Gamma Ray Astrophysics Experiments

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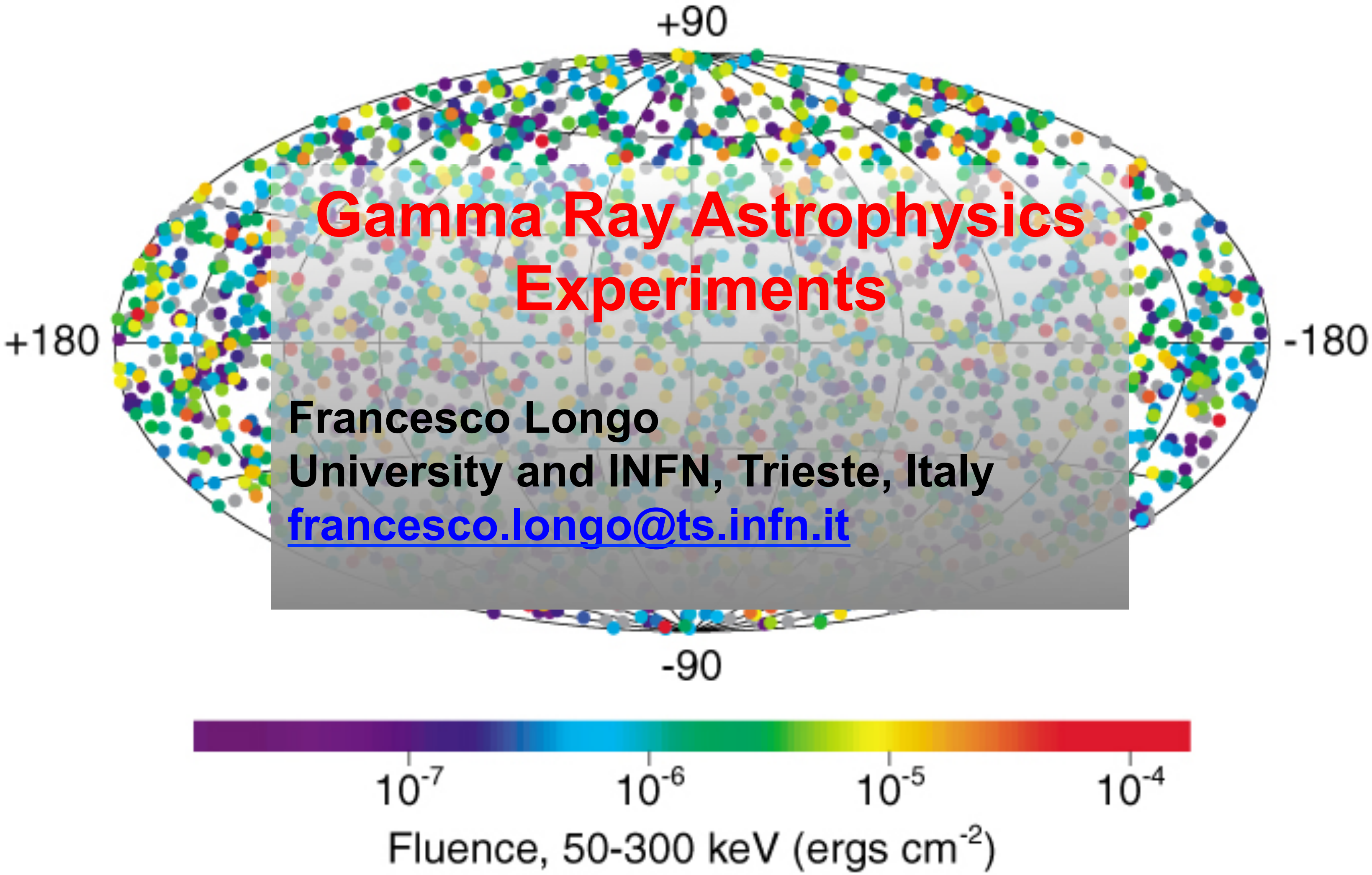
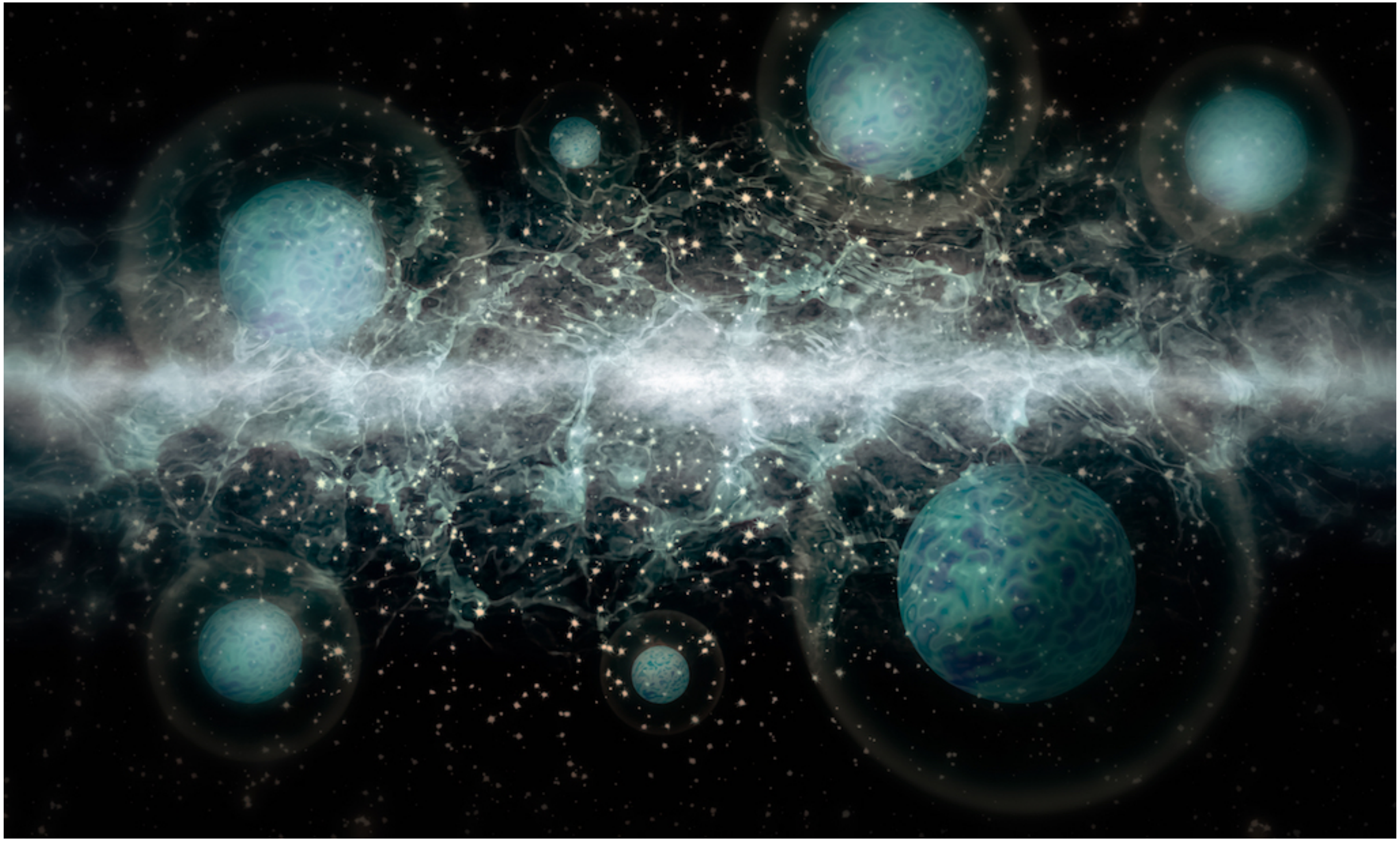
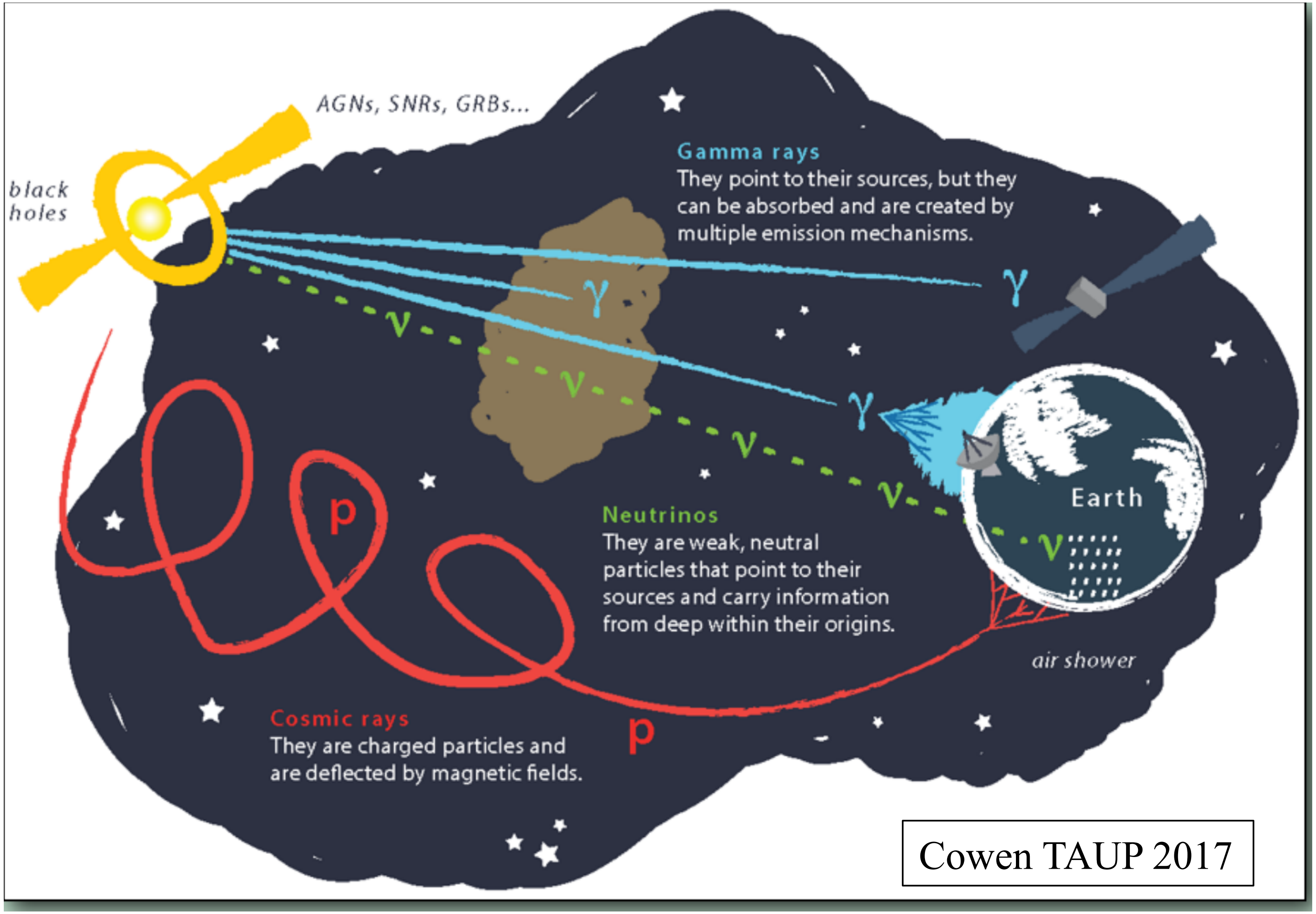


