Istituto Nazionale di Fisica Nucleare
UNIVERSITÀ DEGLI STUDI DI TRIESTE
cherenkov telescope array

VHE emission from GRBs in the Theseus era

Francesco Longo on behalf of the CTA consortium

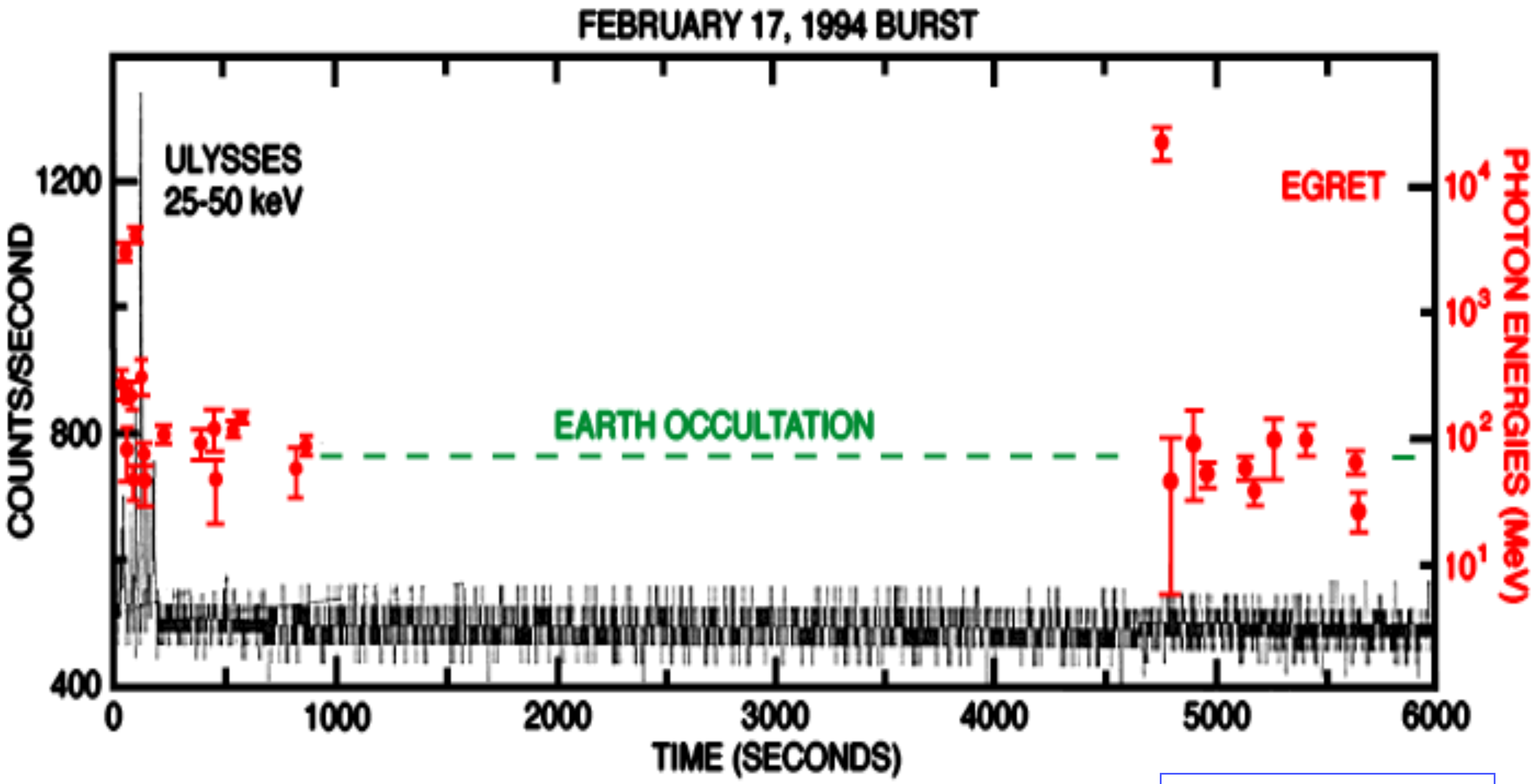
Thanks to E.Bissaldi, U.Barres, F.Schüssler, G.Ghirlanda, R.Zanin

Theseus Scientific conference

Outline

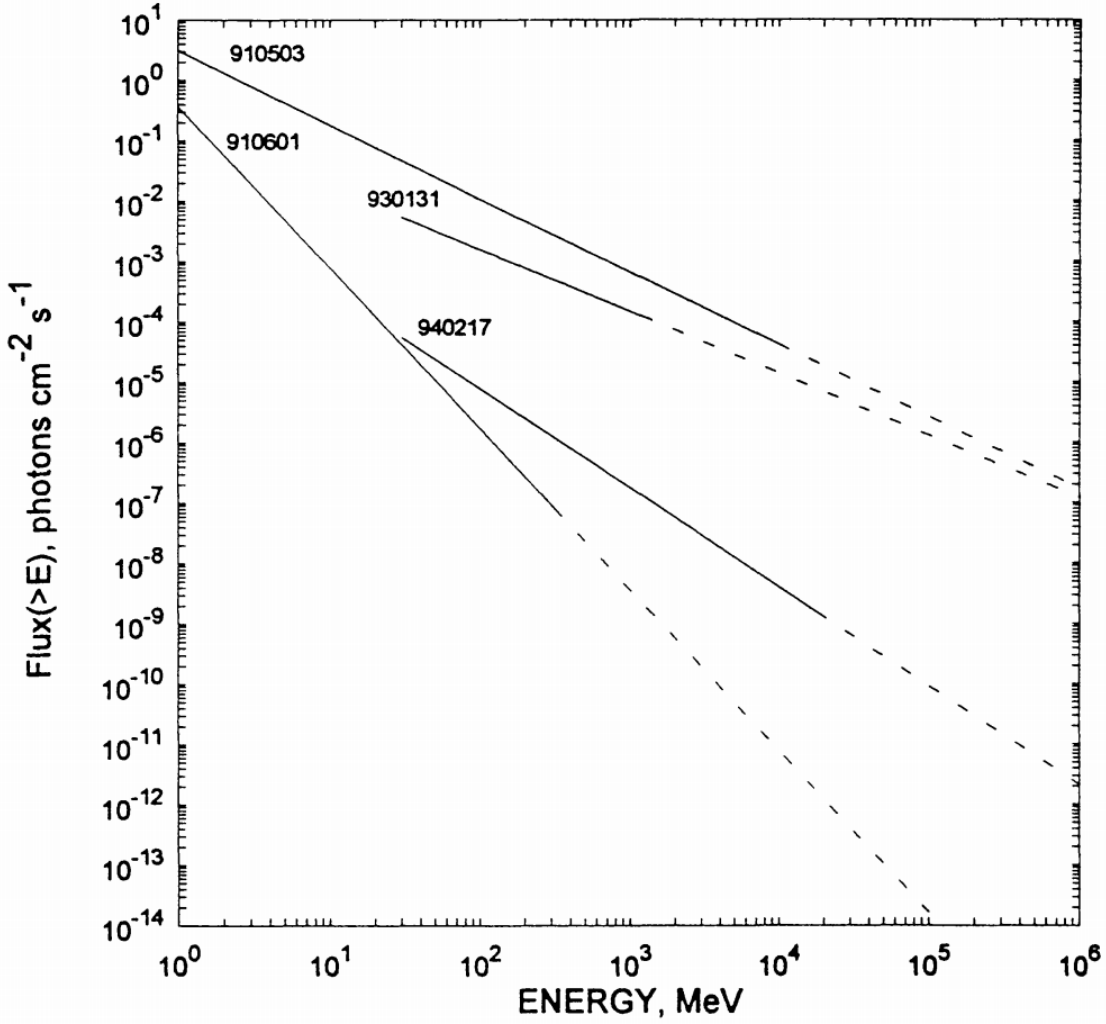
- Observing the sky at Very High Energies: the IACT technique
- GRB at VHE … "A Long-expected Party"
- The Cherenkov Telescope Array
- The Transient Key Science Project
- Possible joint collaboration projects with Theseus

GRB delayed emission .. Single photons matter!



Hurley et al. 1994

Search for GRBs at VHE … a long story made short ..

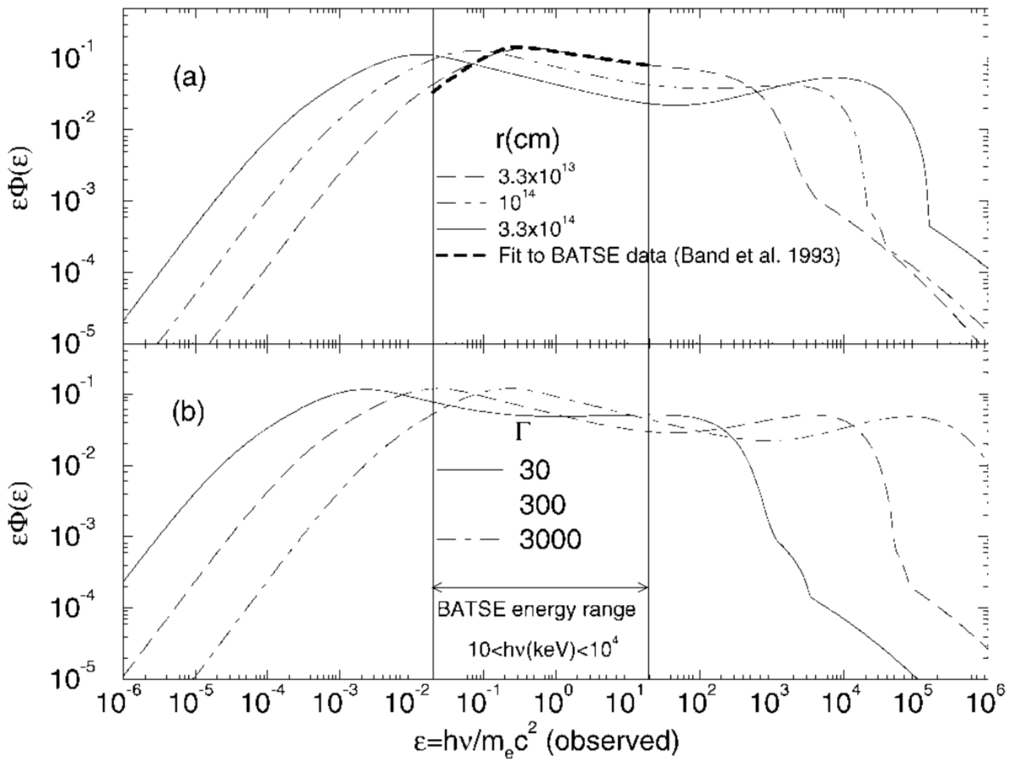


Hurley 1996

Theoretical Expectation

EMISSION SPECTRA FROM INTERNAL SHOCKS IN GAMMA-RAY BURST SOURCES

Ravi P. Pilla
Department of Physics, Columbia University, 538 W. 120th Street, New York, NY 10027; ravi@cuphyb.phys.columbia.edu
and
Abraham Loeb
Astronomy Department, Harvard University, 60 Garden Street, Cambridge, MA 02138; aloeb@cfa.harvard.edu
Received 1997 October 20; accepted 1997 December 19; published 1998 February 5



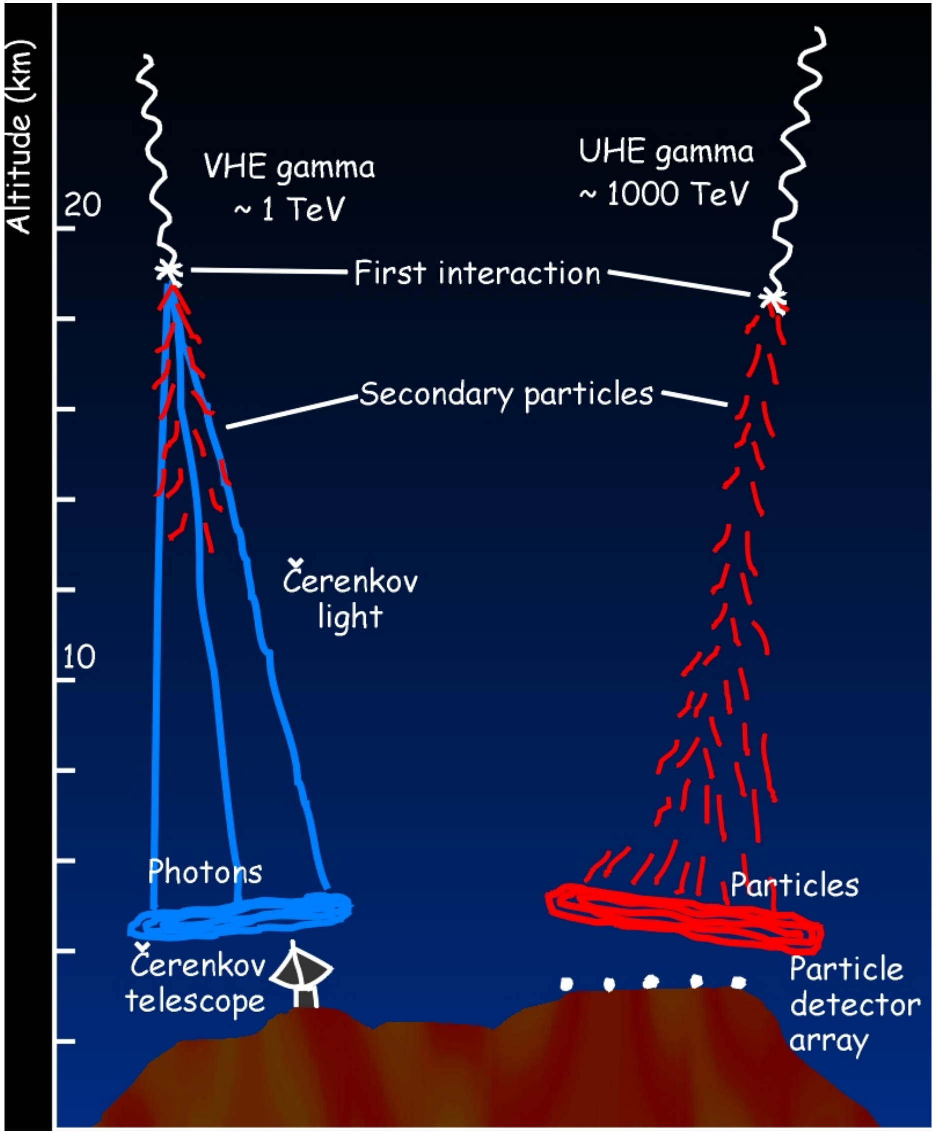
Pilla and Loeb 1998

Search for GRBs at VHE … a long story made short ..

- The scientific benefits of the detection of a TeV component to a classical gamma-ray burst (GRB) would be the following:
- It would constrain the particle acceleration models for the sources and provide valuable insights into the source radiation mechanisms;
- It would set an upper limit to the source distance because of the predicted absorption of TeV photons by pair production with intergalactic infrared photons;
- It would give a more accurate measure of the location of the burst and thus contribute to source identification;
- It would open a new window to the study of GRB phenomena from the ground

Connaughton et al 1997

IACT & EAS experiments



- Cherenkov experiments consist of almost-optical telescopes devoted to detect Cherenkov light.
- EAS (Extensive Air Shower) experiments are huge arrays or carpets of particle detectors.
- Cherenkov experiments have lower energy thresholds, but also a lower duty-cycle as well as a smaller field of view.

Search for GRBs at VHE … a long story made short ..

