ-ray
e⁻
Shock
Black hole
Inverse-Compton scattering

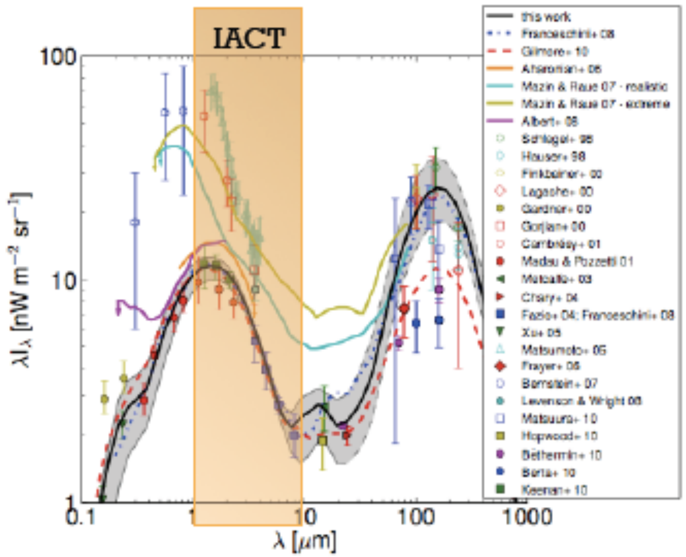
MAGIC – EBL measurements

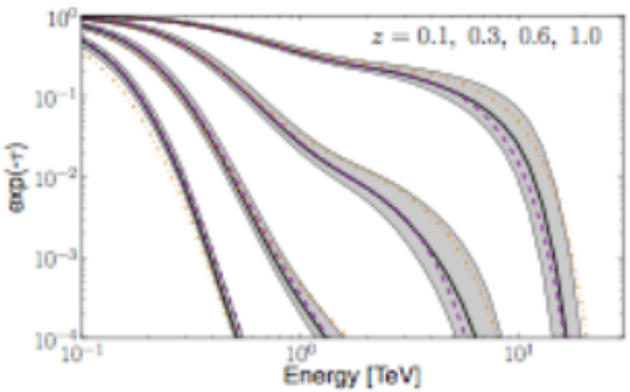


Albert et al. 2008

EBL measurements

+ Gamma-ray horizon





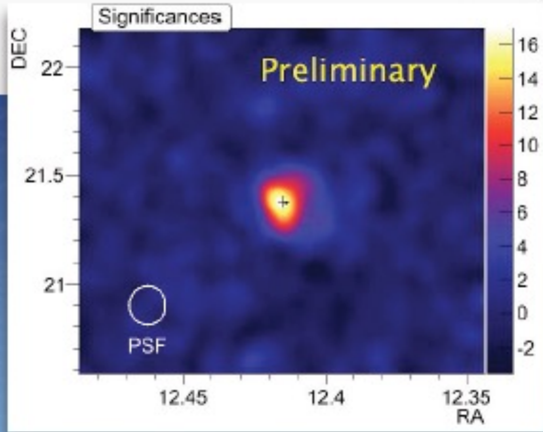
- VHE gamma-ray interacting with UV and far-IR photons, may pair produce:
  - Optical depth $\tau = \tau(E,z)$
- Distant AGNs are optimal targets (if distance is known):
  - 3C279 (z=0.536)
  - 3C66A (z=0.444?)
  - PG1553+113 (z=0.4)
  - S5 0716+714 (z=0.310?)
  - …
- Absorption above 100 GeV makes observed spectrum:
  - Softer (steeper)
  - Difficult to observe
- IACT observation already constrained models to their minimum allowance (universe is more transparent)
- Distant AGNs are monitored by M-stereo (PG1553, 3C279)

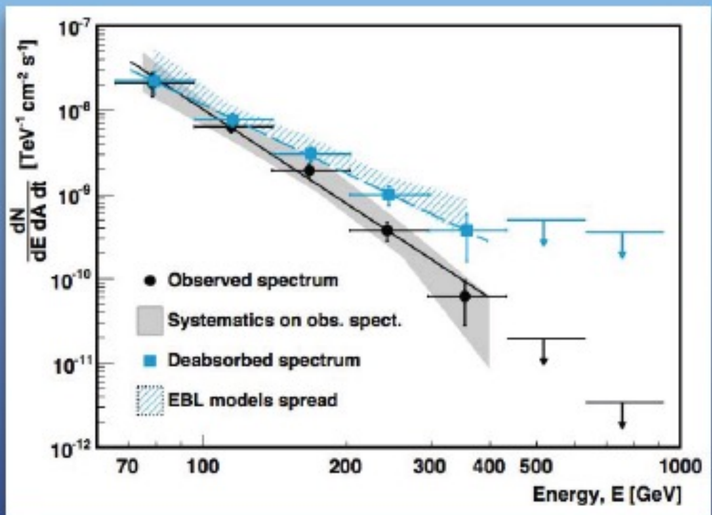
EBL measurements

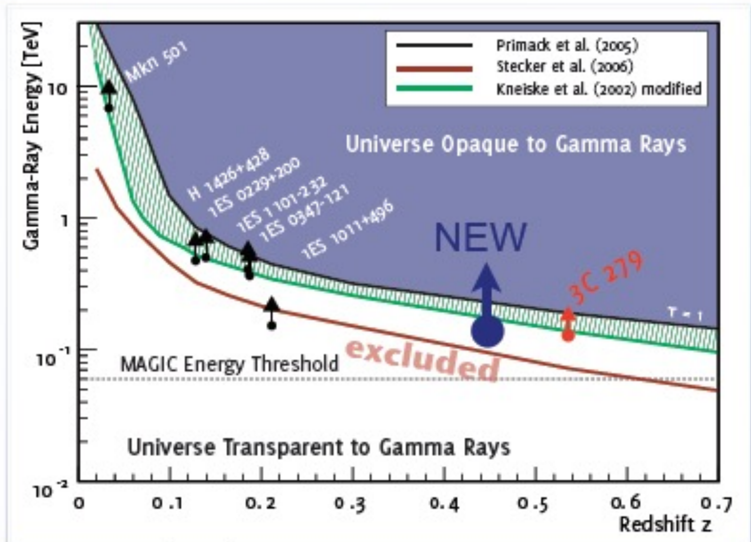
4C +21.35 aka PKS 1222+21

MAGIC Coll., A&A subm.

- 2010 June 17, flare state
- PKS 1222+21 (4C +21.35) is a high redshift (z=0.43) FSRQ
  (only 3C279, PKS1510-089 so far)
- Observations triggered by a high state reported by Fermi-LAT
- Can be used for EBL studies







Science 320 (2008) 1752

Photon – Axion Oscillation

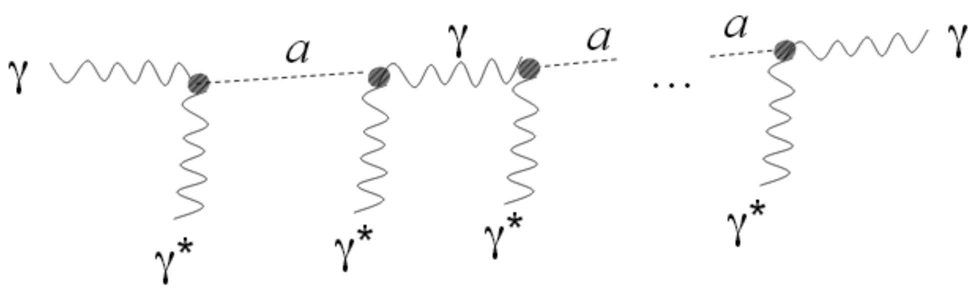
Axion Like Particle (ALP)

One intriguing possibility that have been recently proposed (DeAngelis-Mansutti-Roncadelli, 2007; DeAngelis-Mansutti-Persic-Roncadelli, 2008) is that conversion of γ's into axions into the random extragalactic magnetic fields give rise to a sort of cosmic *light-shining through wall* effect.

Axions have been introduced by Peccei & Quinn to solve the strong CP problem. Axion like particles with aγγ coupling are predicted in many extensions of the Standard Model. Pseudoscalar axions couple with the EM field through the effective Lagrangian

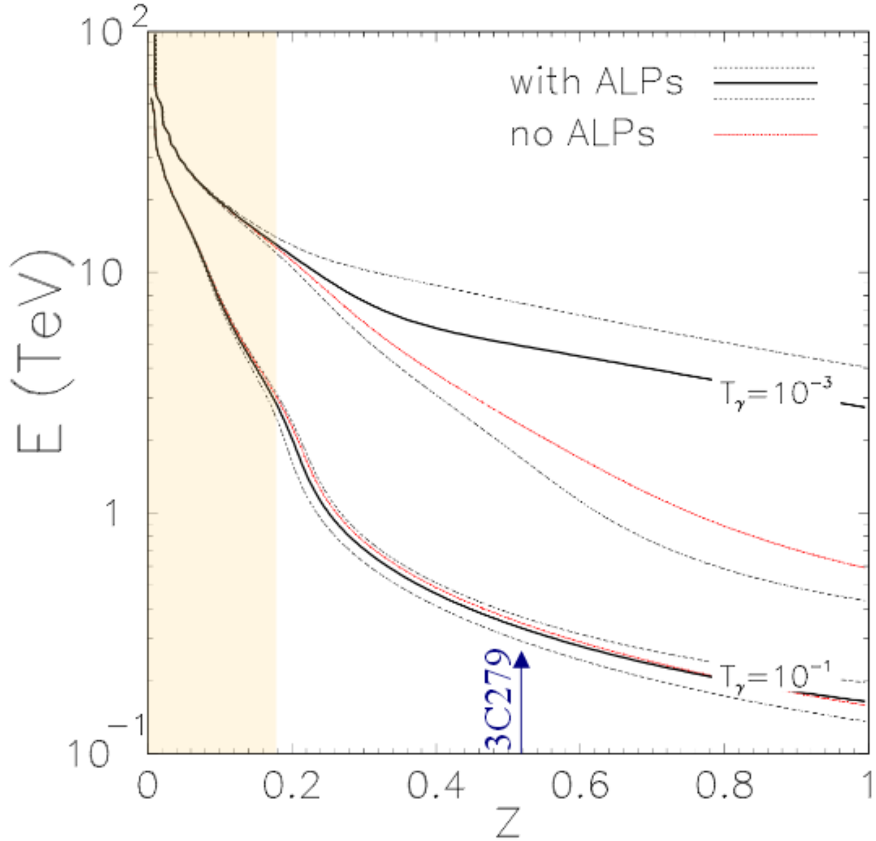
$$\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a$$

Photons propagating in an external magnetic field can undergo to photon-axion oscillations



Photon – Axion Oscillation

Realistic transfer function



For $z \leq 0.2$ the inclusion of the ALPs does not produce any significant change in the photon transfer function. Thus, it would be difficult to interpret in terms of ALP conversions the presumed transparency to gamma radiations for the sources at $z = 0.165$ and $z = 0.186$.

Conversely, ALP conversions could play a significant role for the source 3C279 at redshift $z = 0.54$

GRB repoint

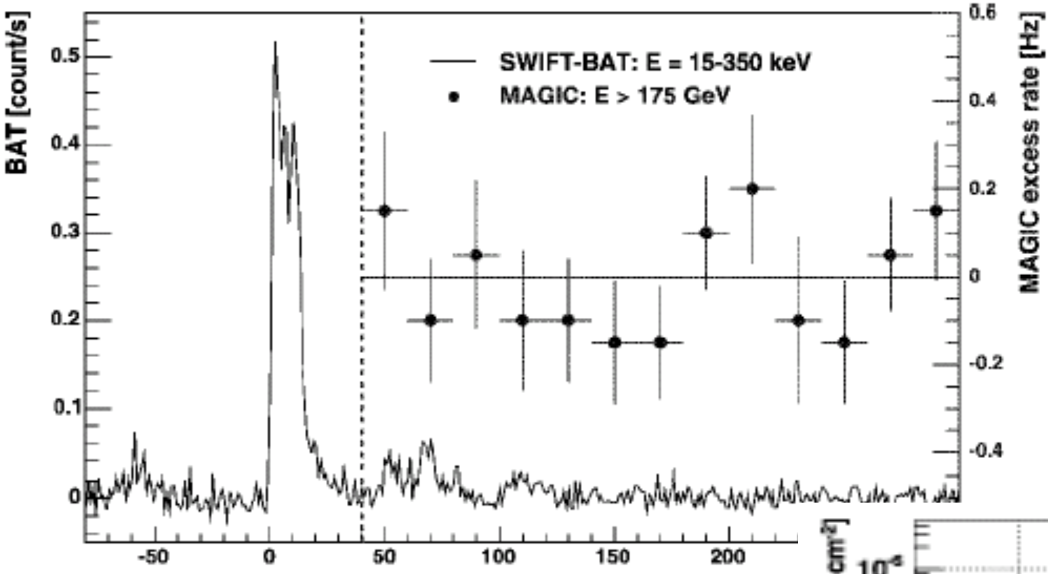
Current satellites giving alerts in short time: *FERMI, INTEGRAL, SWIFT*

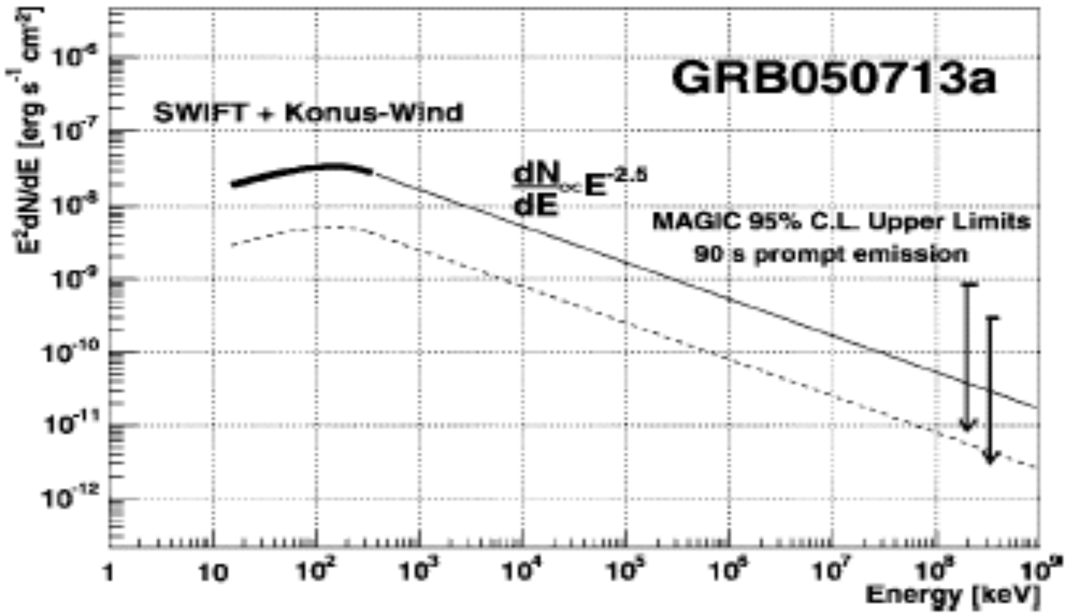
Delays of alerts from less than 10s to some minutes

Very fast repositioning capabilities are therefore requested:

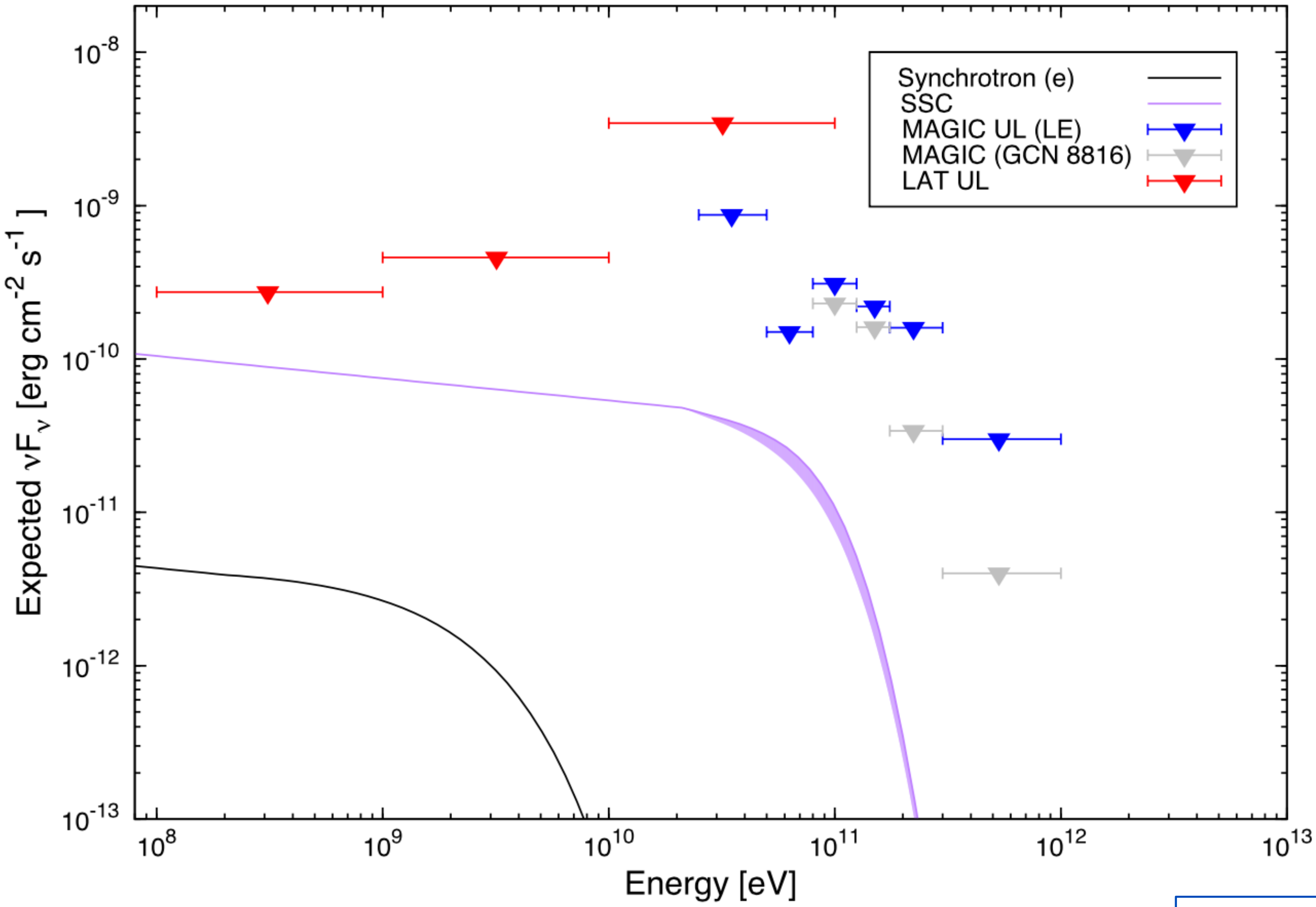
10 to 20 seconds!

GRBs


BAT [count/s]
MAGIC excess rate [Hz]
SWIFT-BAT: E = 15-350 keV
MAGIC: E > 175 GeV


GRB050713a
SWIFT + Konus-Wind
$\frac{dN}{dE} \propto E^{-2.5}$
MAGIC 95% C.L. Upper Limits
90 s prompt emission
E^2dN/dE [erg s^{-1} cm^{-2}]
Energy [keV]

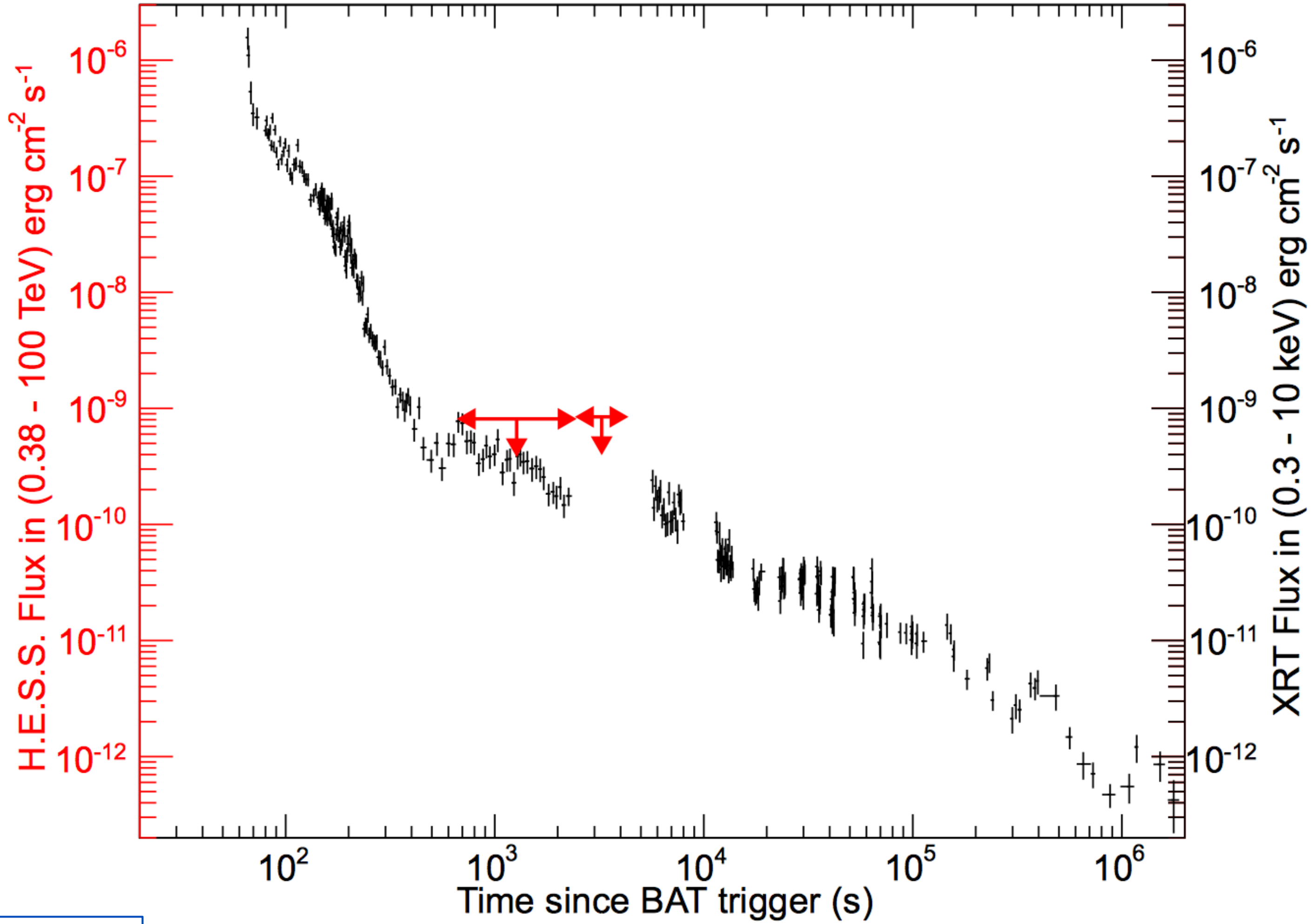
MAGIC– I upper limits



GRB 090102

J. Aleksic et al., 2014

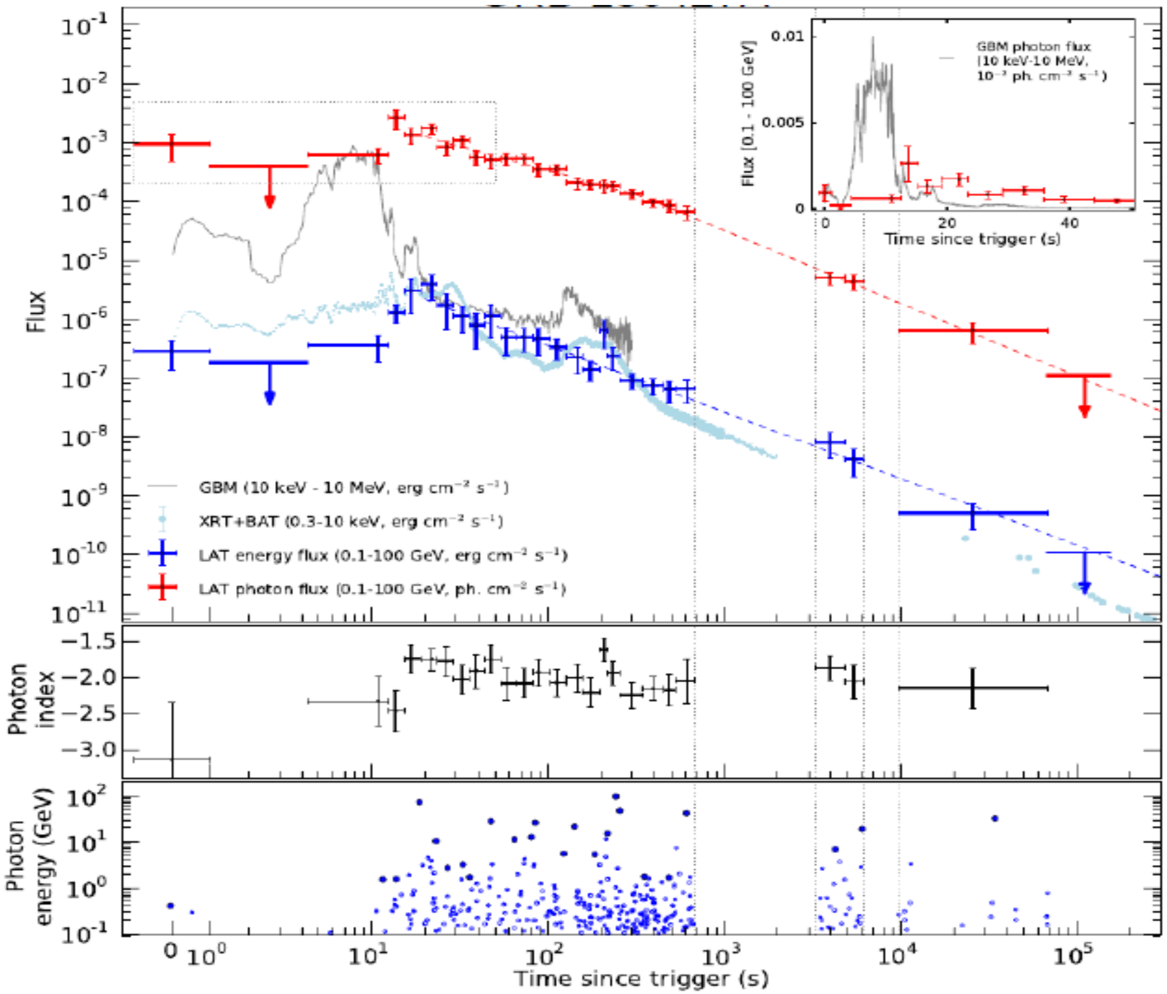
HESS - I upper limits



GRB 100621A

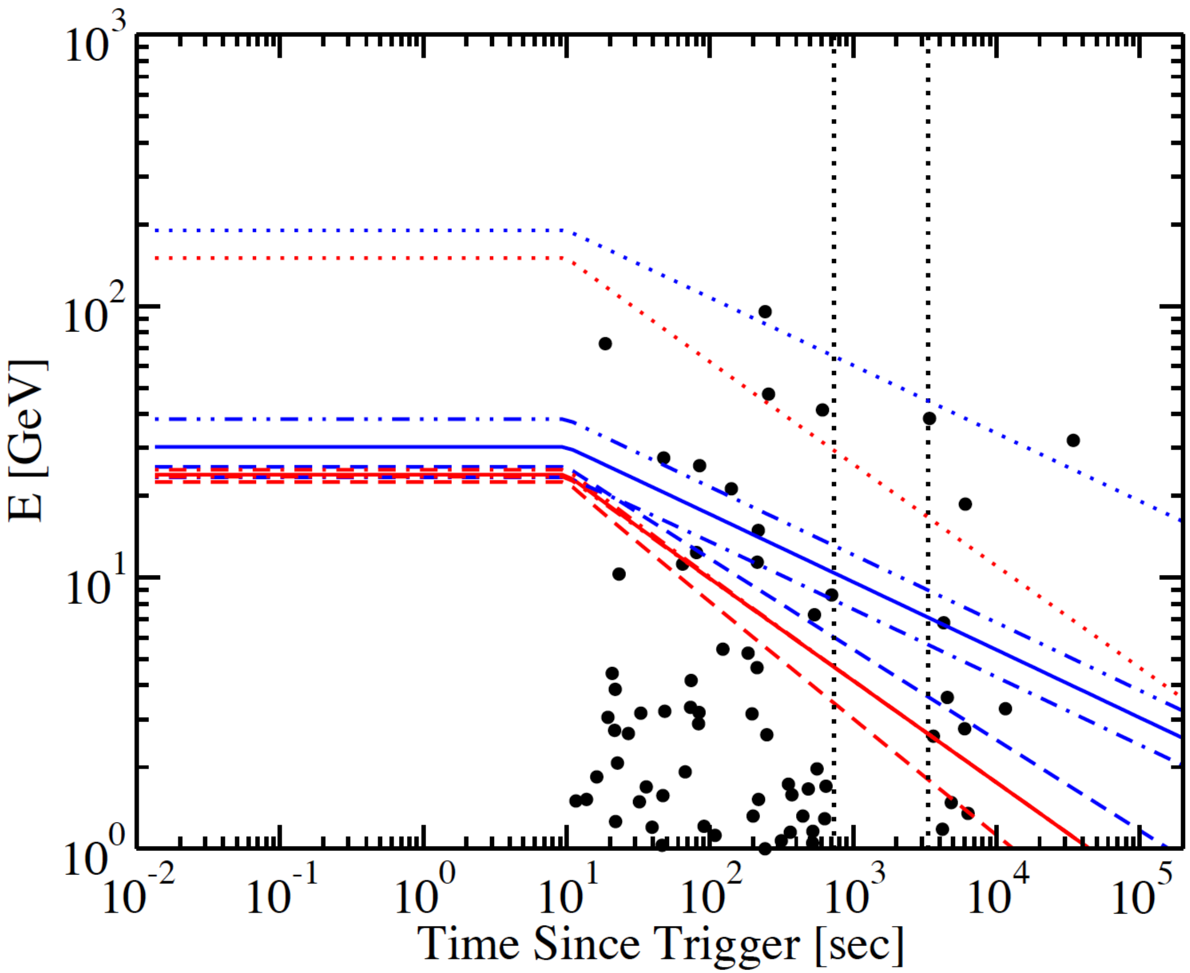
Abramowski et al. 2014

GRB 130427A



in today poster session
(Ackermann et al.,
Science, Vol. 343 no. 6166
pp. 42-47)

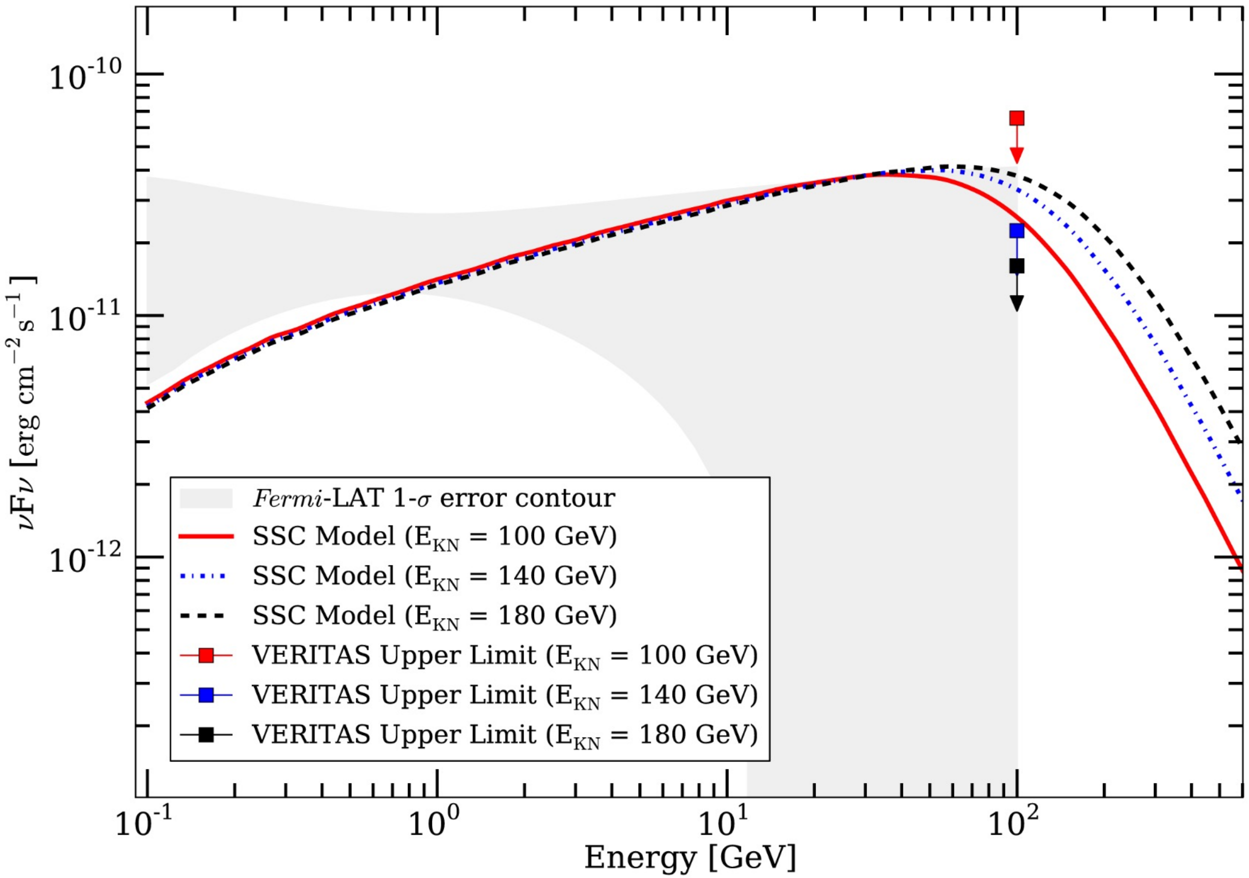
GRB VHE emission. Single photons matter



GRB 130427A

Ackermann et al. 2014

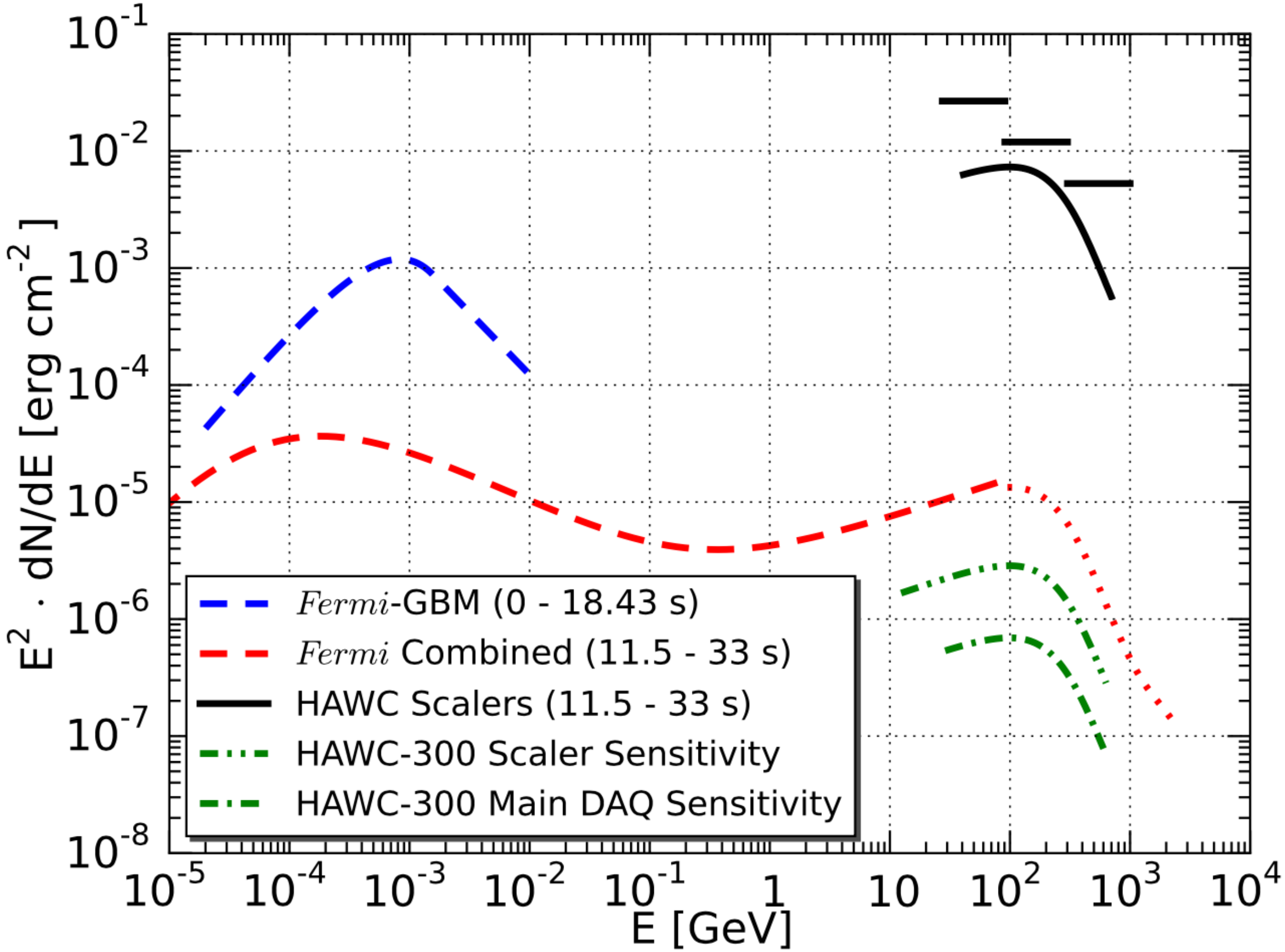
VERITAS upper limits



GRB 130427A

Aliu et al. 2014

HAWC upper limits



Abeysekara et al. 2015

GRB 130427A

MAGIC detection

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)