Quantum Gravity Phenomenology



Multimessenger Astrophysics



How to?

Tests of quantum gravity from observations of γ-ray bursts

G. Amelino-Camelia*†, John Ellis‡, N. E. Mavromatos*, D. V. Nanopoulos§ & Subir Sarkar*

The recent confirmation that at least some γ-ray bursts originate at cosmological distances[1–4] suggests that the radiation from them could be used to probe some of the fundamental laws of physics. Here we show that γ-ray bursts will be sensitive to an energy dispersion predicted by some approaches to quantum gravity. Many of the bursts have structure on relatively rapid timescales[5], which means that in principle it is possible to look for energy-dependent dispersion of the radiation, manifested in the arrival times of the photons, if several different energy bands are observed simultaneously. A simple estimate indicates that, because of their high energies and distant origin, observations of these bursts should be sensitive to a dispersion scale that is comparable to the Planck energy scale ($\sim 10^{19}$ GeV), which is sufficient to test theories of quantum gravity. Such observations are already possible using existing γ-ray burst detectors.

$$\Delta t \approx \xi \frac{E}{E_{QG}} \frac{L}{c}$$

Nature volume 393, pages763–765 (1998)

How to?

Pulsar radiation and quantum gravity

Philip Kaaret

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Abstract. Quantum gravity may lead to an energy dependence in the speed of light. The high energy radiation from gamma-ray pulsars can be used to place limits on such effects. We find that emission from the Crab pulsar at energies above 2 GeV trails that at 70–100 MeV by no more than 0.35 ms (95% confidence) and place a lower bound on the energy scale of quantum gravitational effects on the speed of light of 1.8×10^{15} GeV. This bound might be improved by two orders of magnitude by observation of pulsations from the Crab at higher energies, 50–100 GeV, in the near future.

Astronomy and Astrophysics, v.345, p.L32-L34 (1999)

How to?

Limits to Quantum Gravity Effects on Energy Dependence of the Speed of Light from Observations of TeV Flares in Active Galaxies

S. D. Biller,[1] A. C. Breslin,[2] J. Buckley,[3] M. Catanese,[4] M. Carson,[2] D. A. Carter-Lewis,[4] M. F. Cawley,[5] D. J. Fegan,[2] J. P. Finley,[6] J. A. Gaidos,[6] A. M. Hillas,[7] F. Krennrich,[4] R. C. Lamb,[8] R. Lessard,[6] C. Masterson,[2] J. E. McEnery,[9] B. McKernan,[2] P. Moriarty,[10] J. Quinn,[11] H. J. Rose,[7] F. Samuelson,[4] G. Sembroski,[6] P. Skelton,[7] and T. C. Weekes[11]

We have used data from a TeV γ-ray flare associated with the active galaxy Markarian 421 to place bounds on the possible energy dependence of the speed of light in the context of an effective quantum gravitational energy scale. Recent theoretical work suggests that such an energy scale could be less than the Planck mass and perhaps as low as 10^{16} GeV. The limits derived here indicate this energy scale to be in excess of 6×10^{16} GeV for at least one approach to quantum gravity in the context of D-brane string theory. To the best of our knowledge, this constitutes the first convincing limit on such phenomena in this energy regime.

Phys. Rev. Lett. 83, 2108, 1999

How to?

Invariance violation extends the cosmic ray horizon ?