Search for gamma-ray bursts above 20 TeV with the HEGRA AIROBICC Cherenkov array

L. Padilla[1], B. Funk[2], H. Krawczynski[3,4], J.L. Contreras[1], A. Moralejo[1], F. Aharonian[3], A.G. Akhperjanian[5], J.A. Barrio[1,6], J.G. Beteta[1], J. Cortina[1], T. Deckers[7], V. Fonseca[1], H.-J. Gebauer[6], J.C. González[1,6], G. Heinzelmann[4], D. Horns[4], H. Kornmayer[6], A. Lindner[4], E. Lorenz[6], N. Magnussen[2], H. Meyer[2], R. Mirzoyan[5,6], D. Petry[2,6], R. Plaga[6], J. Prahl[4], C. Prosch[6], G. Rauterberg[7], W. Rhode[2], A. Röhring[4], V. Sahakian[5], M. Samorski[7], D. Schmele[4], W. Stamm[7], B. Wiebel-Sooth[2], M. Willmer[7], and W. Wittek[6]

[1] Facultad de Ciencias Físicas, Universidad Complutense, E-28040 Madrid, Spain
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[5] Yerevan Physics Institute, Yerevan, Armenia
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[7] Universität Kiel, Institut für Experimentelle und Angewandte Physik, D-24098 Kiel, Germany

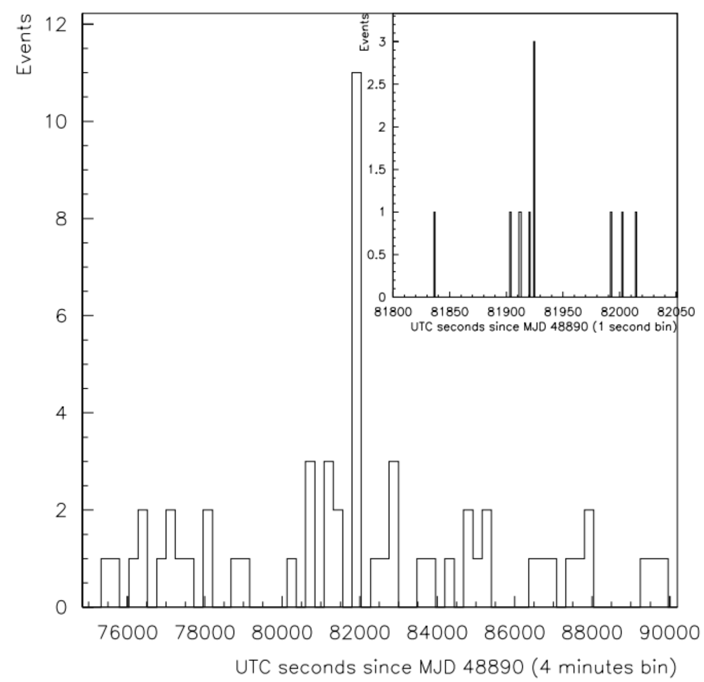
Received 6 April 1998 / Accepted 13 May 1998

Abstract. A search for gamma-ray bursts (GRBs) above 20 TeV within the field of view (1 sr) of the HEGRA AIROBICC Cherenkov array (29°N, 18°W, 2200 m a.s.l.) has been performed using data taken between March 1992 and March 1993. The search is based on an all-sky survey using four time scales, 10 seconds, 1 minute, 4 minutes and 1 hour. No evidence for TeV-emission has been found for the data sample. Flux upper limits are given. A special analysis has been performed for GRBs detected by BATSE and WATCH. Two partially and two fully contained GRBs in our field of view (FOV) were studied. For GRB 920925c which was fully contained in our FOV, the most significant excess has a probability of $7.7 \cdot 10^{-8}$ (corresponding to 5.4σ) of being caused by a background fluctuation. Correcting this probability with the appropriate trial factor, yields a 99.7% confidence level (CL) for this excess to be related to the GRB (corresponding to 2.7σ). This result is discussed within the framework of the WATCH detection.

Key words: gamma rays: bursts – ISM: cosmic rays

Padilla et al 1998

GRB 920925c



MILAGRITO

THE ASTROPHYSICAL JOURNAL, 533:L119–L122, 2000 April 20

EVIDENCE FOR TeV EMISSION FROM GRB 970417a

R. ATKINS,[1] W. BENBOW,[2] D. BERLEY,[3,4] M. L. CHEN,[3,5] D. G. COYNE,[2] B. L. DINGUS,[1] D. E. DORFAN,[2] R. W. ELLSWORTH,[6] D. EVANS,[3] A. FALCONE,[7] L. FLEYSHER,[8] R. FLEYSHER,[8] G. GISLER,[9] J. A. GOODMAN,[3] T. J. HAINES,[9] C. M. HOFFMAN,[9] S. HUGENBERGER,[10] L. A. KELLEY,[2] I. LEONOR,[10] M. MCCONNELL,[7] J. F. MCCULLOUGH,[2] J. E. MCENERY,[1] R. S. MILLER,[7,9] A. I. MINCER,[8] M. F. MORALES,[2] P. NEMETHY,[8] J. M. RYAN,[7] B. SHEN,[11] A. SHOUP,[10] C. SINNIS,[9] A. J. SMITH,[3,11] G. W. SULLIVAN,[3] T. TUMER,[11] K. WANG,[11] M. O. WASCKO,[11] S. WESTERHOFF,[2] D. A. WILLIAMS,[2] T. YANG,[2] AND G. B. YODH[10]
Received 1999 December 15; accepted 2000 March 3; published 2000 April 04

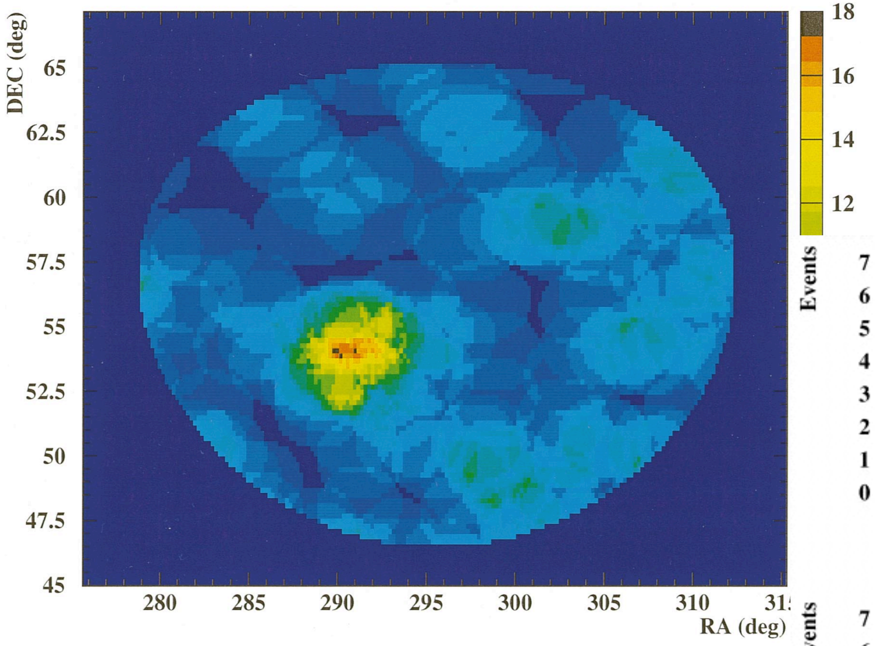
ABSTRACT

Milagrito, a detector sensitive to very high energy gamma rays, monitored the northern sky from 1997 February through 1998 May. With a large field of view and a high duty cycle, this instrument was well suited to perform a search for TeV gamma-ray bursts (GRBs). We report on a search made for TeV counterparts to GRBs observed by BATSE. BATSE detected 54 GRBs within the field of view of Milagrito during this period. An excess of events coincident in time and space with one of these bursts, GRB 970417a, was observed by Milagrito. The excess has a chance probability of 2.8×10^{-5} of being a fluctuation of the background. The probability for observing an excess at least this large from any of the 54 bursts is 1.5×10^{-3}. No significant correlations were detected from the other bursts.

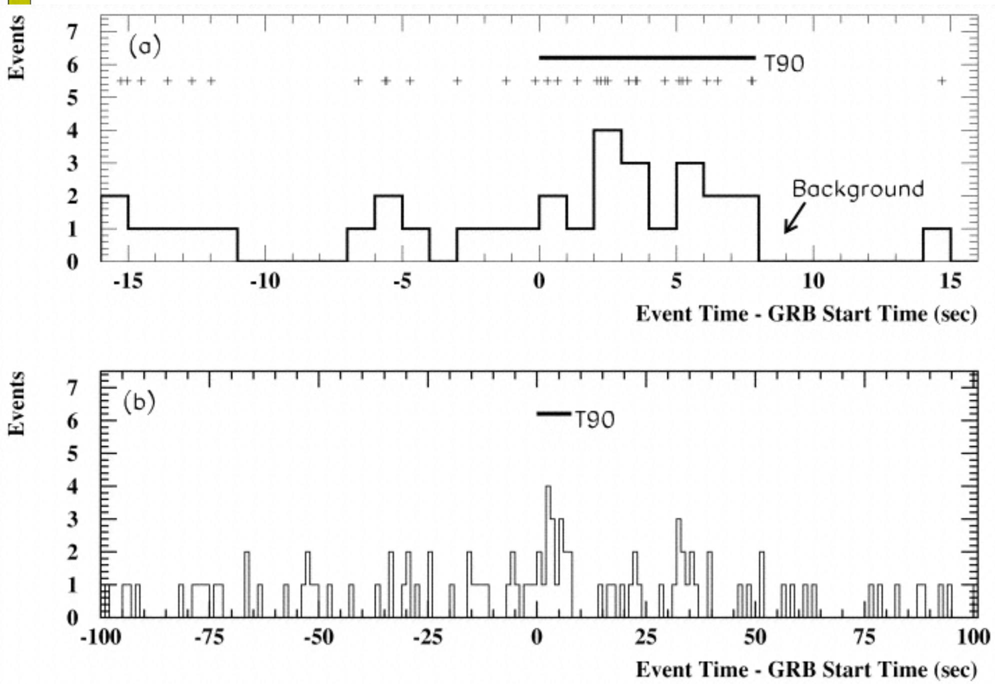
Subject headings: gamma rays: bursts — gamma rays: observations