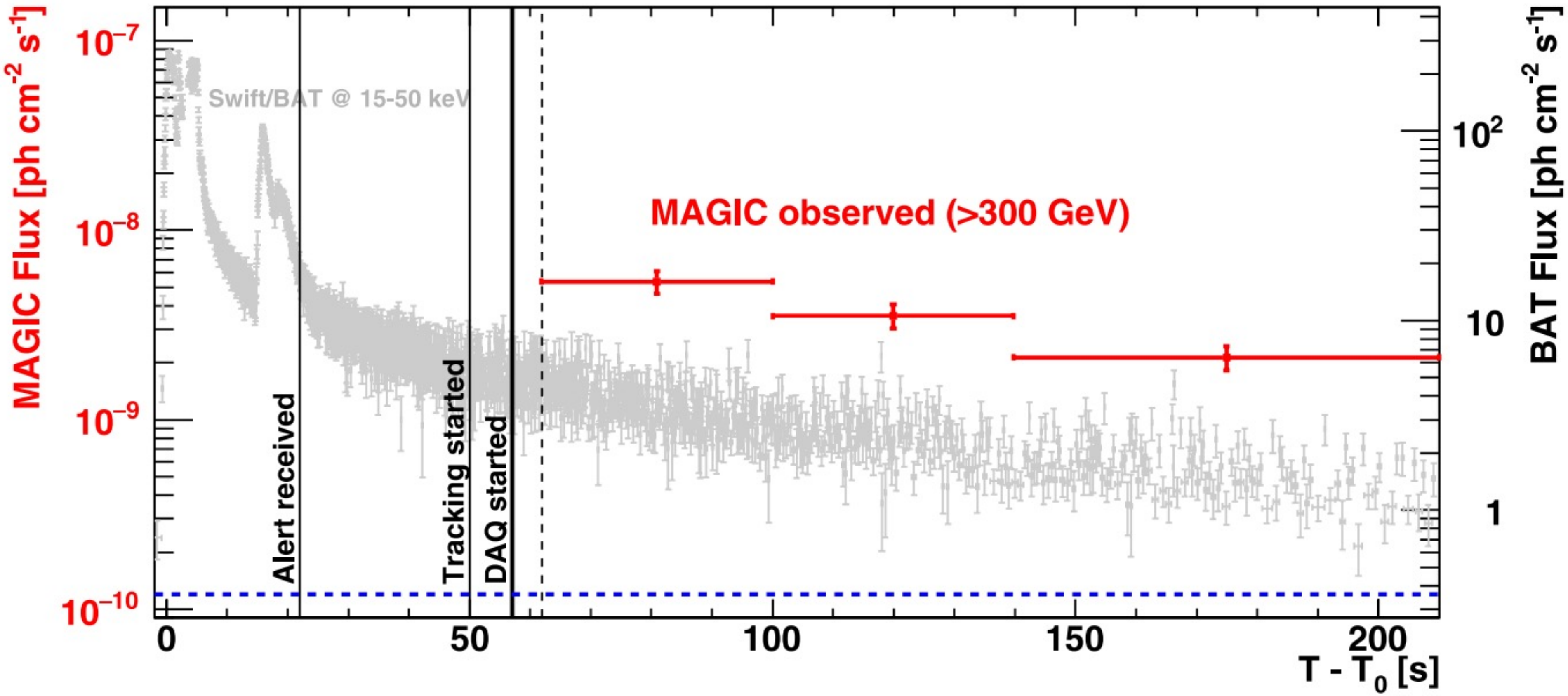
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

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 observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

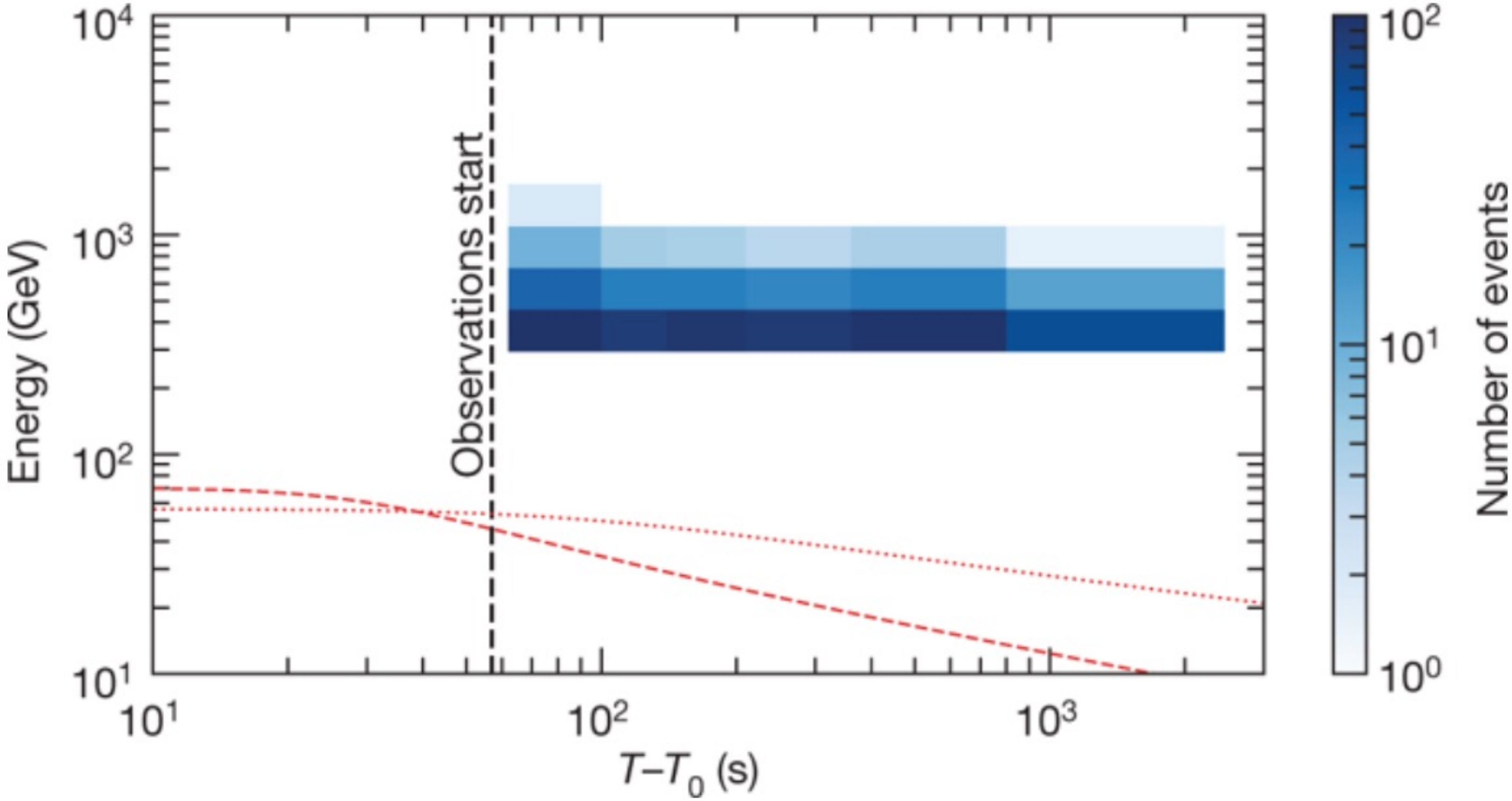
MAGIC detection



GRB 190114C

Acciari et al. 2019a

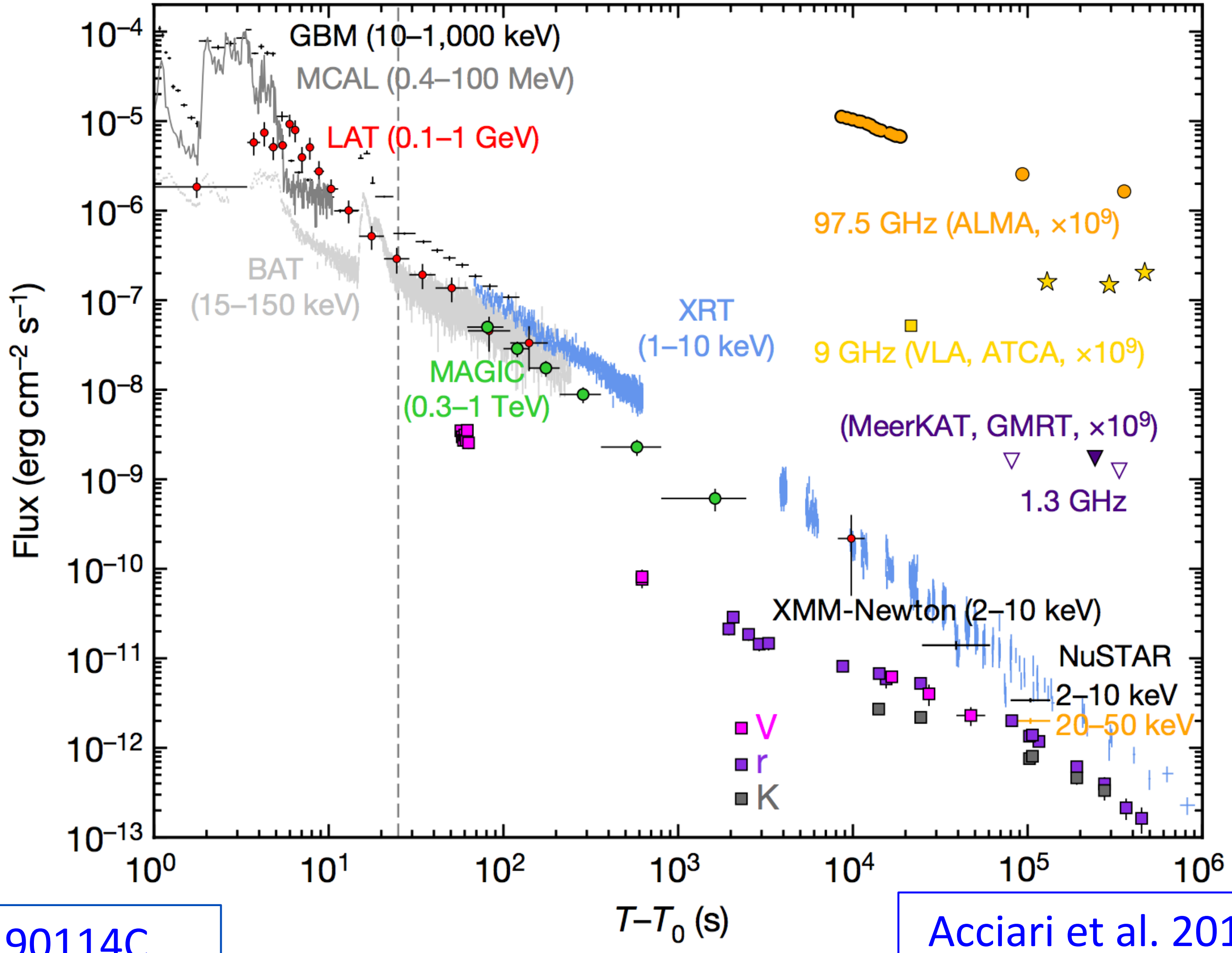
MAGIC detection



GRB 190114C

Acciari et al. 2019a

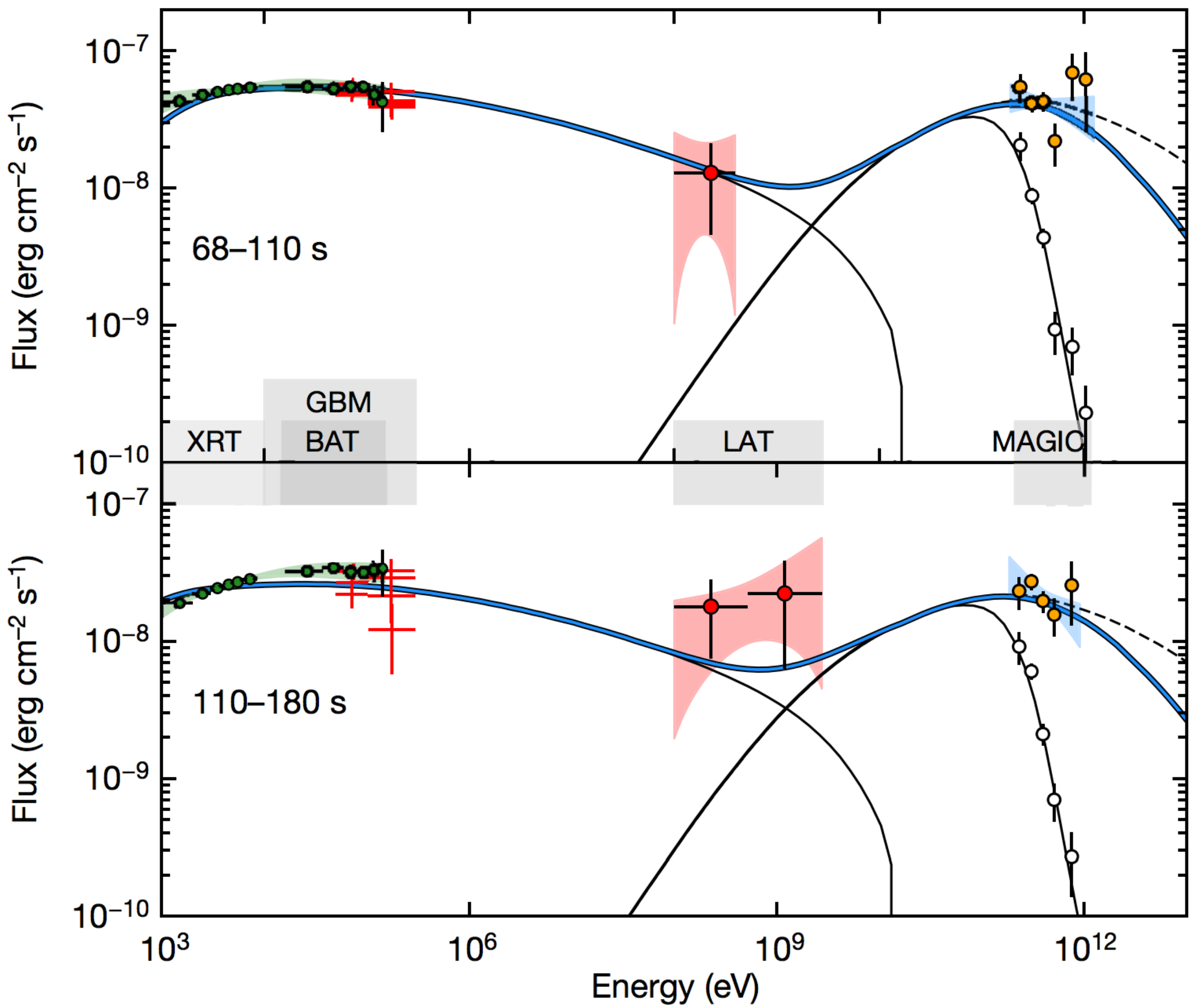
MAGIC detection



GRB 190114C

Acciari et al. 2019b

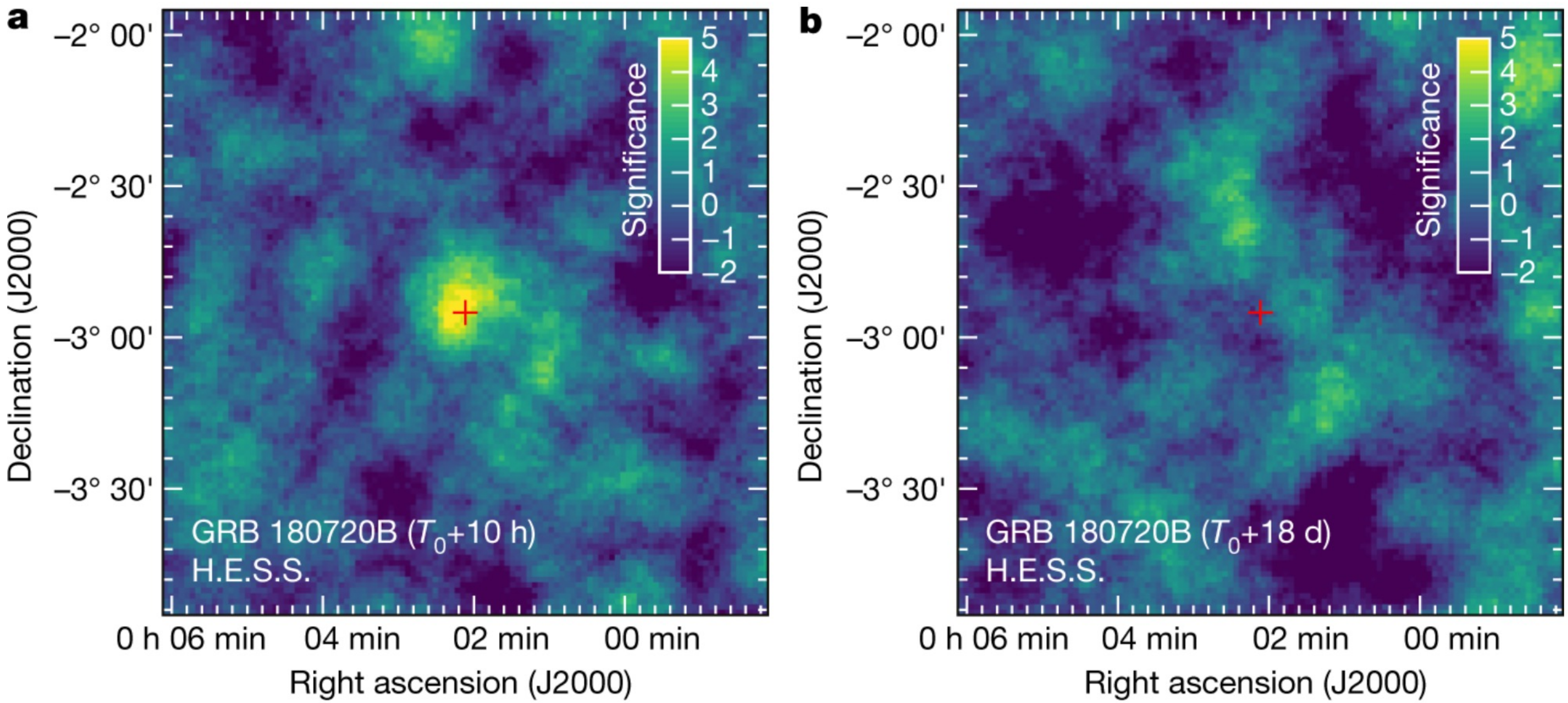
MAGIC detection



GRB 190114C

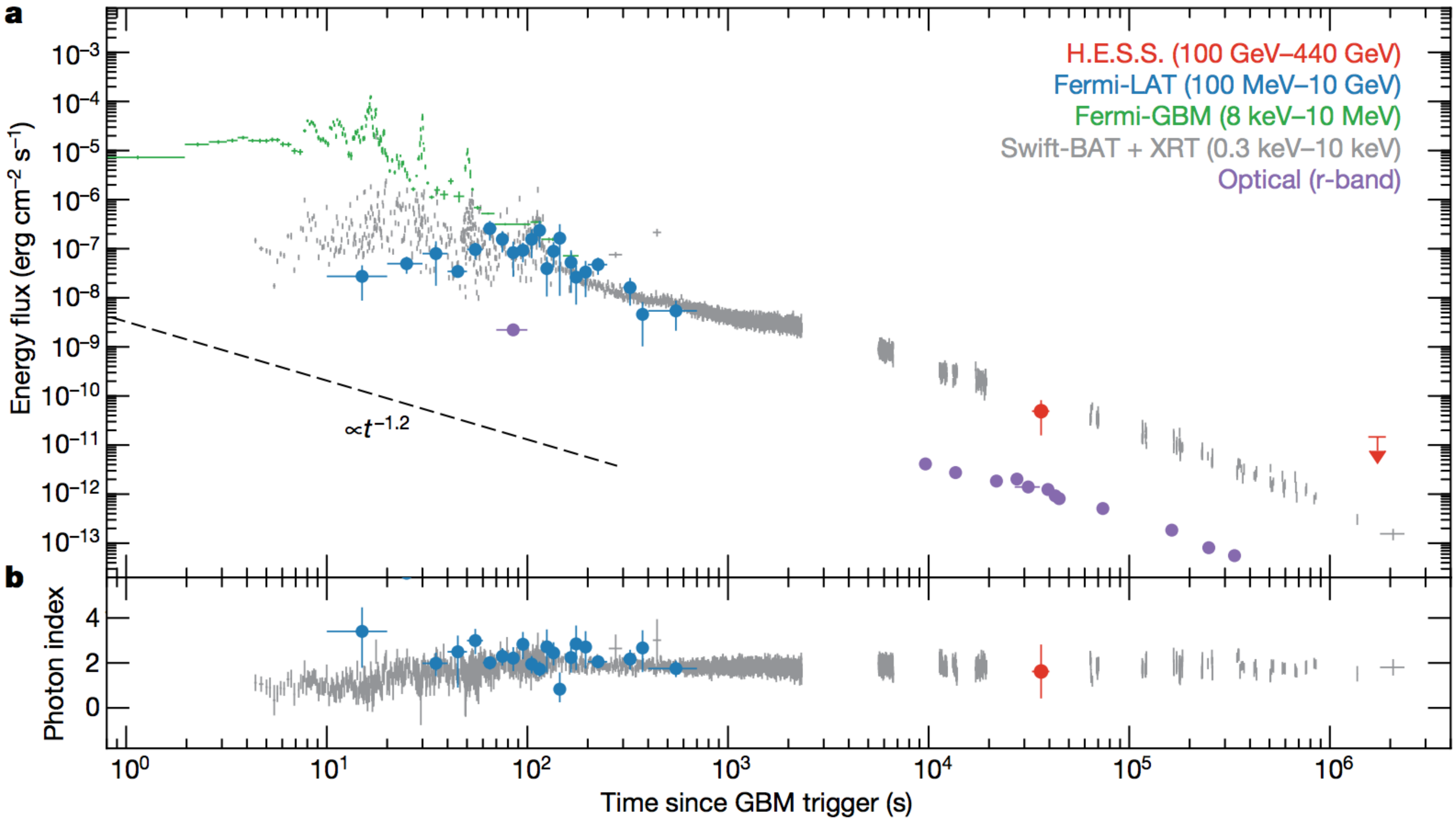
Acciari et al. 2019b

GRBs @ VHE ! (GRB 180720B)



Abdalla et al. 2019

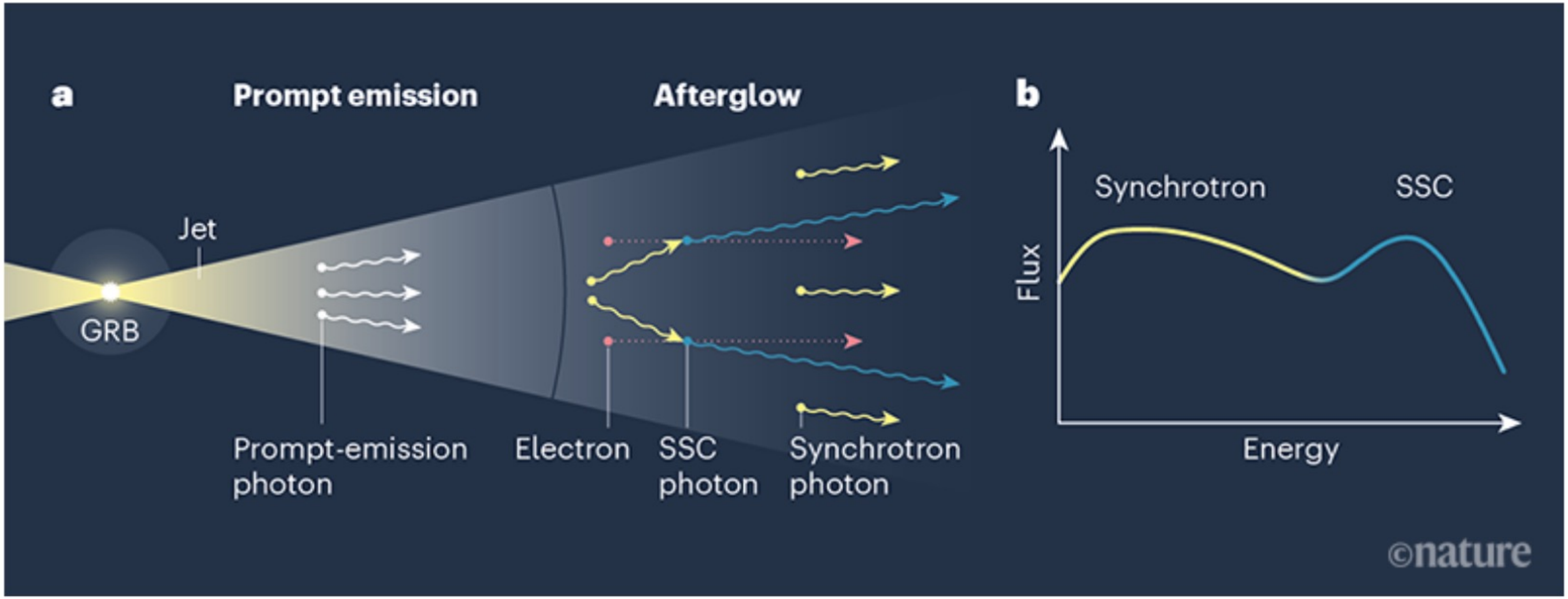
GRBs @ VHE ! (GRB 180720B)



GRB 180720B

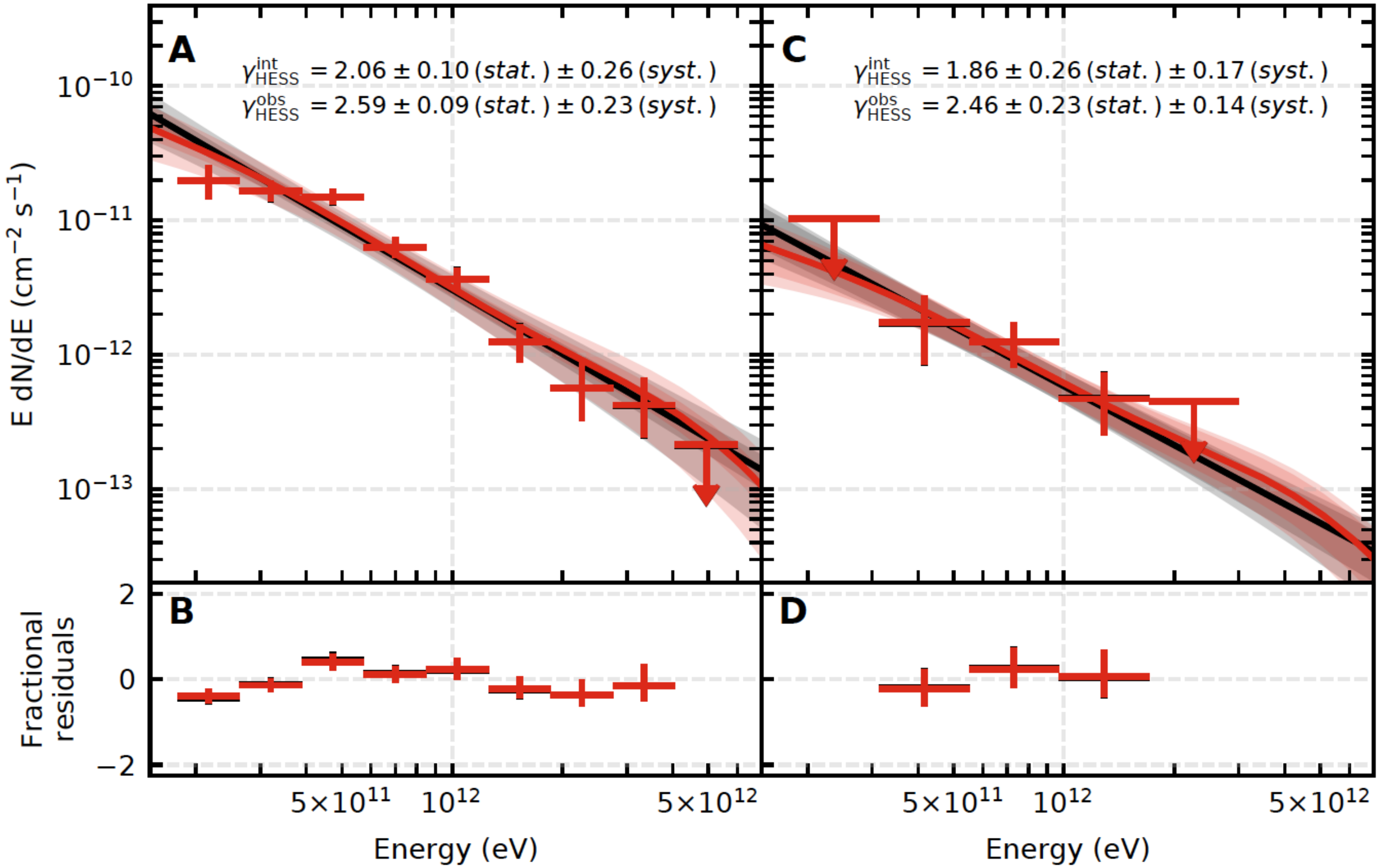
Abdalla et al. 2019

MAGIC & HESS detection



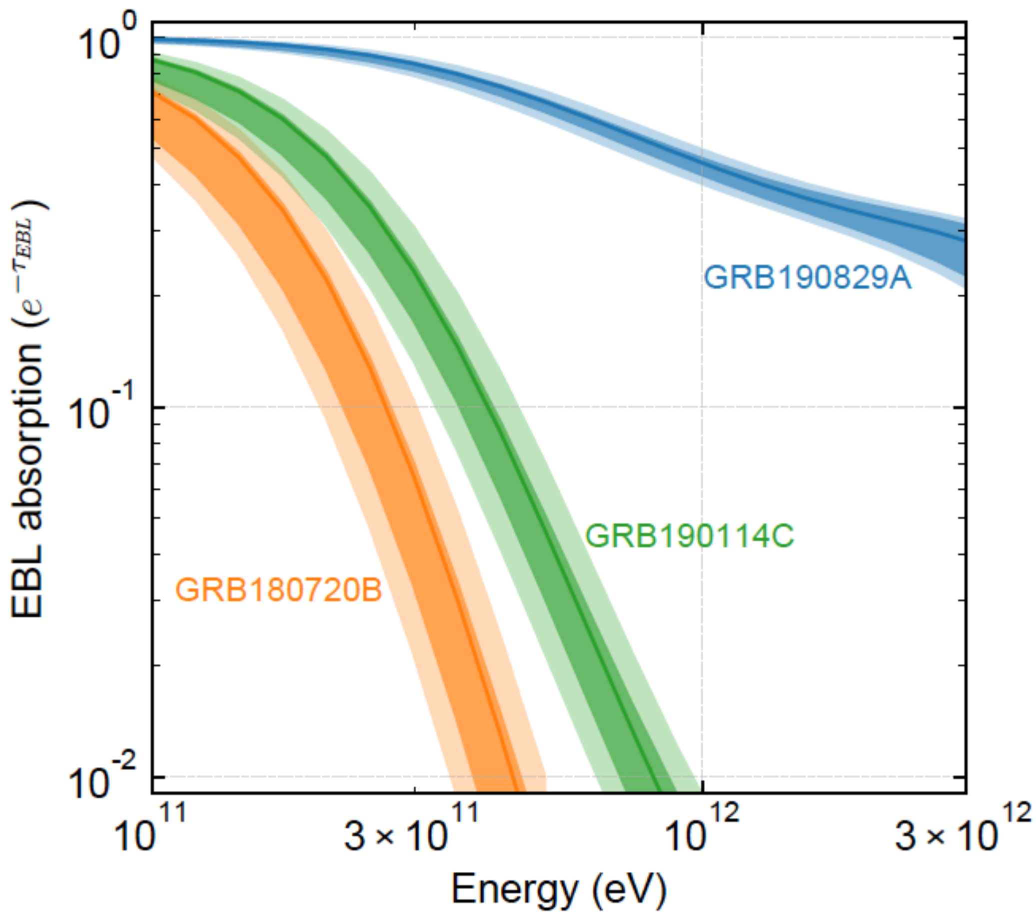
Zhang B., Nature News & Views (20/11/2019)