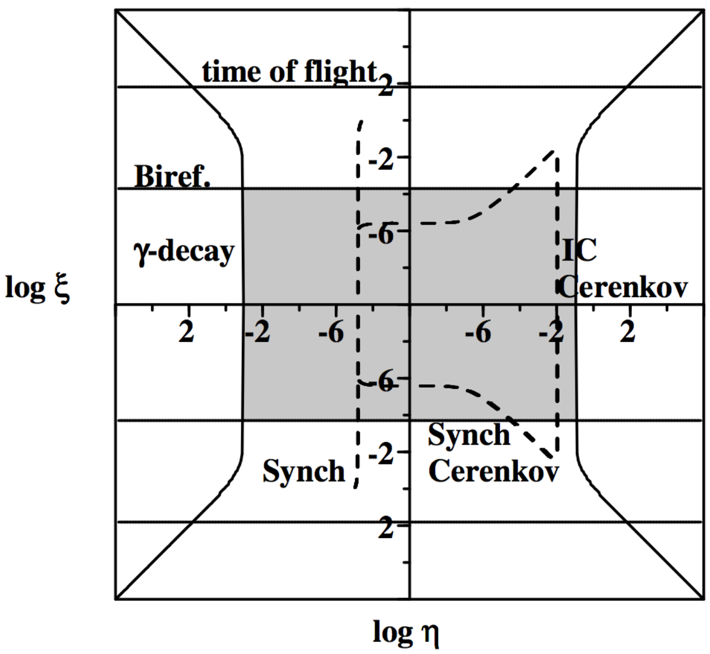
Tadashi Kifune

ABSTRACT

We postulate that the energy-momentum relation is modified for very high energy particles to violate Lorentz invariance and the speed of photon is changed from the light velocity c. The violation effect is amplified, in a sensitive way to detection, through the modified kinematical constraints on the conservation of energy and momentum, in the absorption process of γ-rays colliding against photons of longer wavelengths and converting into an electron-positron pair. For γ-rays of energies higher than 10^{13} eV, the minimum energy of the soft photons for the reaction and then the absorption mean free path of γ-rays are altered by orders of magnitude from the ones conventionally estimated. Consideration is similarly applied to high energy cosmic ray protons. The consequences may require the standard assumptions on the maximum distance that very high energy radiation can travel from to be revised.

Astrophys. J. Lett., 518 (1999), pp. L21-L24

How to?



Lorentz violation at high energy: concepts, phenomena and astrophysical constraints

Ted Jacobson [a], Stefano Liberati [b], David Mattingly [c]

Abstract

We consider here the possibility of quantum gravity induced violation of Lorentz symmetry (LV). Even if suppressed by the inverse Planck mass such LV can be tested by current experiments and astrophysical observations. We review the effective field theory approach to describing LV, the issue of naturalness, and many phenomena characteristic of LV. We discuss some of the current observational bounds on LV, focusing mostly on those from high energy astrophysics in the QED sector at order $E/M_{\rm Planck}$. In this context we present a number of new results which include the explicit computation of rates of the most relevant LV processes, the derivation of a new photon decay constraint, and modification of previous constraints taking proper account of the helicity dependence of the LV parameters implied by effective field theory.

Annals of Physics, Volume 321, Issue 1, p. 150-196. (2006)

How to?

Review

Quantum gravity phenomenology at the dawn of the multi-messenger era—A review

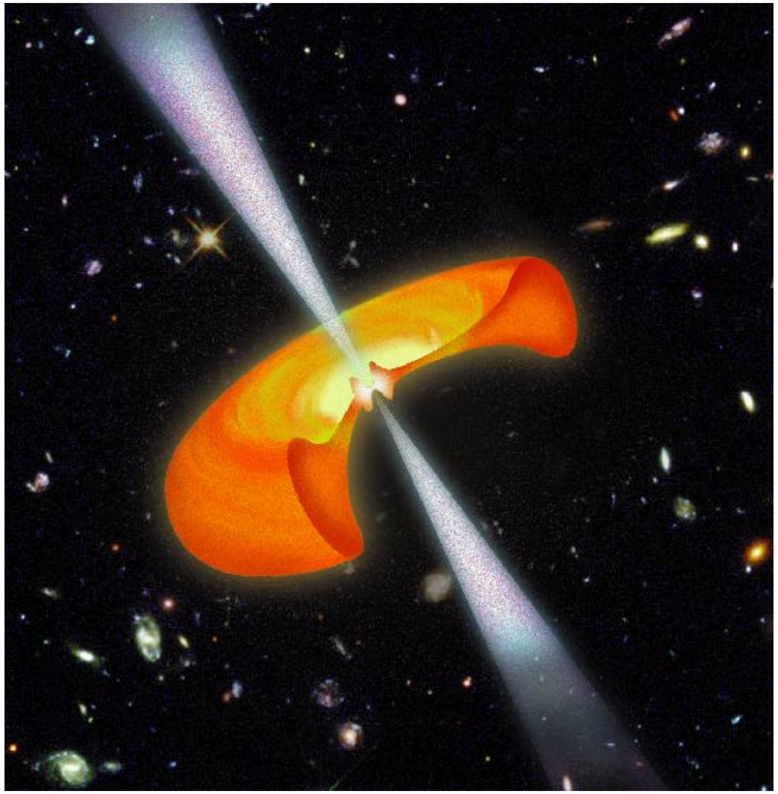
Progress in Particle and Nuclear Physics
Volume 125, July 2022, 103948

A B S T R A C T

The exploration of the universe has recently entered a new era thanks to the multi-messenger paradigm, characterized by a continuous increase in the quantity and quality of experimental data that is obtained by the detection of the various cosmic messengers (photons, neutrinos, cosmic rays and gravitational waves) from numerous origins. They give us information about their sources in the universe and the properties of the intergalactic medium. Moreover, multi-messenger astronomy opens up the possibility to search for phenomenological signatures of quantum gravity. On the one hand, the most energetic events allow us to test our physical theories at energy regimes which are not directly accessible in accelerators; on the other hand, tiny effects in the propagation of very high energy particles could be amplified by cosmological distances. After decades of merely theoretical investigations, the possibility of obtaining phenomenological indications of Planck-scale effects is a revolutionary step in the quest for a quantum theory of gravity, but it requires cooperation between different communities of physicists (both theoretical and experimental). This review, prepared within the COST Action CA18108 "Quantum gravity phenomenology in the multi-messenger approach", is aimed at promoting this cooperation by giving a state-of-the art account of the interdisciplinary expertise that is needed in the effective search of quantum gravity footprints in the production, propagation and detection of cosmic messengers.