Atkins et al 2000

MILAGRITO

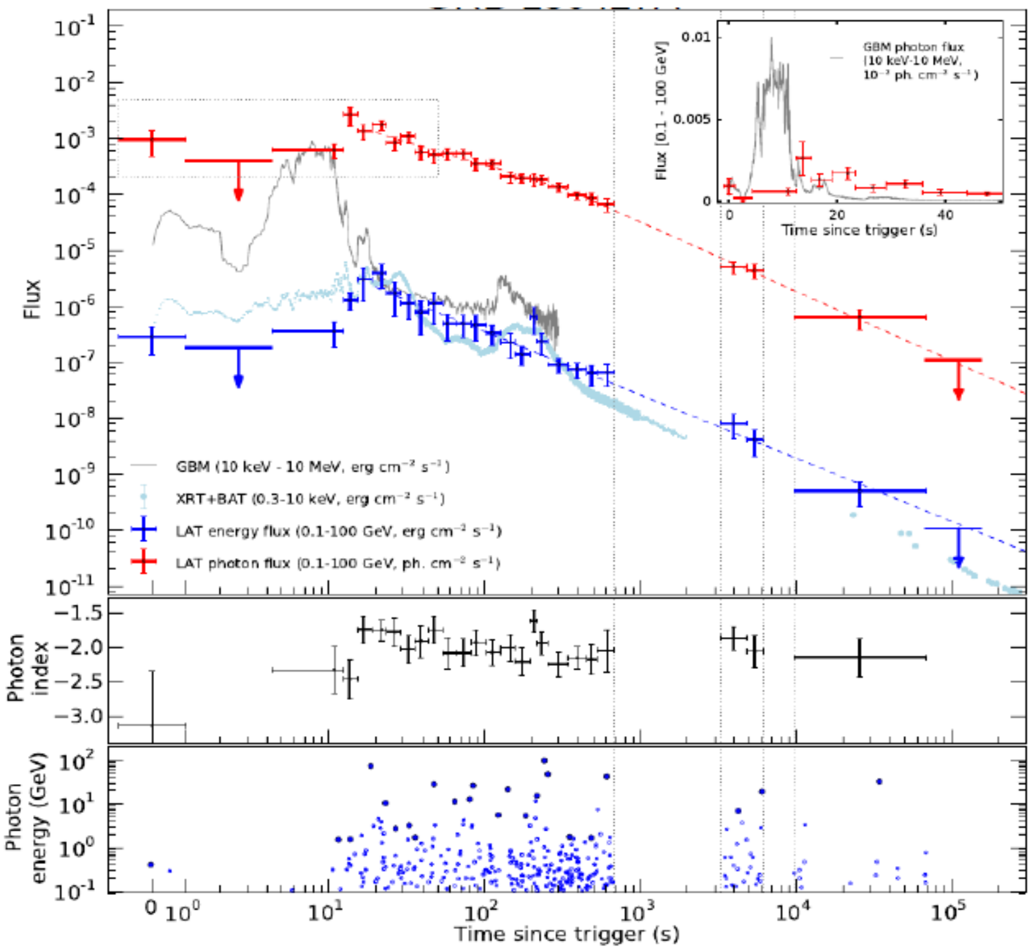


GRB 970417a



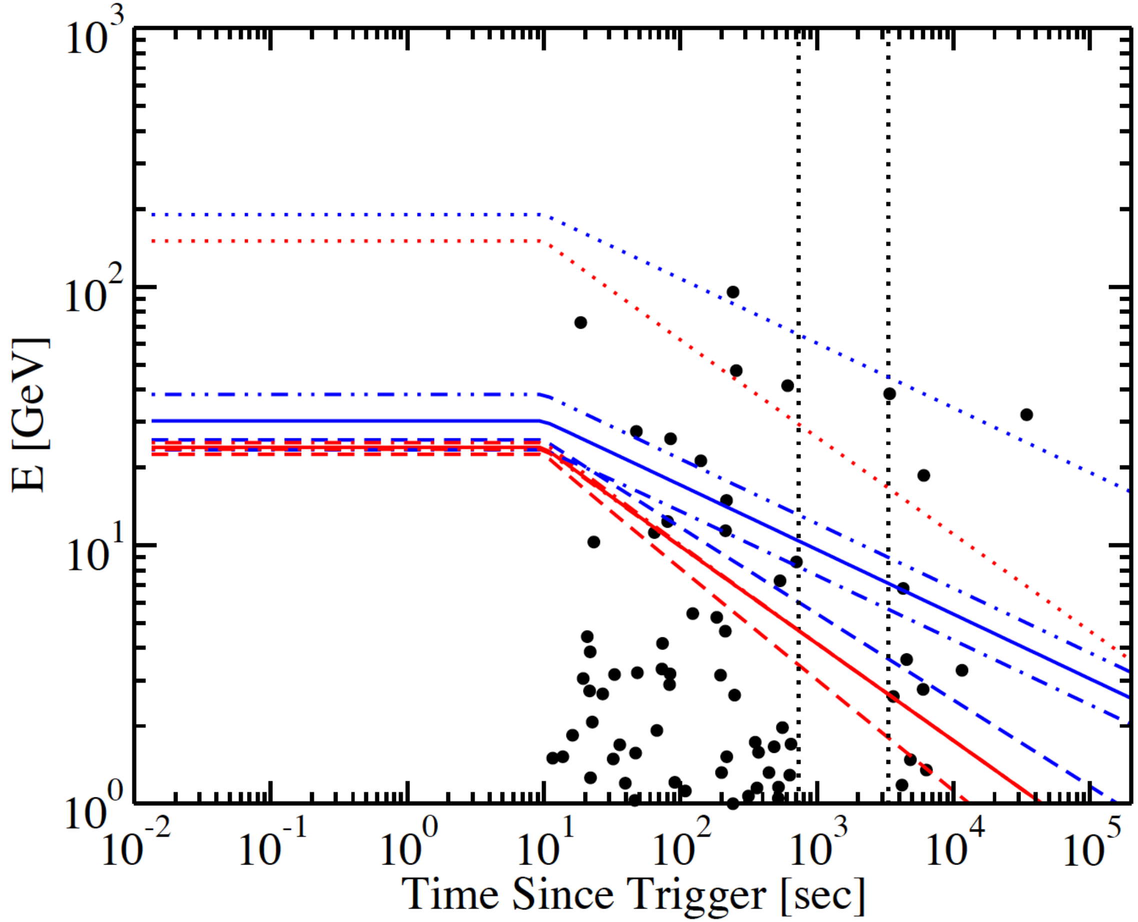
Atkins et al 2000

GRB 130427A



Ackermann et al. 2014

GRB HE emission. Single photons matter

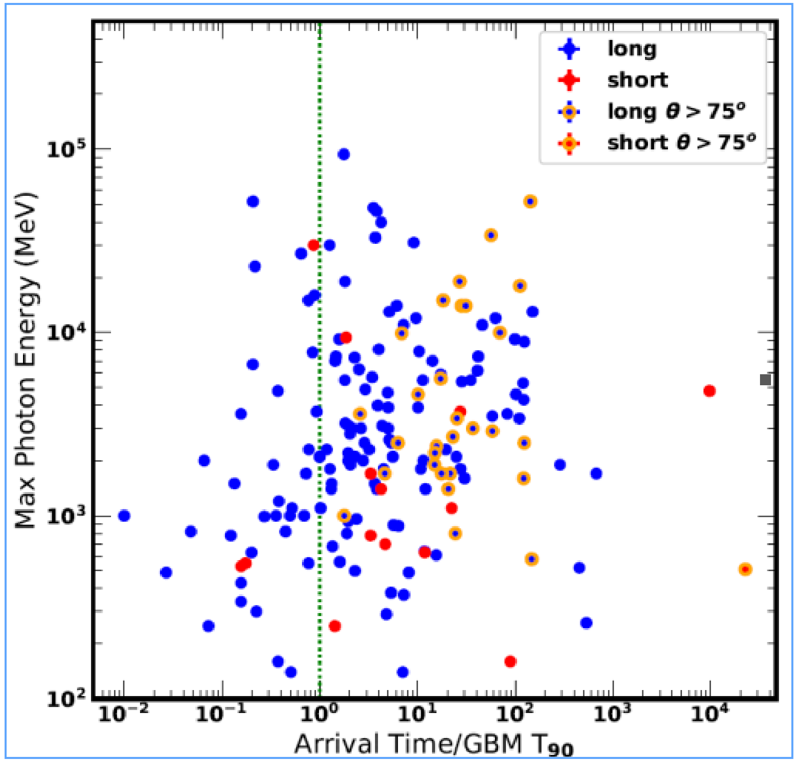


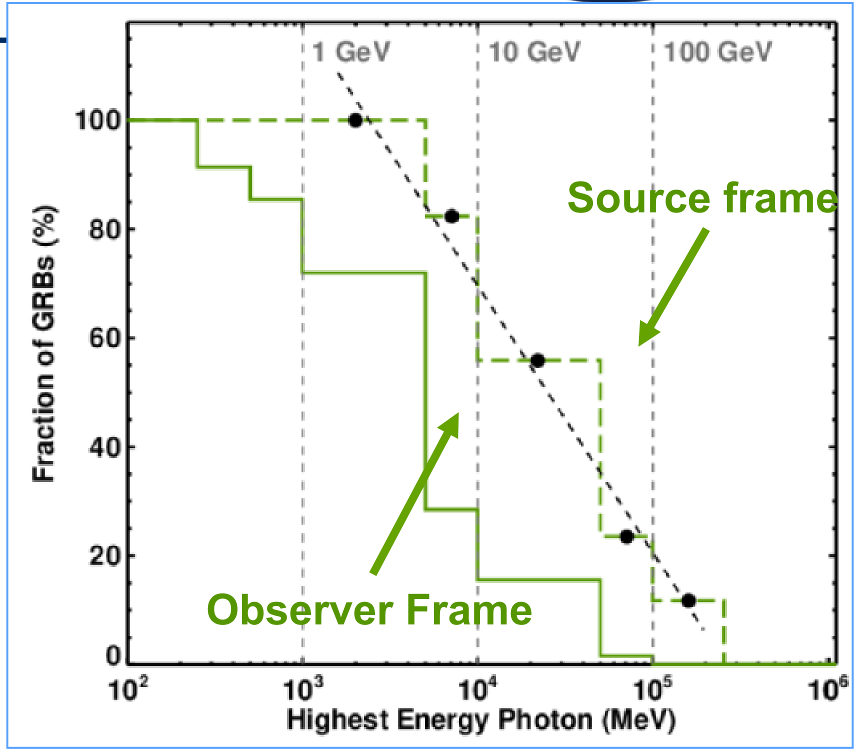
GRB 130427A

Ackermann et al. 2014

Highest-energy photons from GRBs

- <5% of GRBs have E > 50 GeV
- Sharp drop @5 GeV (obs.frame)
  - Record holder: GRB 130427A
    - 95 GeV @243 s
    - 77 GeV @19s
    - 34 GeV @34 ks





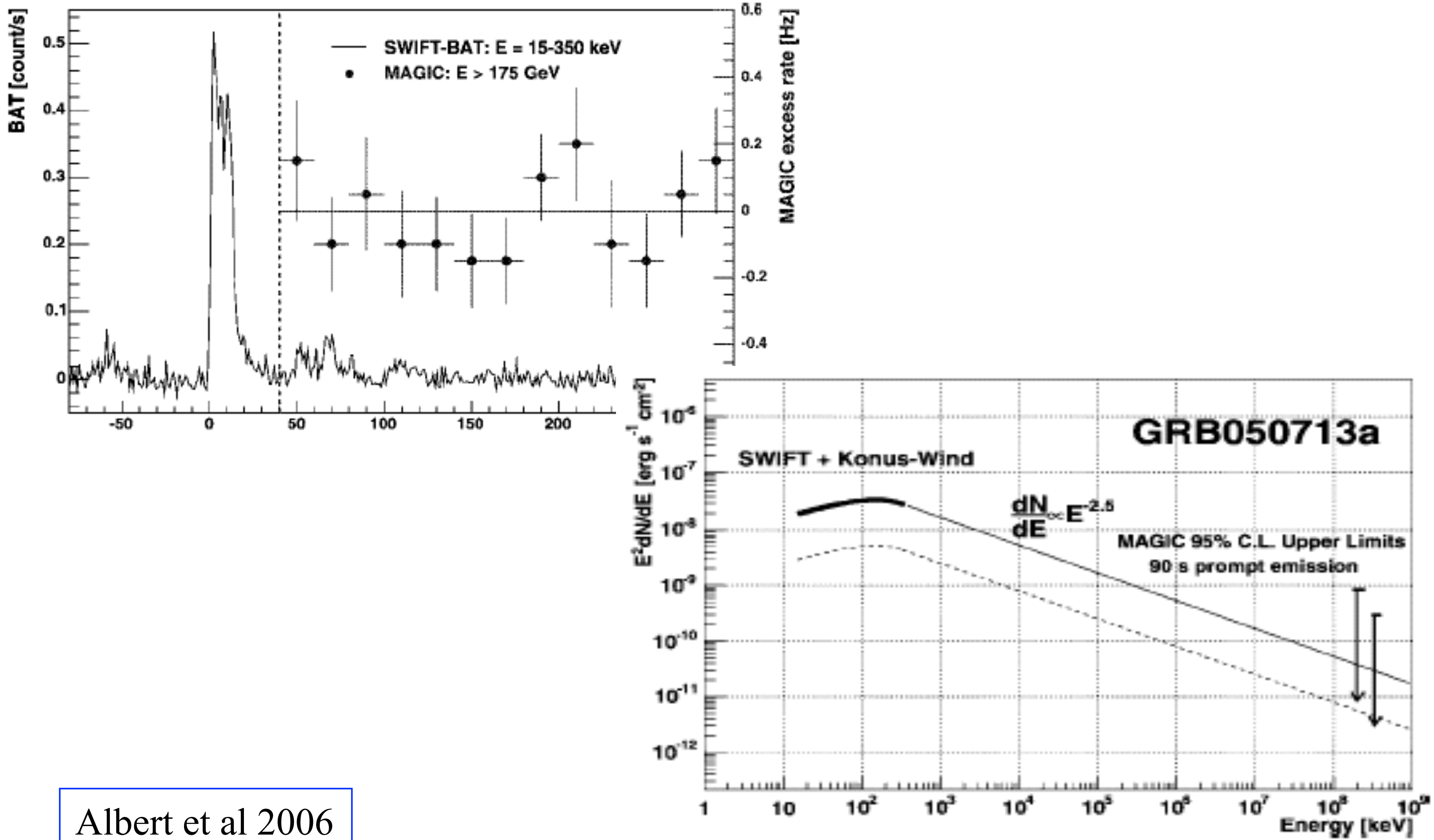
HE photons often arrive after the low-energy emission is over BUT

- Highest energies can be produced either very quickly or very late: challenge for models!