GRBs @ VHE ! (GRB 190829A)



Abdalla et al. 2021

GRBs @ VHE ! (GRB 190829A)



Abdalla et al. 2021

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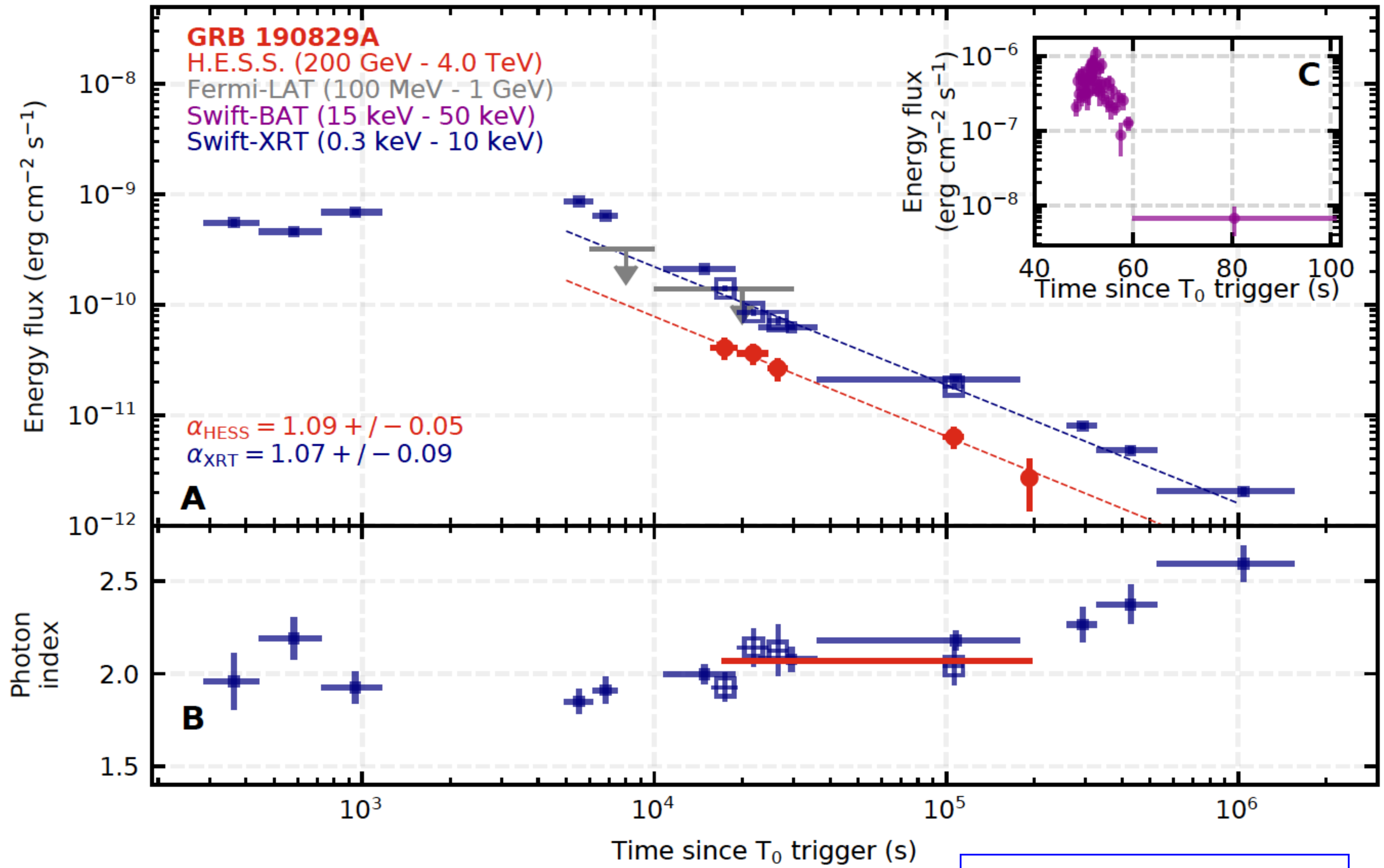

Abdalla et al. 2021

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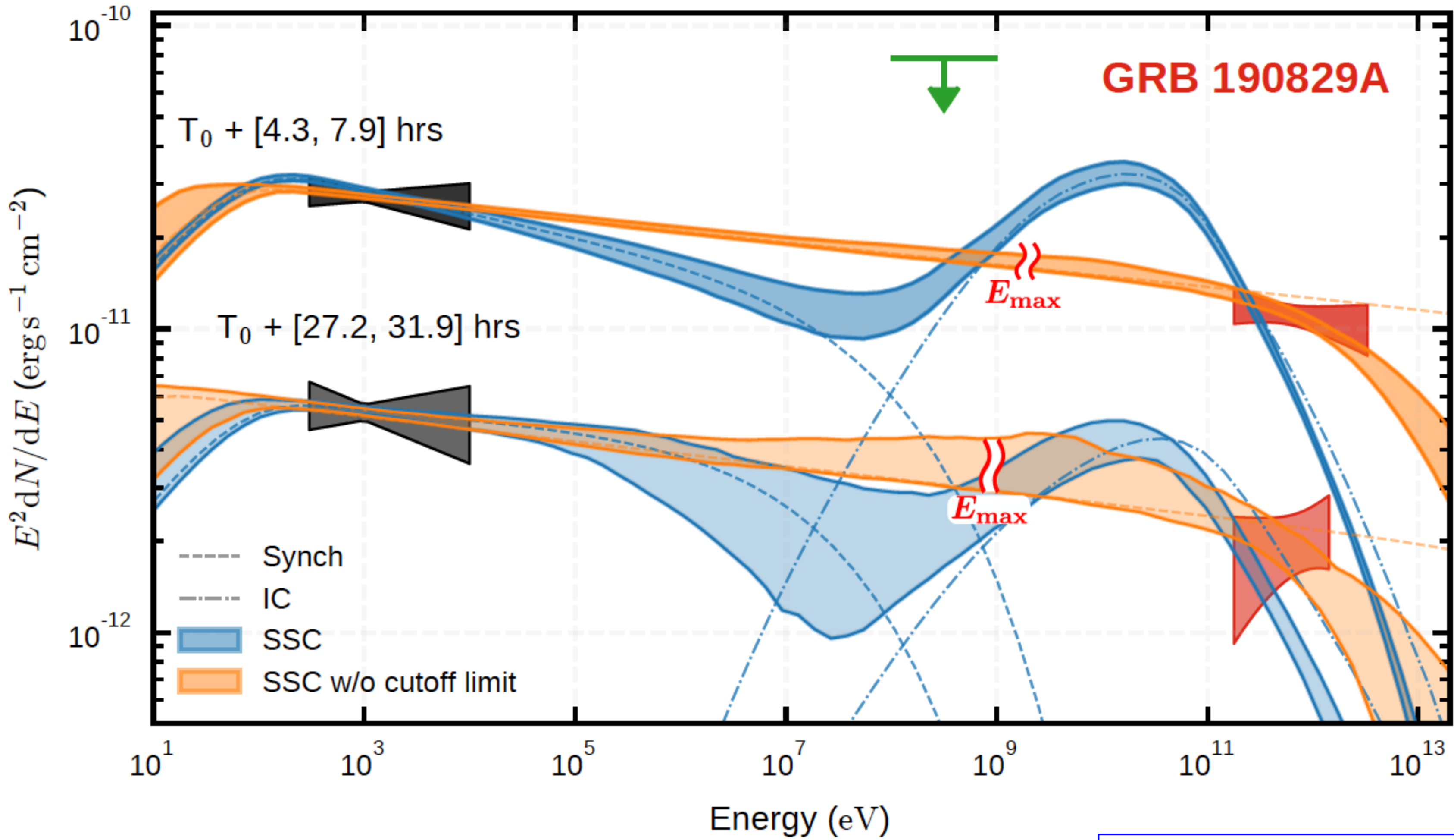
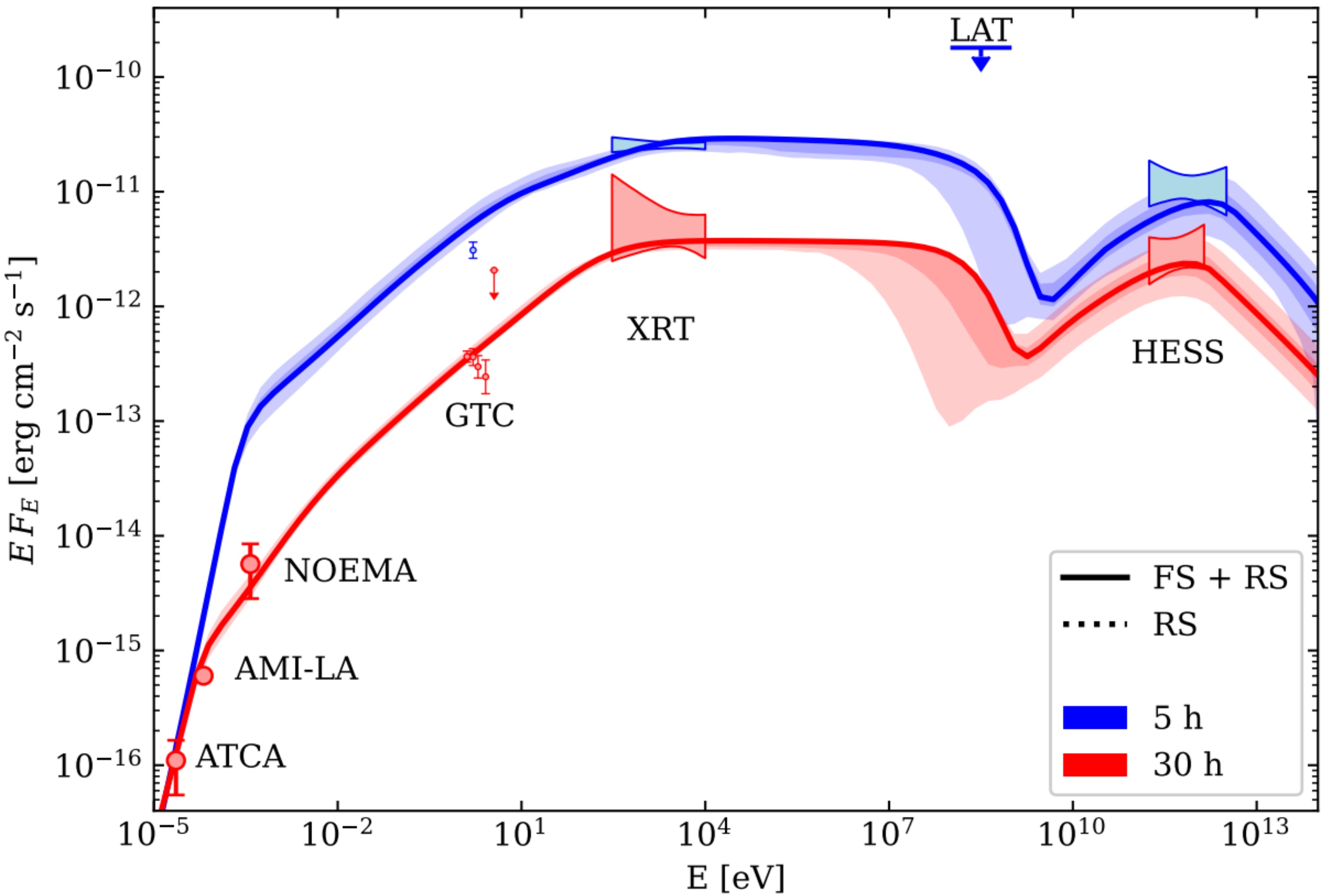


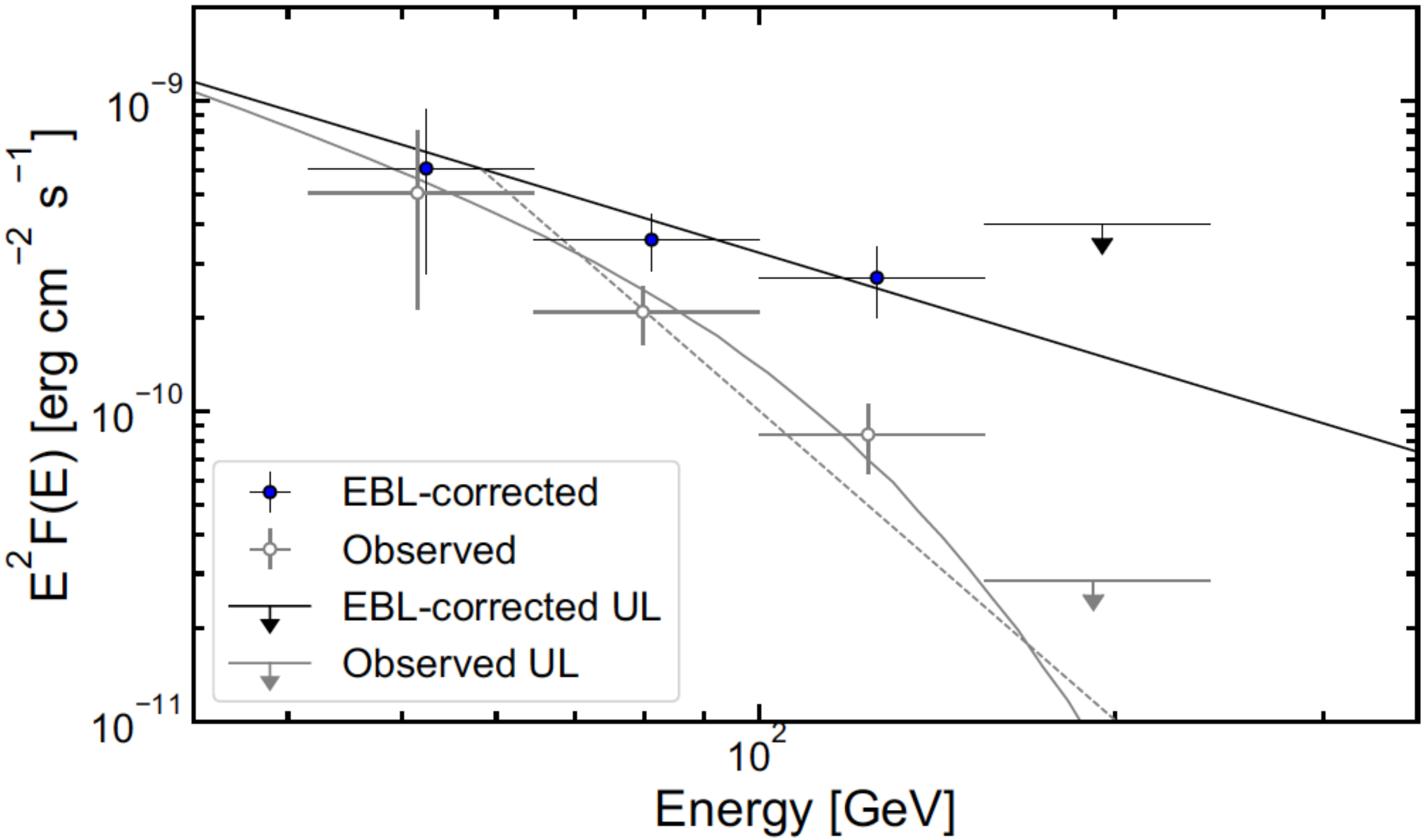
Abdalla et al. 2021

GRBs @ VHE ! (GRB 190829A)



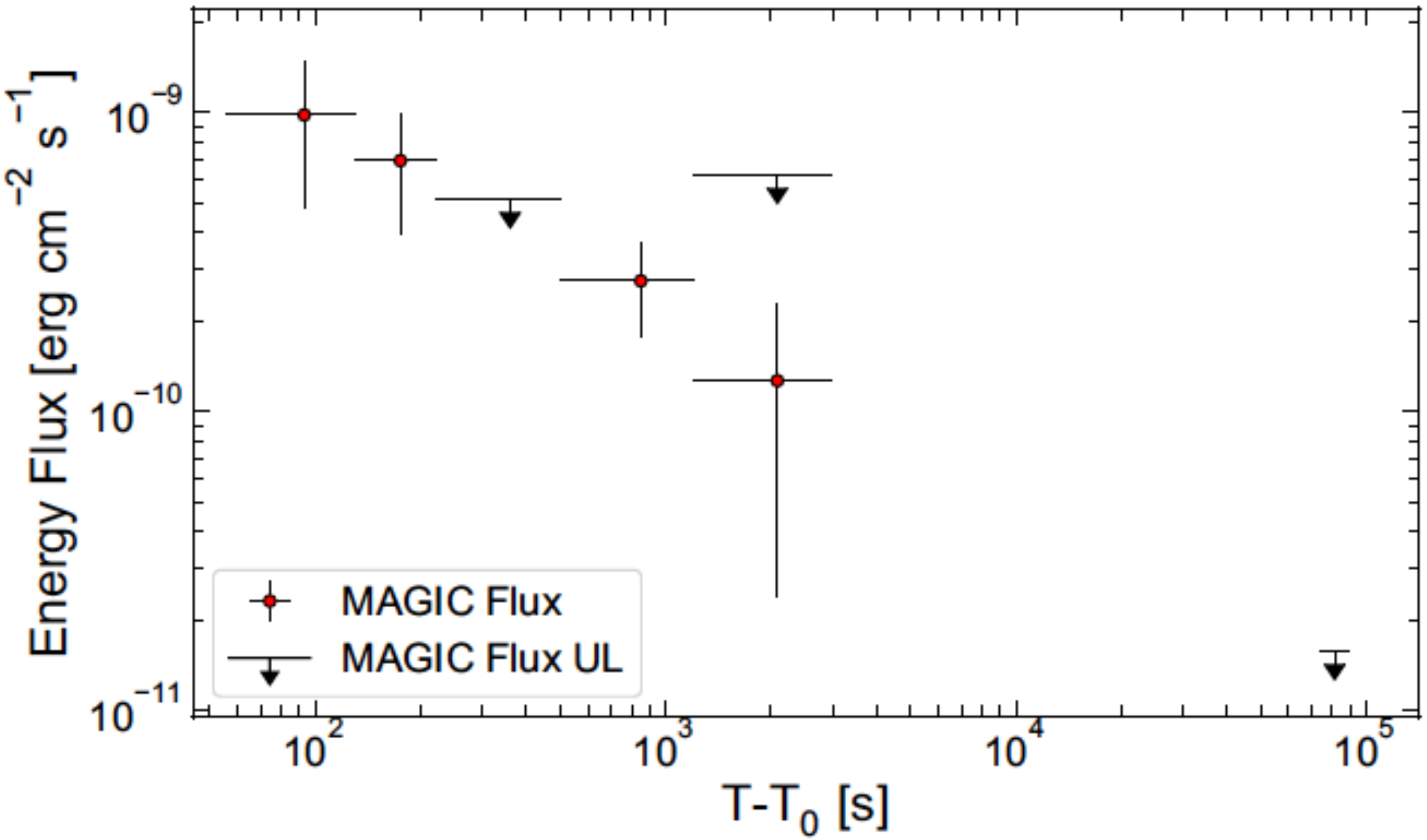
Salafia et al 2022

GRBs @ VHE ! (GRB 201216C)



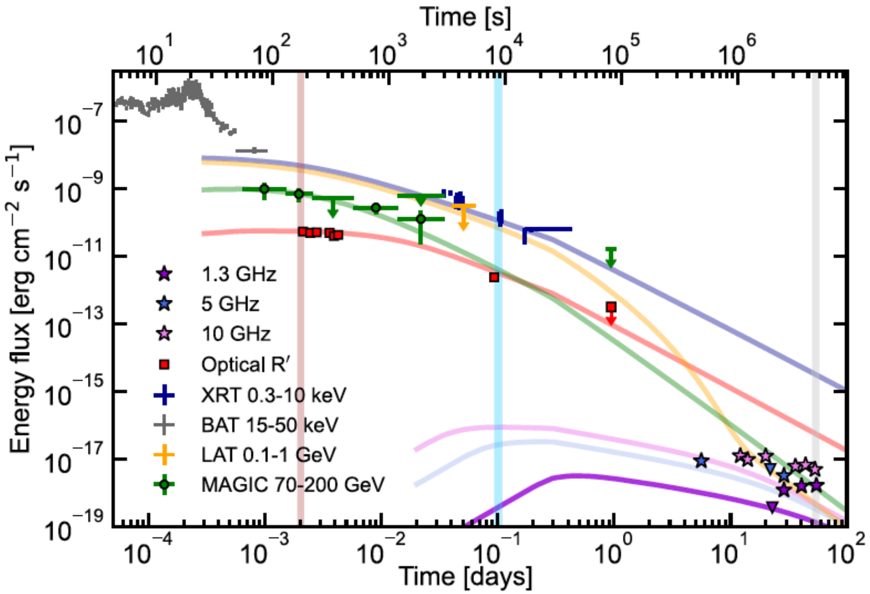
Abe et al. 2023

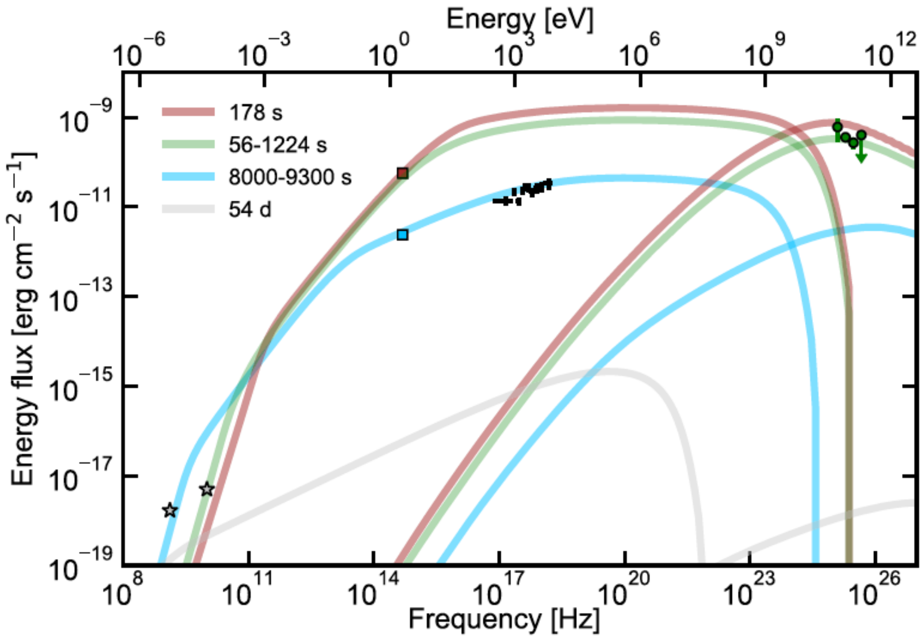
GRBs @ VHE ! (GRB 201216C)



Abe et al. 2023

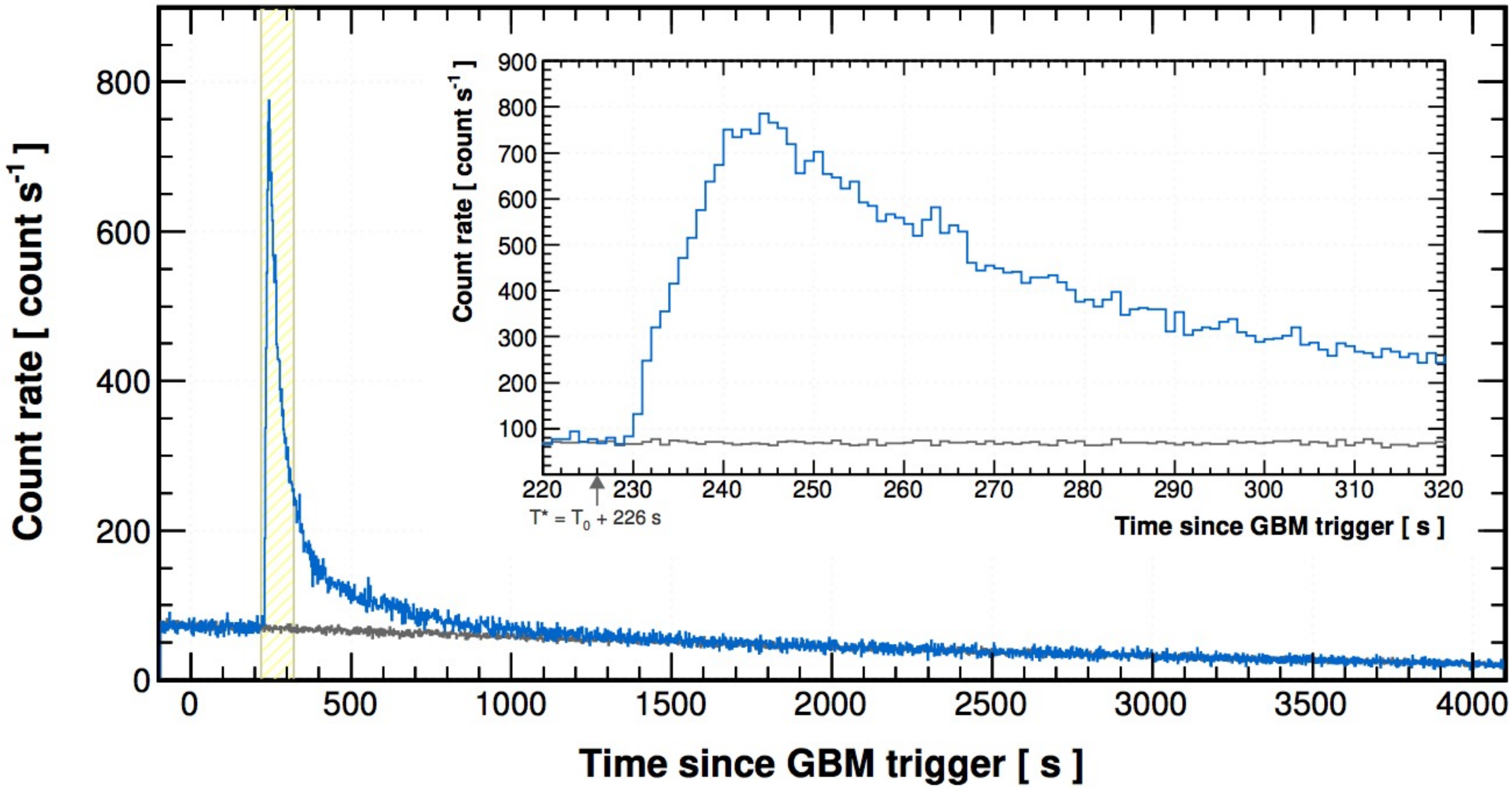
GRBs @ VHE ! (GRB 201216C)





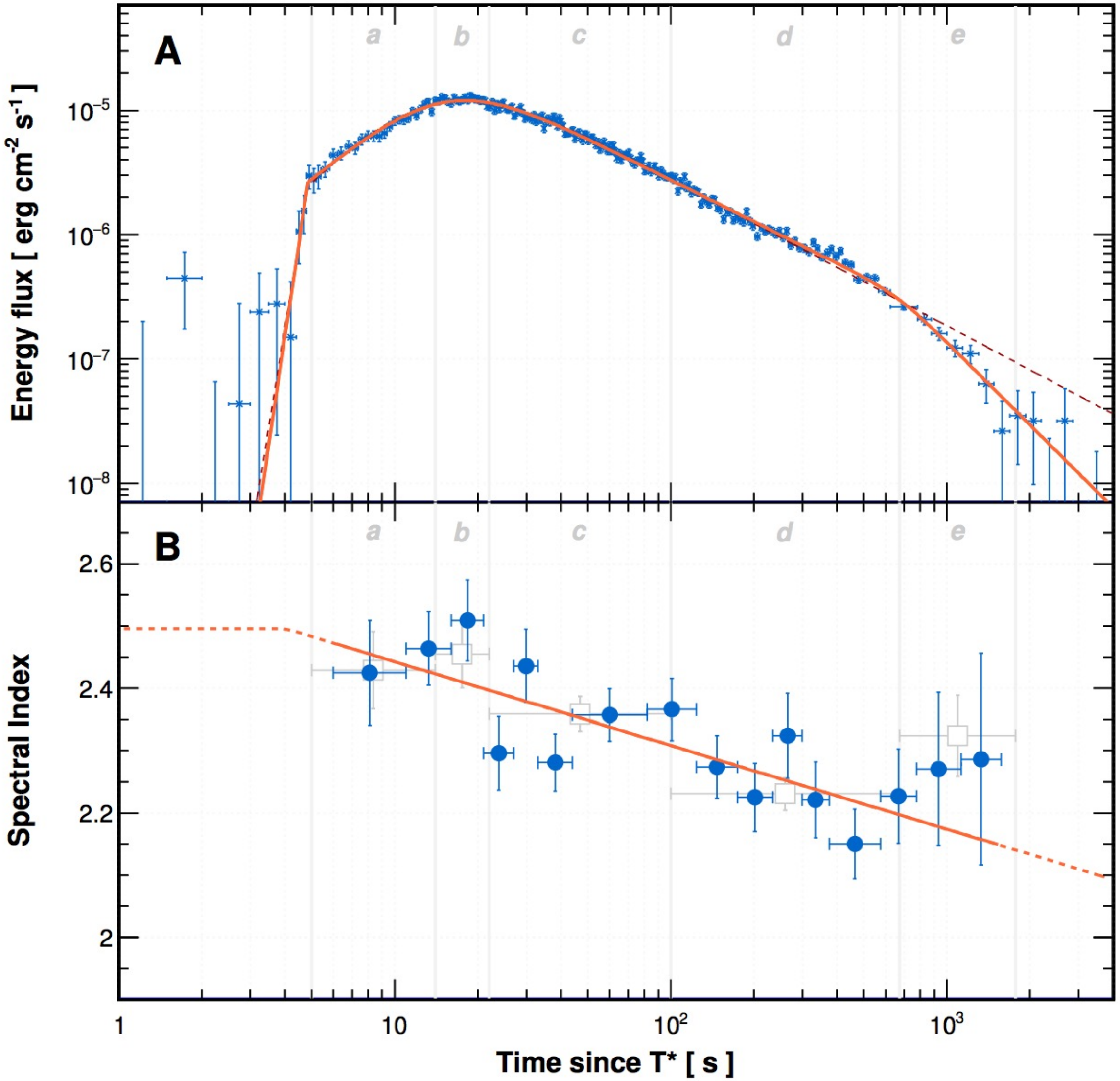
Abe et al. 2023

GRBs @ VHE ! (GRB 221009A)



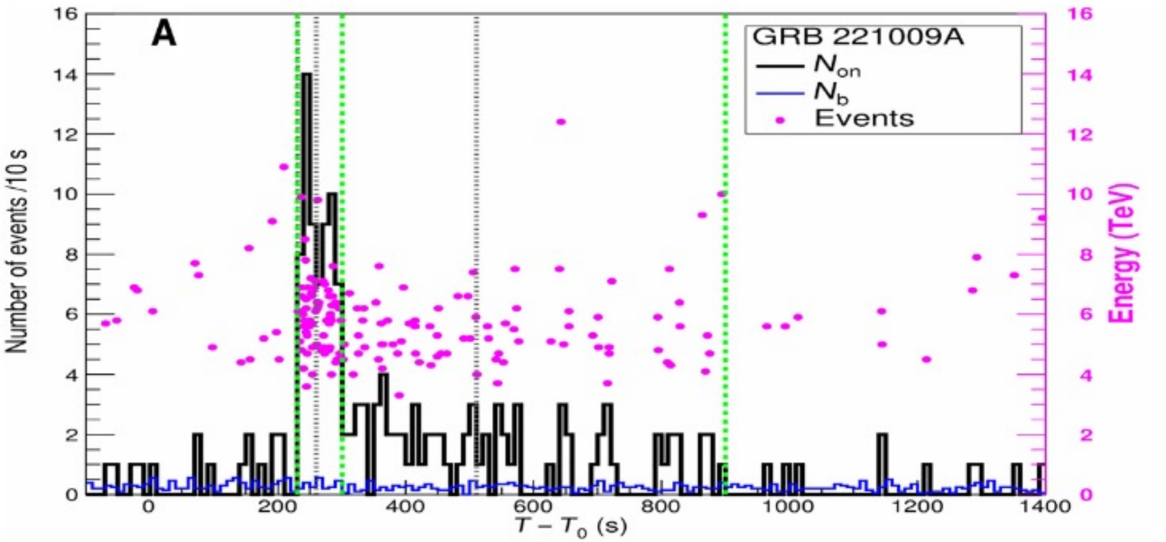
Cao et al. 2023

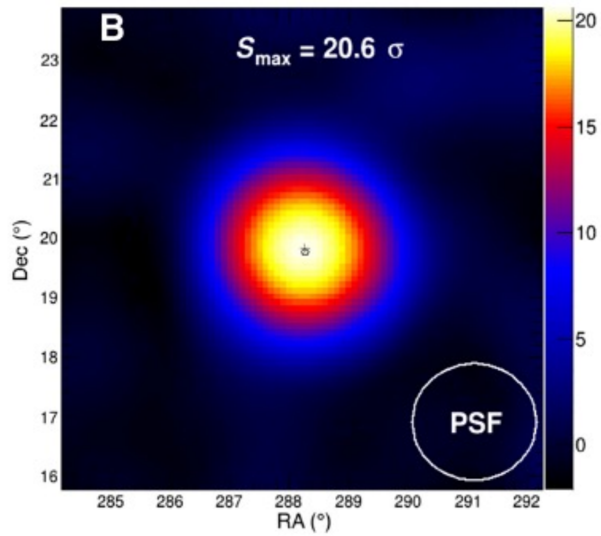
GRBs @ VHE ! (GRB 221009A)

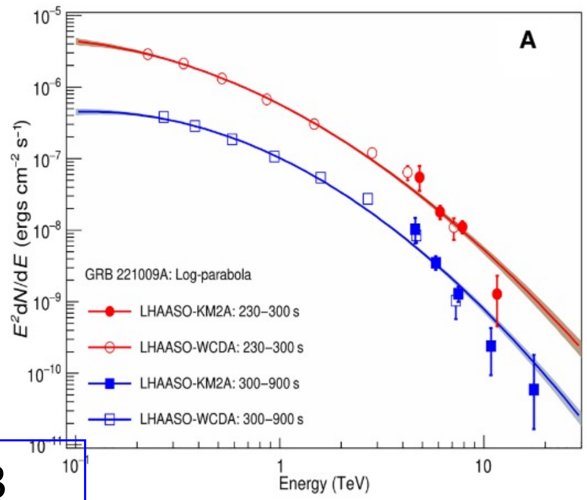


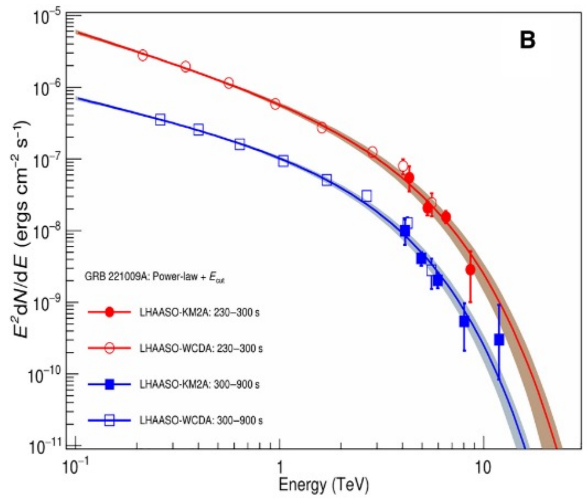
Cao et al. 2023

GRBs @ VHE ! (GRB 221009A)