Outline

- HE and VHE gamma astrophysics
  - Introduction to Gamma Astrophysics
  - Few Science Topics
  - Experiment types
- MeV Gamma Ray experiments
  - BATSE - Swift/BAT - Fermi GBM – AGILE/MCAL
  - GRB physics
  - eASTROGAM - HERMES
- GeV Gamma Ray experiments
  - AGILE/GRID – Fermi/LAT
  - PSR physics
- TeV gamma Astrophysics
  - MAGIC, HESS, VERITAS
  - HAWC – LHAASO
  - AGN physics
  - CTAO – SWGO
- Quantum Gravity searches (just a sample…)
  - GRB , PSR, AGN …
  - Other channels ? What about polarimetry -- IXPE?



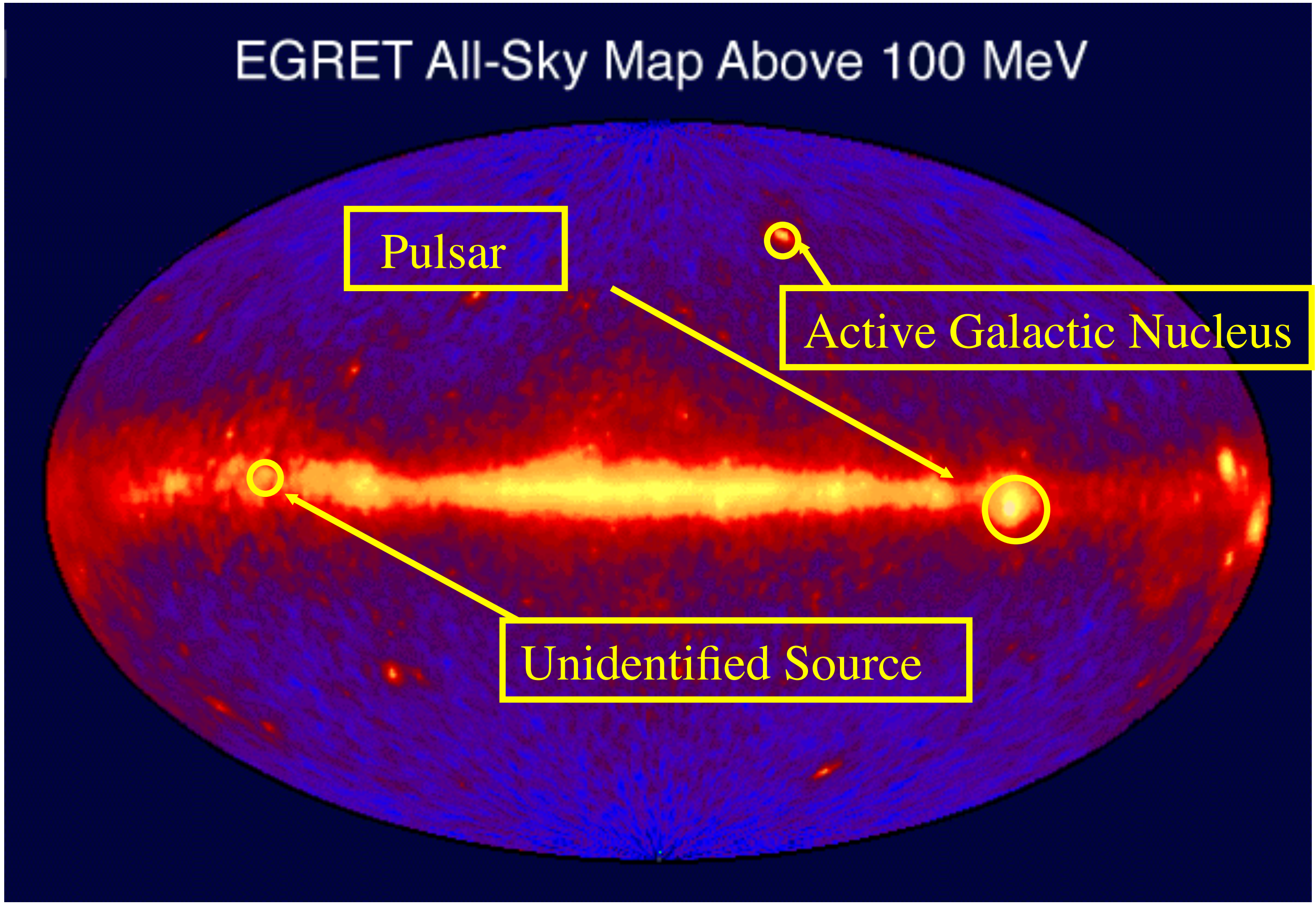
Take home messages

If dispersion were to be detected it would need to be present in a wide variety of sources to be sure it was due to LIV.