Ajello et al. 2019

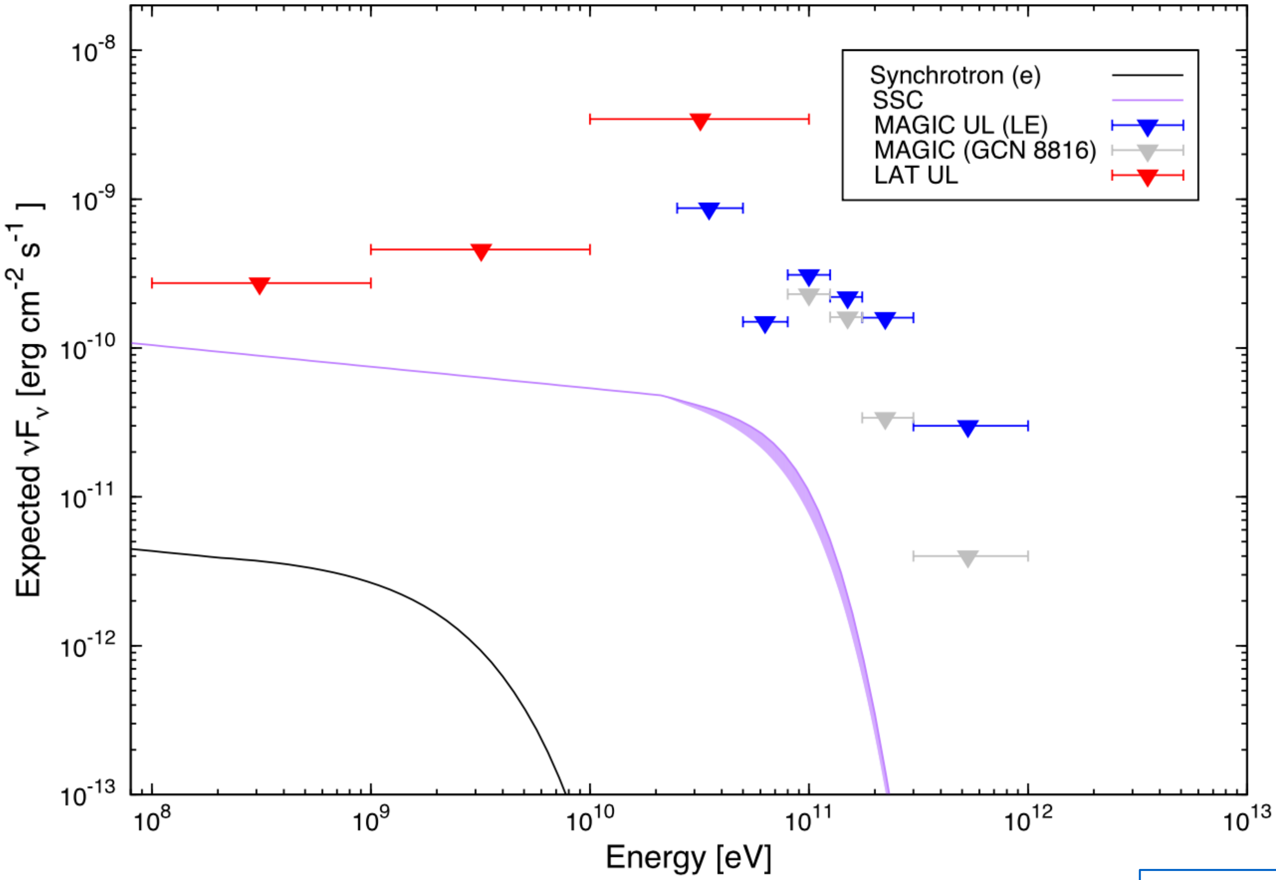
MAGIC telescopes

MAGIC – I upper limits



Albert et al 2006

MAGIC– I upper limits

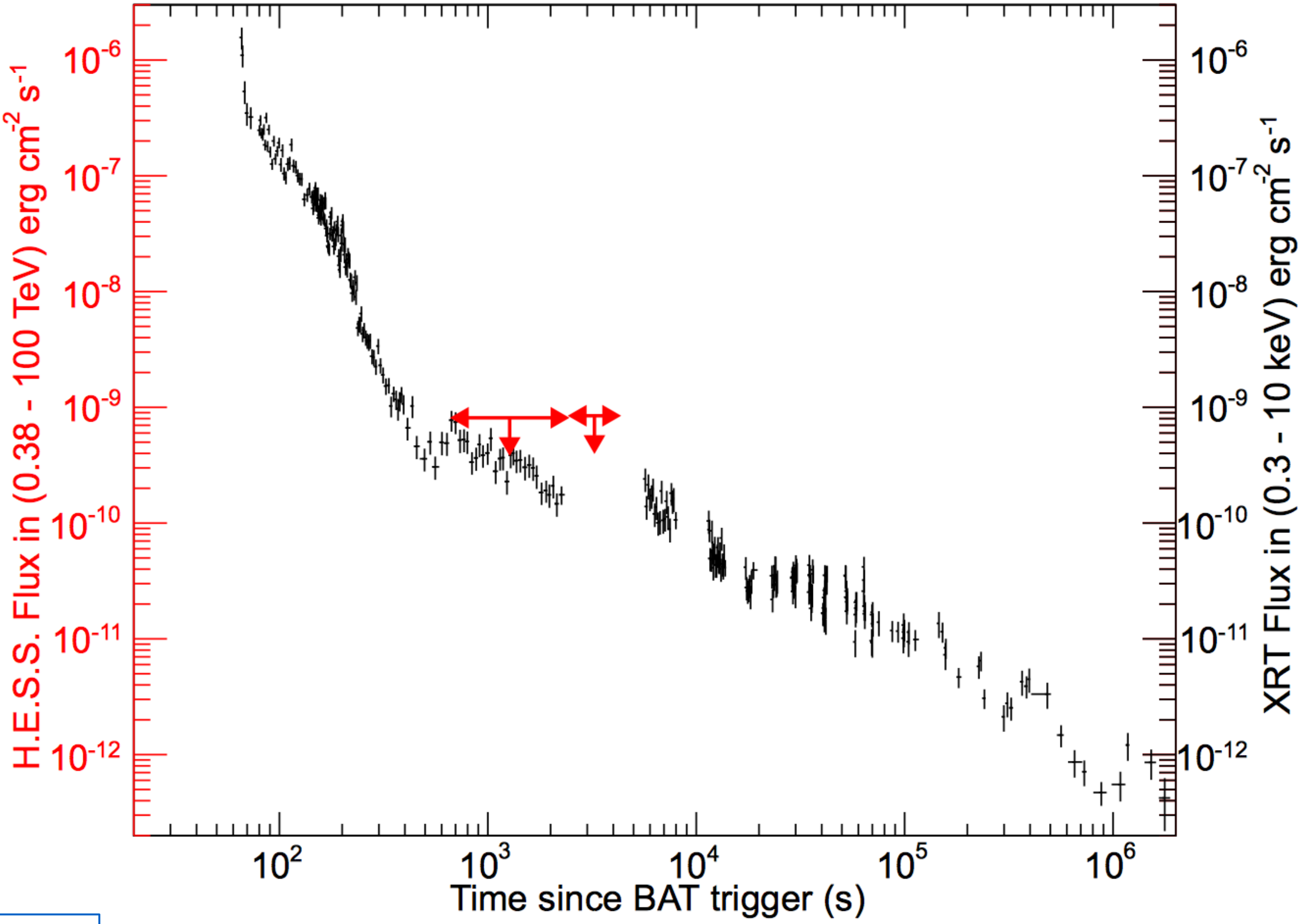


GRB 090102

J. Aleksic et al., 2014

HESS

HESS - I upper limits

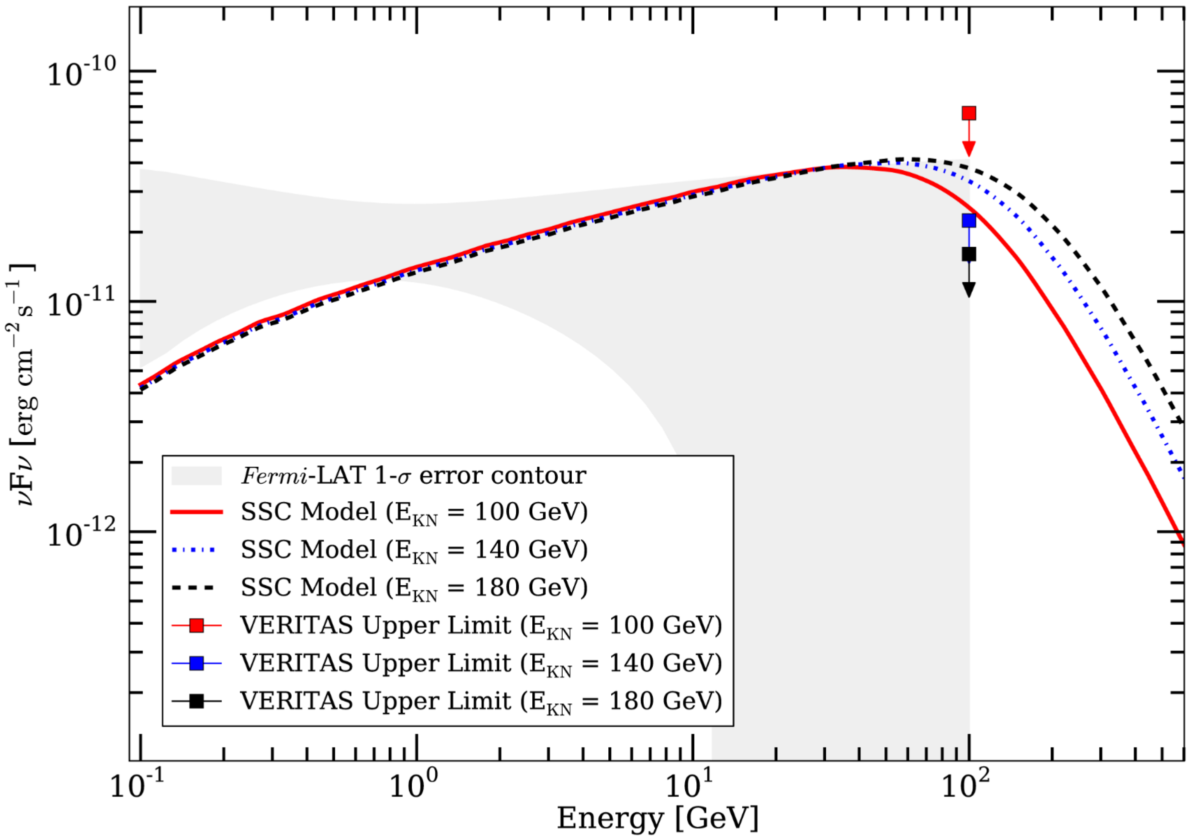


GRB 100621A

Abramowski et al. 2014

VERITAS

VERITAS upper limits

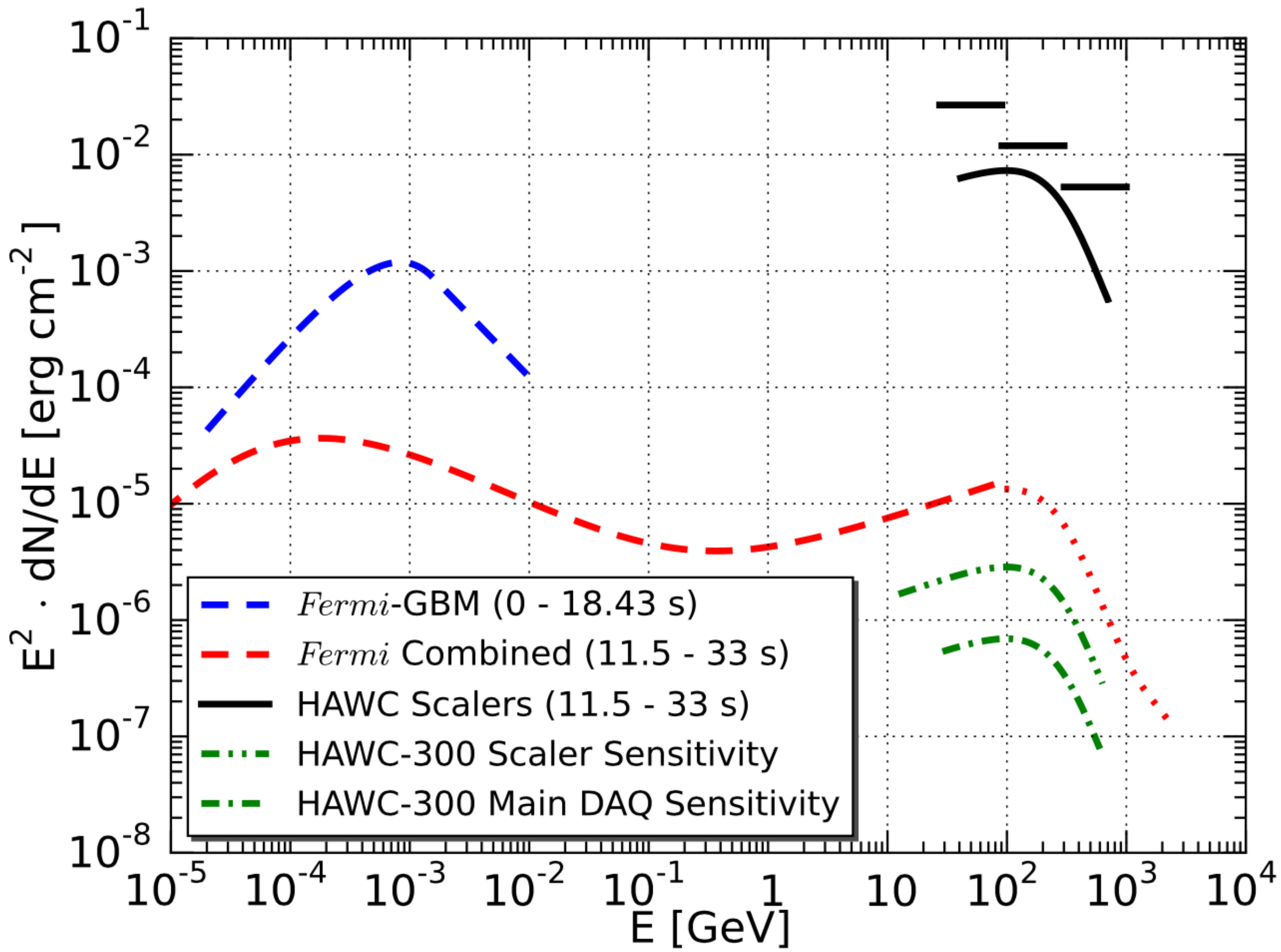


GRB 130427A

Aliu et al. 2014

HAWC

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)

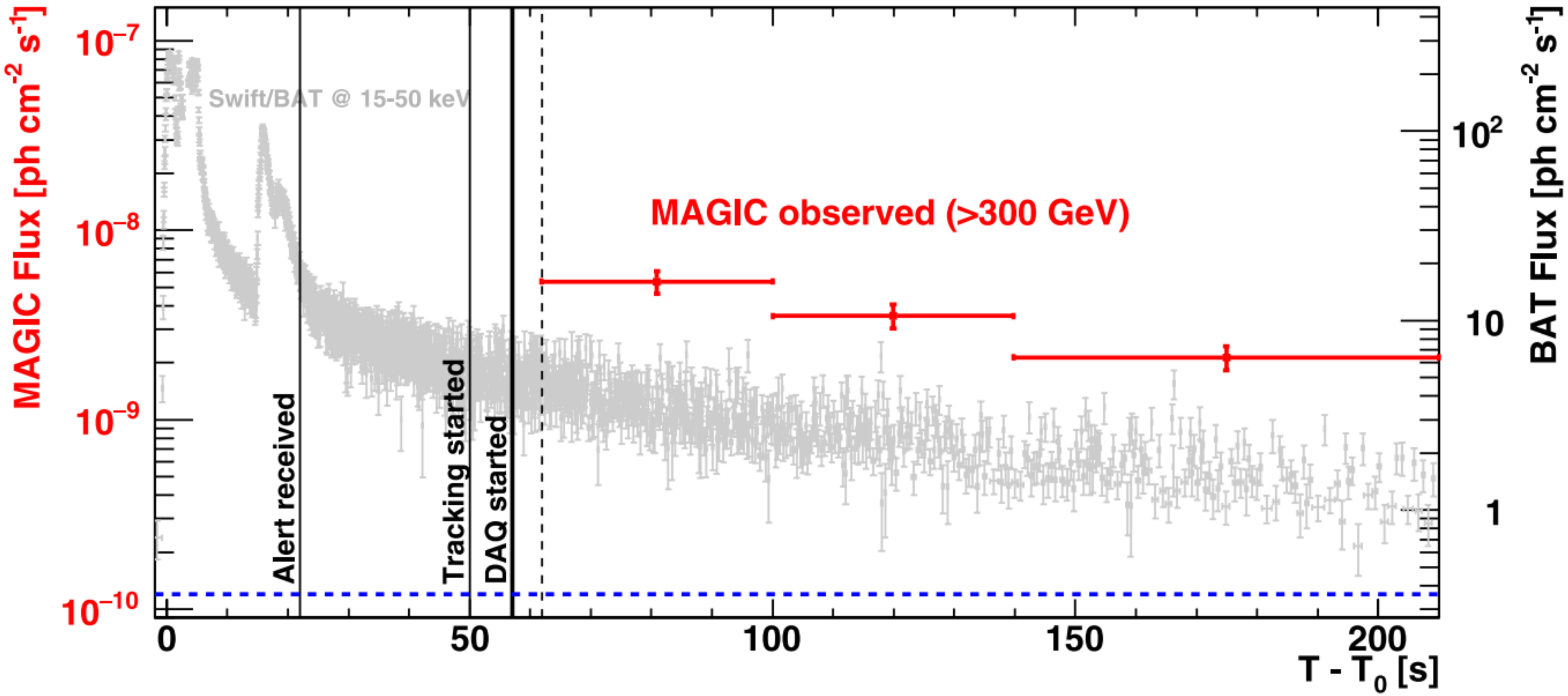
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

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.