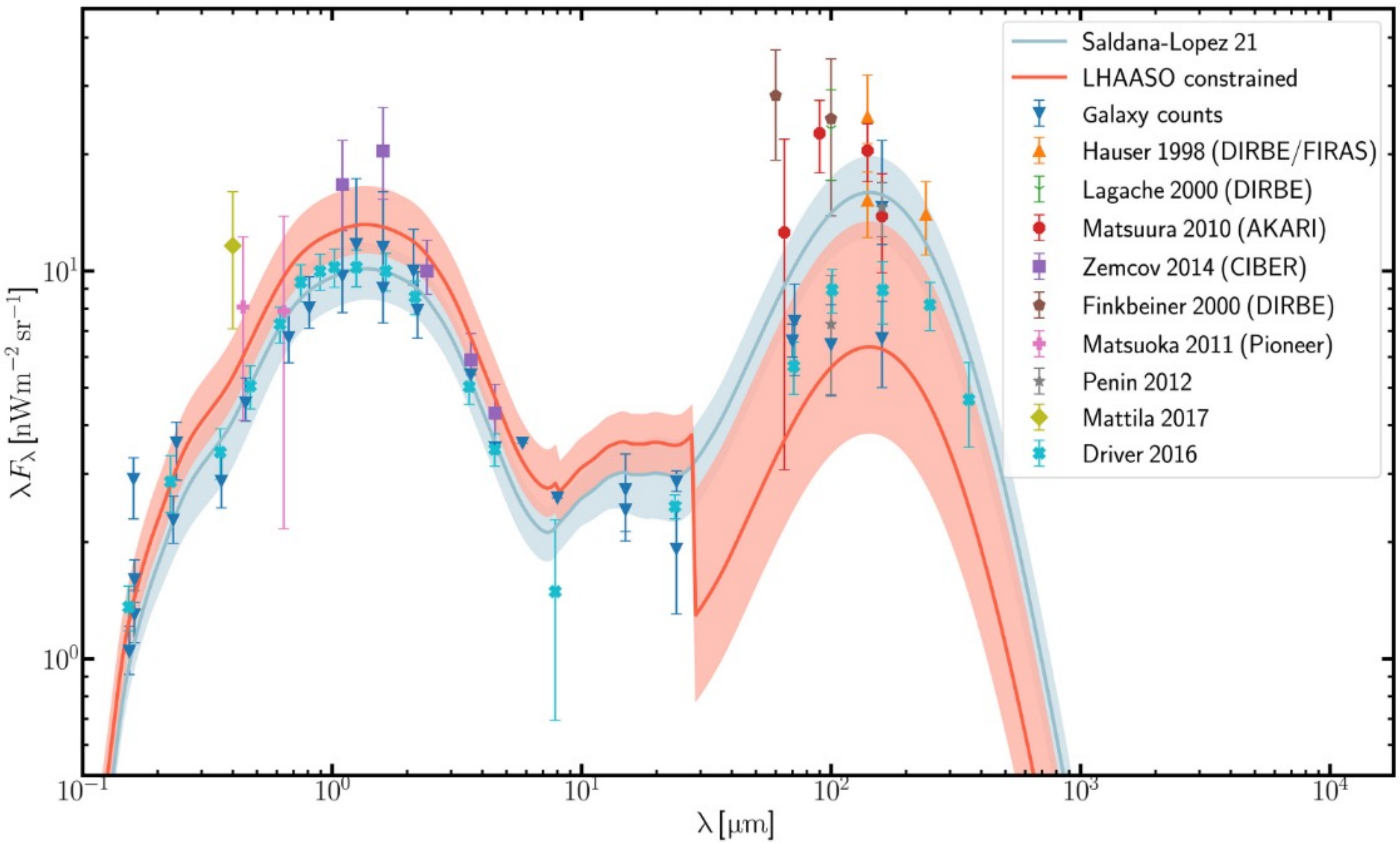






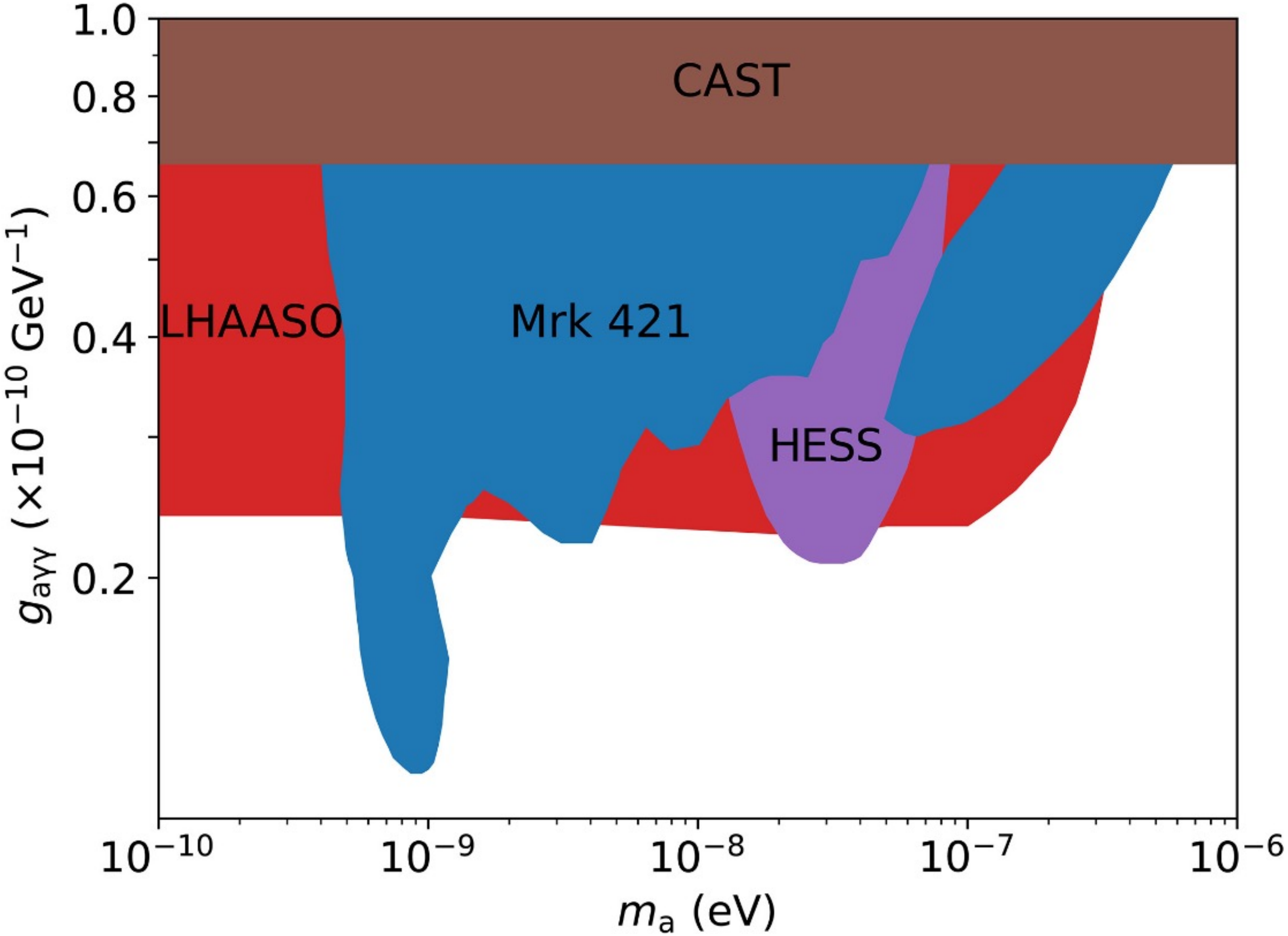
LHAASO Collaboration et al. 2023

GRBs @ VHE ! (GRB 221009A)



LHAASO Collaboration et al. 2023

GRBs @ VHE ! (GRB 221009A)



LHAASO Collaboration et al. 2023

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

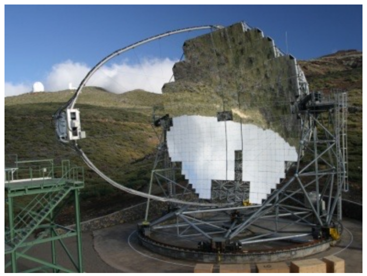
Design Study of Wide Angle Telescope

Advanced photon detector

Science Review

Final Conceptual Design under New collaboratio

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

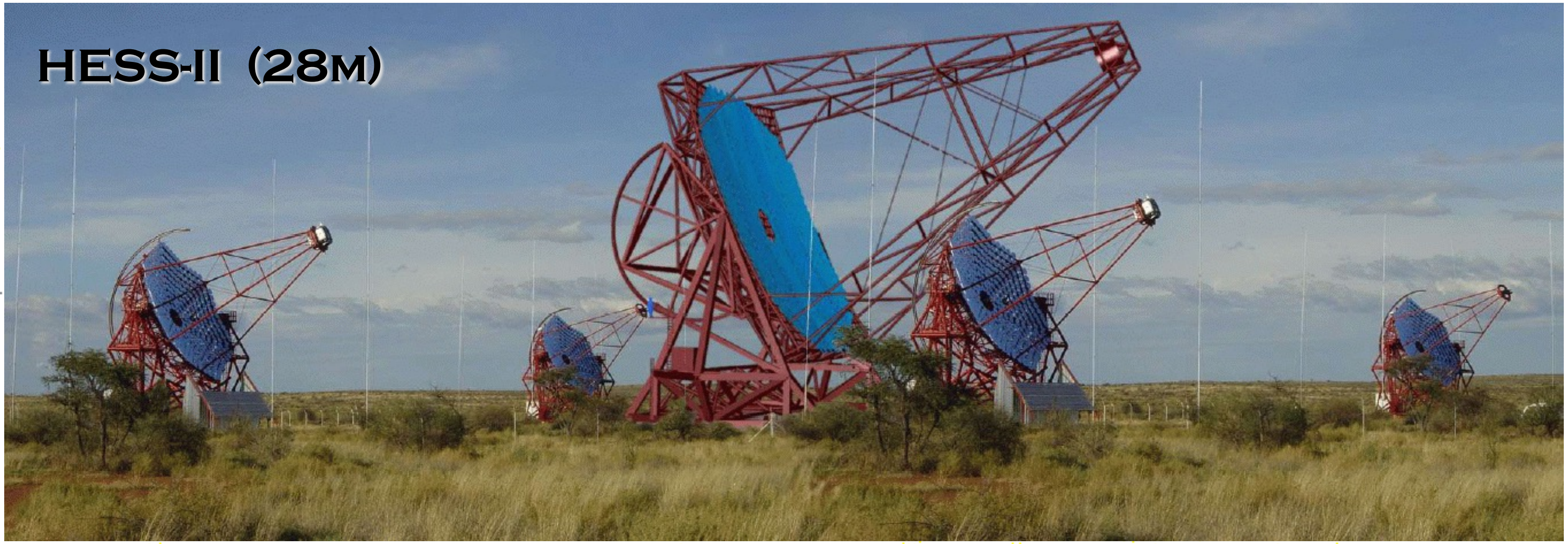

MAGIC


MAGIC II

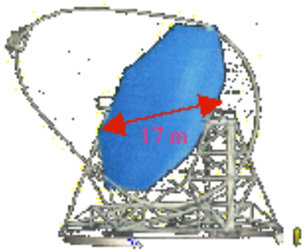
International collaboration CANGAROO, VERITAS, etc.

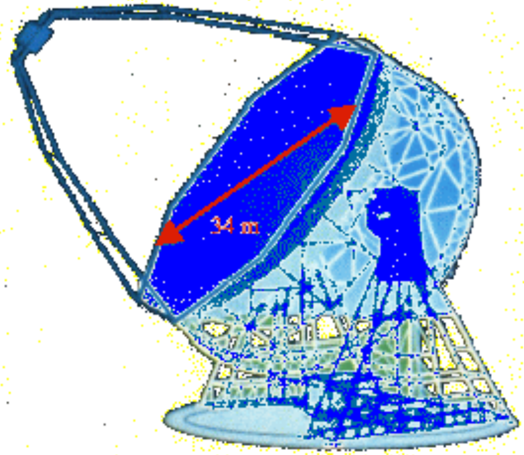
New Cherenkov telescopes

HUNT FOR LOWEST THRESHOLD: BIGGER IS BETTER !!!???

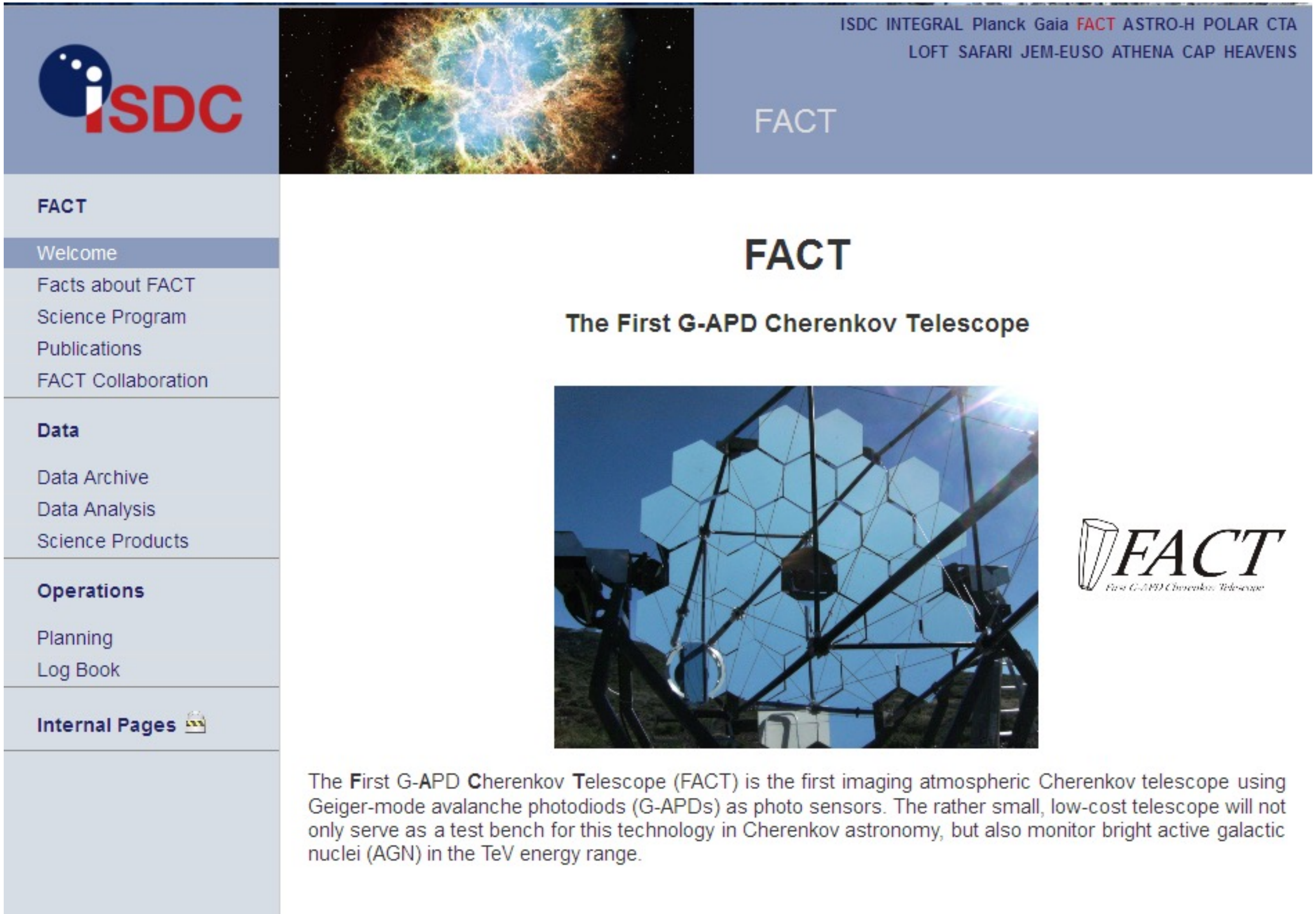


ECO-1000 ? (34M)





New Cherenkov telescopes


ISDC INTEGRAL Planck Gaia FACT ASTRO-H POLAR CTA
LOFT SAFARI JEM-EUSO ATHENA CAP HEAVENS

FACT

FACT

- Welcome
- Facts about FACT
- Science Program
- Publications
- FACT Collaboration

Data

- Data Archive
- Data Analysis
- Science Products

Operations

- Planning
- Log Book

Internal Pages

FACT

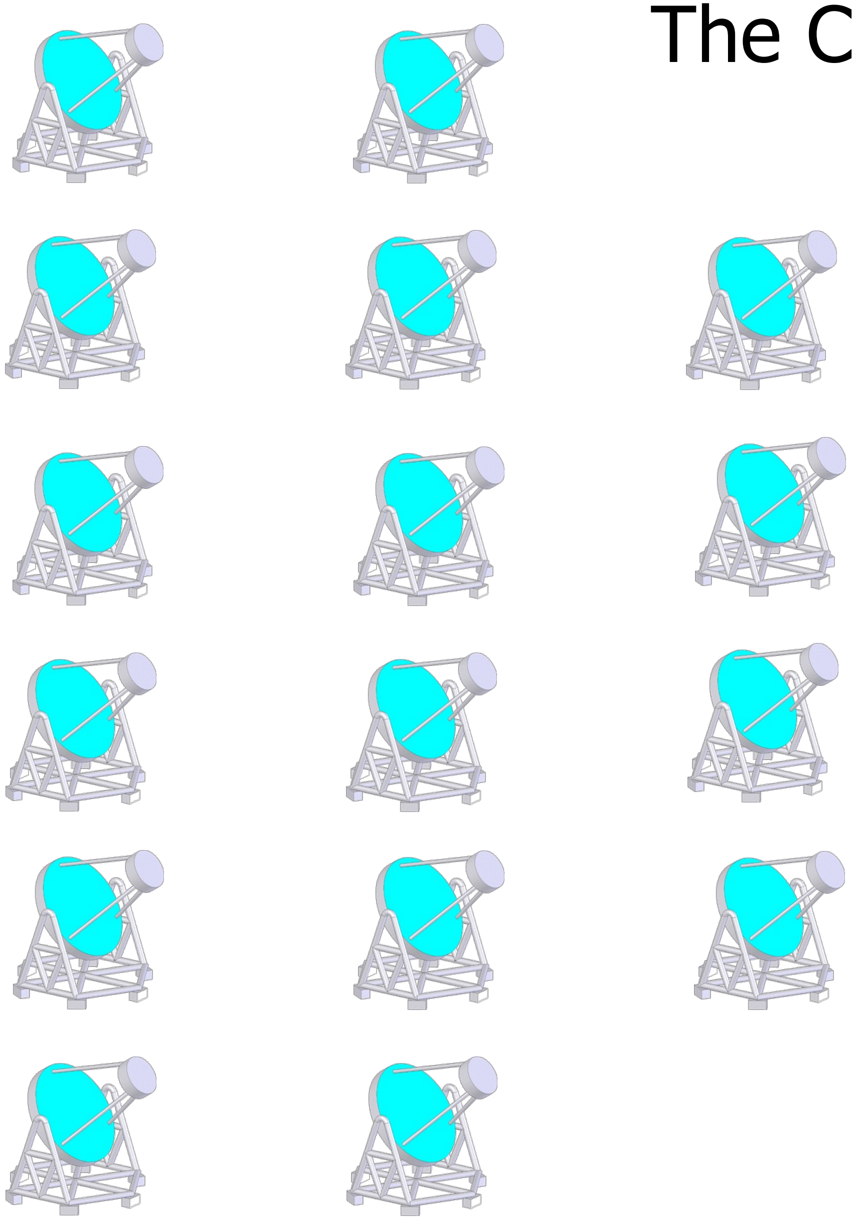
The First G-APD Cherenkov Telescope

The **F**irst G-**A**PD **C**herenkov **T**elescope (FACT) is the first imaging atmospheric Cherenkov telescope using Geiger-mode avalanche photodiods (G-APDs) as photo sensors. The rather small, low-cost telescope will not only serve as a test bench for this technology in Cherenkov astronomy, but also monitor bright active galactic nuclei (AGN) in the TeV energy range.

http://isdc.unige.ch/fact/

Outlook: What next ?

The Cherenkov Telescope Array (CTA)

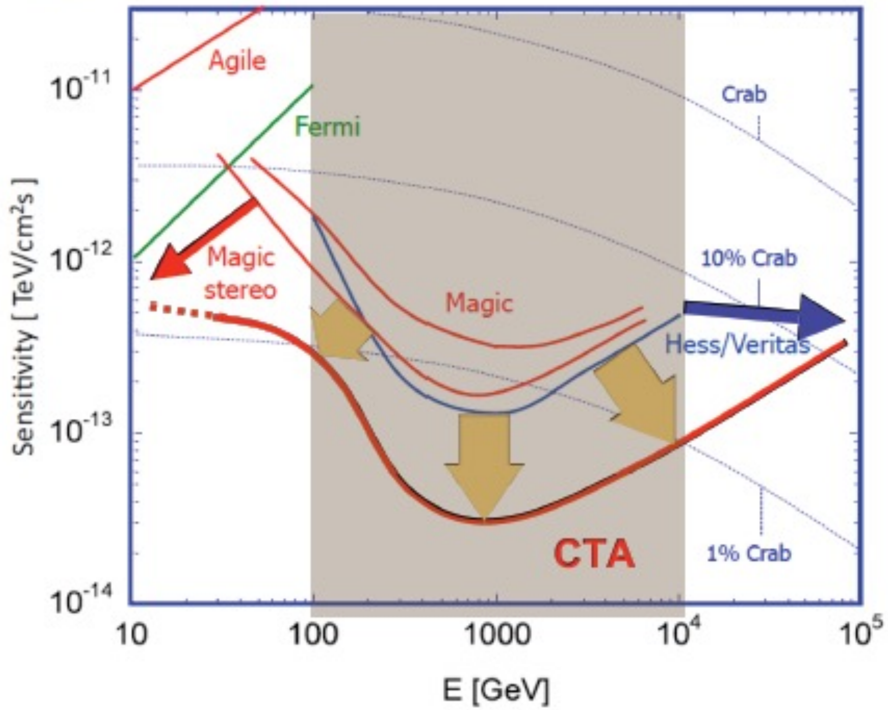


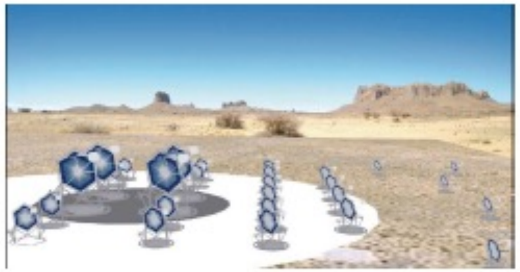
- aims to explore the sky in the 10 GeV to 100 TeV energy range
- builds on demonstrated technologies
- combines guaranteed science with significant discovery potential
- is a cornerstone towards a multi-messenger exploration of the nonthermal universe

CTA

cta cherenkov telescope array

Improve sensitivity





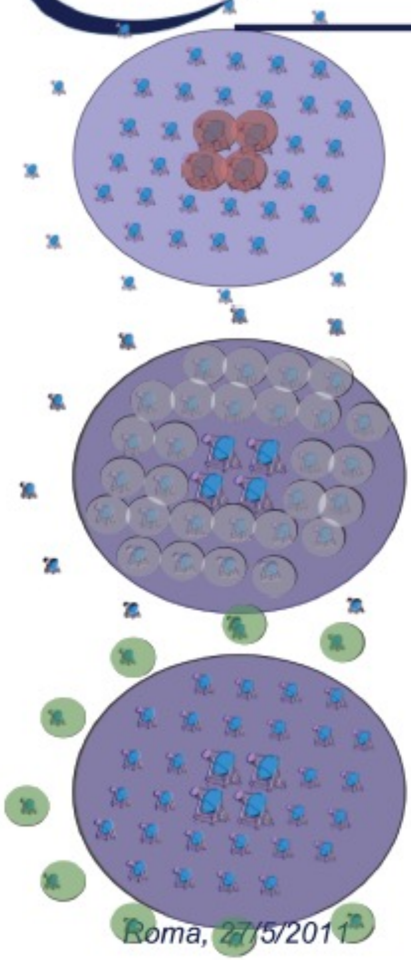
CTA will be about a factor of 10 more sensitive than any existing instrument in the 100 GeV-10 TeV energy band.

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

CTA

CTA concept

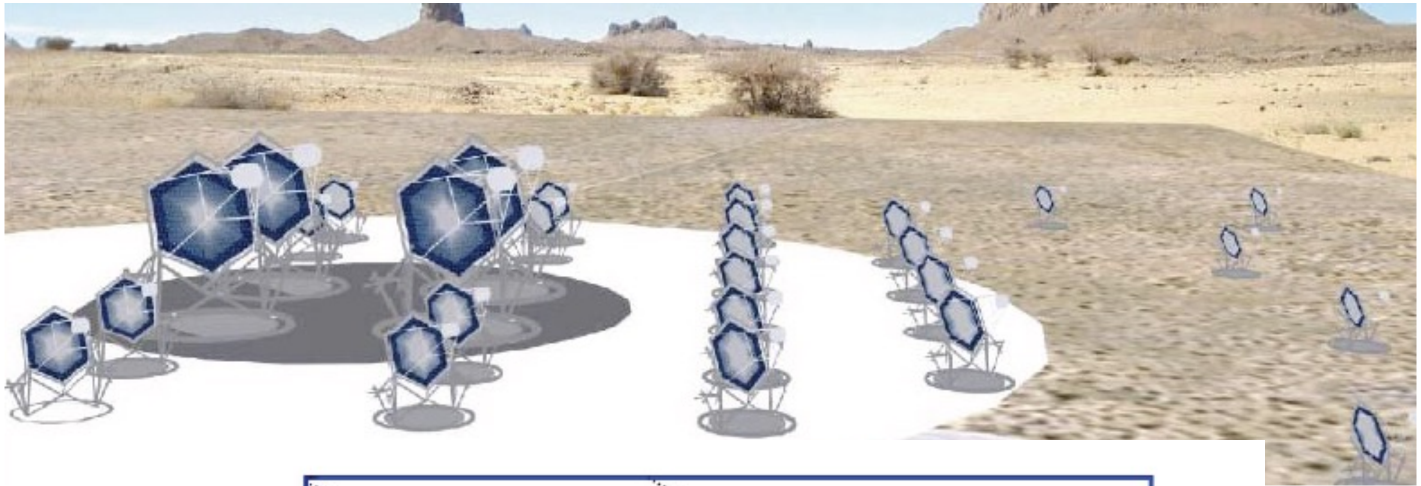
cta
cherenkov telescope array

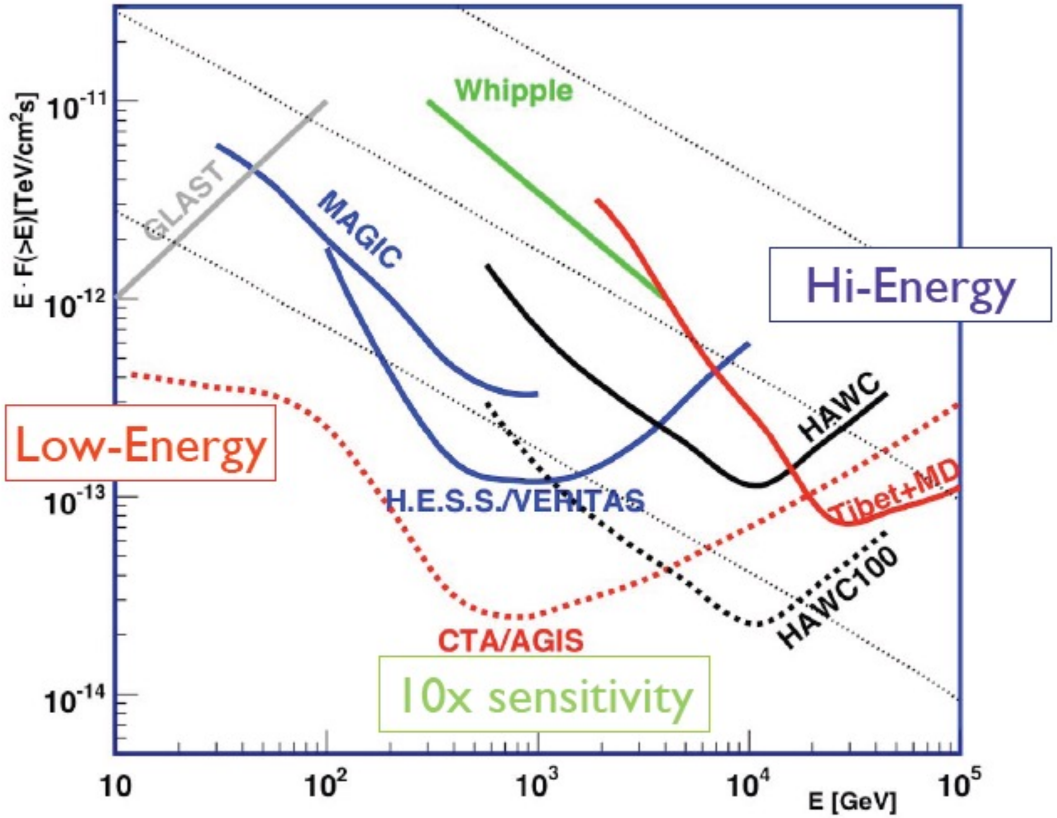


- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
- Several Medium Size Telescopes perform 100 GeV-50 TeV observation
- well-proven techniques (HESS, MAGIC)
- goal is to reduce costs and maintenance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

CTA



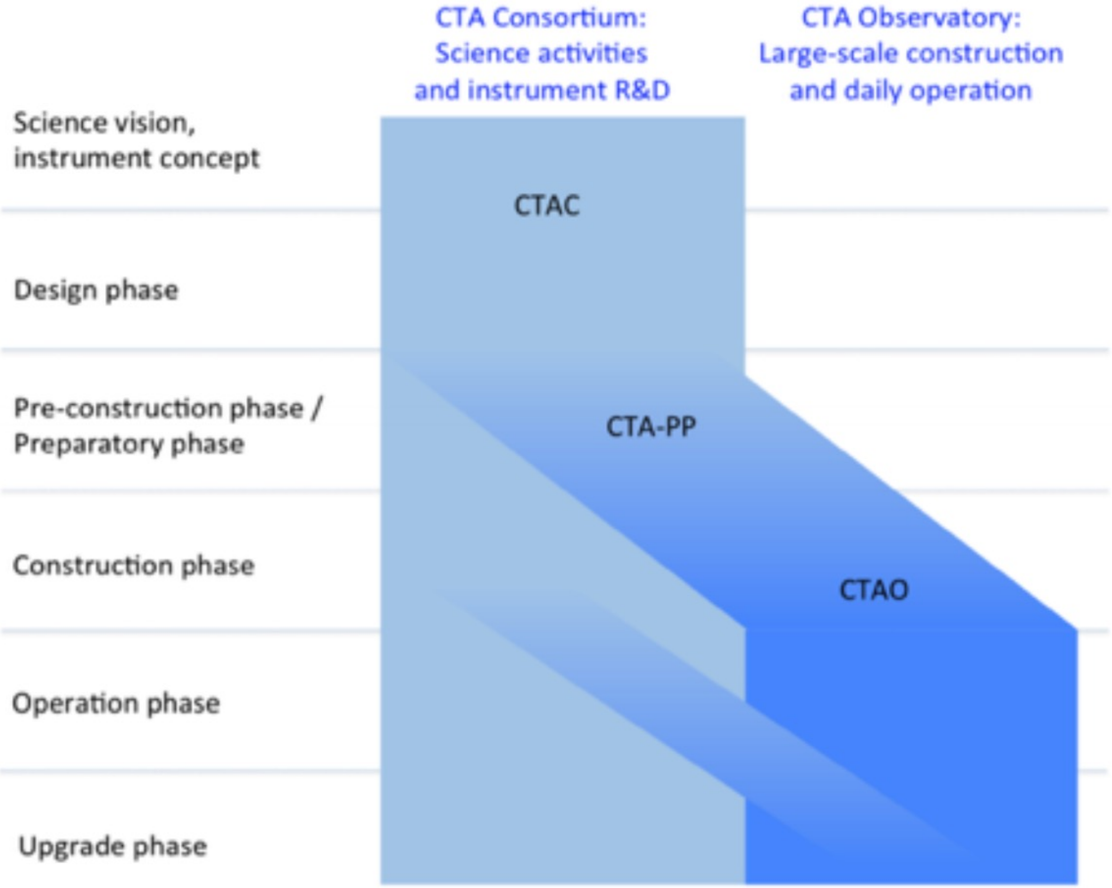


Whipple
GLAST
MAGIC
Hi-Energy
Low-Energy
HAWC
H.E.S.S./VERITAS
Tibet+MD
HAWC100
CTA/AGIS
10x sensitivity
E · F(>E)[TeV/cm²s]
E [GeV]
10
10²
10³
10⁴
10⁵
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴

Toward the future!