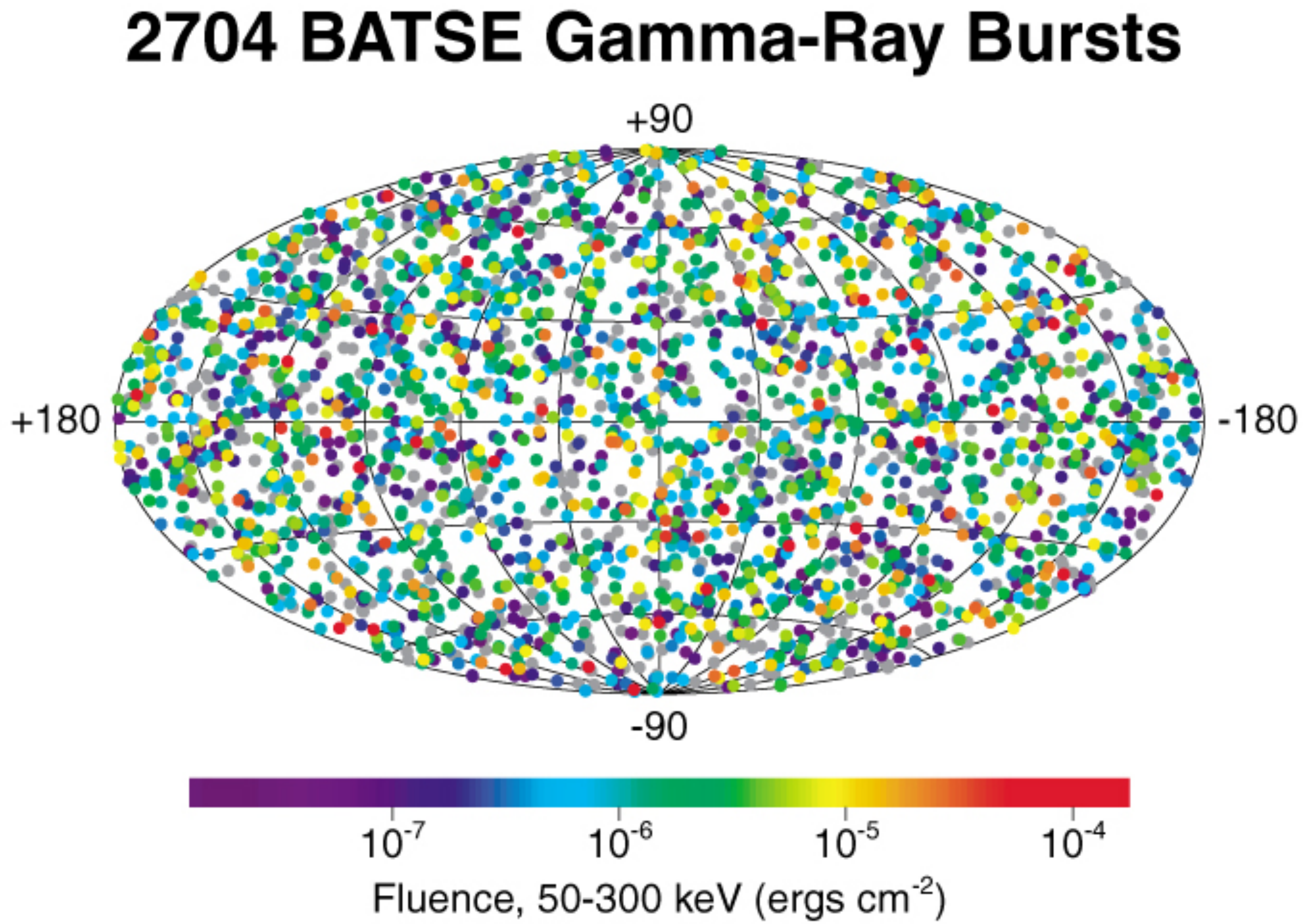
object	fast	far	High Energy	comments
GRBs	Y	Y	GeV	serendipity required
AGN flares	Y	N	TeV	still serendipitous, but know where to look
AGN Monitoring	N	Y	TeV	good redshift coverage
gamma-ray horizon	N	-	TeV++	hard spectrum AGN required
pulsars	Y	N	?	better for higher order effects