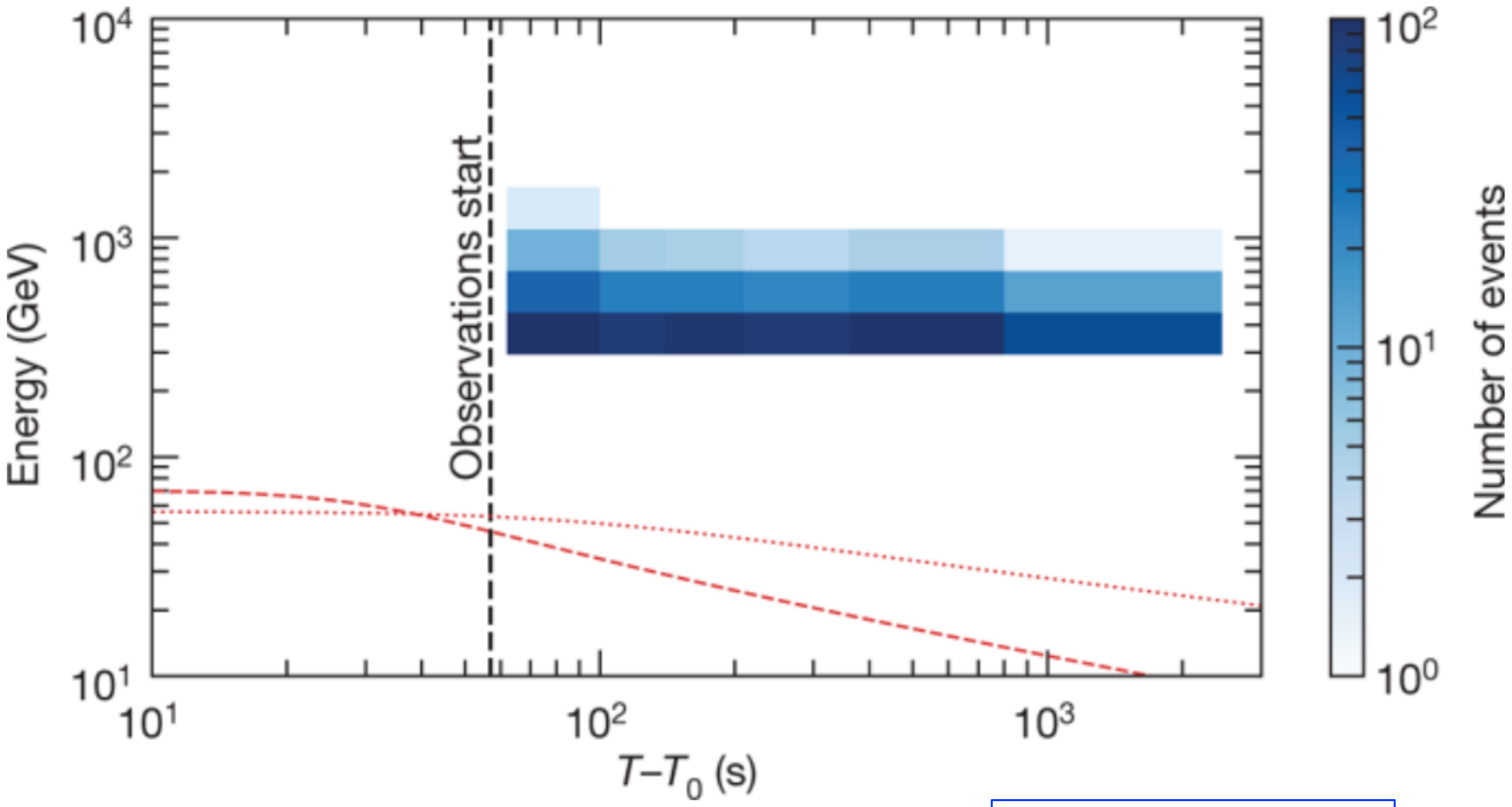
MAGIC detection



GRB 190114C

Acciari et al. 2019a

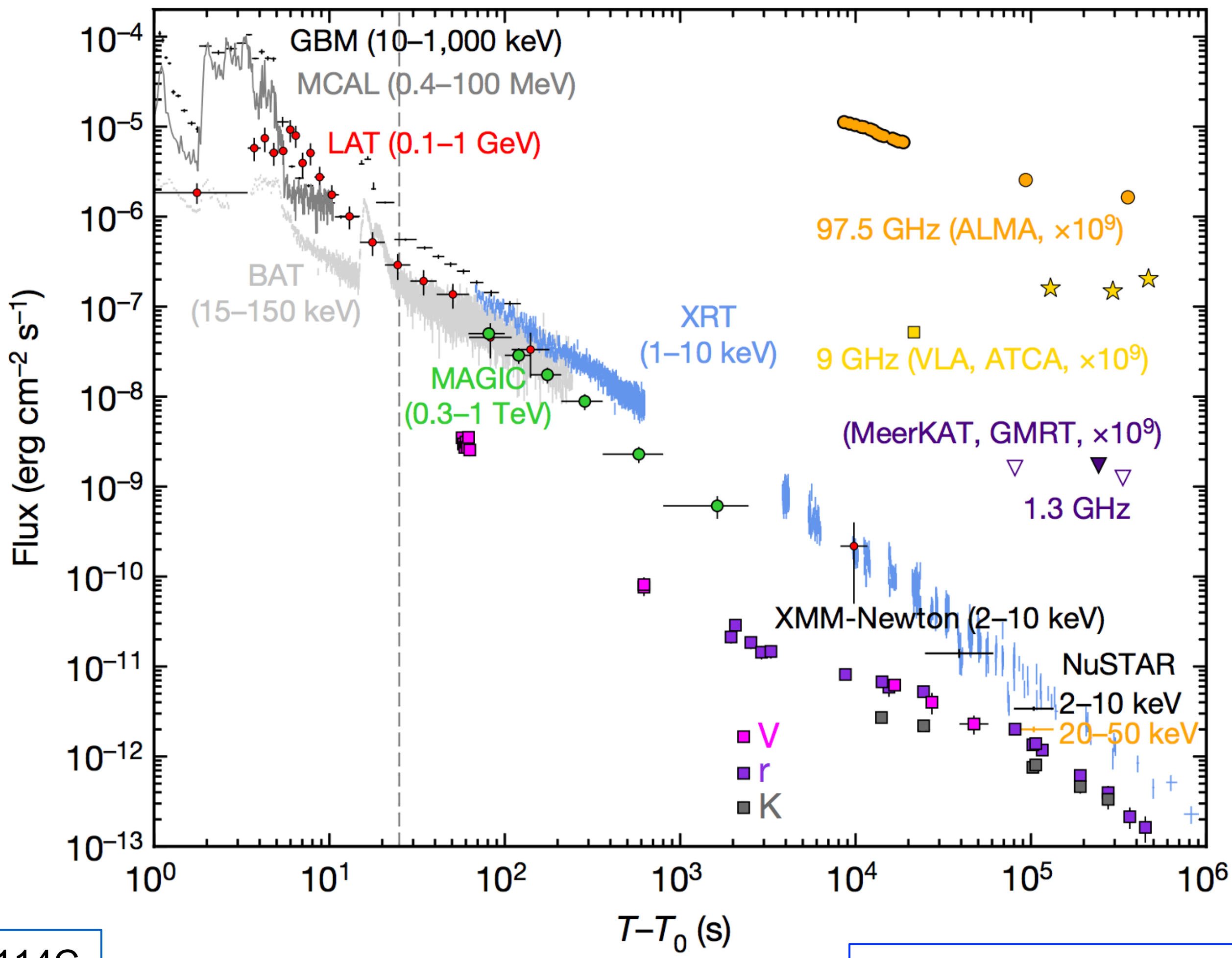
MAGIC detection



GRB 190114C

Acciari et al. 2019a

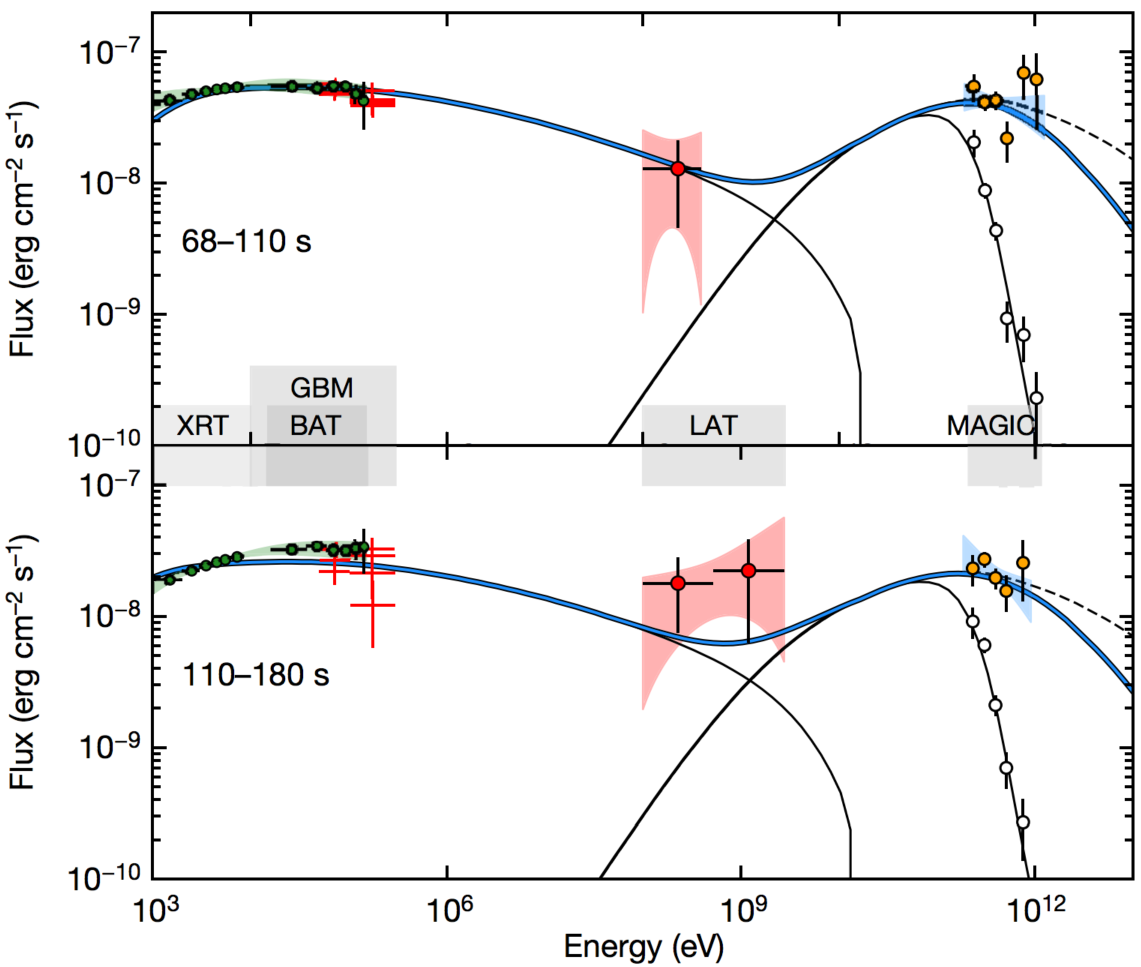
MAGIC detection



GRB 190114C

Acciari et al. 2019b

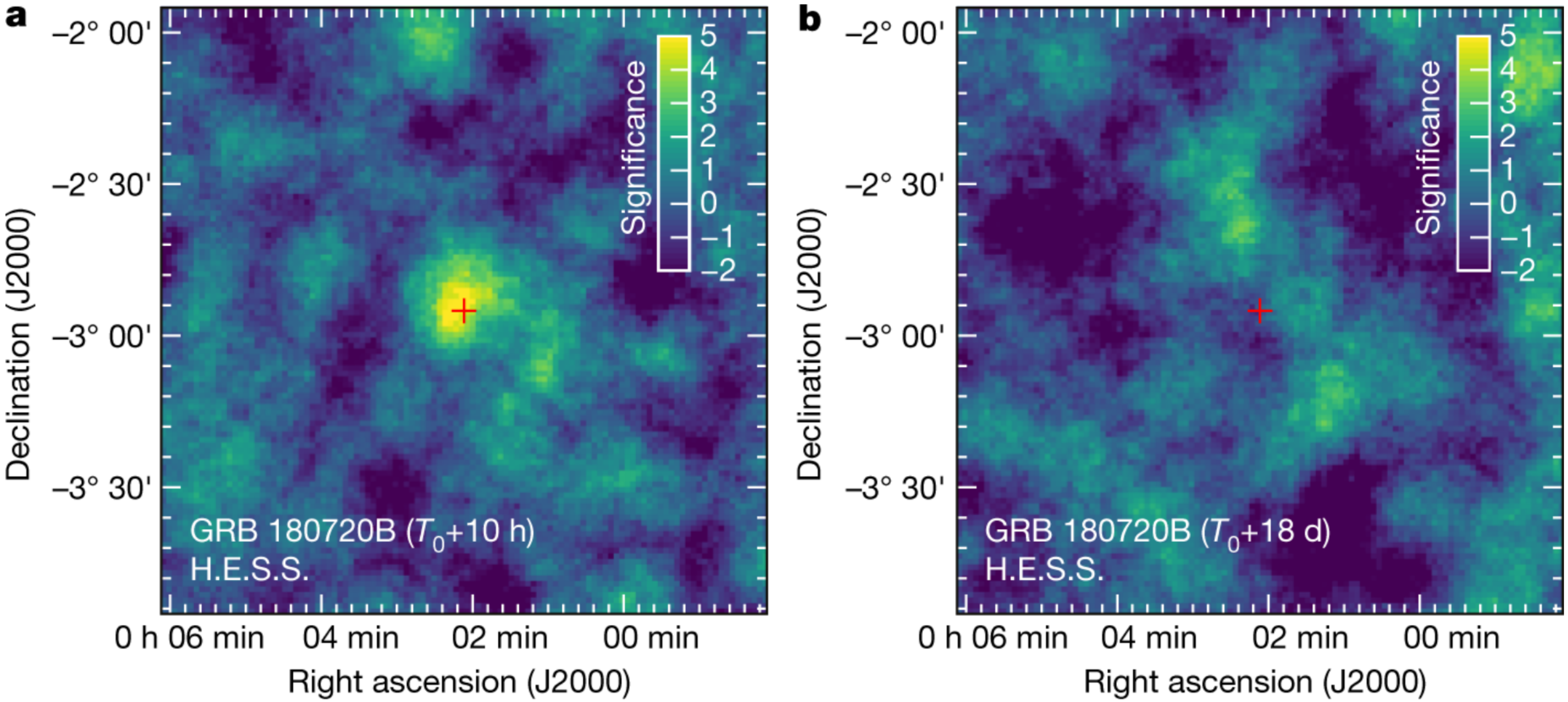
MAGIC detection



GRB 190114C

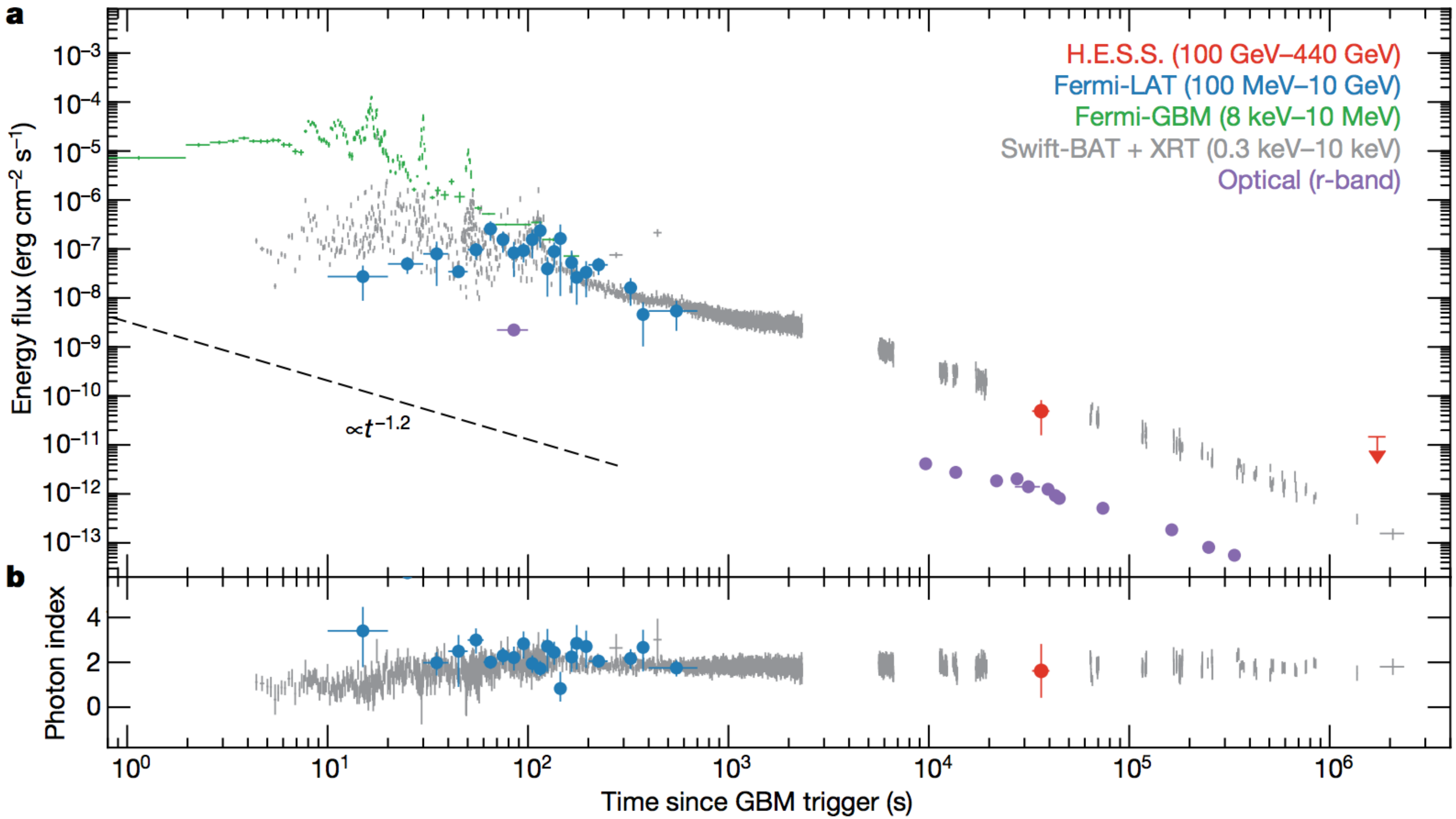
Acciari et al. 2019b

HESS detection



Abdalla et al. 2019

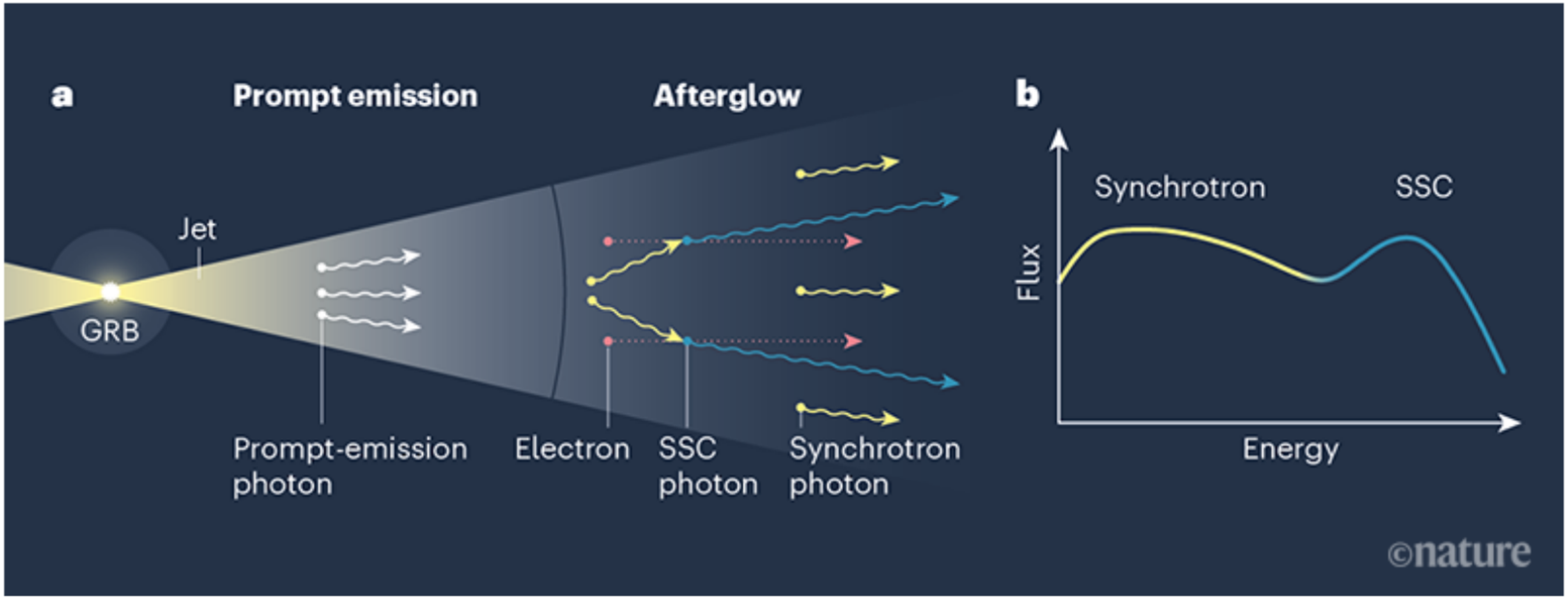
HESS detection



GRB 180720B

Abdalla et al. 2019

MAGIC & HESS detection



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

GRBs @ VHE ! – GRB 190829A

TITLE: GCN CIRCULAR
NUMBER: 25566
SUBJECT: GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.
DATE: 19/08/30 07:08:37 GMT
FROM: Fabian Schussler at CEA <fabian.schussler@cea.fr>

M. de Naurois on behalf of the H.E.S.S. collaboration

The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out follow-up observations of the afterglow of GRB 190829A (Dichiara et al., GCN 25552).
At a redshift of z = 0.0785 +/- 0.005 (A.F. Valeev et al., GCN 25565) this is one of the nearest GRBs detected to date.
H.E.S.S. Observations started July 30 at 00:16 UTC (i.e. T0 + 4h20), lasted until 3h50 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >5sigma gamma-ray excess compatible with the direction of GRB190829A.
Further analyses of the data are on-going and further H.E.S.S. observations are planned.
We strongly encourage follow-up at all wavelengths.