A next generation Cherenkov Observatory

Status and observatory planning…

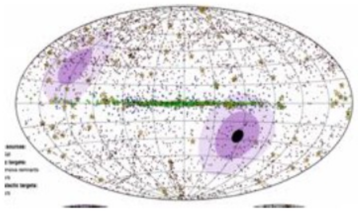


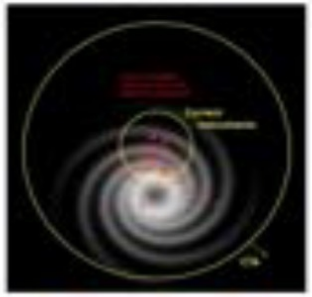
- CTA as open observatory
- Regular AOs
- Proposals evaluated by TAC
- Observations carried out in queue mode
- Fully calibrated photon lists and analysis tools provided to observers
- Data open after proprietary period of 1 year

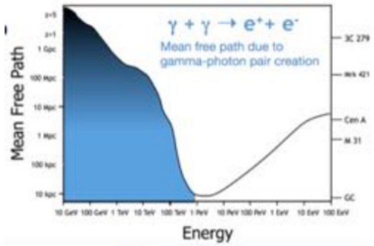
From:
Concept for CTA
construction and operation
WH 2011/12

U.Barres – COSPAR 2020

Design drivers

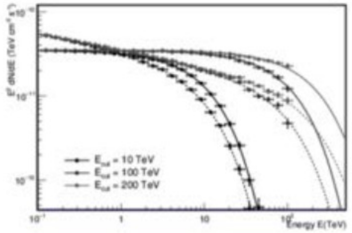






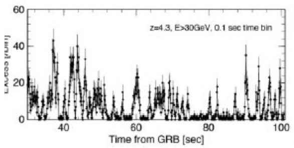
Full sky coverage

10 x sensitivity



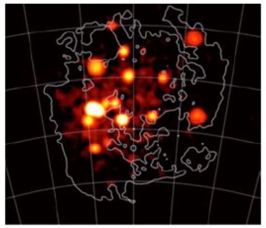
Energies down to 20 GeV

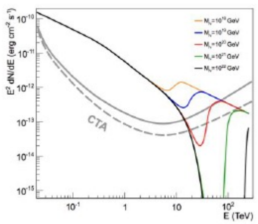
Energies up to 300 TeV



Rapid slewing 20 sec

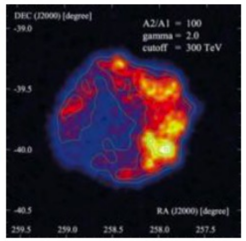
~ 10° FoV



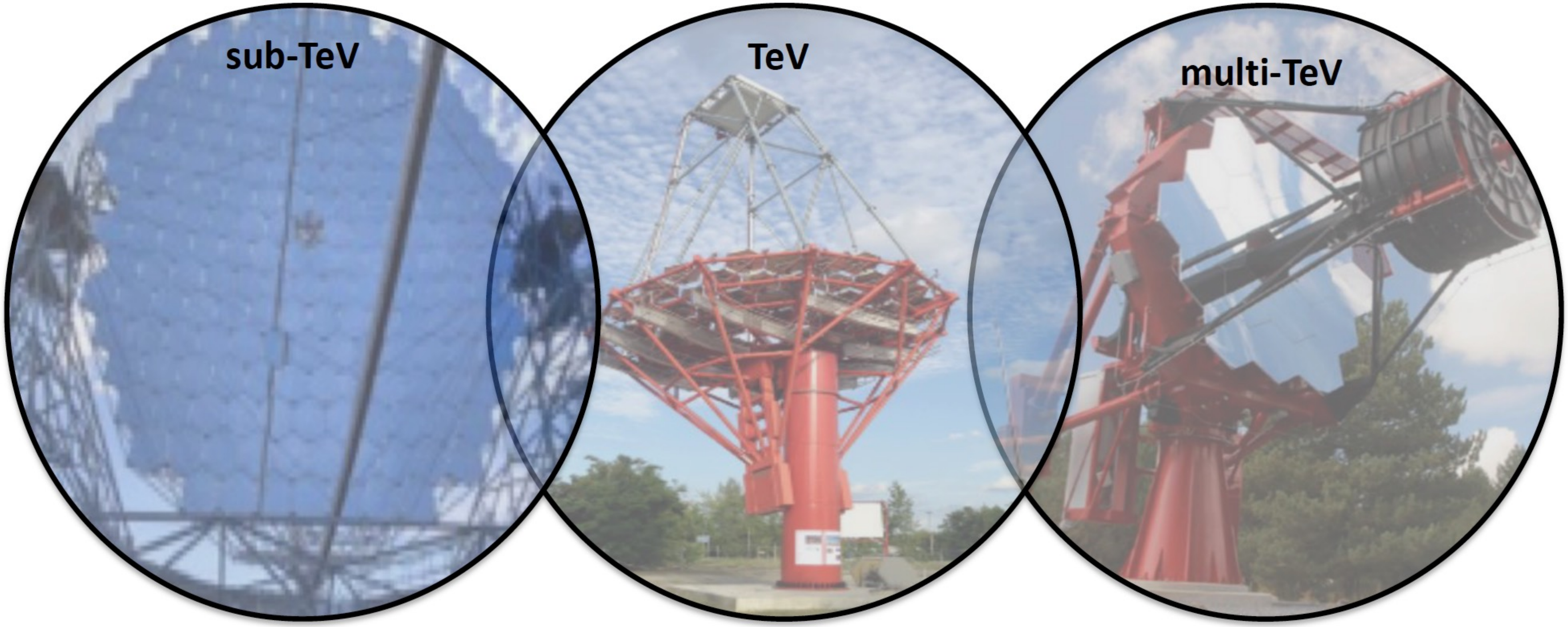


10% energy resolution

arcmin angular resolution



Science cases and design

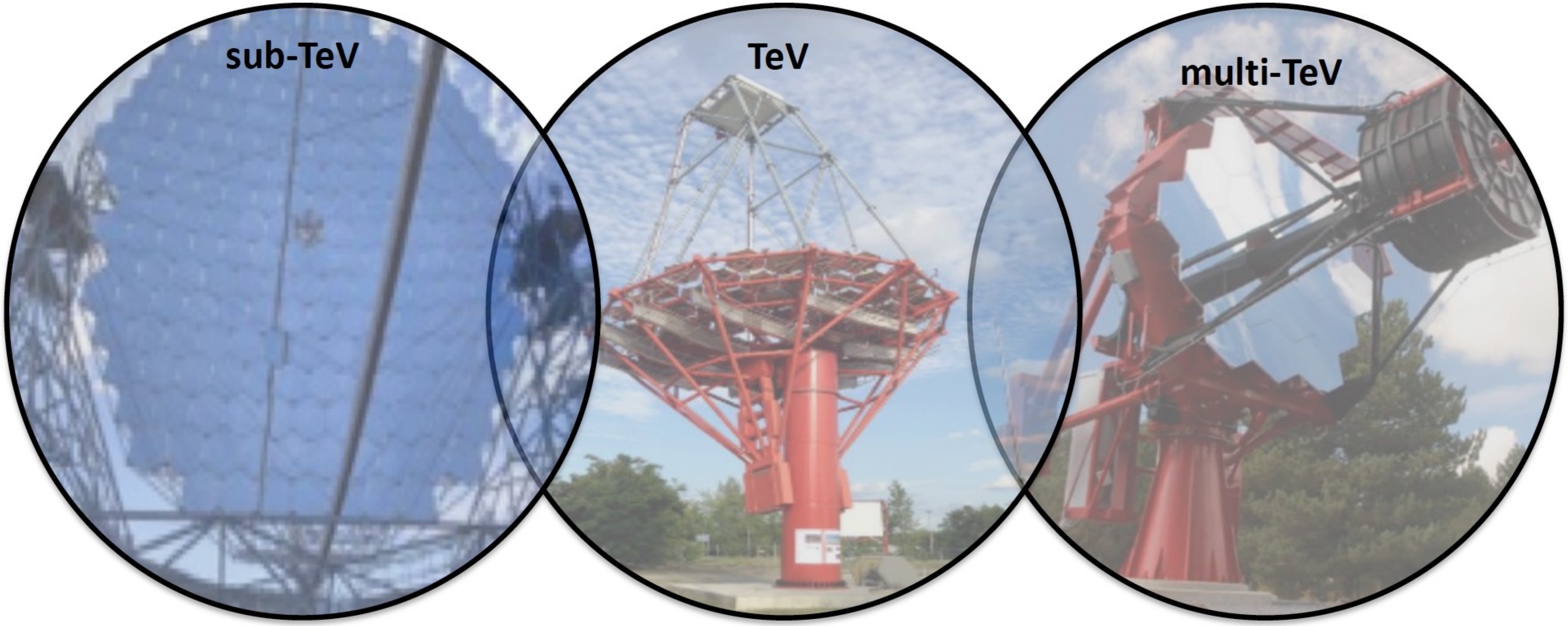


- Parabolic optical design
- 23 m mirror diameter
- PMT camera

- 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**

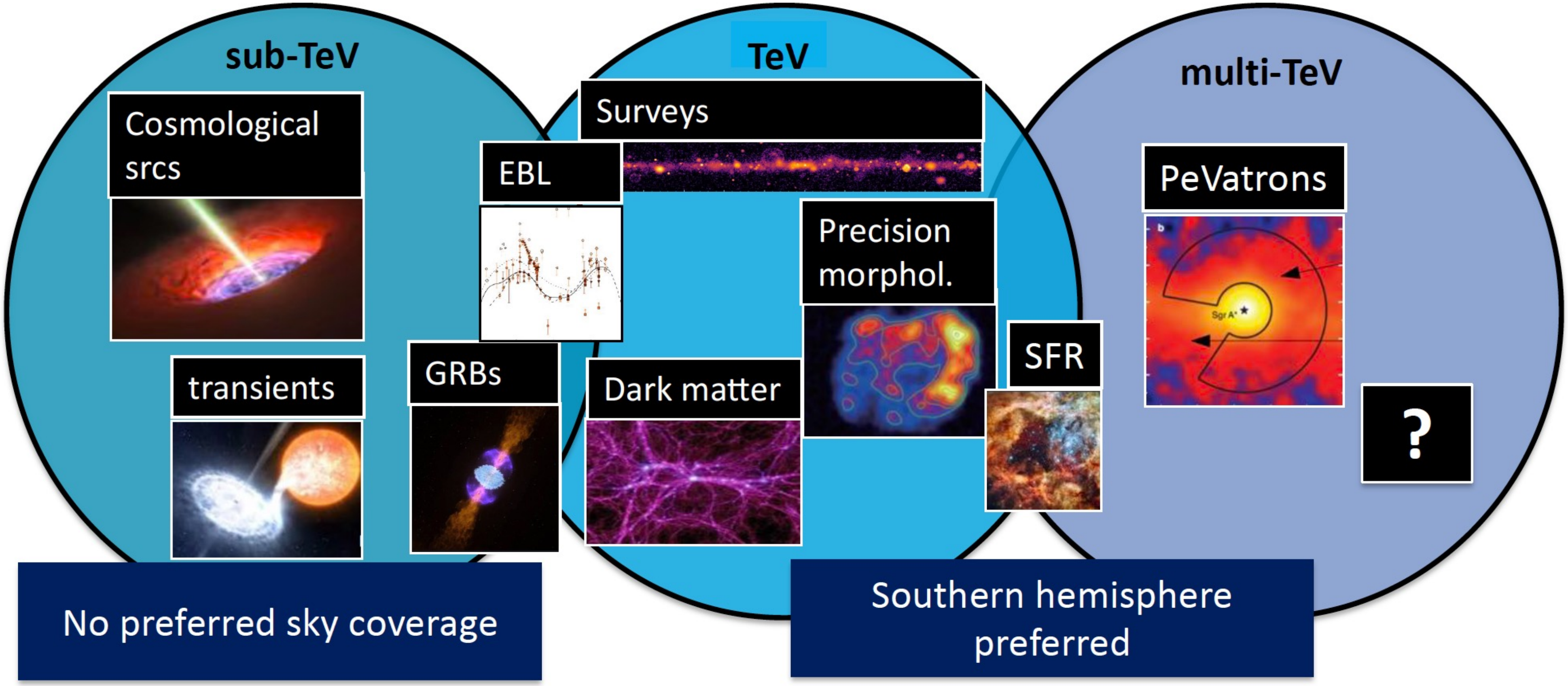
- deepest sensitivity ever
- arcmin angular resolution
- large FoV

- Surveys & precision studies

- Precision measurements in a still little explored energy range

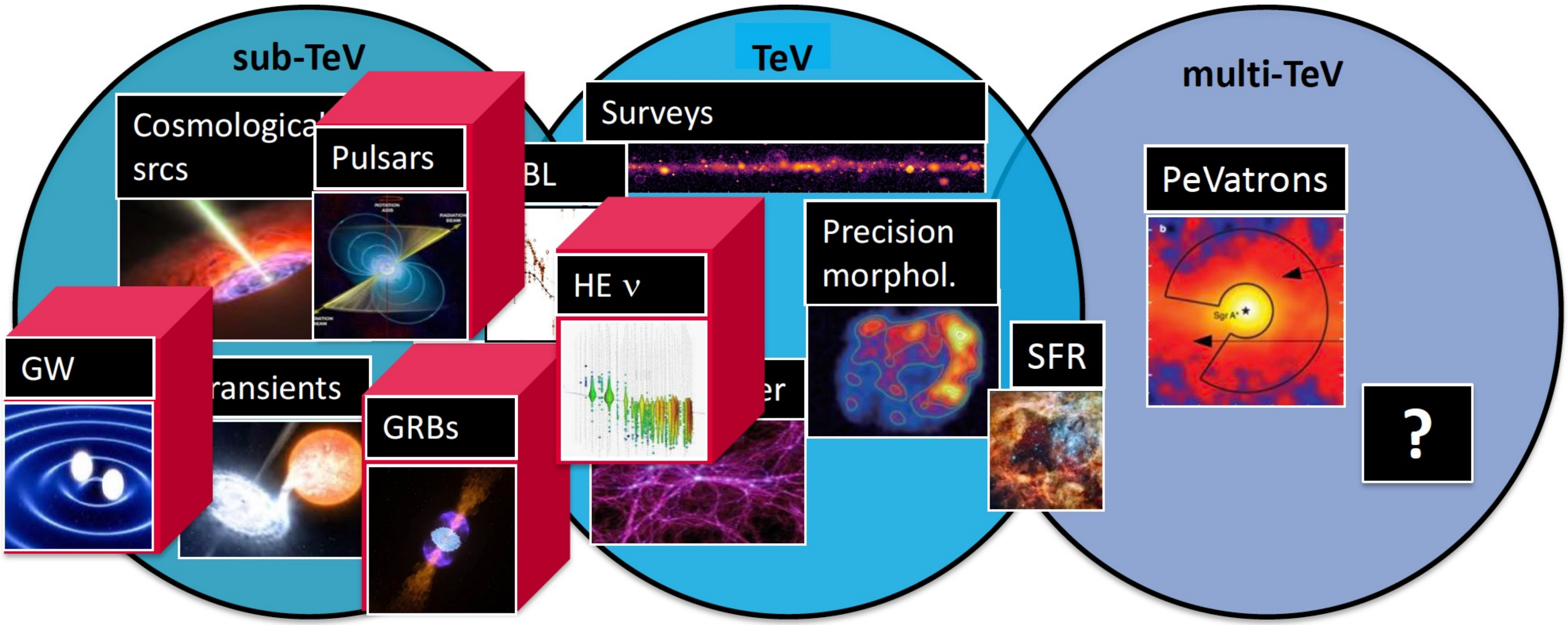
- **100 TeV range unexplored**
- **precision studies**

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)

Science cases



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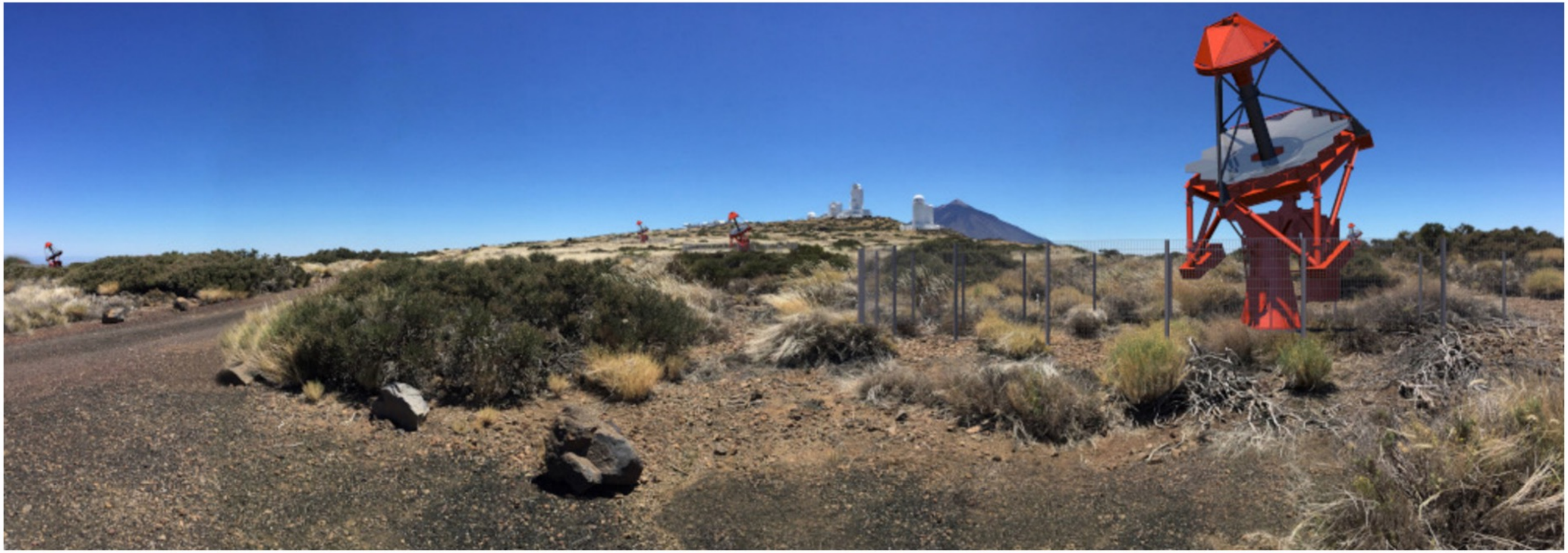
(Science with CTA, CTA Consortium 2019 - https://doi.org/10.1142/10986)

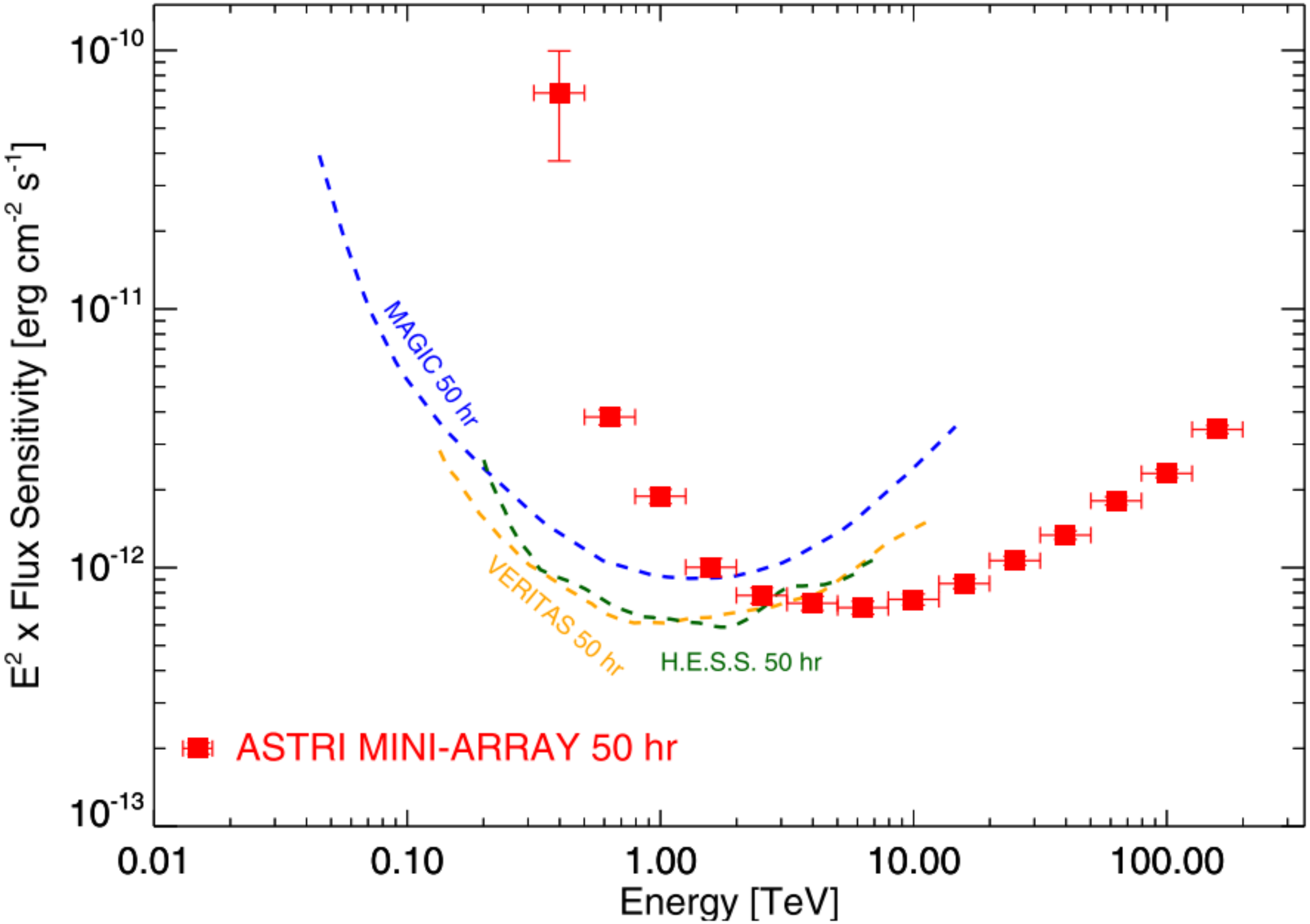
ASTRI



ASTRI

Carretera de La Esperanza
Meteo-1
ASTRI-7
ASTRI-6
Control Room
Transformer Station
ASTRI-3
ASTRI-4
ASTRI-5
ASTRI-1
LIDAR
ASTRI-2
ASTRI-9
Meteo-2
ASTRI-8
Data Centre

ASTRI



E^2 x Flux Sensitivity [erg cm^{-2} s^{-1}]
10^{-10}
10^{-11}
10^{-12}
10^{-13}
MAGIC 50 hr
VERITAS 50 hr
H.E.S.S. 50 hr
ASTRI MINI-ARRAY 50 hr
0.01
0.10
1.00
10.00
100.00
Energy [TeV]

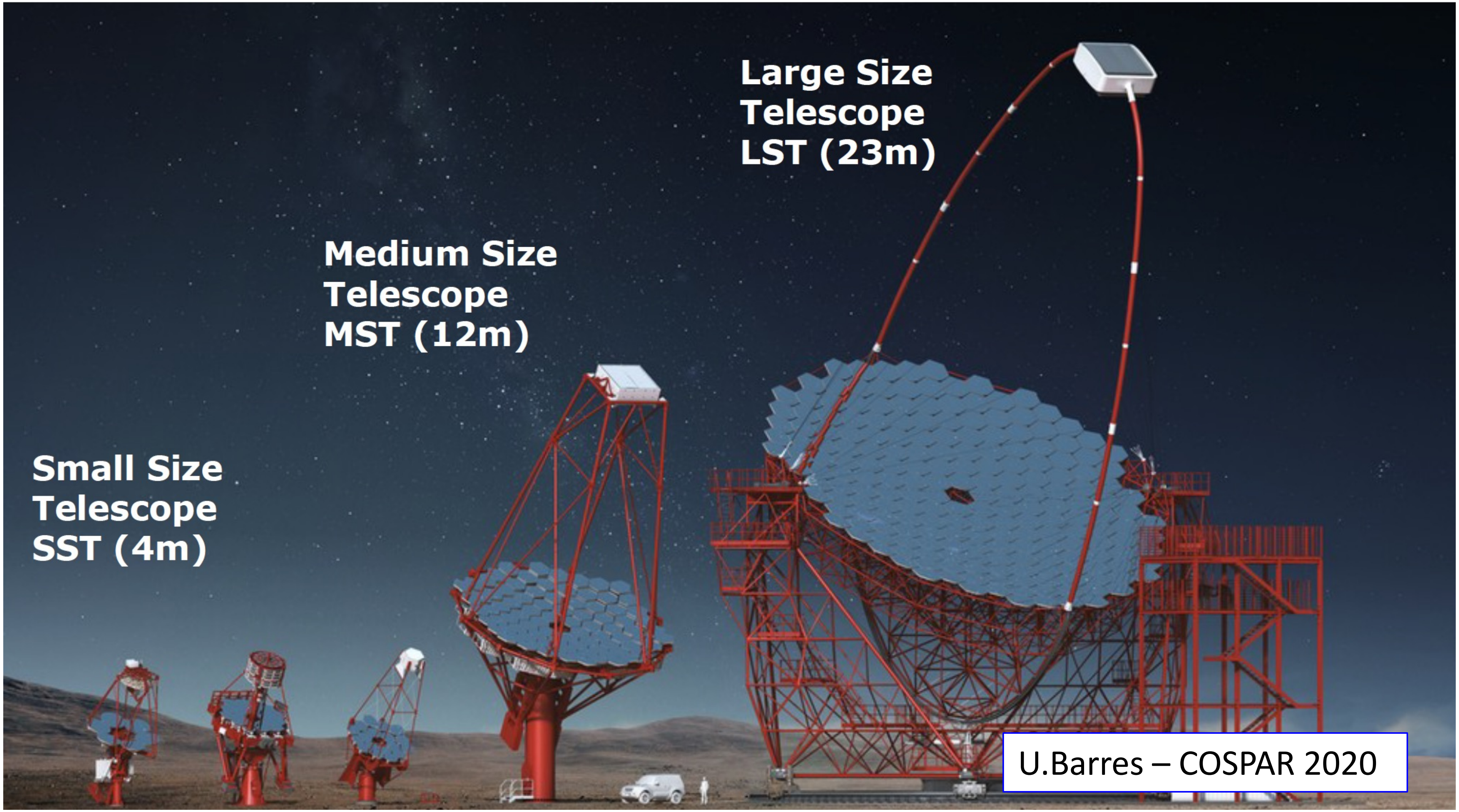
The CTA Sites

A Global Observatory…

U.Barres – COSPAR 2020

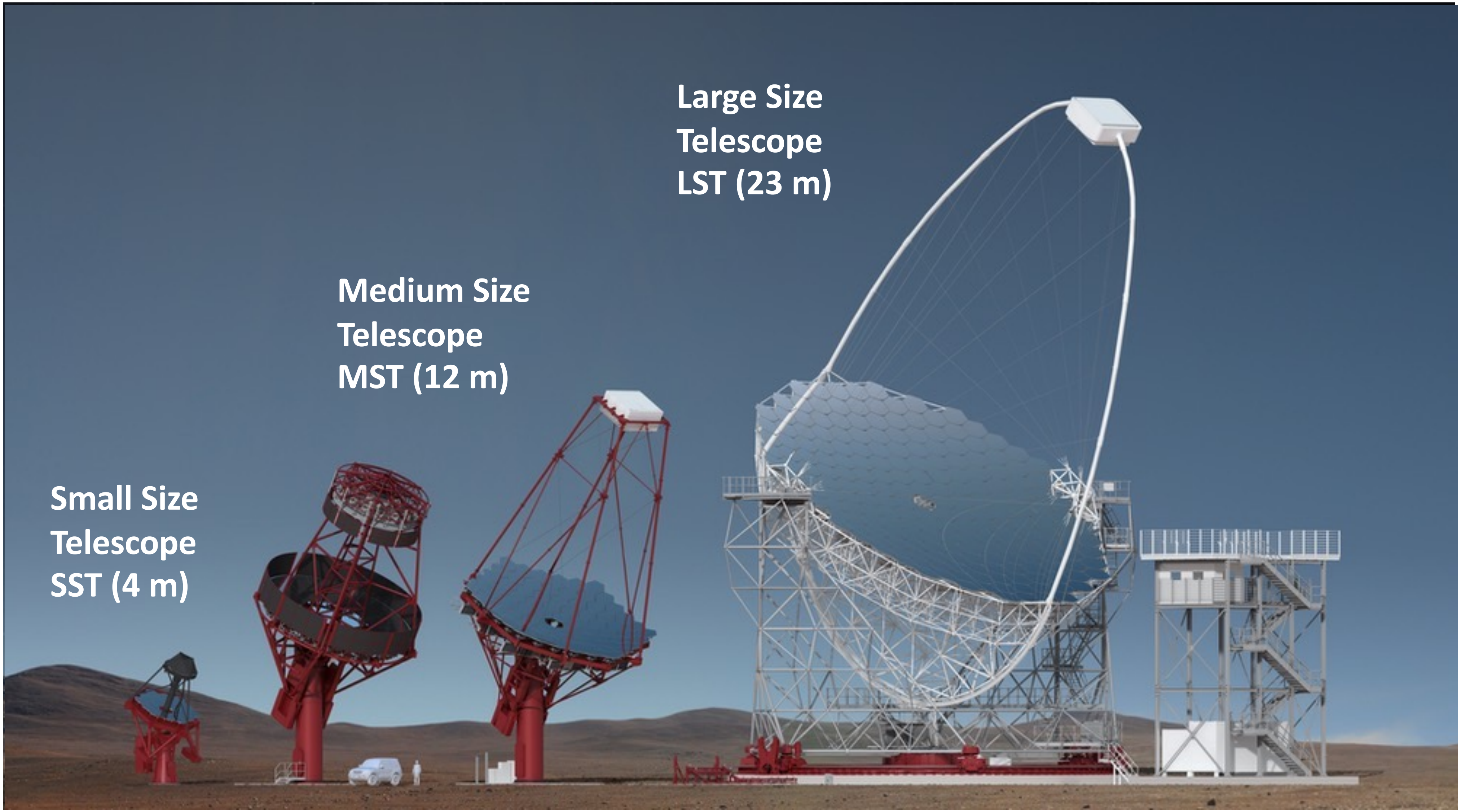
The CTA Telescopes

A Hybrid Observatory…



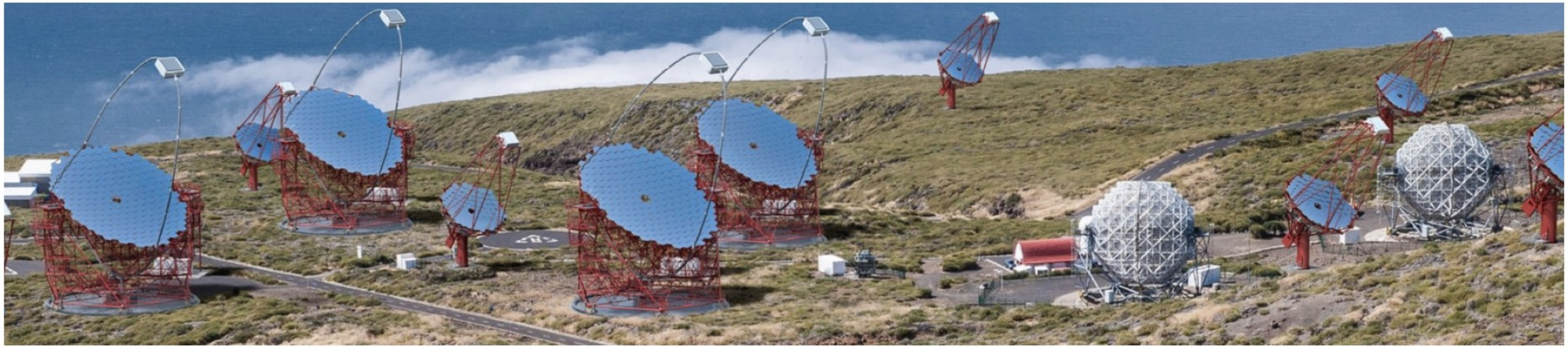
The CTA Telescopes

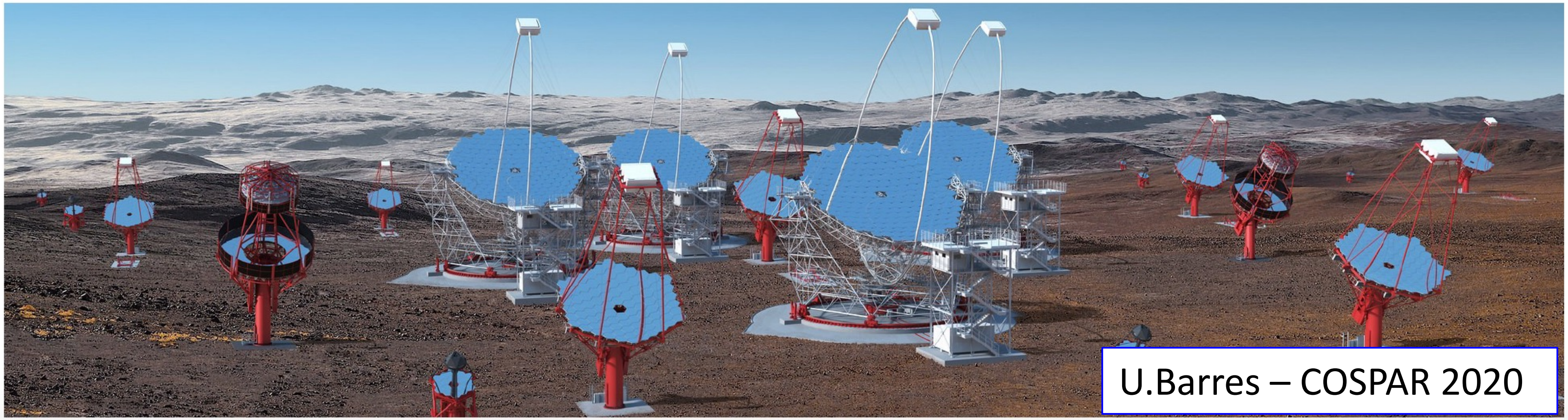
A Hybrid Observatory…



CTA North & CTA South

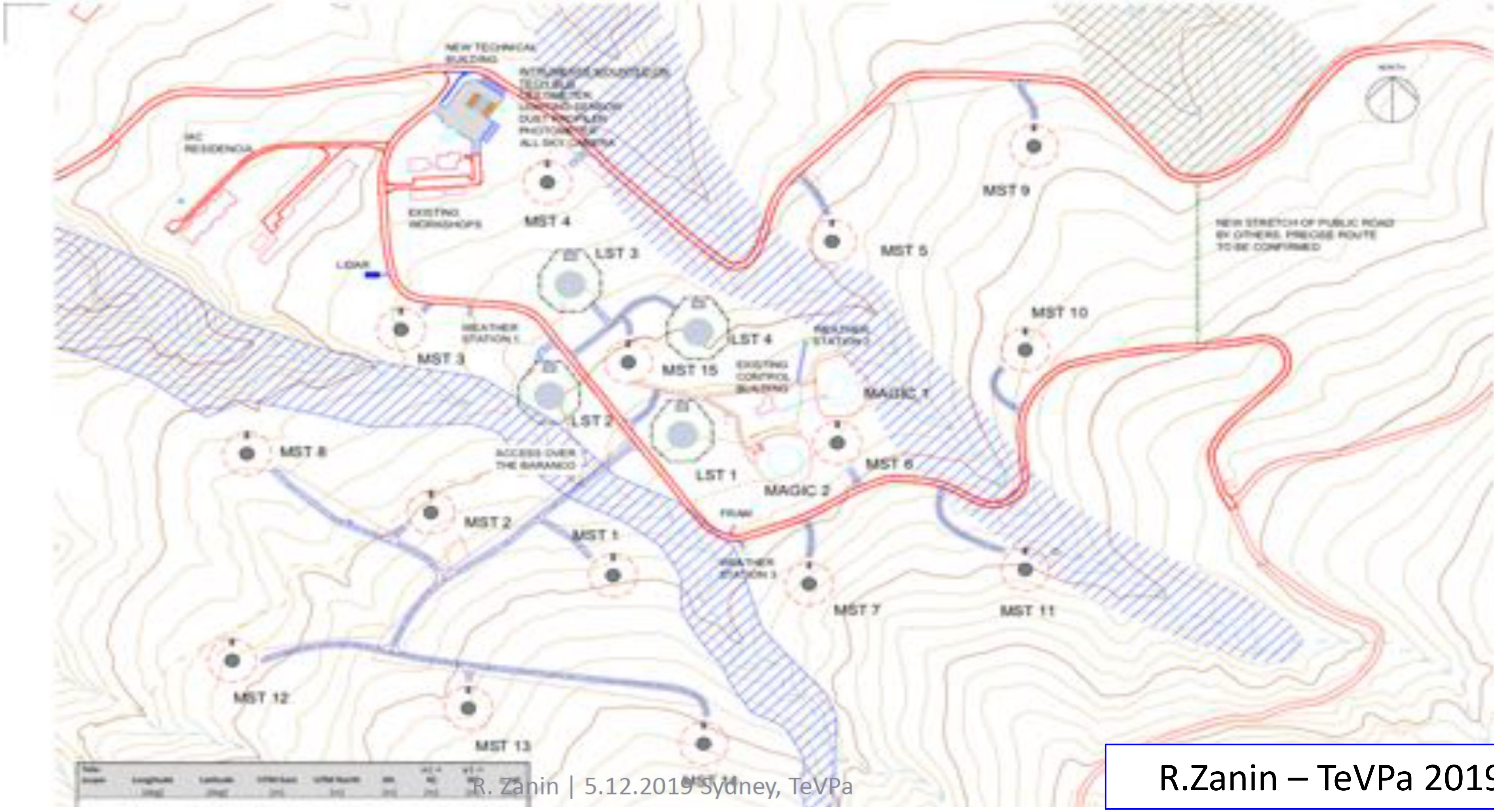
Phase 1		CTA Construction
Northern Array	Number of LSTs	4
	Number of MSTs	5
Southern Array	Number of LSTs	0
	Number of MSTs	15
	Number of SSTs	50
Total		74