Daniel – NOW 2014

HE Gamma Astrophysics

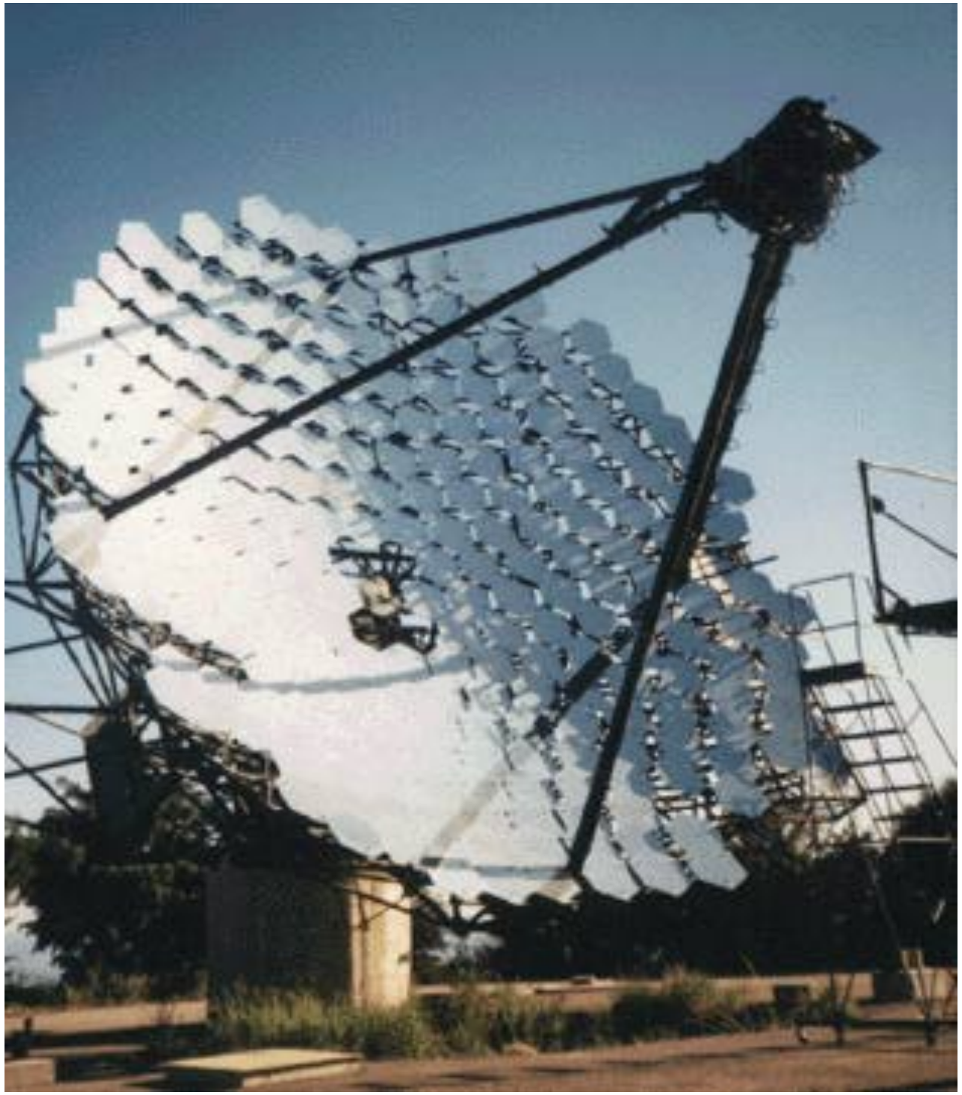


HE Gamma Astrophysics



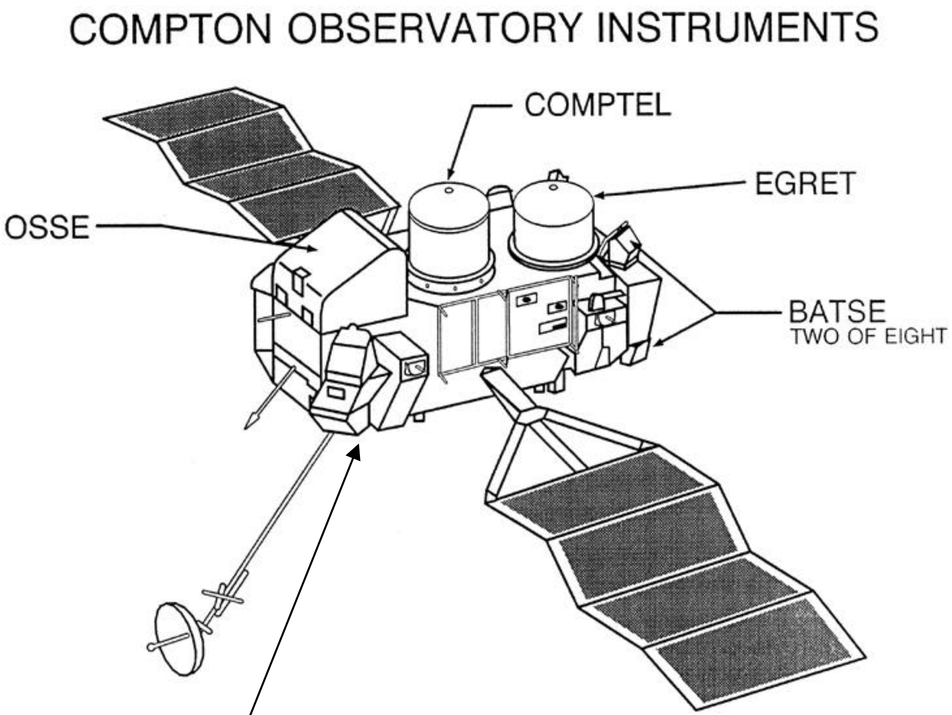
HE Gamma-ray Telescopes

VHE Gamma-ray telescopes