H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia.
It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia.
For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

https://gcn.gsfc.nasa.gov/gcn3/25566.gcn3

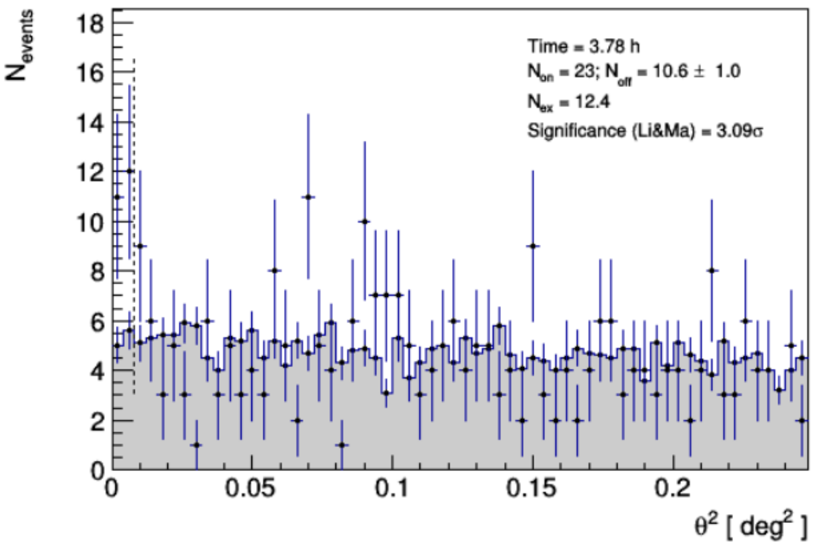
GRBs @ VHE ! (GRB 160821B)

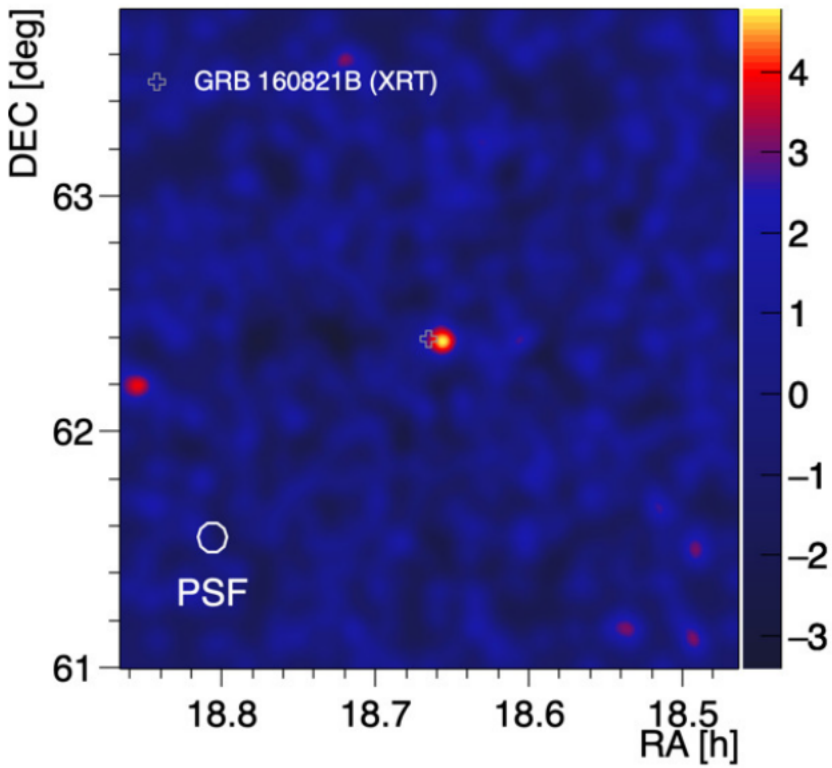
ABSTRACT

The coincident detection of GW170817 in gravitational waves and electromagnetic radiation spanning the radio to MeV gamma-ray bands provided the first direct evidence that short gamma-ray bursts (GRBs) can originate from binary neutron star (BNS) mergers. On the other hand, the properties of short GRBs in high-energy gamma rays are still poorly constrained, with only ~20 events detected in the GeV band, and none in the TeV band. GRB 160821B is one of the nearest short GRBs known at $z = 0.162$. Recent analyses of the multiwavelength observational data of its afterglow emission revealed an optical-infrared kilonova component, characteristic of heavy-element nucleosynthesis in a BNS merger. Aiming to better clarify the nature of short GRBs, this burst was automatically followed up with the MAGIC telescopes, starting from 24 seconds after the burst trigger. Evidence of a gamma-ray signal is found above ~0.5 TeV at a significance of $\sim 3\sigma$ during observations that lasted until 4 hours after the burst. Assuming that the observed excess events correspond to gamma-ray emission from GRB 160821B, in conjunction with data at other wavelengths, we investigate its origin in the framework of GRB afterglow models. The simplest interpretation with one-zone models of synchrotron-self-Compton emission from the external forward shock has difficulty accounting for the putative TeV flux. Alternative scenarios are discussed where the TeV emission can be relatively enhanced. The role of future GeV-TeV observations of short GRBs in advancing our understanding of BNS mergers and related topics is briefly addressed.

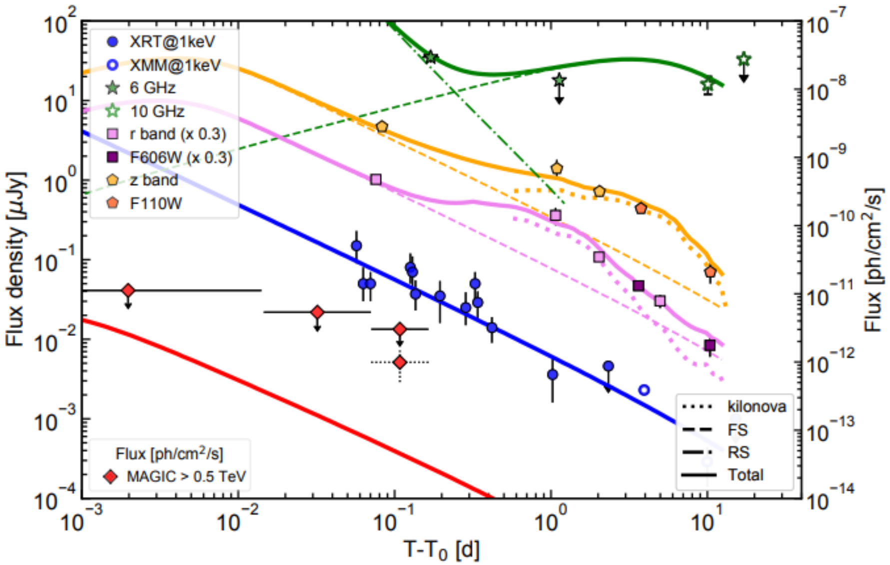
Keywords: Radiation mechanisms: non-thermal - Gamma rays: general - Gamma-ray burst: individual: GRB 160821B

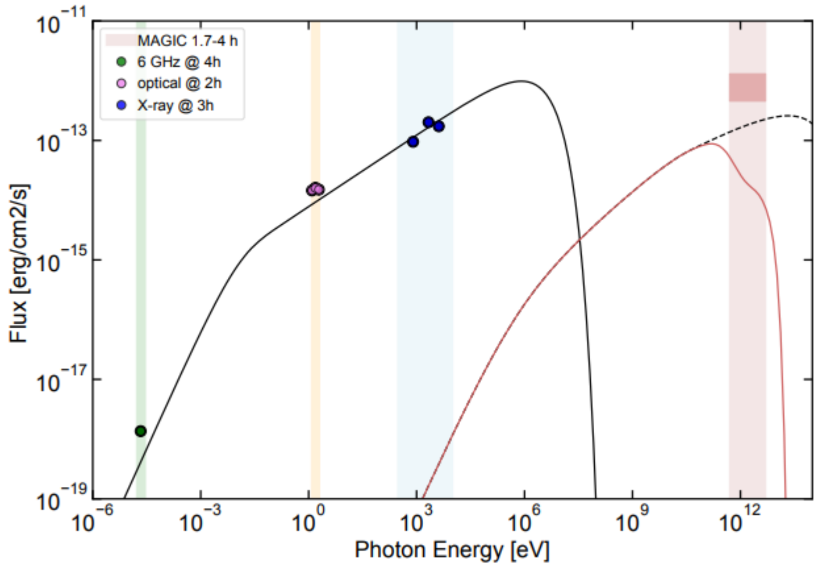
Acciari et al 2021





Acciari et al 2021





GRBs @ VHE ! – GRB 201216C

TITLE: GCN CIRCULAR
NUMBER: 29075
SUBJECT: GRB 201216C: MAGIC detection in very high energy gamma rays
DATE: 20/12/17 17:23:13 GMT
FROM: Oscar Blanch at MAGIC Collaboration <blanch@ifae.es>
O.Blanch (IFAE-BIST Barcelona), F. Longo (University and INFN Trieste), A. Berti (INFN Torino),
S. Fukami (ICRR University of Tokyo), Y. Suda (MPP Munich), S. Loporchio (University and INFN Bari),
S. Micanovic (University of Rijeka), J. G. Green (INAF Rome), V. Pinter (IFAE-BIST),
M. Takahashi (ICRR University of Tokyo), on behalf of the MAGIC collaboration report:

On December 16, 2020, the MAGIC telescopes observed GRB 201216C following the trigger by Swift-BAT and Fermi-GBM (Beardmore et al., GCN 29061, Fermi/GBM team GCN 29063).
MAGIC started under good conditions about 57 seconds after the GRB onset.
The preliminary offline analyses show an excess above 5 sigma, compatible with the GRB position reported by the Swift and Fermi teams. Refined off-line analyses of the data are ongoing.

We strongly encourage follow-up observations by other instruments at all wavelengths.

The MAGIC point of contact for this burst is O. Blanch (blanch@ifae.es).
Burst Advocate for this burst is F. Longo (francesco.longo@ts.infn.it).

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.

https://gcn.gsfc.nasa.gov/gcn3/29075.gcn3

A next generation Cherenkov Observatory

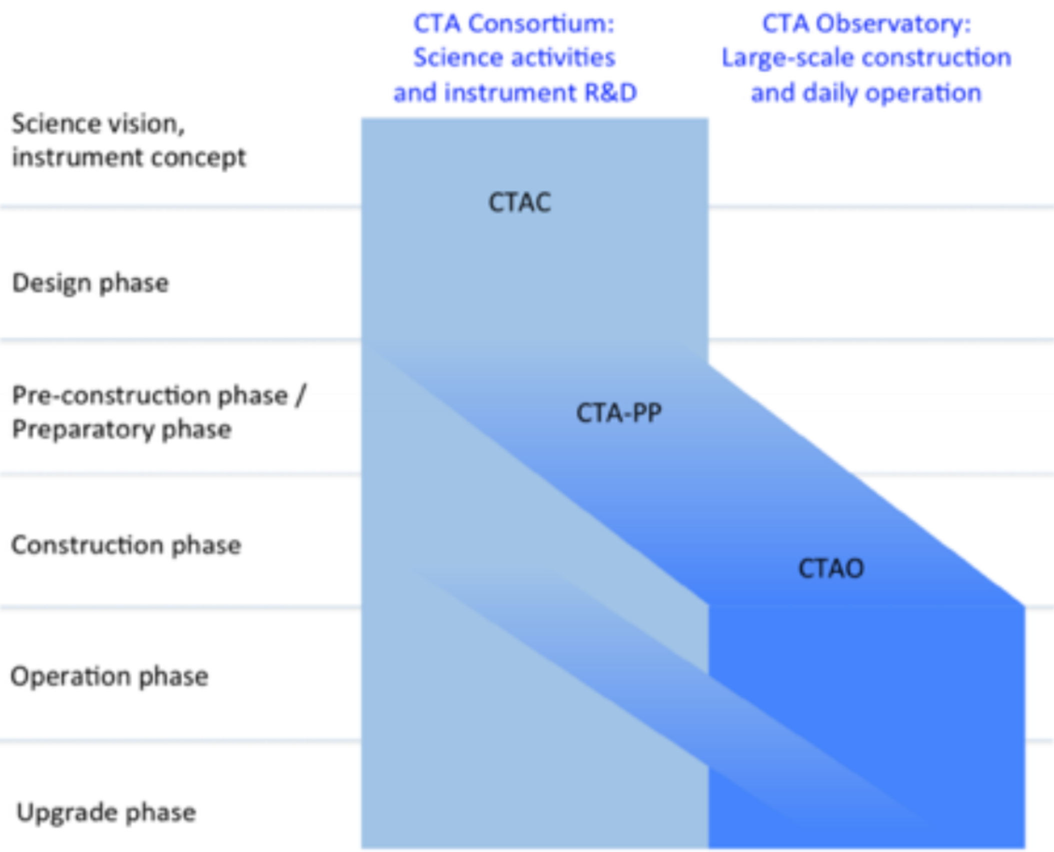
- **Cherenkov Telescope Array :** the next-generation Imaging Atmospheric Gamma-ray Observatory
  - Broadest energy range amongst IACTs: 20 GeV to 300 TeV
  - The first Open Observatory in the field
  - Full-Sky Coverage
    - Northern Site at the Canary Islands, Spain
    - Southern Site at the Chilean Andes, in Cerro Paranal
  - **CTA Observatory**
    - Headquarters in Bologna, Italy and Data Center in Zeuthen, Germany
    - Responsible for building and operating CTA
  - **CTA Consortium**
    - Responsible for the concept and design of CTA
    - Will provide in-kind contributions to the Observatory
    - Fraction of observation time allocated to CTA-C for Key Science Projects

The CTA Sites

A Global Observatory…

A next generation Cherenkov Observatory

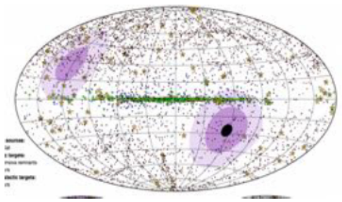
Status and observatory planning…

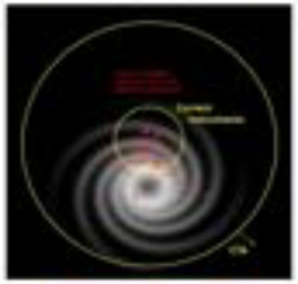


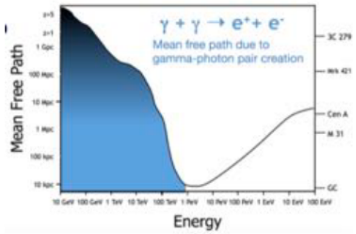
From:
Concept for CTA
construction and operation
WH 2011/12