CTA-North site

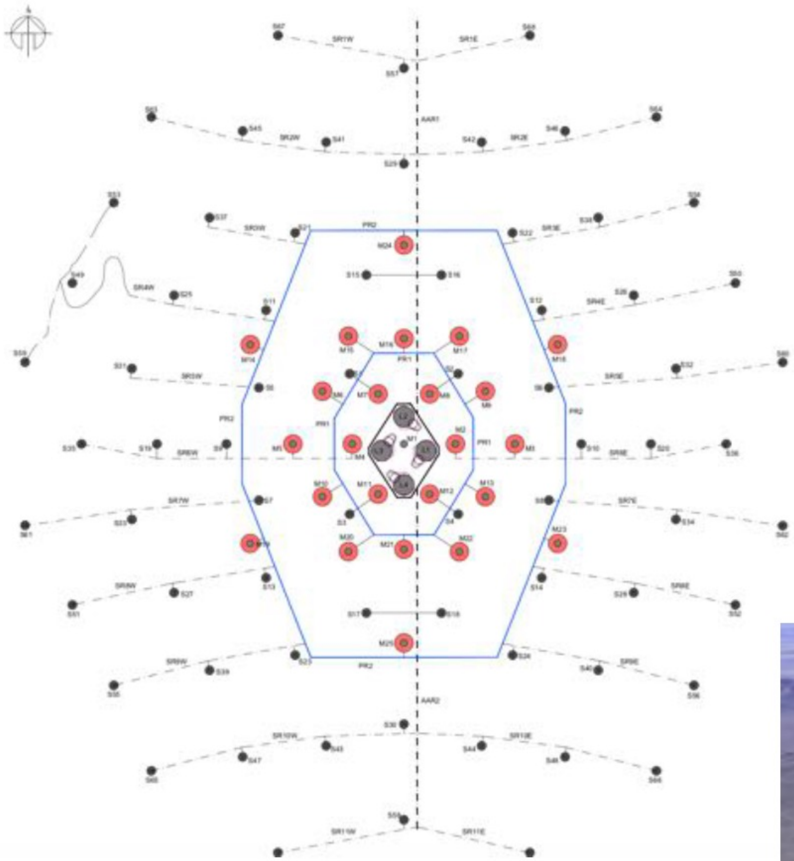
- **4 LSTs + 15 MSTs (baseline configuration)**
  - **Focus on sub-TeV and TeV energy range**



R.Zanin – TeVPa 2019

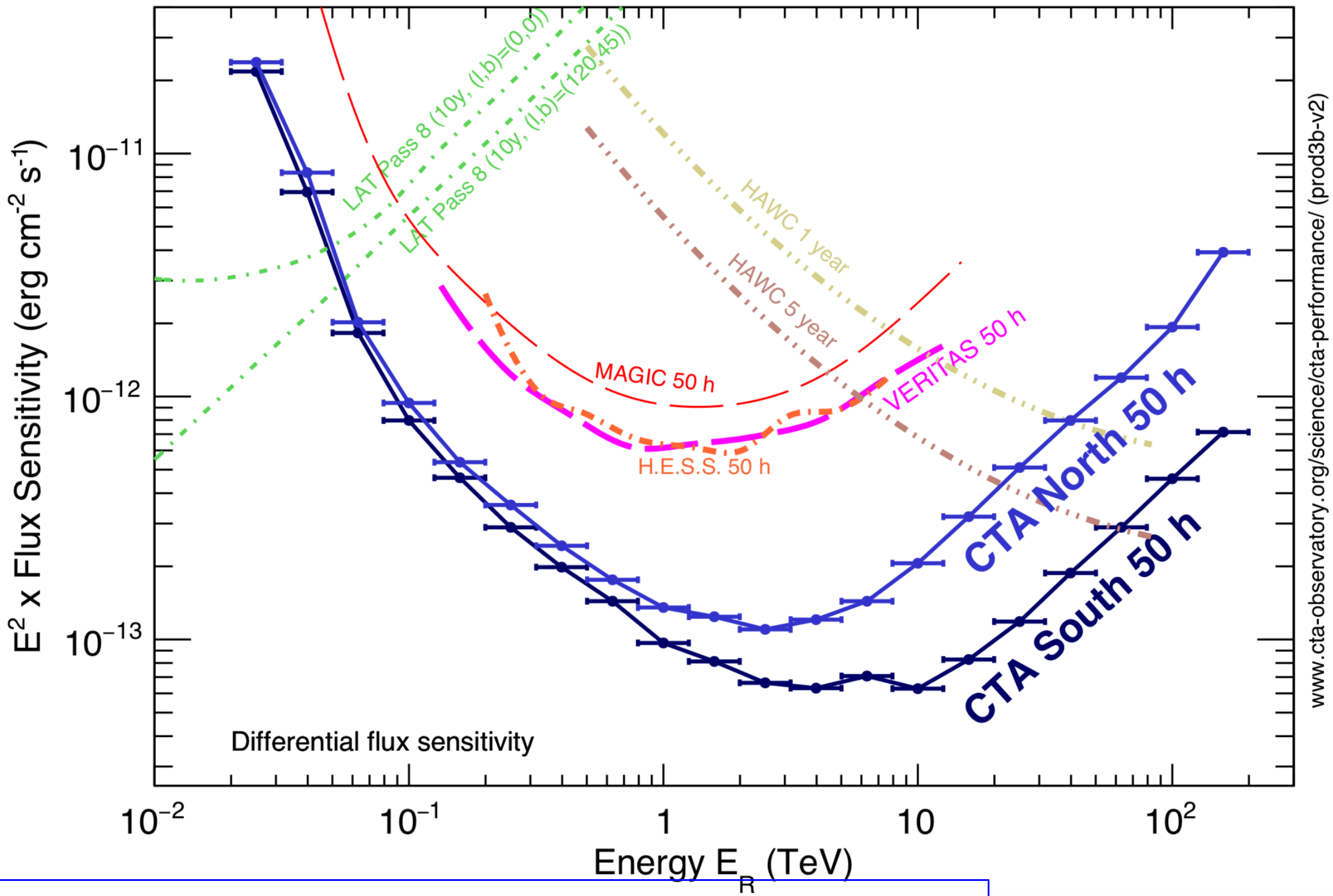
CTA-South site

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



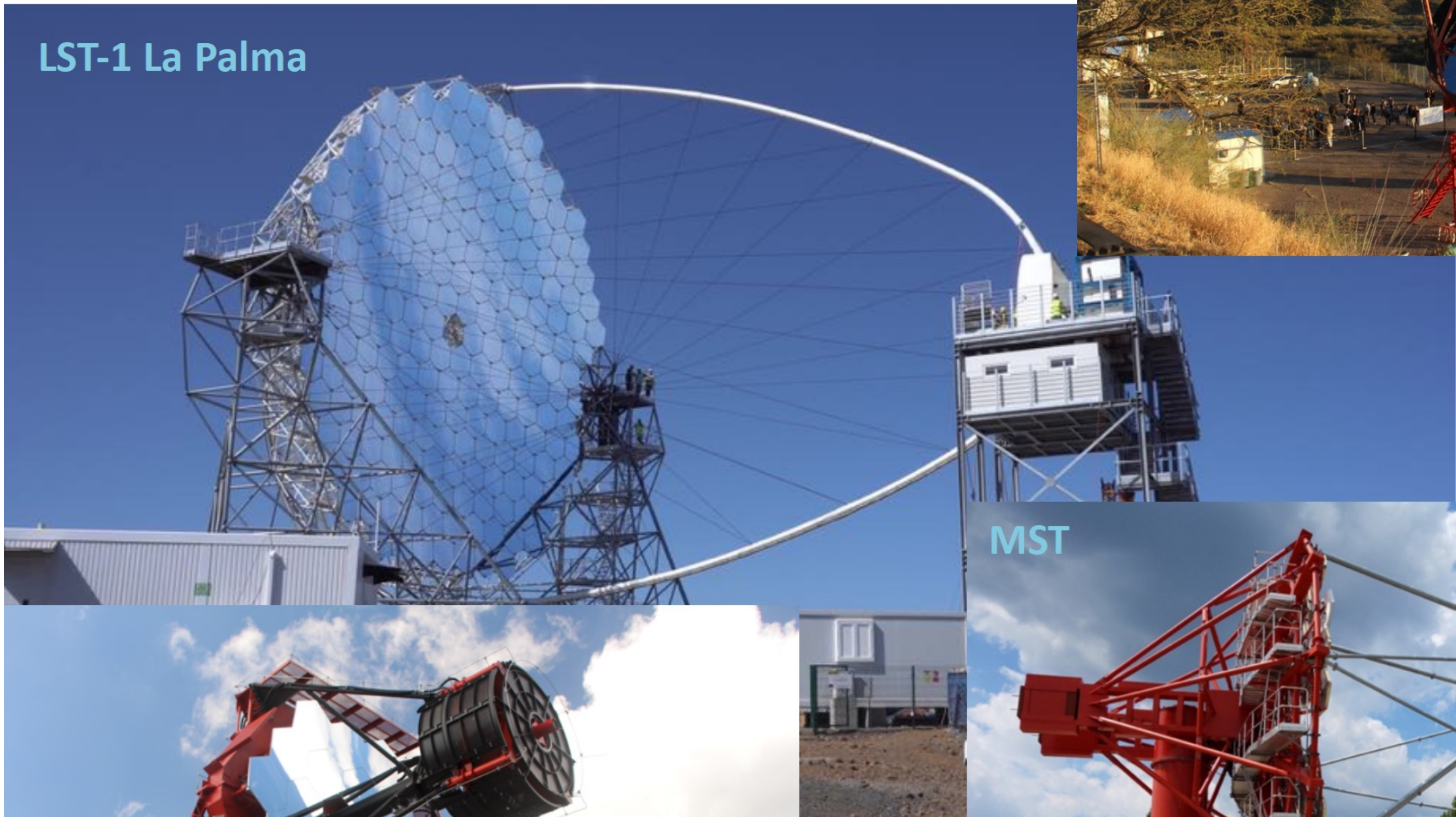
- **Site agreement signed in Dec 2018**
- **Aim to start with site infrastructure construction soon**

CTA performance



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

The CTA Telescopes



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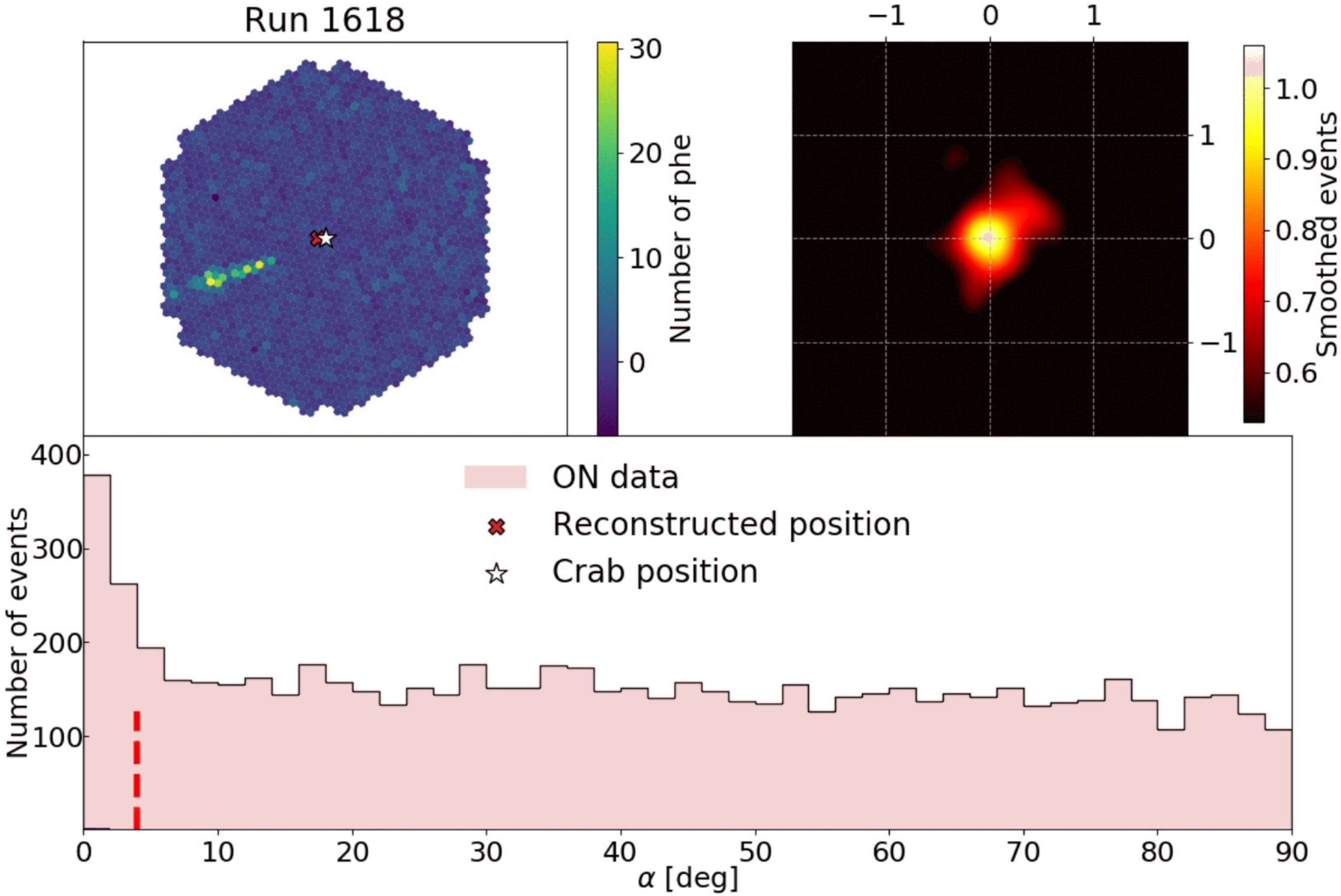
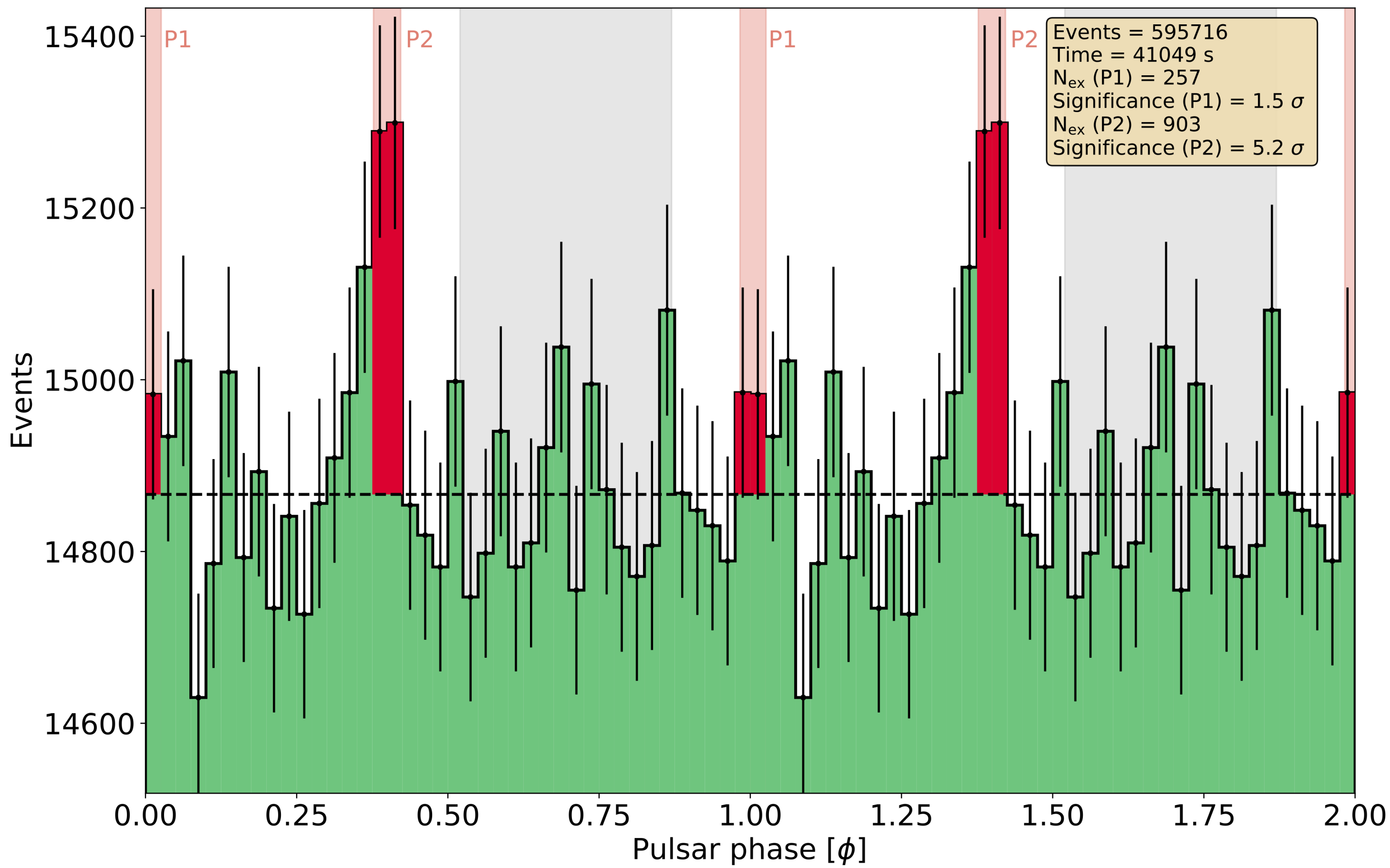
CTA

CTA telescopes – first results



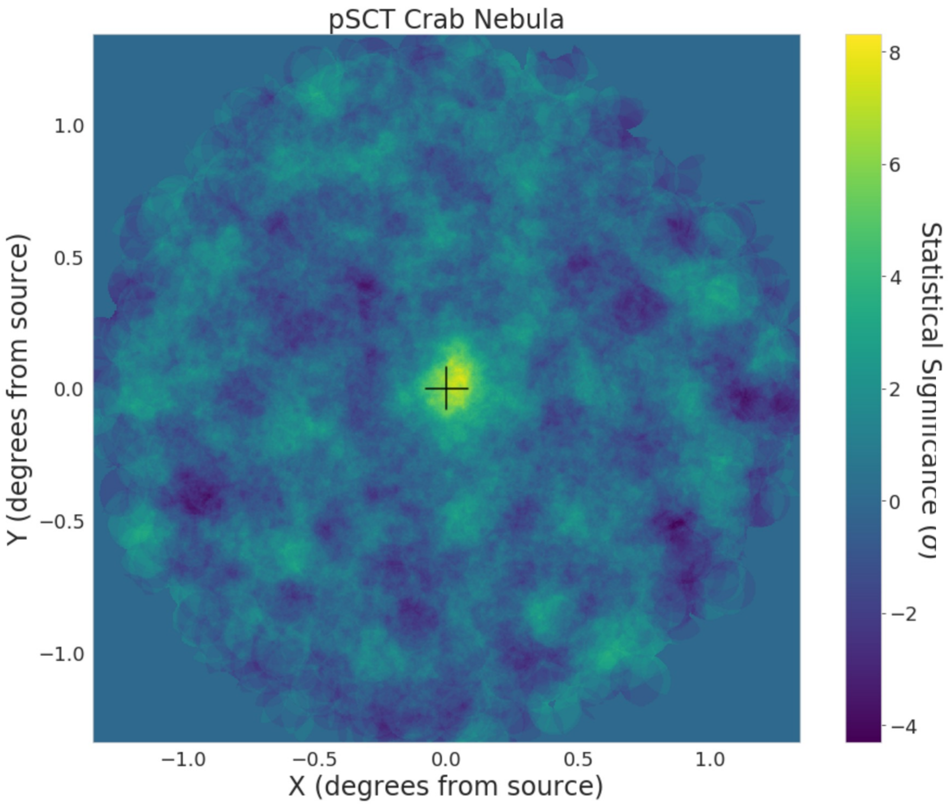
https://www.cta-observatory.org/lst1-detects-first-gamma-ray-signal/

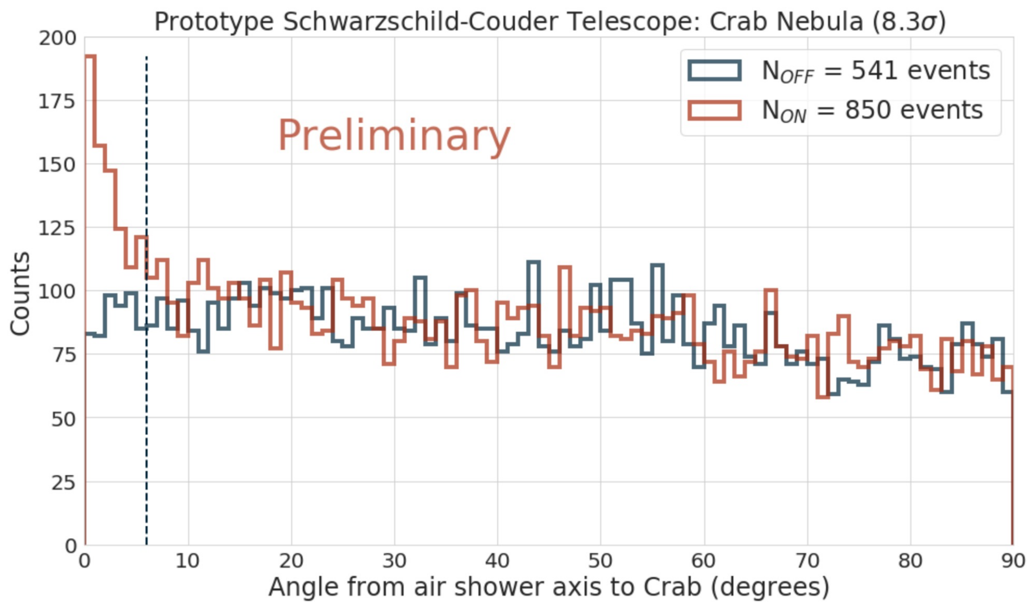
CTA telescopes – first results



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

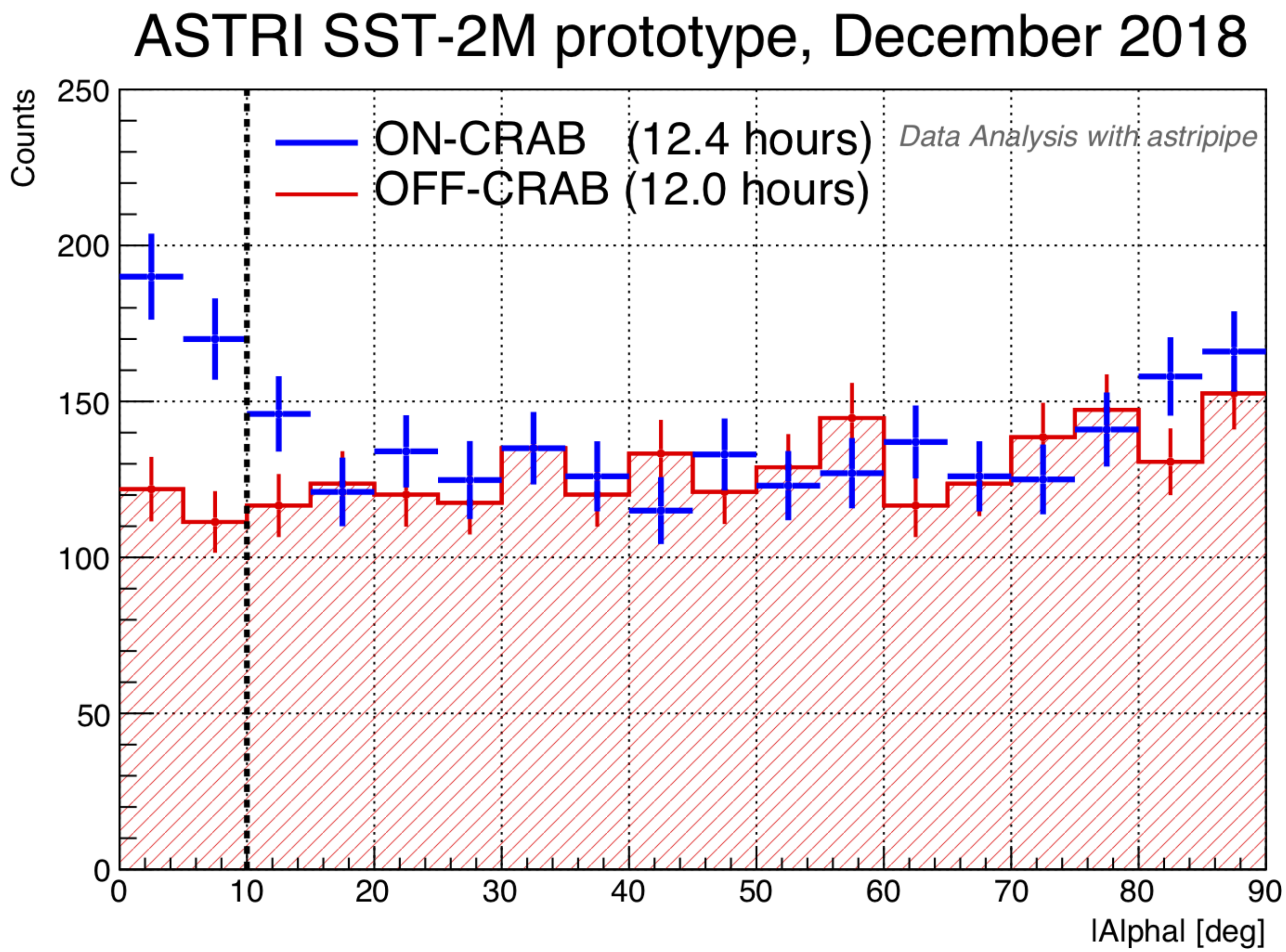
CTA telescopes – first results





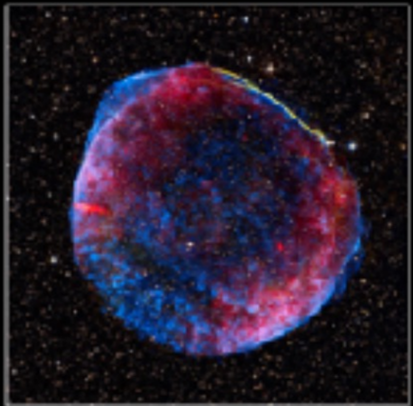
https://www.cta-observatory.org/sct-detects-

CTA telescopes – first results



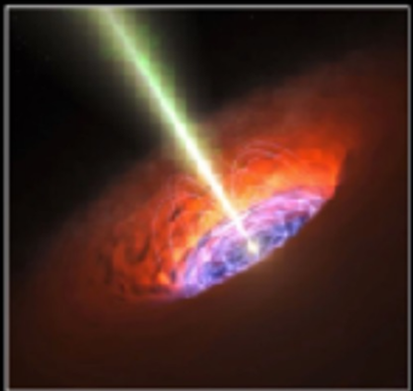
https://www.cta-observatory.org/astri-detects-crab-at-

Astrophysics with IACTs



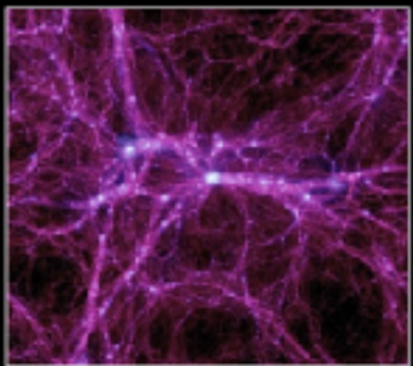
- **COSMIC PARTICLE ACCELERATION**

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

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

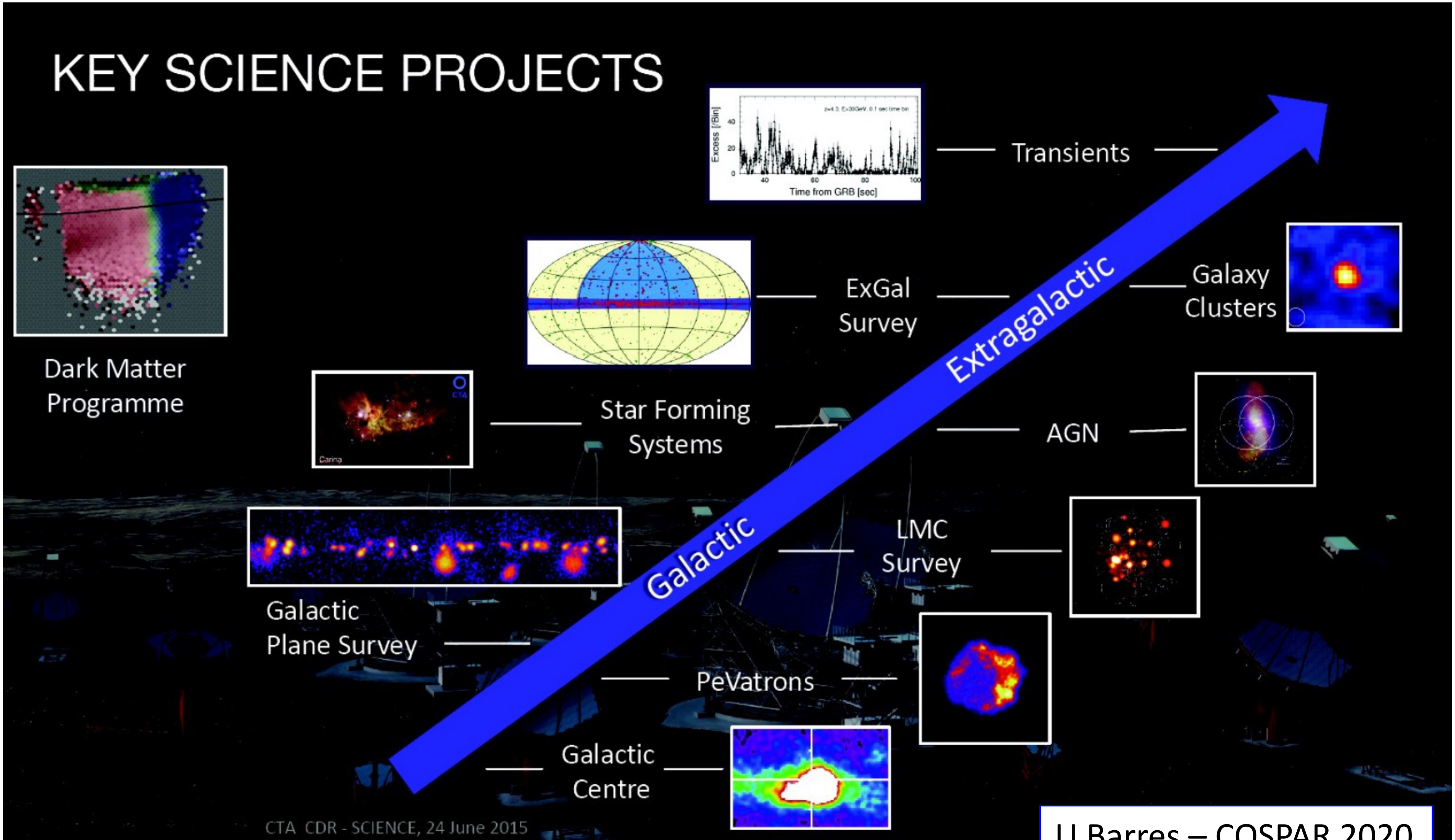
Deep Targeted Observations

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

Follow-ups of Transient and Multi-messenger events

Monitoring of Variability notably of AGN

A Census of particle accelerators across all cosmic scales



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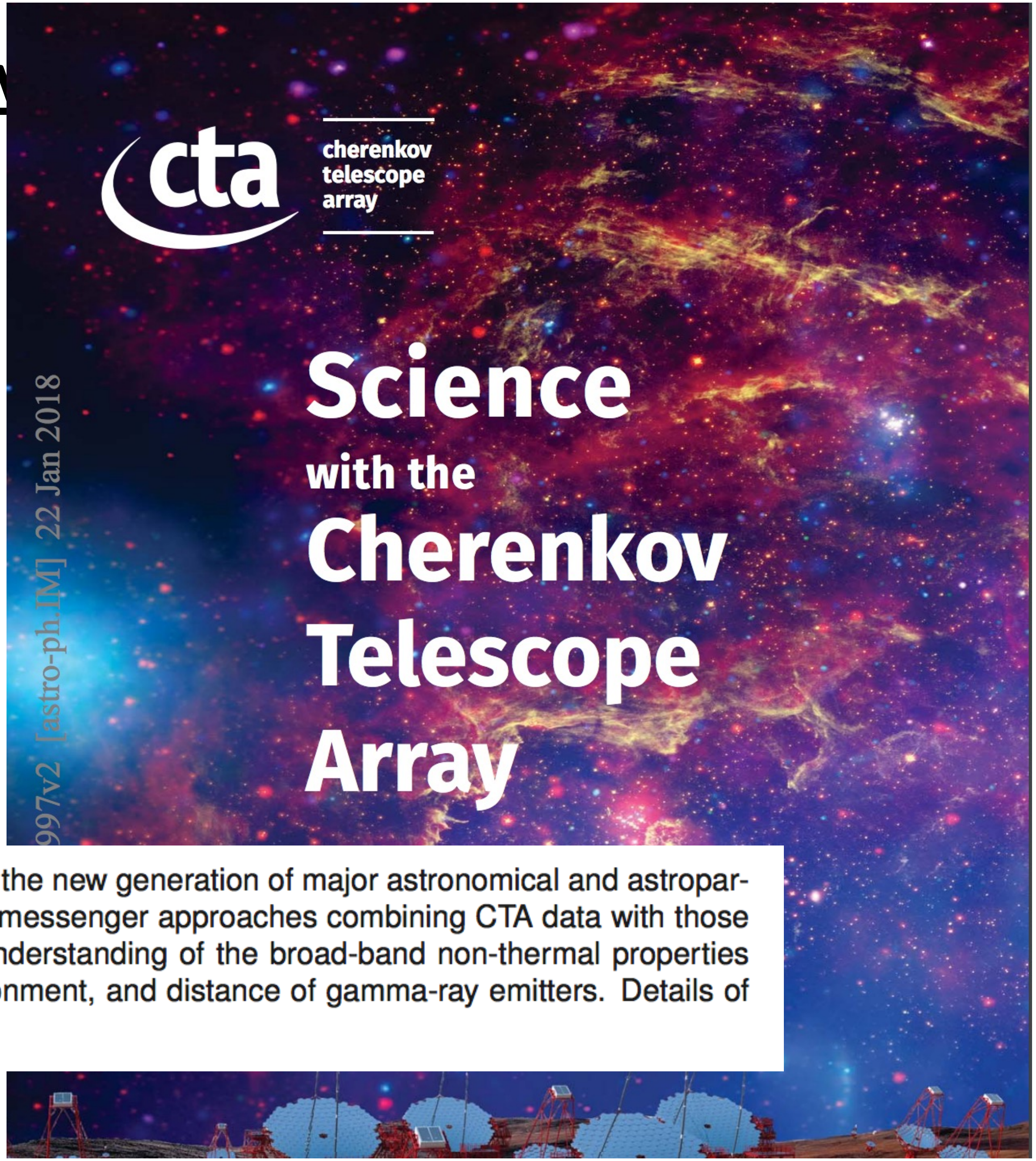
Science with CTA