- 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

Design drivers

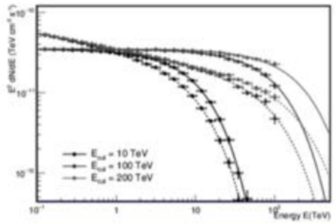






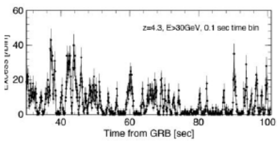
Full sky coverage

10 x sensitivity



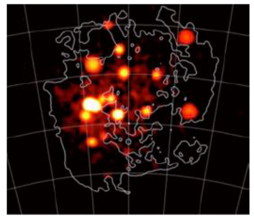
Energies down to 20 GeV

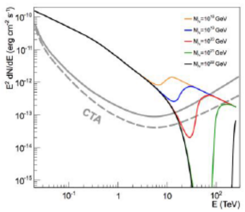
Energies up to 300 TeV



Rapid slewing 20 sec

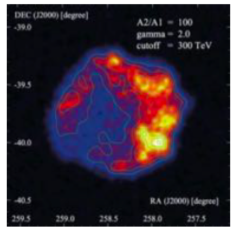
~ 10° FoV





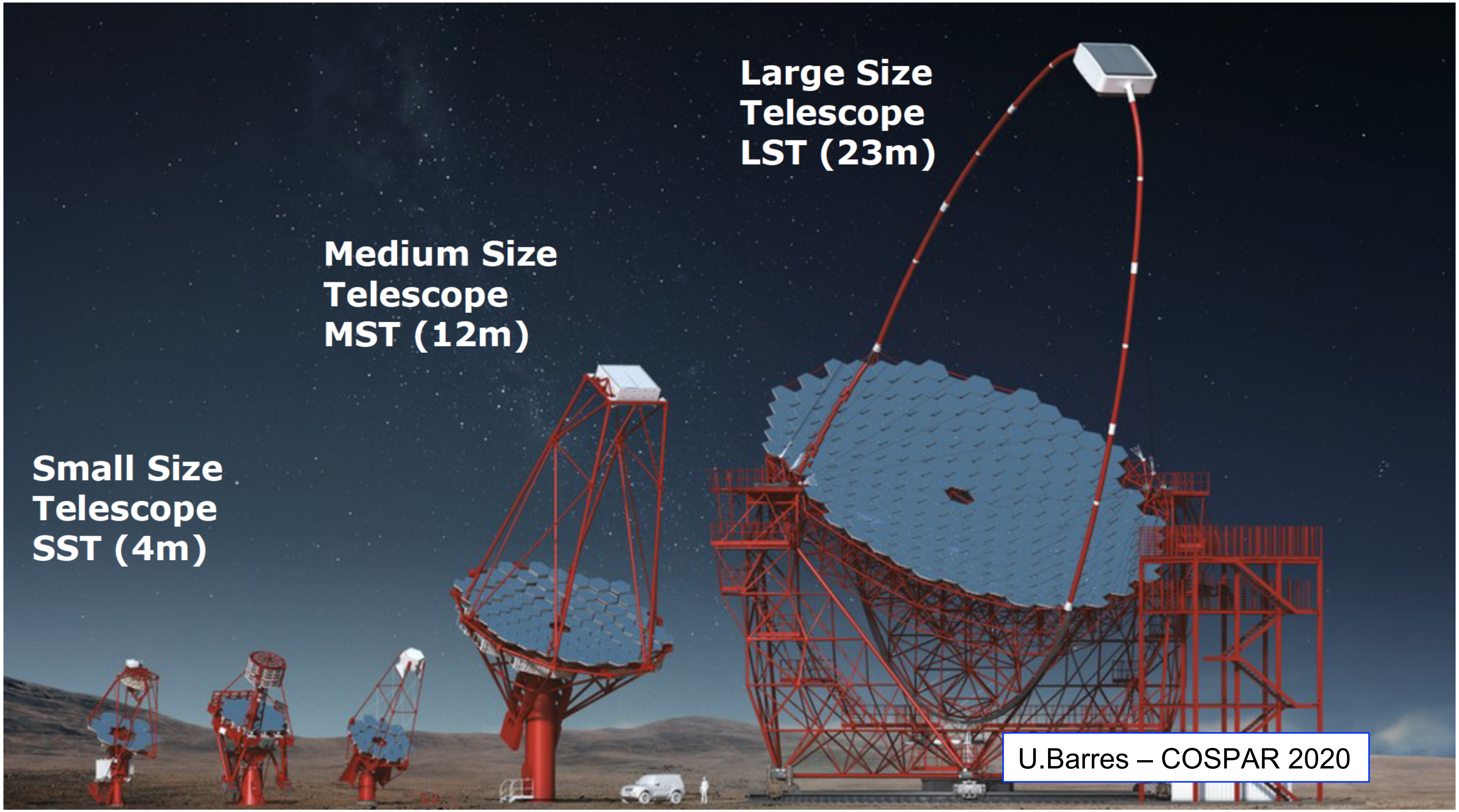
10% energy resolution

arcmin angular resolution



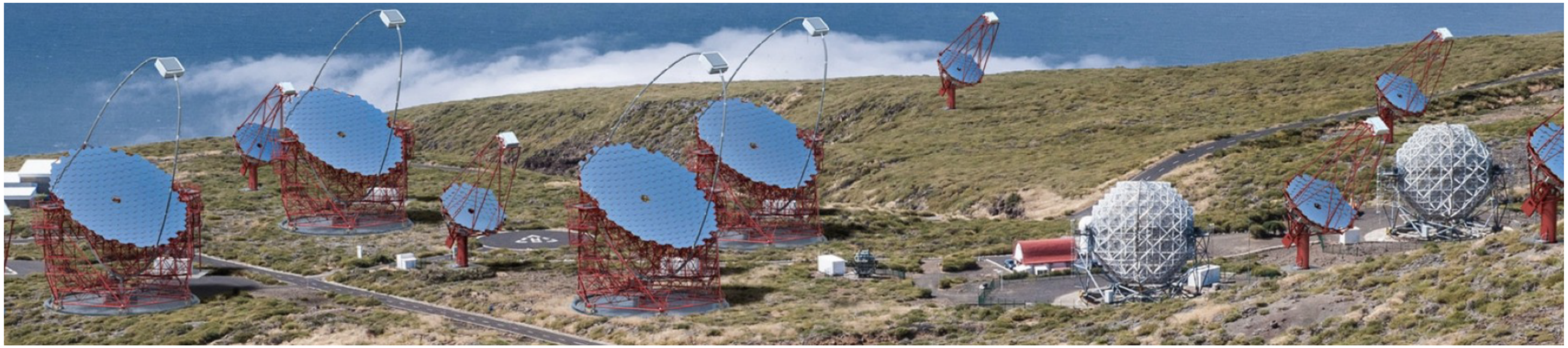
The CTA Telescopes

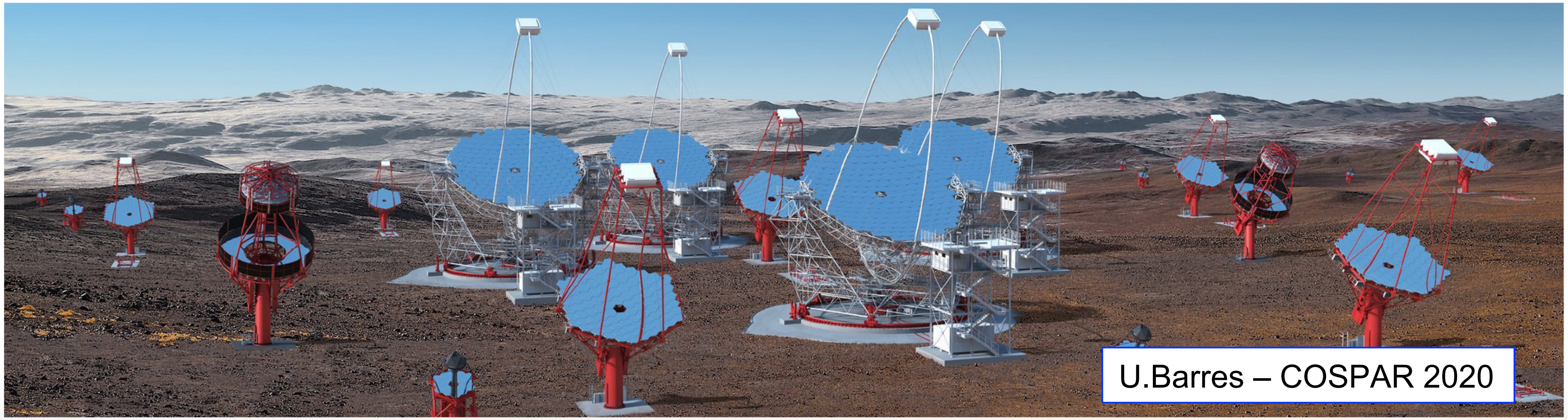
A Hybrid Observatory…



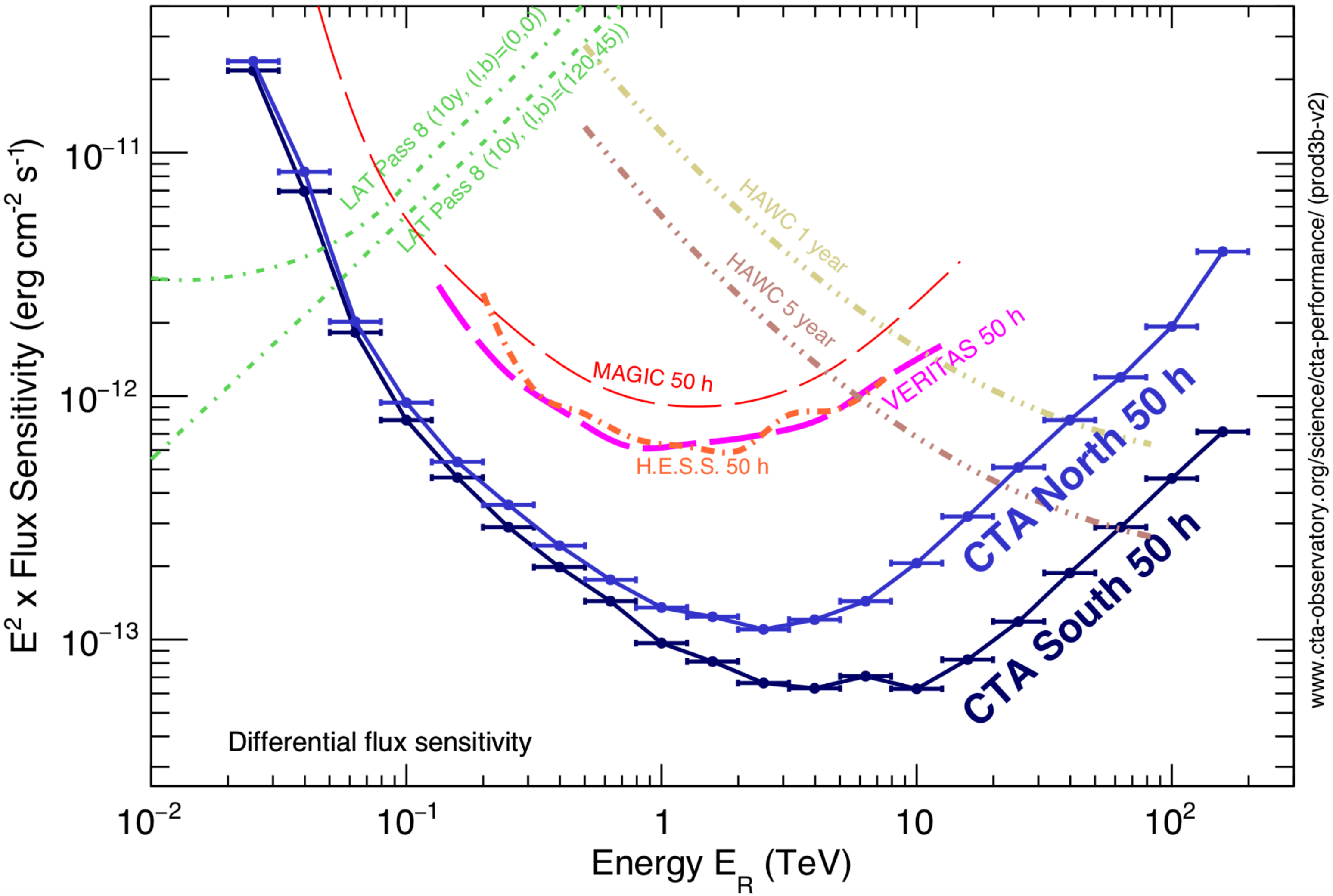
CTA North & CTA South

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

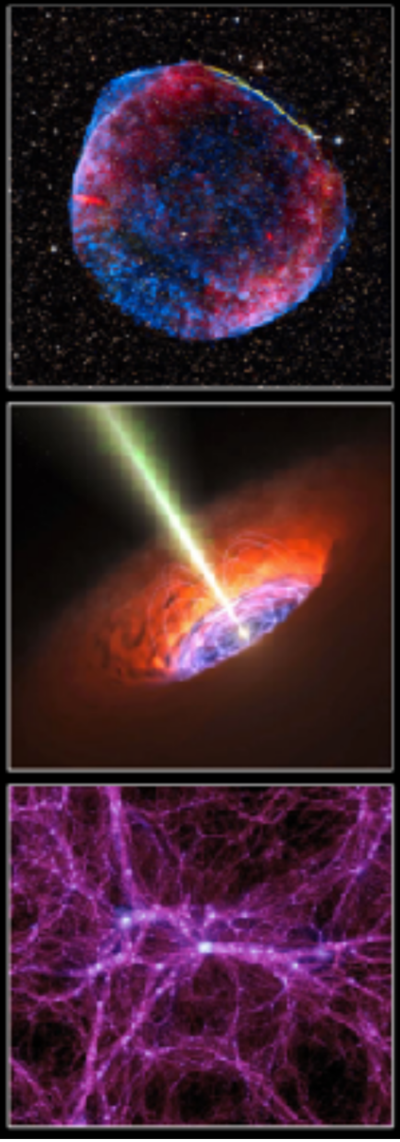




CTA performance



Astrophysics with IACTs



- **COSMIC PARTICLE ACCELERATION**

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

- **EXTREME ASTROPHYSICAL ENVIRONMENTS**

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

- **FUNDAMENTAL PHYSICS FRONTIERS**

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

U.Barres – COSPAR 2020

The Science of CTA

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

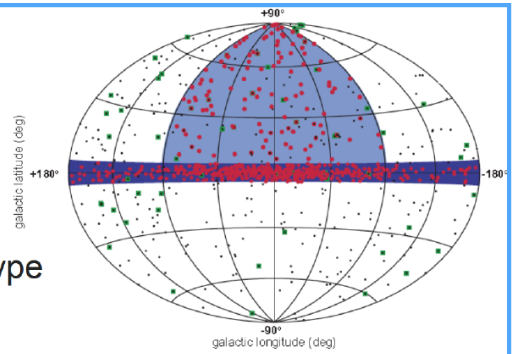
Monitoring of Variability notably of AGN

U.Barres – COSPAR 2020

CTA Surveys

The Key Science projects

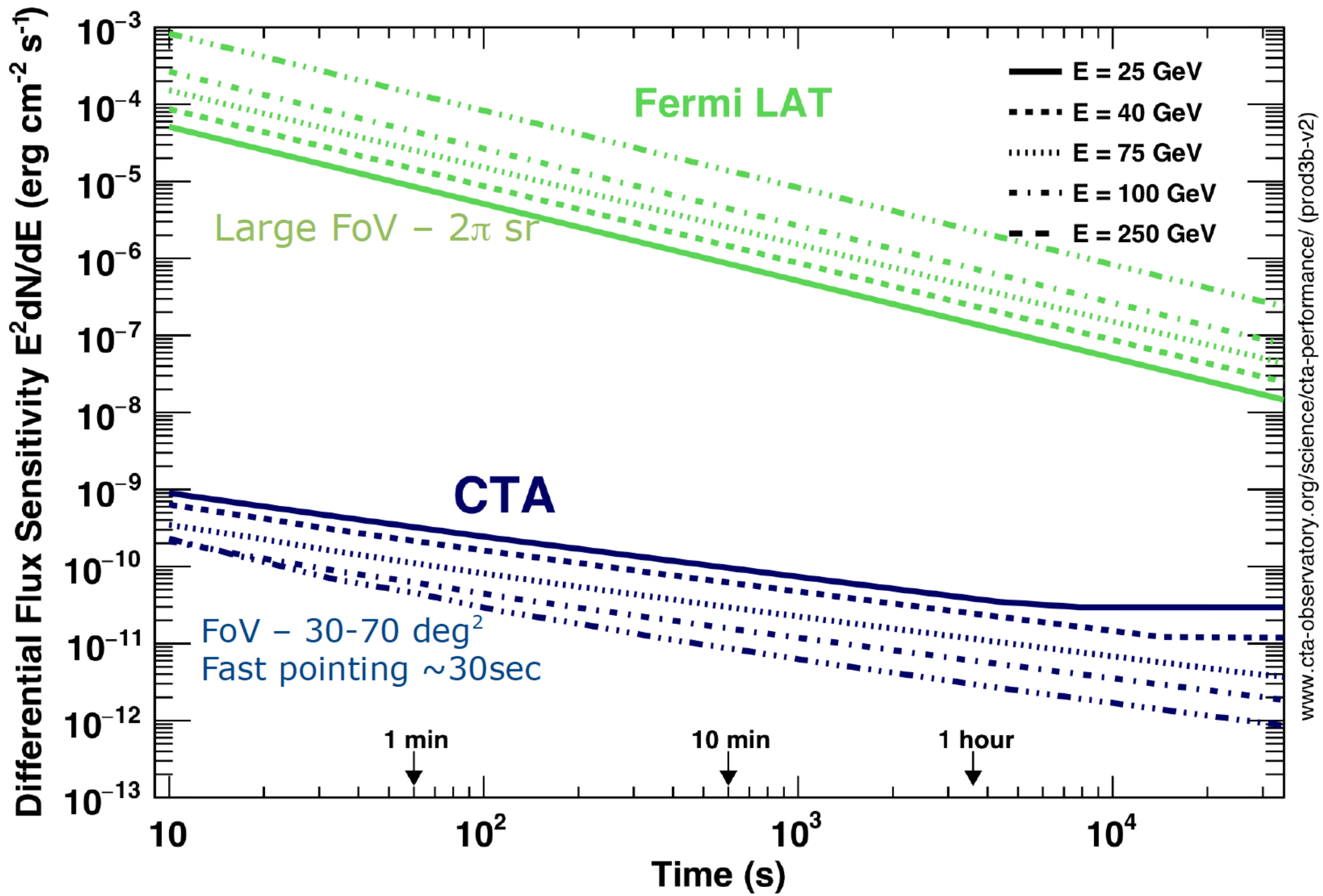
CTA surveys



- CTA will cover large portions of the sky
  - large telescope FoV: 4 - 10deg depending on telescope type
  - may be increased by divergent pointing
- important survey programs (Galactic + Extragalactic)
- input for the THESEUS Guest Observer program
  - joint MWL studies of interesting objects
- CTA will be triggering external observatories like THESEUS during all observations (surveys, pointed observations, etc.)
  - Trigger emission timescale: O(30s), i.e. much shorter than THESEUS reaction times