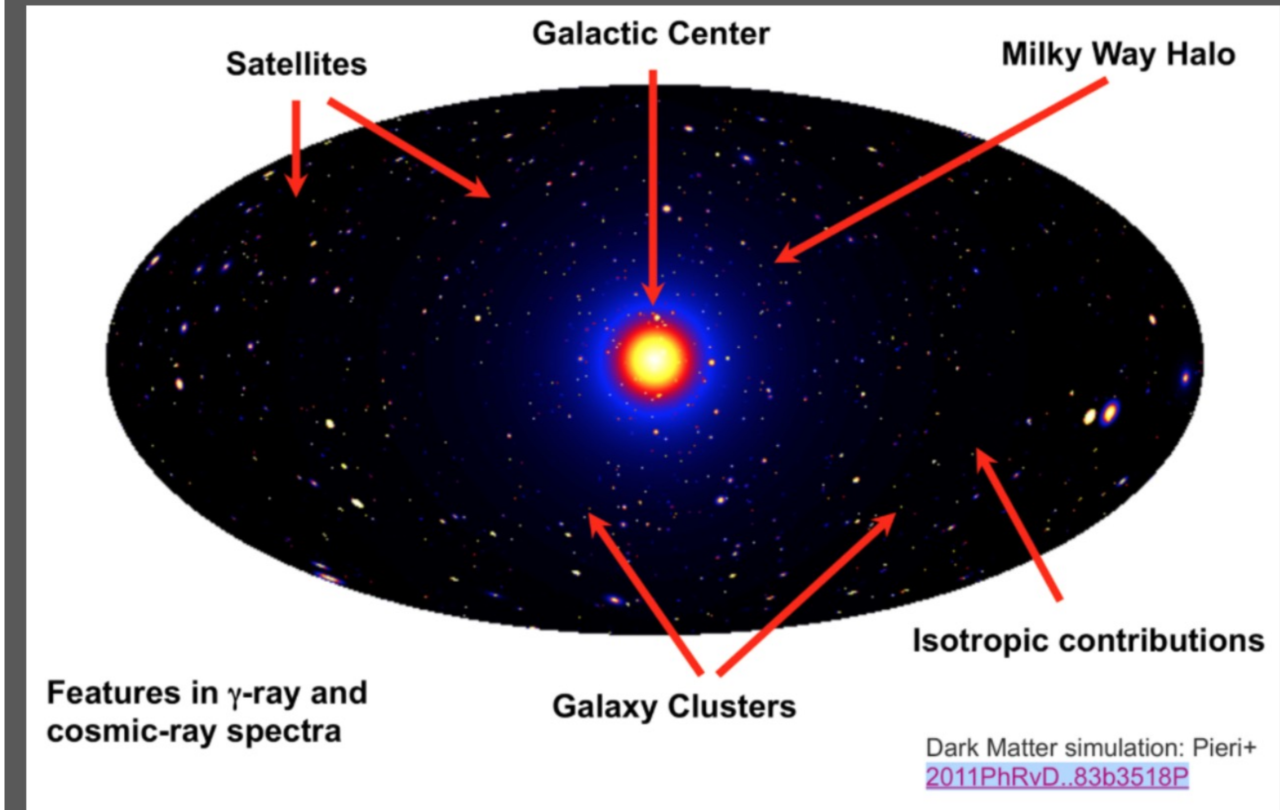


CTA will have important synergies with many of the new generation of major astronomical and astroparticle observatories. Multi-wavelength and multi-messenger approaches combining CTA data with those from other instruments will lead to a deeper understanding of the broad-band non-thermal properties of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

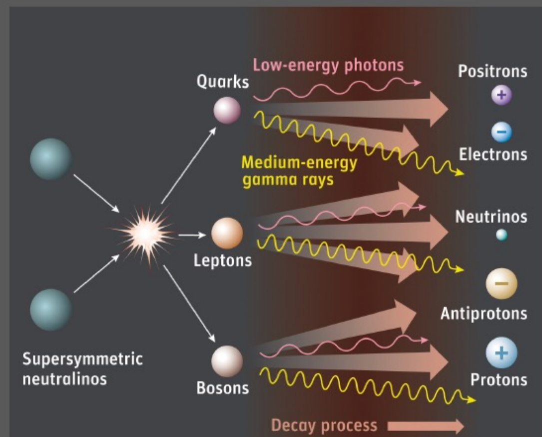
https://arxiv.org/abs/1709.07997

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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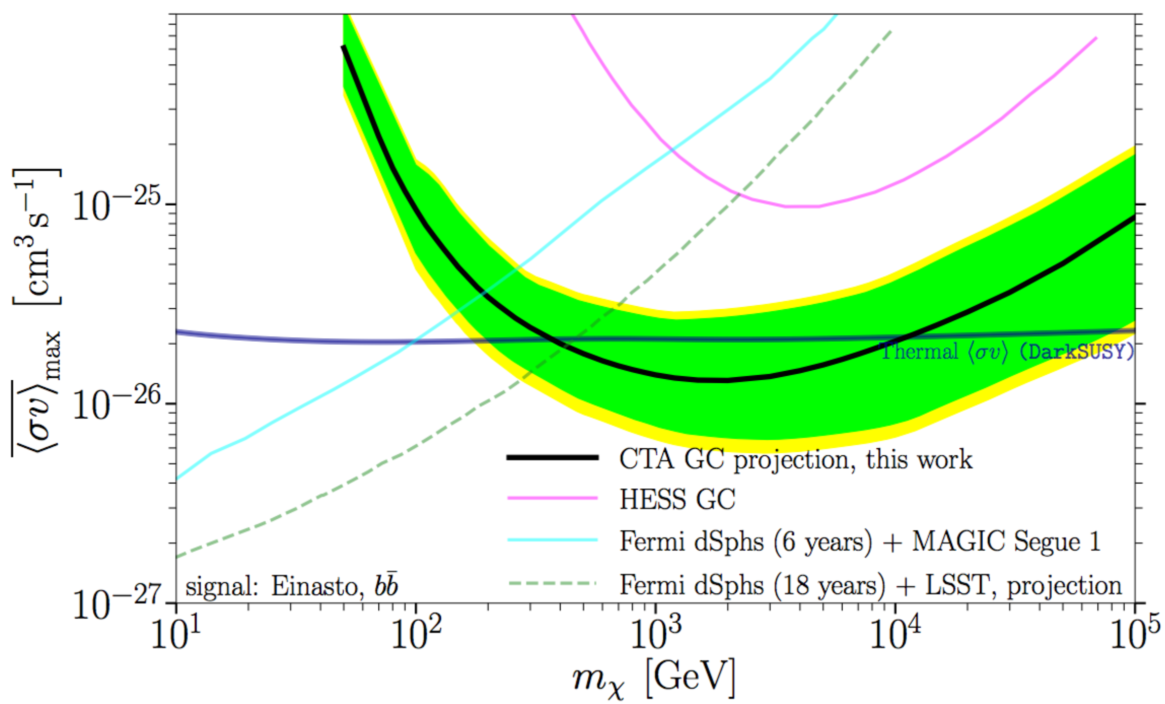
The Dark Matter Programme

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



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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

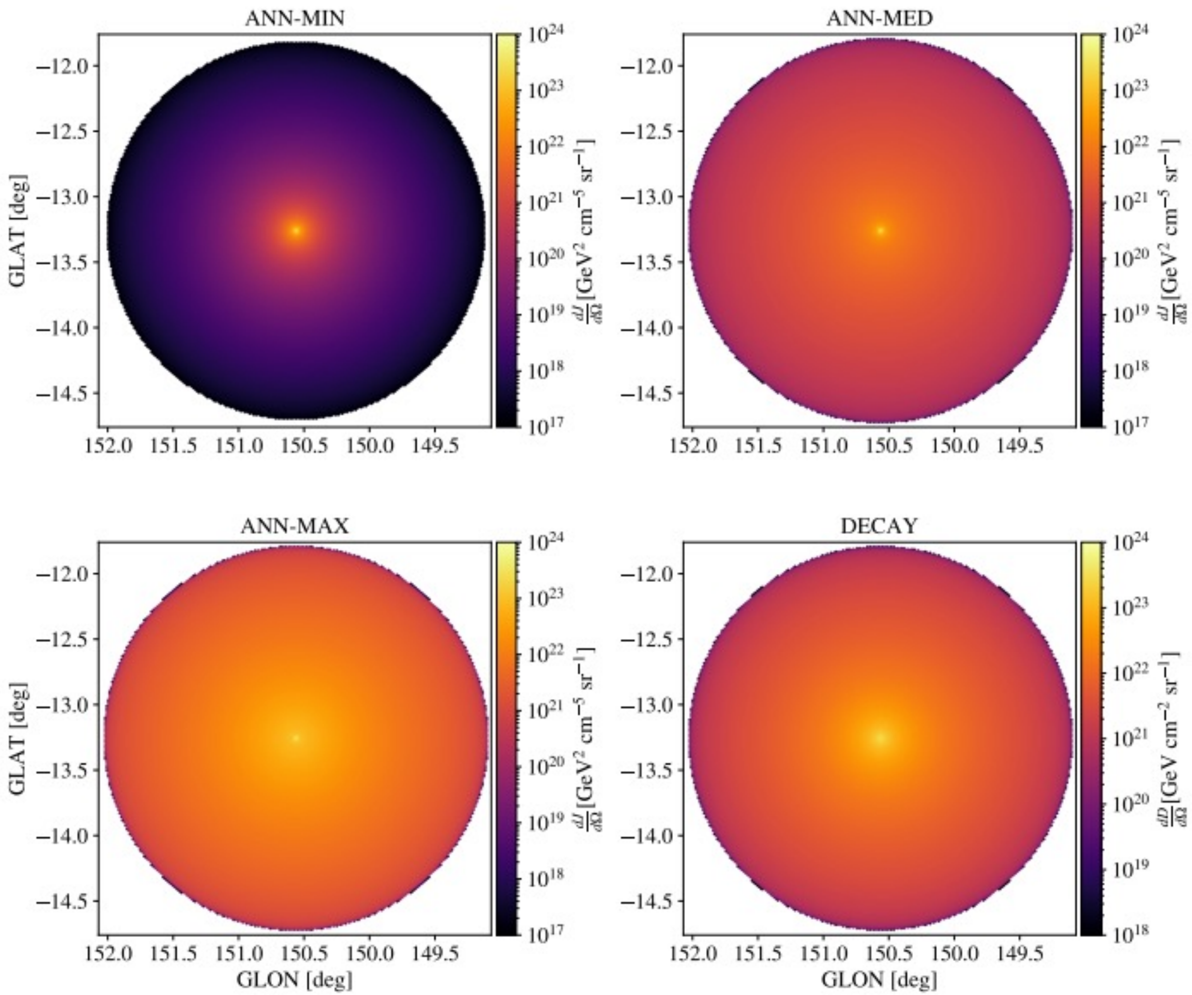
Dark Matter with CTA

Prospects for γ-ray observations of the Perseus galaxy cluster with the Cherenkov Telescope Array

Abstract. Galaxy clusters are expected to be both dark matter (DM) reservoirs and storage rooms for the cosmic-ray protons (CRp) that accumulate along the cluster's formation history. Accordingly, they are excellent targets to search for signals of DM annihilation and decay at γ-ray energies and are predicted to be sources of large-scale γ-ray emission due to hadronic interactions in the intracluster medium (ICM). In this paper, we estimate the sensitivity of the Cherenkov Telescope Array (CTA) to detect diffuse γ-ray emission from the Perseus galaxy cluster. We first perform a detailed spatial and spectral modelling of the expected signal for both the DM and the CRp components. For each case, we compute the expected CTA sensitivity accounting for the CTA instrument response functions. The CTA observing strategy of the Perseus cluster is also discussed. In the absence of a diffuse signal (non-detection), CTA should constrain the CRp to thermal energy ratio X_{500} within the characteristic radius R_{500} down to about $X_{500} < 3 \times 10^{-3}$, for a spatial CRp distribution that follows the thermal gas and a CRp spectral index $\alpha_{\rm CRp} = 2.3$. Under the optimistic assumption of a pure hadronic origin of the Perseus radio mini-halo and depending on the assumed magnetic field profile, CTA should measure $\alpha_{\rm CRp}$ down to about $\Delta\alpha_{\rm CRp} \simeq 0.1$ and the CRp spatial distribution with 10% precision, respectively. Regarding DM, CTA should improve the current ground-based γ-ray DM limits from clusters observations on the velocity-averaged annihilation cross-section by a factor of up to ~ 5, depending on the modelling of DM halo substructure. In the case of decay of DM particles, CTA will explore a new region of the parameter space, reaching models with $\tau_\chi > 10^{27}$s for DM masses above 1 TeV. These constraints will provide unprecedented sensitivity to the physics of both CRp acceleration and

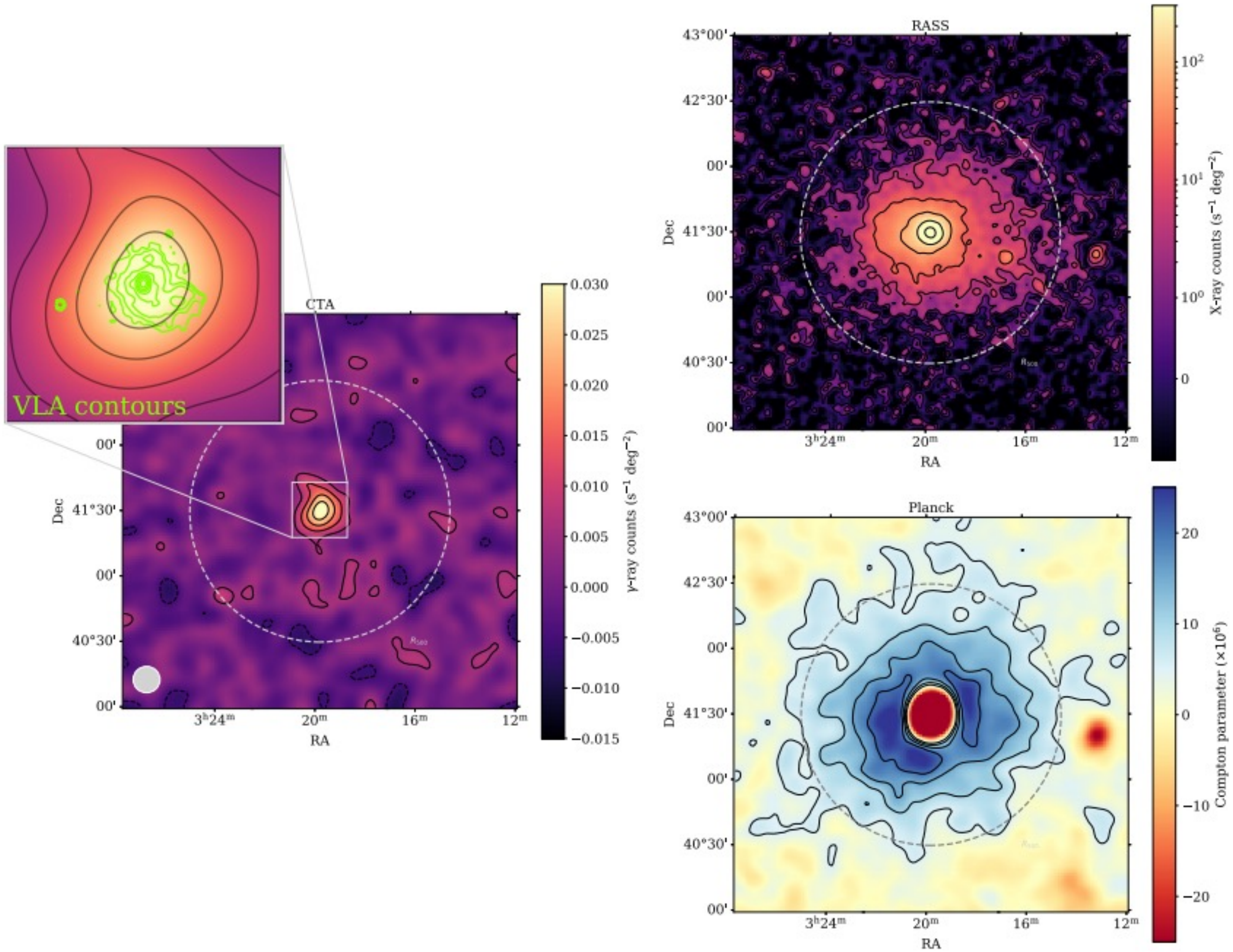
https://arxiv.org/pdf/2309.03712

Dark Matter with CTA



https://arxiv.org/pdf/2309.03712

Dark Matter with CTA



https://arxiv.org/pdf/2309.03712

Dark Matter with CTA

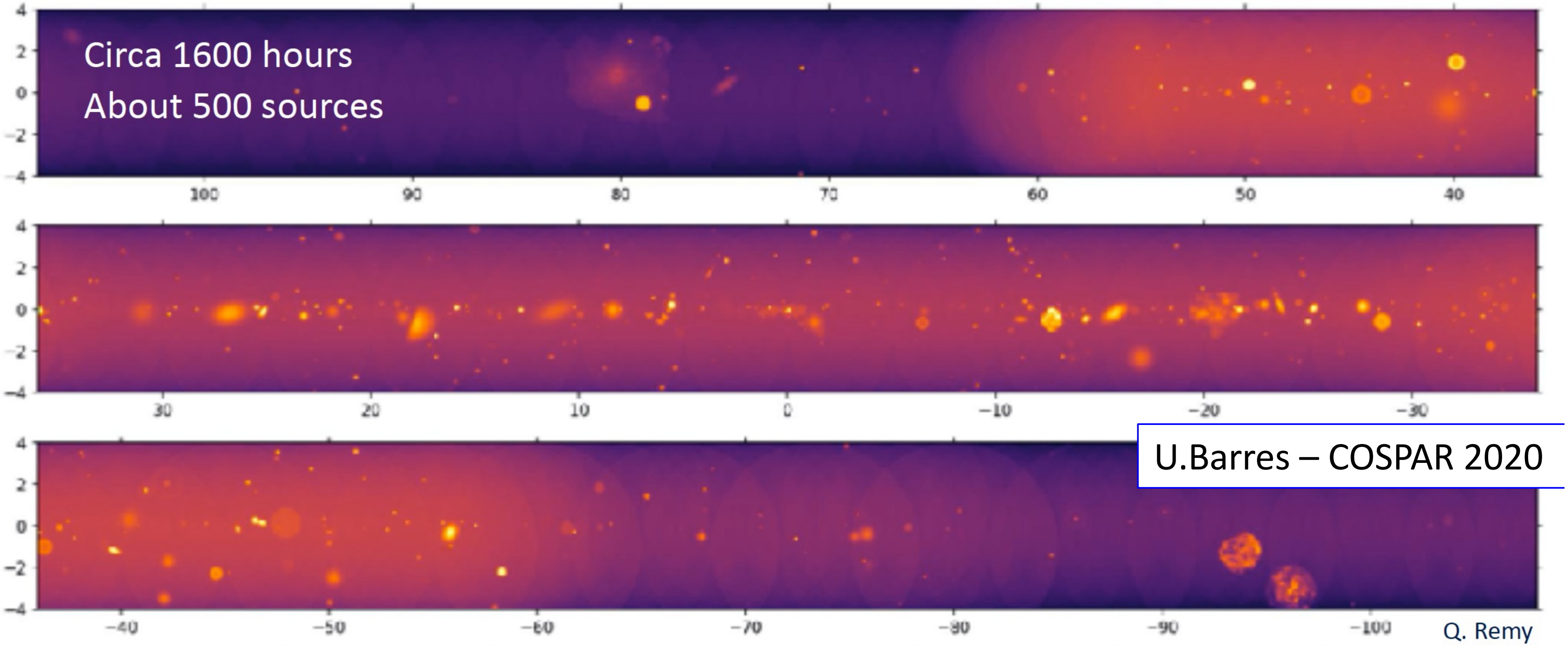
Dark Matter Line Searches with the Cherenkov Telescope Array

Abstract. Monochromatic gamma-ray signals constitute a potential smoking gun signature for annihilating or decaying dark matter particles that could relatively easily be distinguished from astrophysical or instrumental backgrounds. We provide an updated assessment of the sensitivity of the Cherenkov Telescope Array (CTA) to such signals, based on observations of the Galactic centre region as well as of selected dwarf spheroidal galaxies. We find that current limits and detection prospects for dark matter masses above 300 GeV will be significantly improved, by up to an order of magnitude in the multi-TeV range. This demonstrates that CTA will set a new standard for gamma-ray astronomy also in this respect, as the world's largest and most sensitive high-energy gamma-ray observatory, in particular due to its exquisite energy resolution at TeV energies and the adopted observational strategy focussing on regions with large dark matter densities. Throughout our analysis, we use up-to-date instrument response functions, and we thoroughly model the effect of instrumental systematic uncertainties in our statistical treatment. We further present results for other potential signatures with sharp spectral features, e.g. box-shaped spectra, that would likewise very clearly point to a particle dark matter origin.

https://arxiv.org/pdf/2403.04857

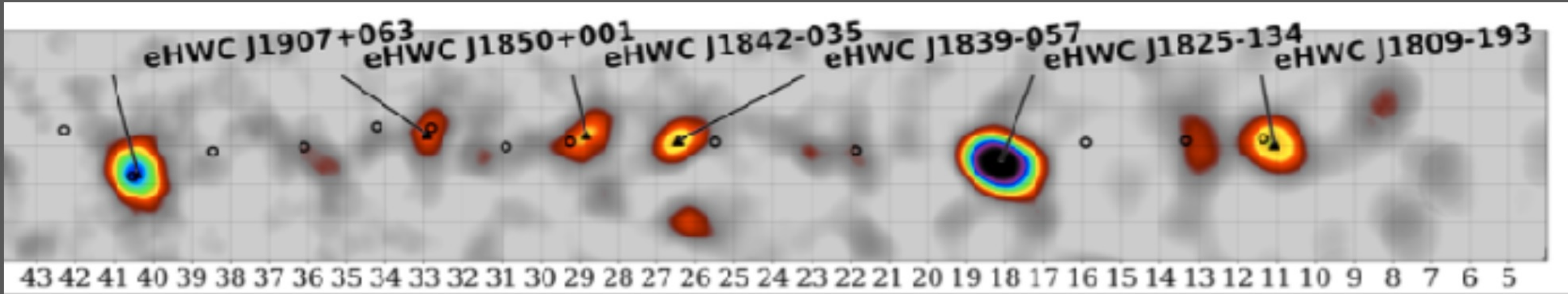
CTA Galactic Science

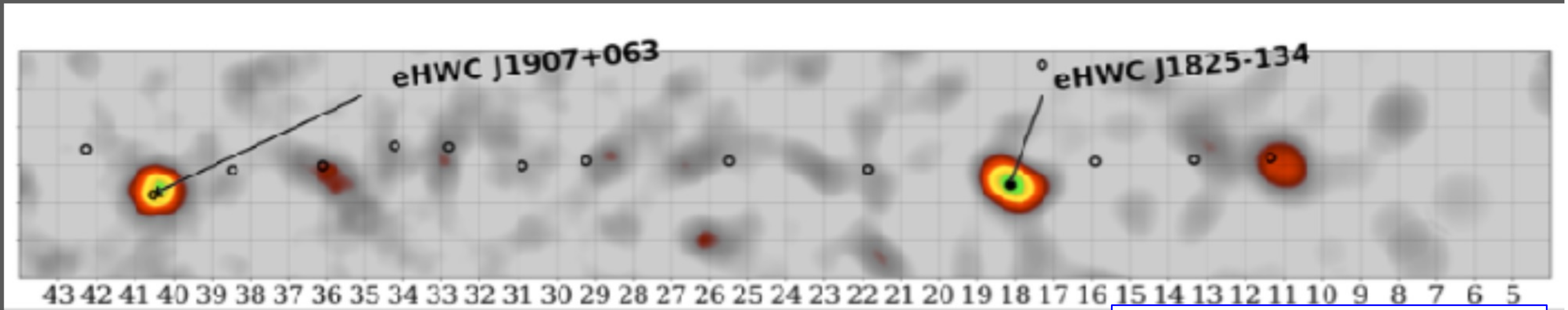
- Survey speed about 300x greater than H.E.S.S.
- Much deeper reach, to scan the entire galaxy for PWNe and SNRs, as opposed to the few-kpc reach of current instruments.



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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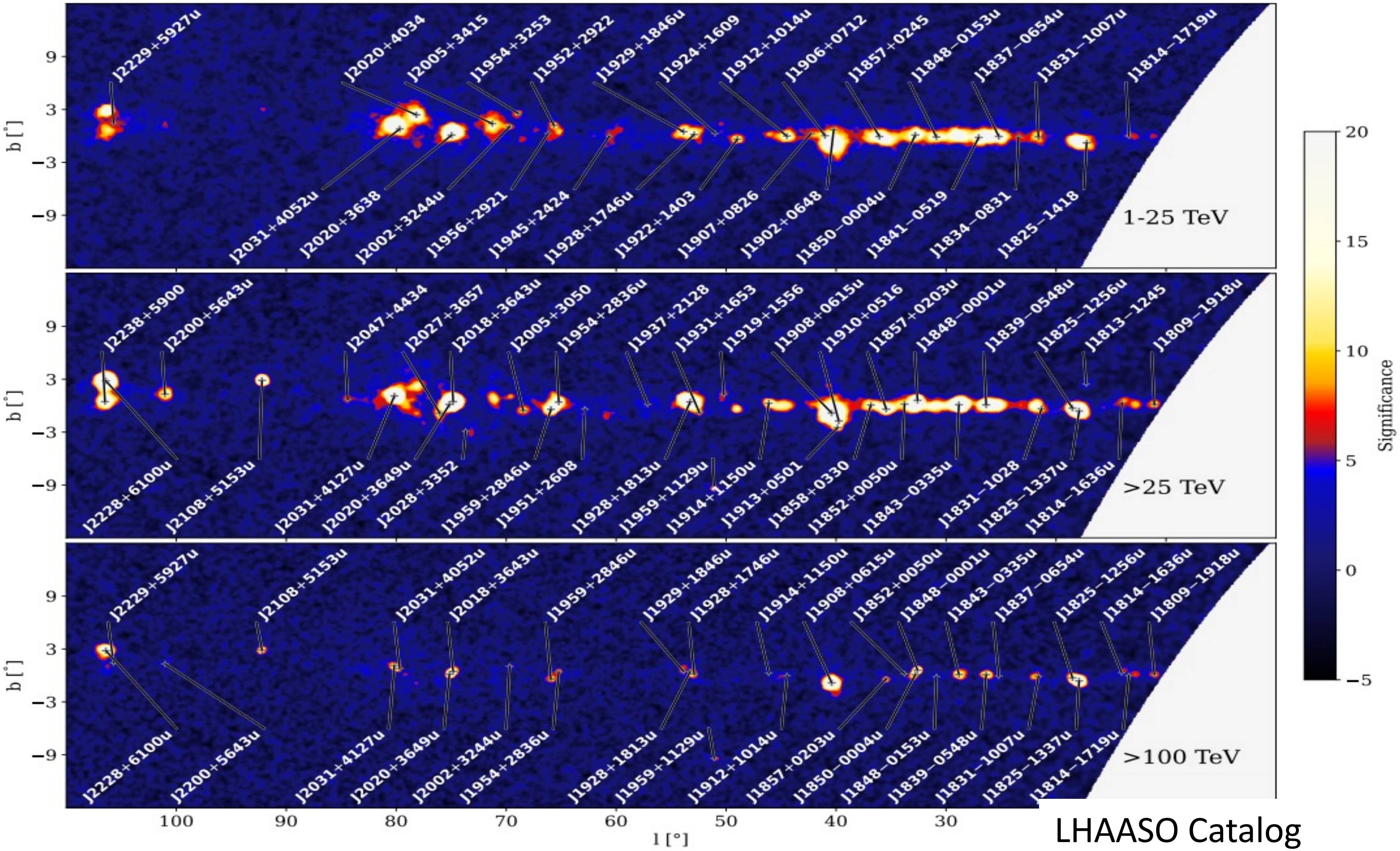
PeVatrons: the extreme energy frontier



LHAASO Catalog

Galactic Science with CTA

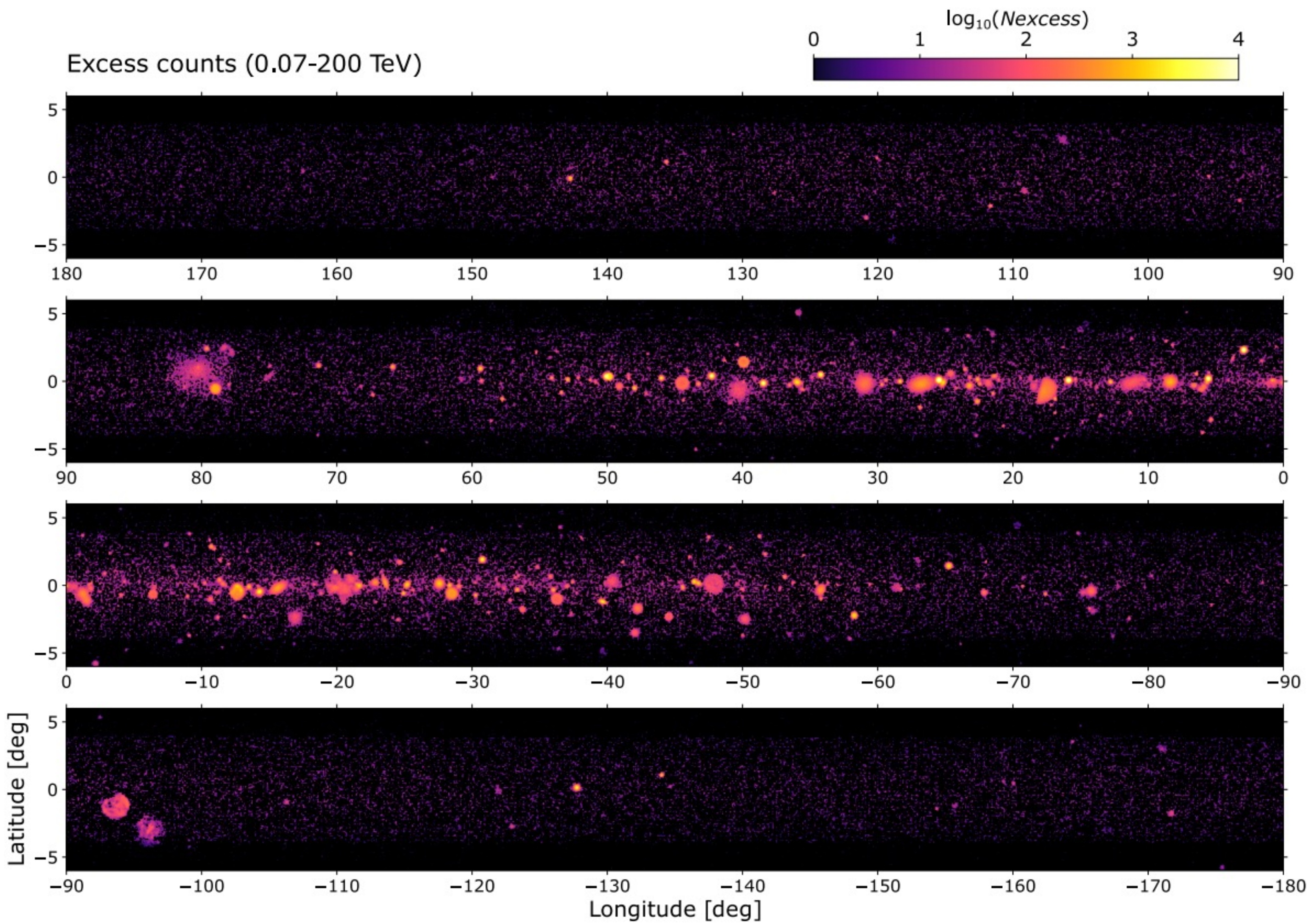
Prospects for a survey of the Galactic plane with the Cherenkov Telescope Array

arXiv:2310.02828v1 [astro-ph.HE] 4 Oct 2023

Abstract. Approximately one hundred sources of very-high-energy (VHE) gamma rays are known in the Milky Way, detected with a combination of targeted observations and surveys. A survey of the entire Galactic Plane in the energy range from a few tens of GeV to a few hundred TeV has been proposed as a Key Science Project for the upcoming Cherenkov Telescope Array Observatory (CTAO). This article presents the status of the studies towards the Galactic Plane Survey (GPS). We build and make publicly available a sky model that combines data from recent observations of known gamma-ray emitters with state-of-the-art physically-driven models of synthetic populations of the three main classes of established Galactic VHE sources (pulsar wind nebulae, young and interacting supernova remnants, and compact binary systems), as well as of interstellar emission from cosmic-ray interactions in the Milky Way. We also perform an optimisation of the observation strategy (pointing pattern and scheduling) based on recent estimations of the instrument performance. We use the improved sky model and observation strategy to simulate GPS data corresponding to a total observation time of 1620 hours spread over ten years. Data are then analysed using the methods and software tools under development for real data. Under our model assumptions and for the realisation considered, we show that the GPS has the potential to increase the number of known Galactic VHE emitters by almost a factor of five. This corresponds to the detection of more than two hundred pulsar wind nebulae and a few tens of supernova remnants at average integral fluxes one order of magnitude lower than in the existing sample above 1 TeV, therefore opening the possibility to perform unprecedented population studies. The GPS also has the potential to provide new VHE detections of binary systems and pulsars, to confirm the existence of a hypothetical population of gamma-ray pulsars with an additional TeV emission component, and to identify any bright sources capable of accelerating particles to PeV energies (PeVatrons). Furthermore, the GPS will constitute a pathfinder for deeper follow-up observations of these source classes. Finally, we show that we can extract from GPS data an estimate of the contribution to diffuse emission from unresolved sources, and that there are good prospects of detecting interstellar emission and statistically distinguishing different scenarios. Thus, a survey of the entire Galactic plane carried out from both hemispheres with CTAO will ensure a transformational advance in our knowledge of Galactic VHE source populations and interstellar emission.