Transients & Variable Sources: CTA Sensitivity vs. Time

(CTA Collab 2019)

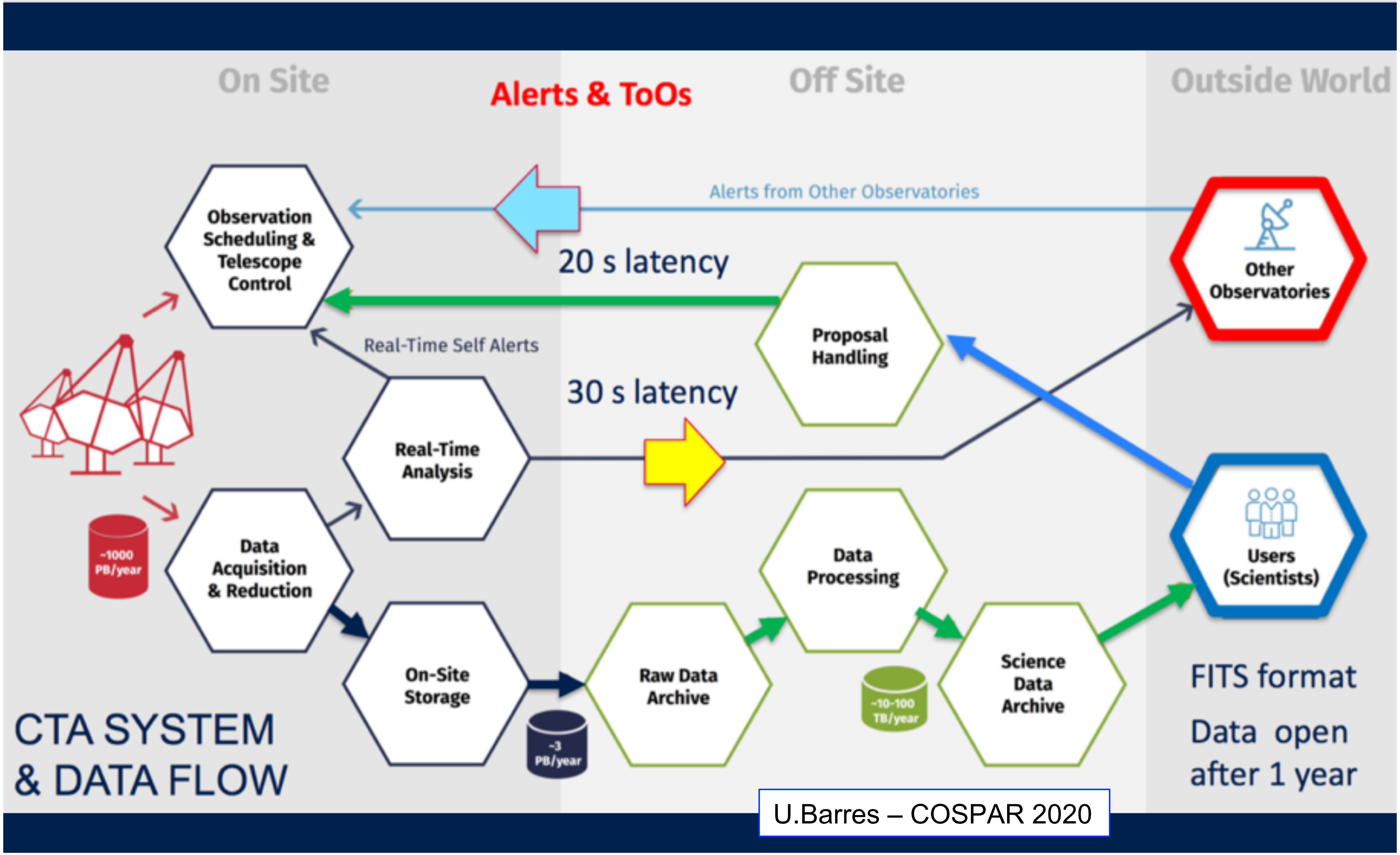


CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range

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

G. Rowell – COSPAR 2020

CTA Transients Science



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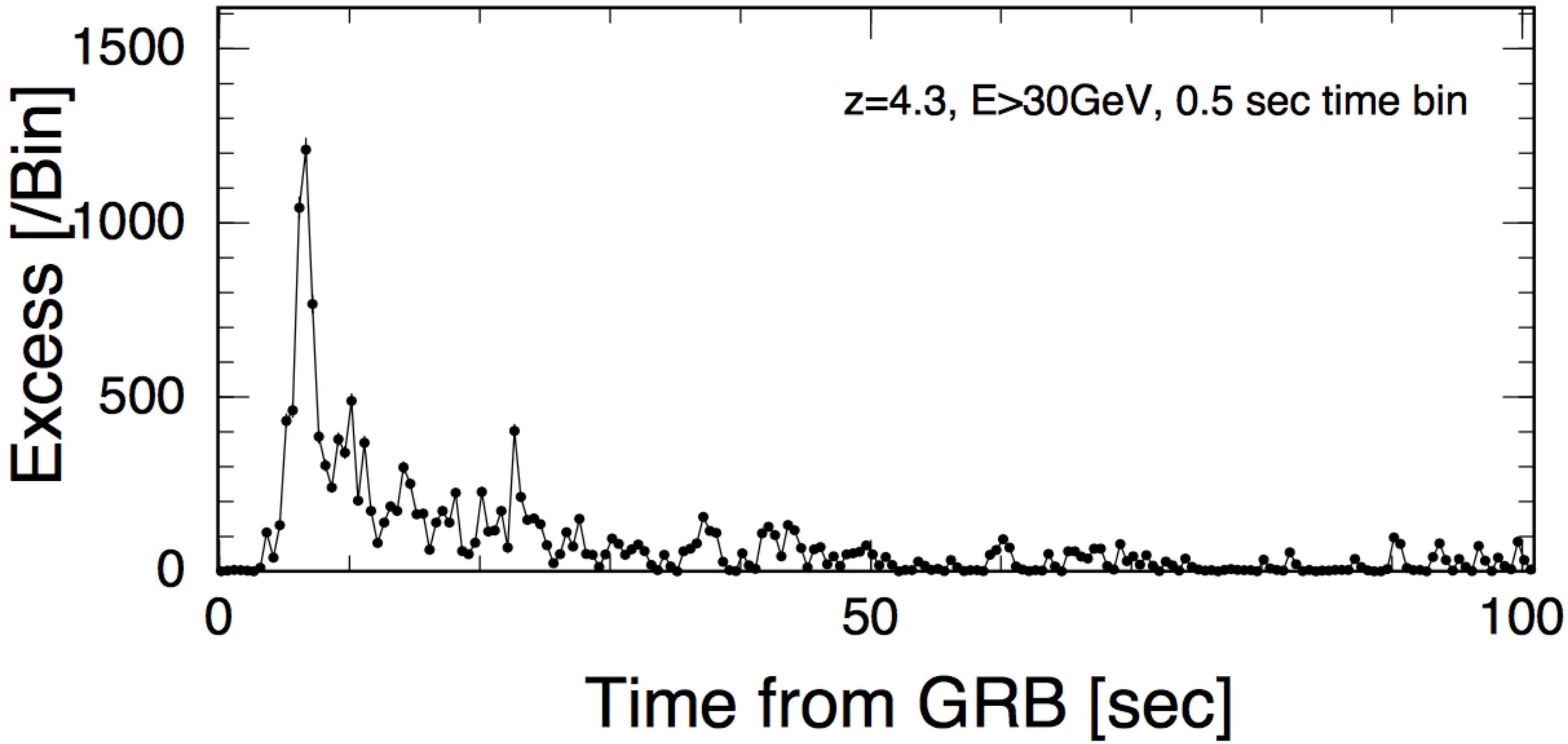
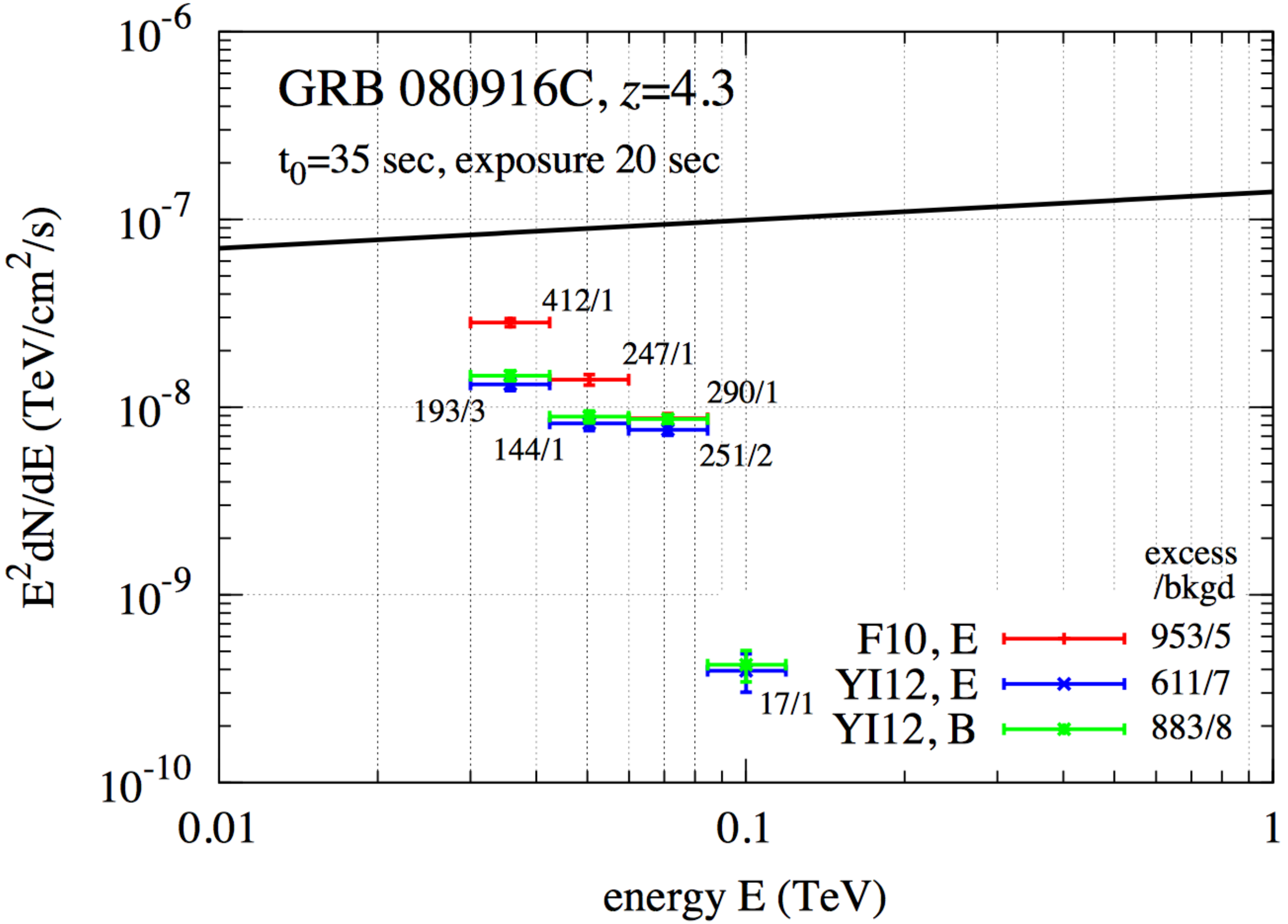
CTA and GRBs



Inoue et al (2013)

CTA and GRB



Inoue et al (2013)

CTA GRB Science

GRB with CTA

- Detailed study to assess the potential of the CTA GRB program
- Core input: GRB population by G. Ghirlanda et al.
  - Clear synergies with THESEUS study
  - Possible extension of the CTA internal study: derive the GRB parameter space accessible by joint CTA and THESEUS

Population synthesis codes
[cosmological short and long GRBs - calibrated on presently observed pops]

Prompt emission [Synchrotron + IC]

Afterglow emission [Synchrotron + IC]
[calibrated with multi-wavelength observations of GRB afterglows]

CTA (+THESEUS) detection
[Gammapy & Ctools]

M.G. Bernardini et al. (CTA), PoS(ICRC2019)598

CTA & Theseus GRB

GRBs with CTA & Theseus

- Theseus will serve as a GRB trigger provider to the world (and for CTA…)
  - A fraction (to be estimated) of the events triggered by Theseus followed and detected by CTA
  - The same approach used by Theseus (based on a population study) is used by CTA. Therefore the predictions on the synergies will be straightforward.
- An interesting case considering the larger detection rates of Theseus at any redshift compared to Swift
- Moreover, the softest energy range probed by the soft X-ray instrument (SXI) will uncover, at low redshift (where the EBL is not going to kill the flux) the soft and sub luminous population of GRBs.
  - It will be relevant to explore the sources and their emission with CTA.
  - The present detections, except 190829A, are all relatively normal-to-energetic GRBs.
  - Focus on the low redshift events.
  - CTA key points in providing a view of GRB in the TeV energy range.

X-rays and TeV connection

The variable absorption in the X-ray spectrum of GRB 190114C

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March 11, 2021

ABSTRACT

GRB 190114C was a bright burst that occurred in the local Universe ($z = 0.425$). It was the first gamma-ray burst (GRB) ever detected at TeV energies, thanks to MAGIC. We characterize the ambient medium properties of the host galaxy through the study of the absorbing X-ray column density. Joining *Swift*, *XMM-Newton*, and *NuSTAR* observations, we find that the GRB X-ray spectrum is characterized by a high column density that is well in excess of the expected Milky Way value and decreases, by a factor of ~ 2, around $\sim 10^5$ s. Such a variability is not common in GRBs. The most straightforward interpretation of the variability in terms of photoionization of the ambient medium is not able to account for the decrease at such late times, when the source flux is less intense. Instead, we interpret the decrease as due to a clumped absorber, denser along the line of sight and surrounded by lower-density gas. After the detection at TeV energies of GRB 190114C, two other GRBs were promptly detected. They share a high value of the intrinsic column density and there are hints for a decrease of the column density, too. We speculate that a high local column density might be a common ingredient for TeV-detected GRBs.

Key words. Gamma-ray burst: general – dust, extinction – Gamma-ray burst: individual: GRB 190114C

https://arxiv.org/abs/2103.05735

Conclusions

- CTA will usher in a new era in VHE Astrophysics
  - Rich science program answering many open questions
  - Large new discovery space
- The full exploitaiton of CTA science cases requires MWL/MM synergies

- CTA will be the first gamma-ray ground-based observatory, openly delivering data to the community

R.Zanin – TeVPa 2019

See you soon !!!