https://arxiv.org/pdf/2310.02828

Galactic Science with CTA



https://arxiv.org/pdf/2310.02828

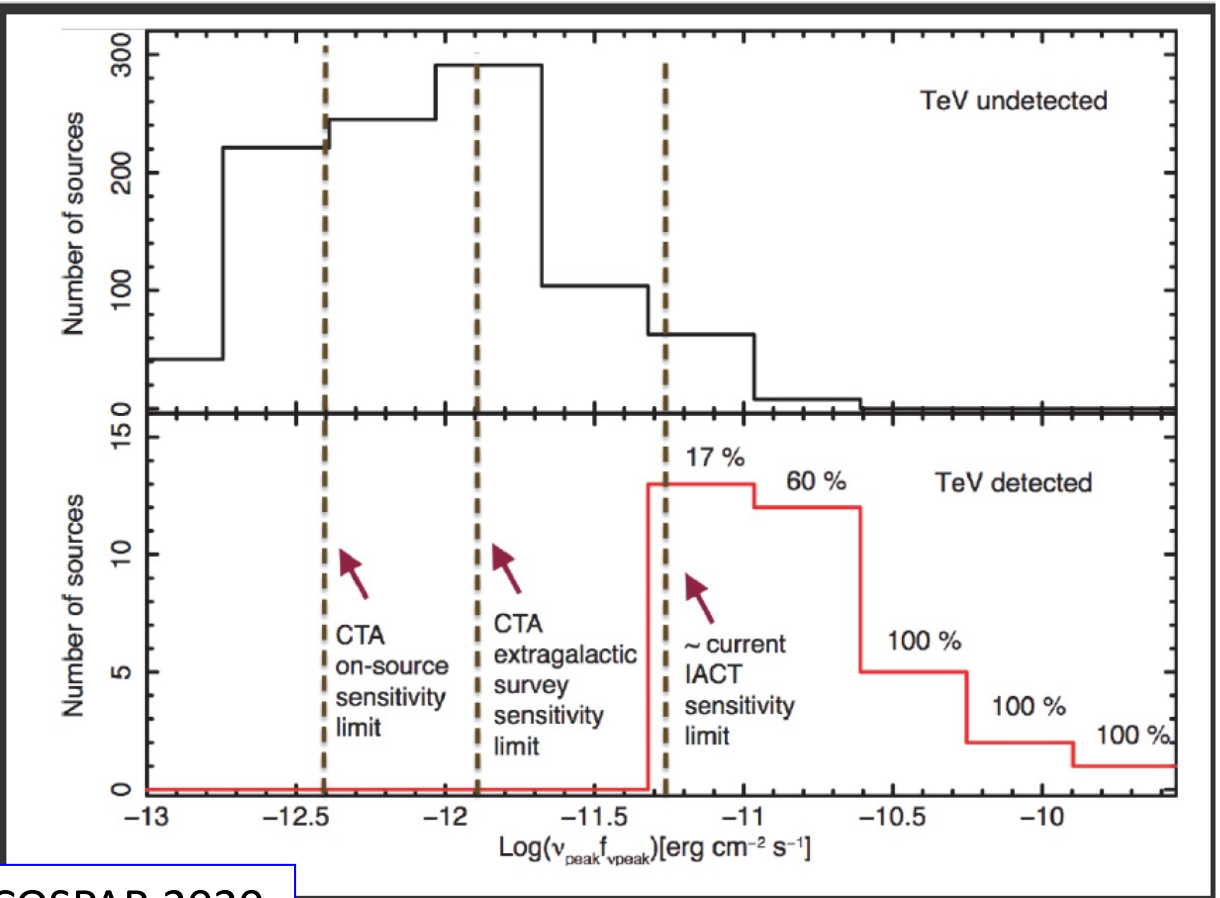
CTA's Prospects for AGN

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

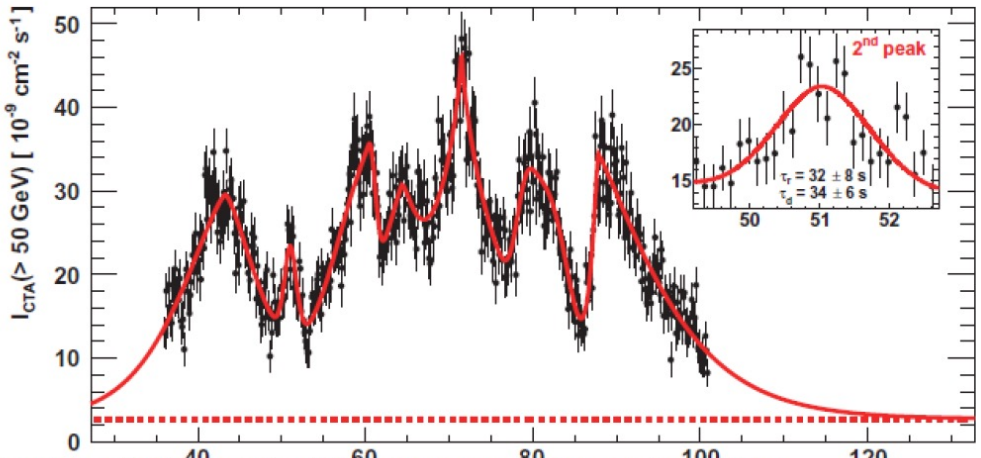
FoV up to 10 degrees → several AGN in FoV at same time.

Light curve details down to sub-minutes.

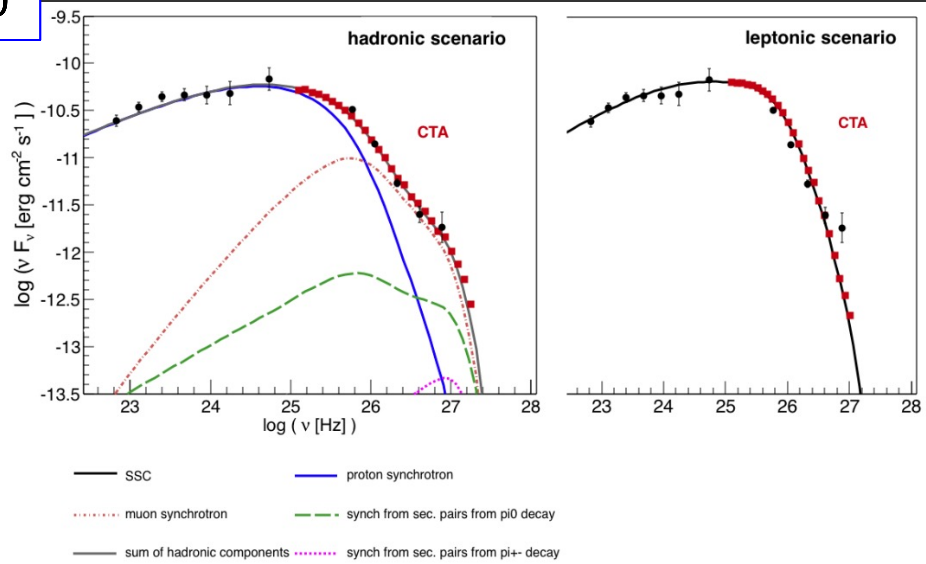
Spectral resolution to reveal sub-components:
- Hadronic (synchrotron from protons, muons, + secondaries)
- Leptonic (SSC)



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

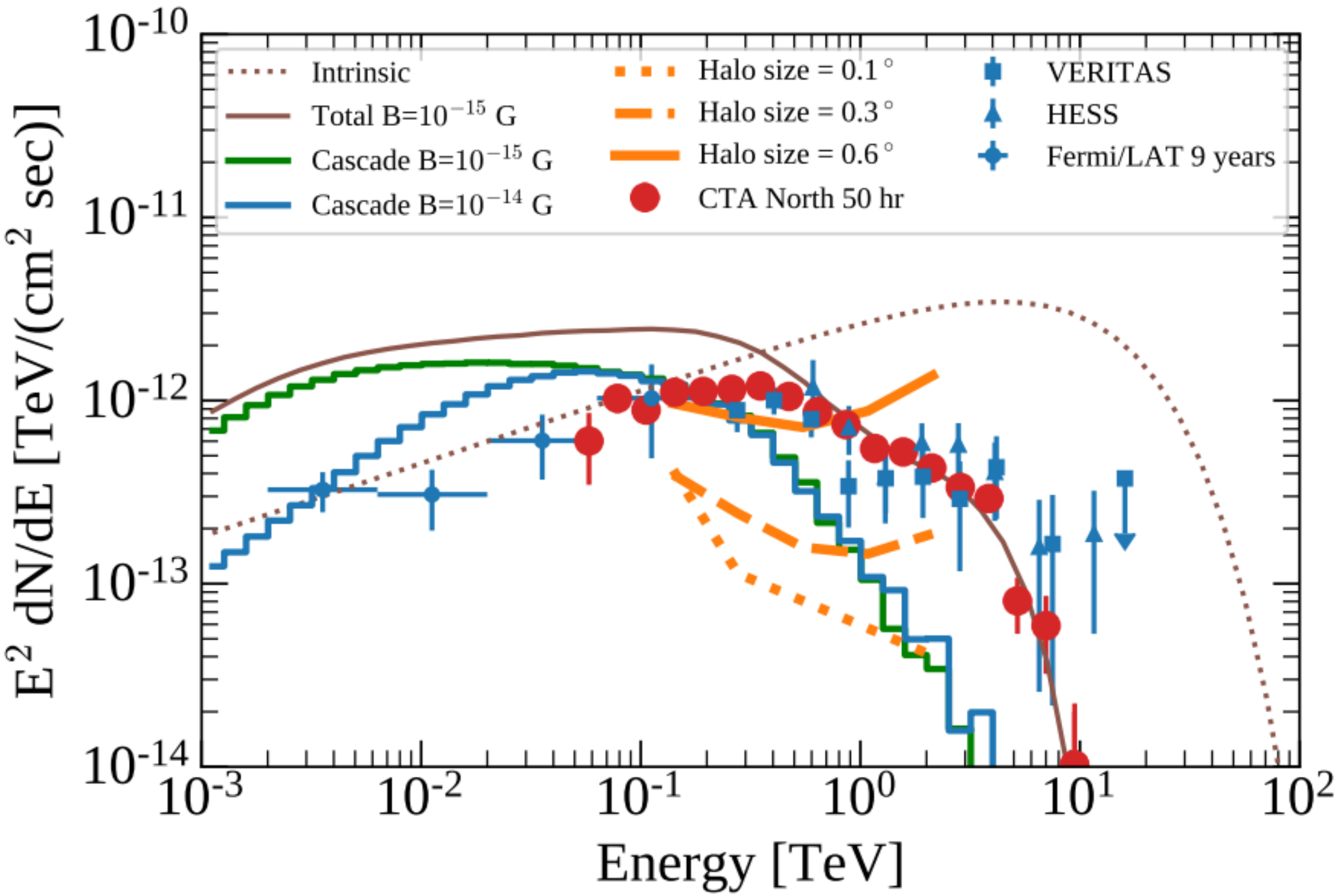
Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation

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

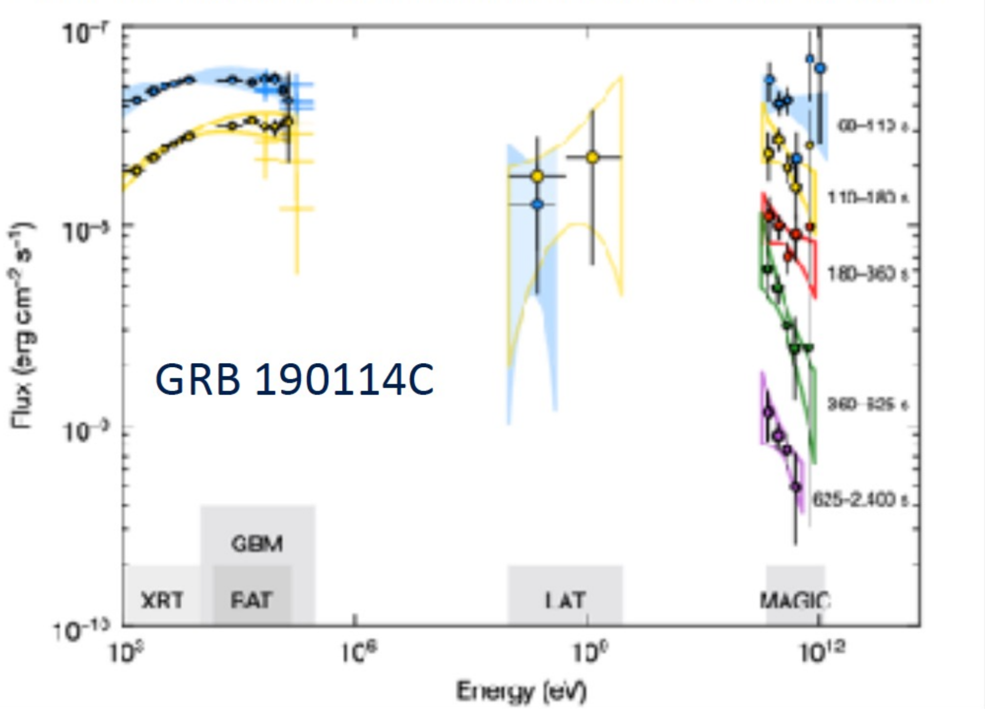
ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

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)

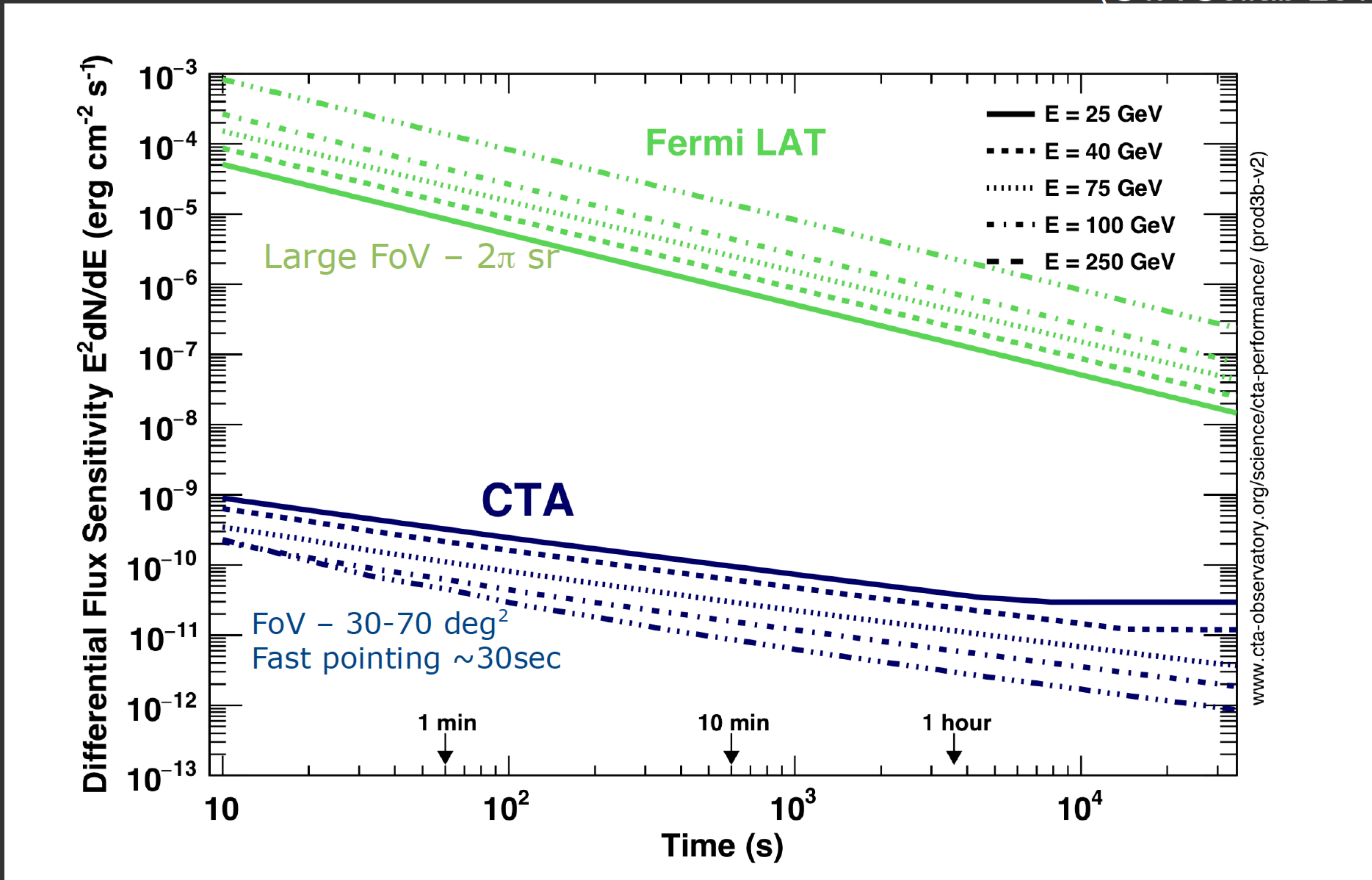
+ GRB 201216C (z = 1.1)

Strong MWL and MM synergies for spectral and variability studies

U.Barres – COSPAR 2020

Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)

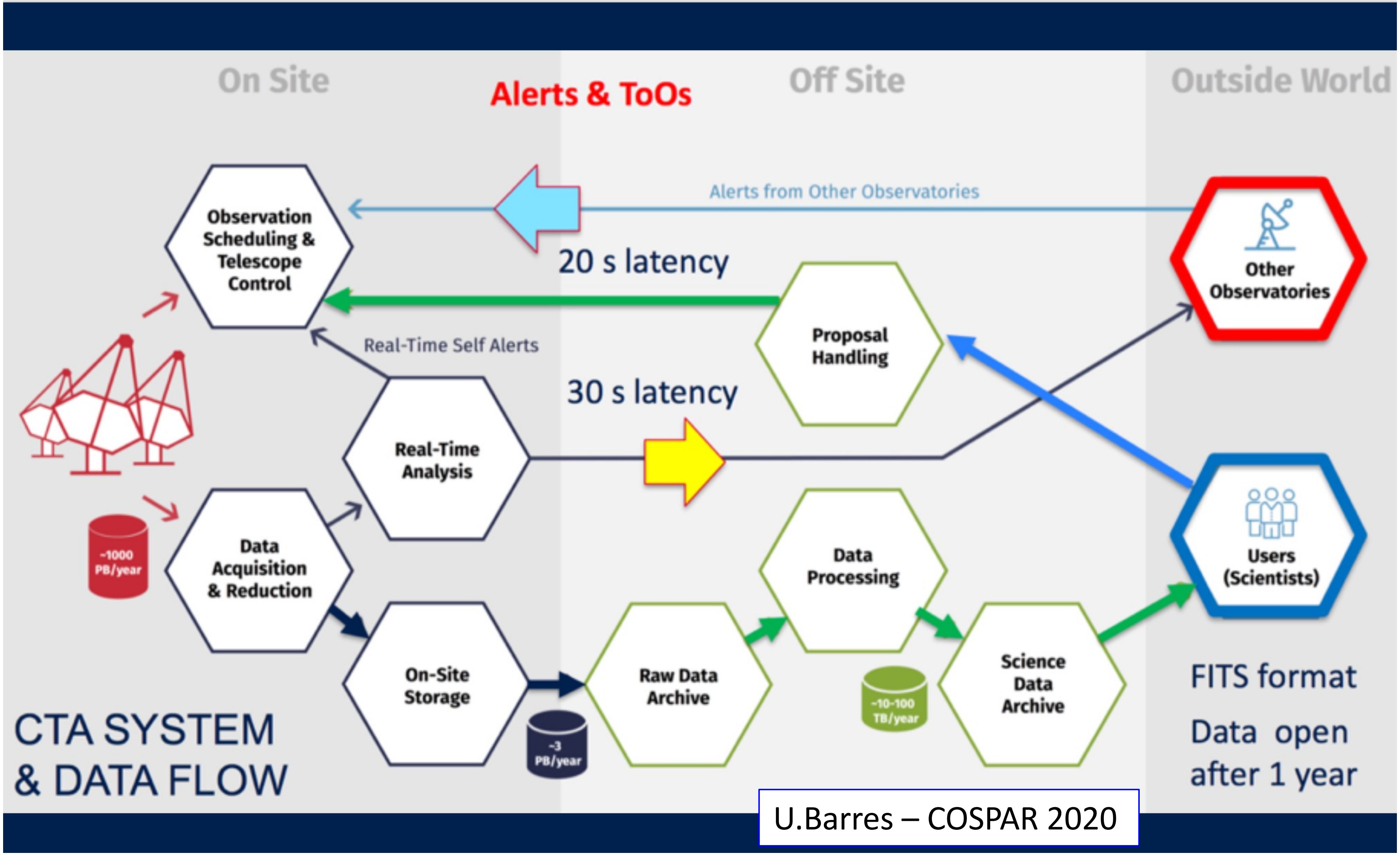


CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range

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

G. Rowell – COSPAR

CTA Transients Science



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Galactic Science with CTA

Galactic transient sources with the Cherenkov Telescope Array

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ABSTRACT

A wide variety of Galactic sources show transient emission at soft and hard X-ray energies: low-mass and high-mass X-ray binaries containing compact objects (e.g., novae, microquasars, transitional millisecond pulsars, supergiant fast X-ray transients), isolated neutron stars exhibiting extreme variability as magnetars as well as pulsar wind nebulae. Although most of them can show emission up to MeV and/or GeV energies, many have not yet been detected in the TeV domain by Imaging Atmospheric Cherenkov Telescopes. In this paper, we explore the feasibility of detecting new Galactic transients with the Cherenkov Telescope Array (CTA) and the prospects for studying them with Target of Opportunity observations. We show that CTA will likely detect new sources in the TeV regime, such as the massive microquasars in the Cygnus region, low-mass X-ray binaries with low-viewing angle, flaring emission from the Crab pulsar-wind nebula or other novae explosions, among others. We also discuss the multi-wavelength synergies with other instruments and large astronomical facilities.

Key words: gamma-rays:general – transients – binaries: general – pulsars:general – stars:novae – stars:magnetars

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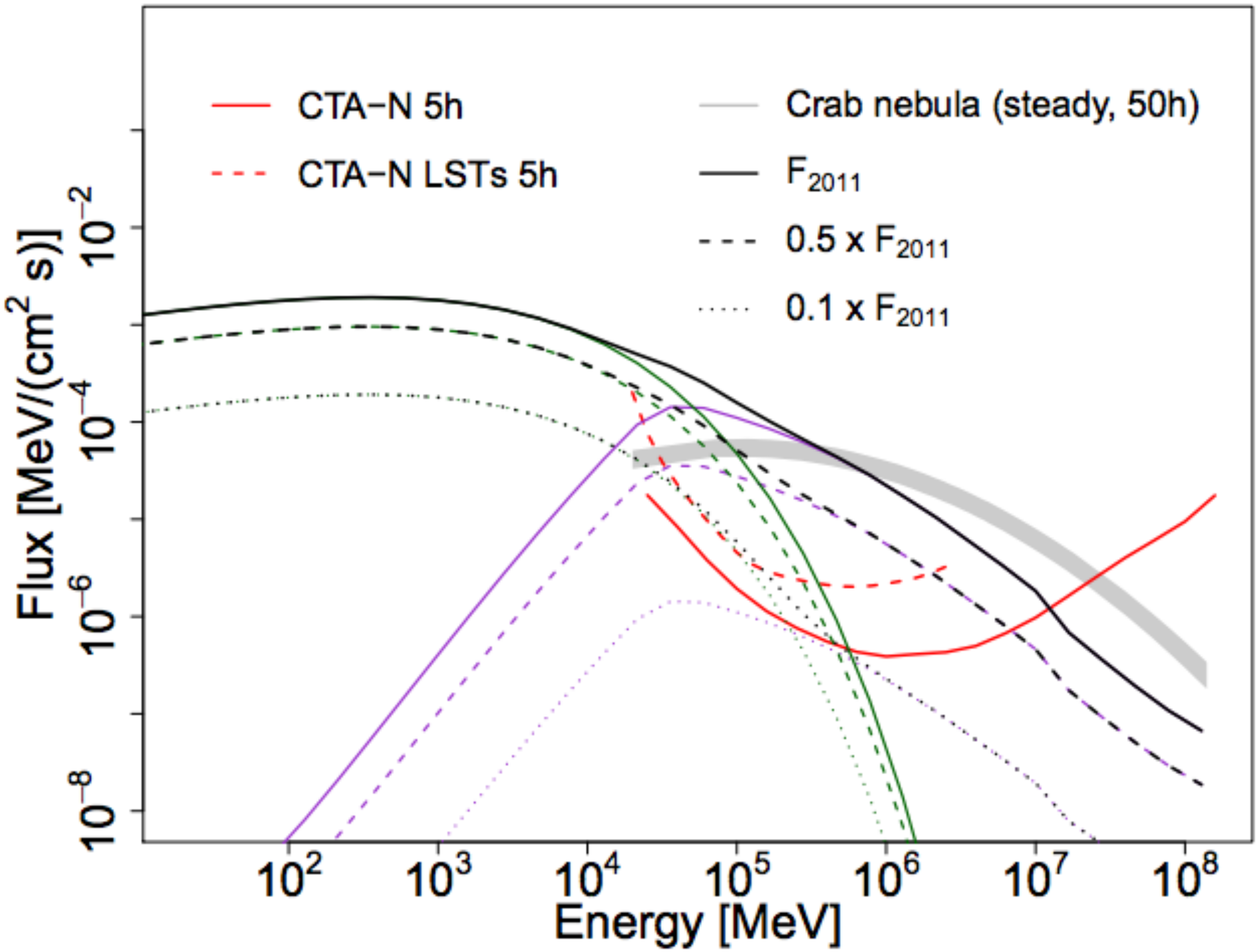

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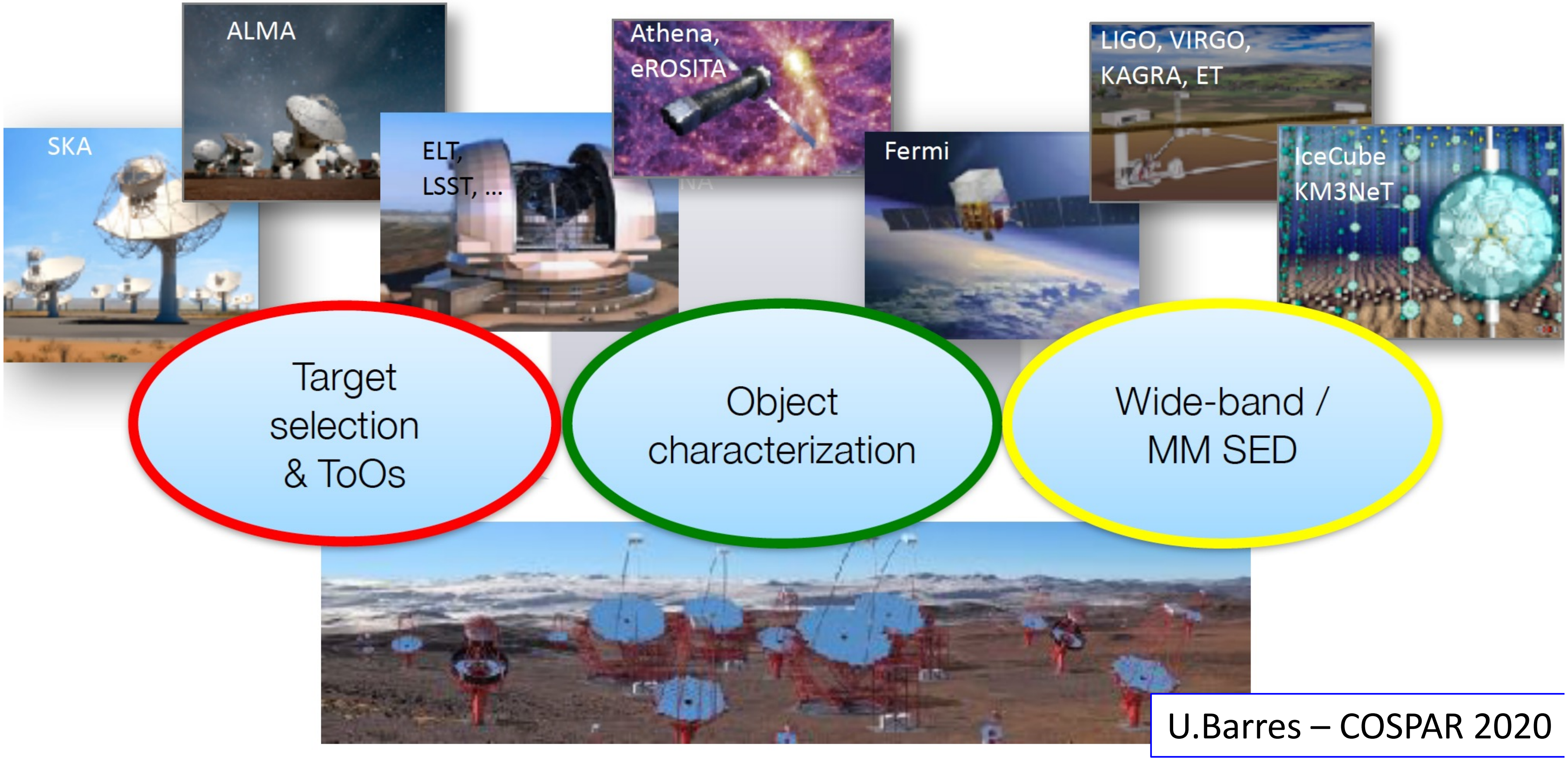
MWL and Multi-Messenger Perspectives

Synergies with astrophysical facilities…



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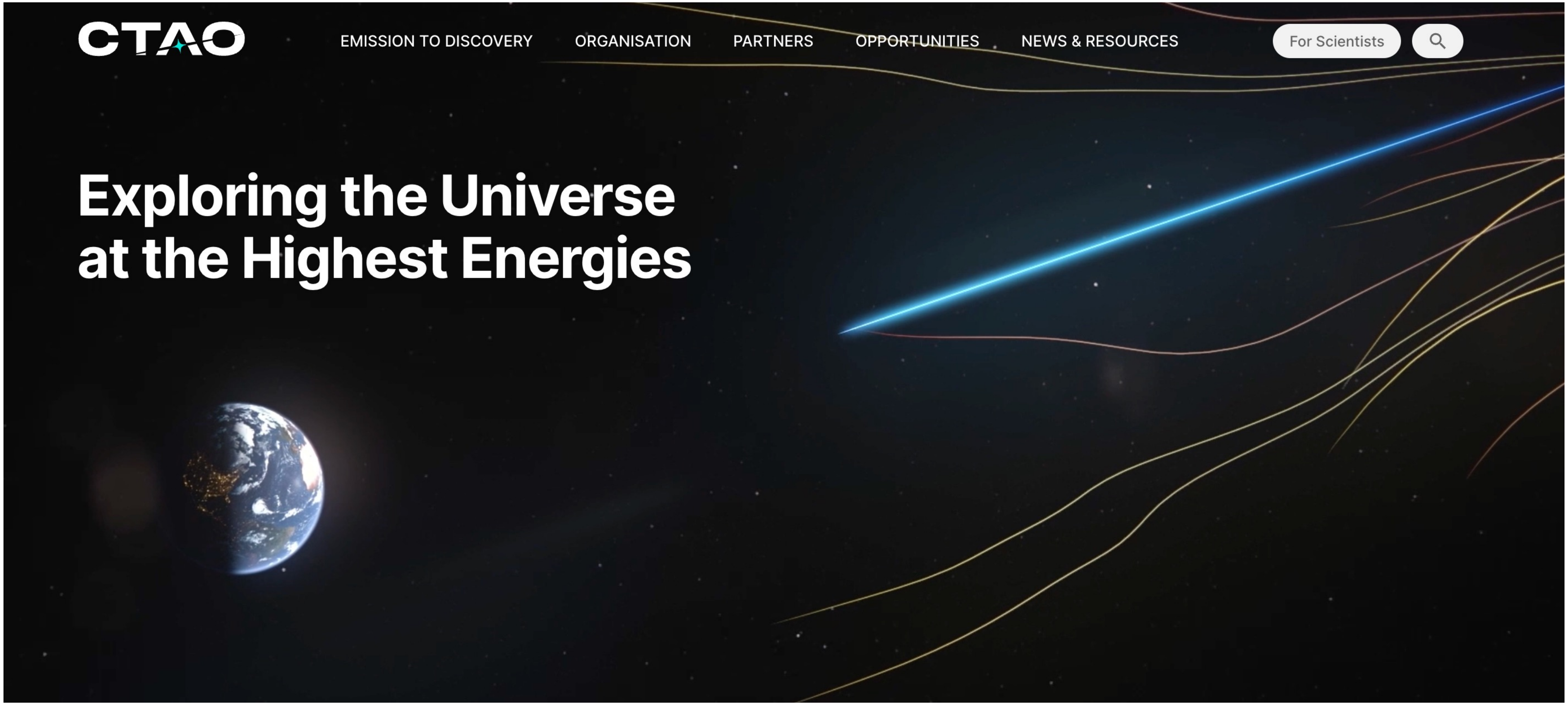

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