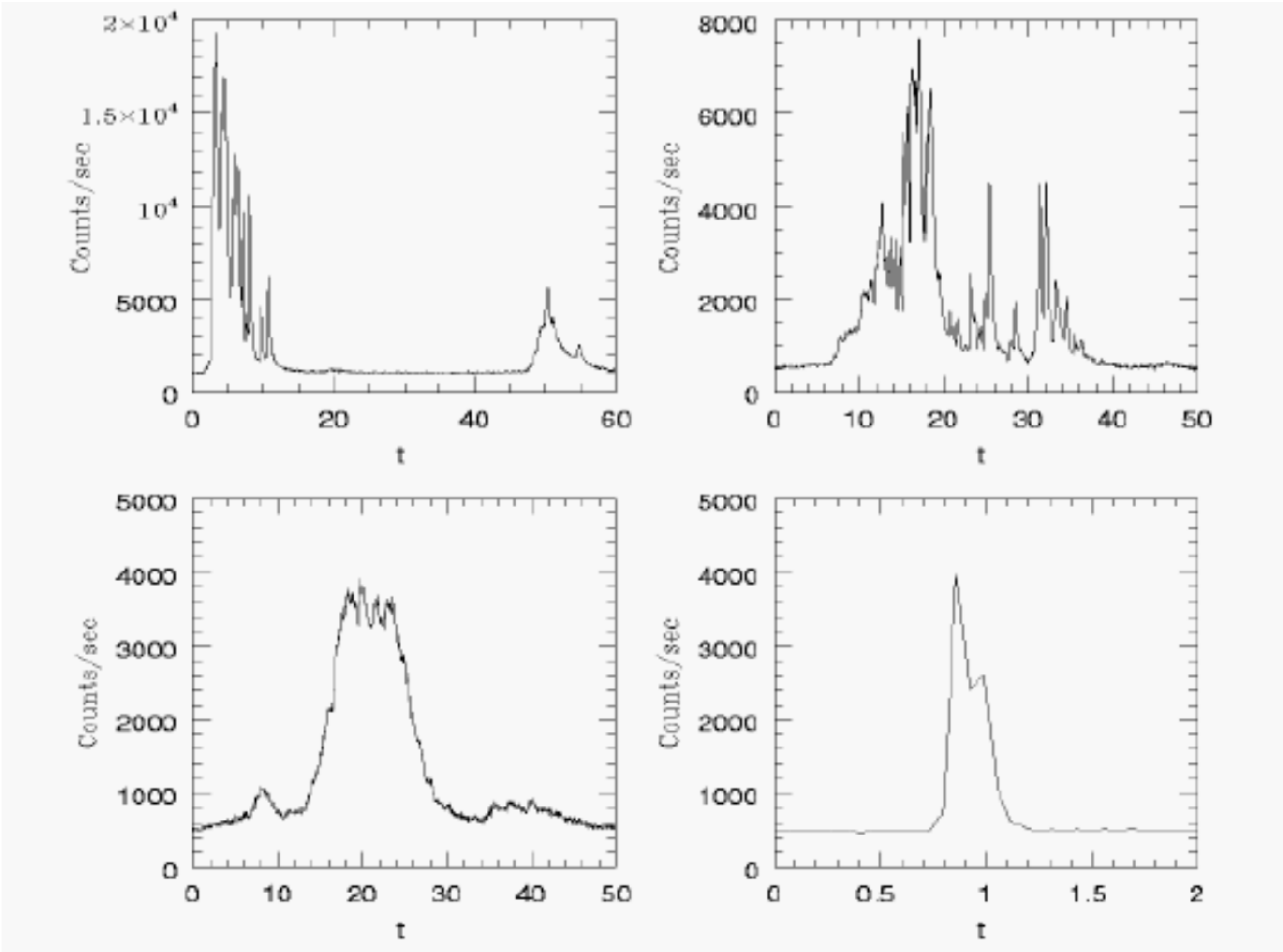
keV/MeV Gamma Ray Astrophysics

CGRO-BATSE (1991-2000)



CGRO/BATSE (25 keV÷10 MeV)

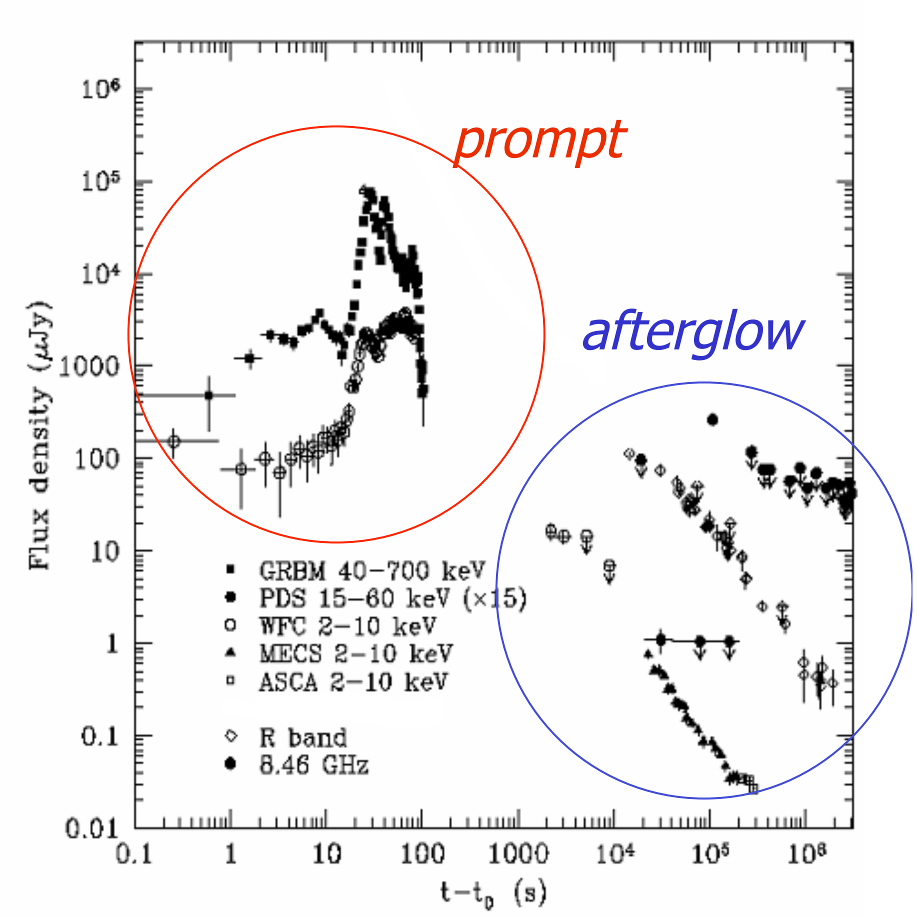
GRB light curves



The GRB phenomenon

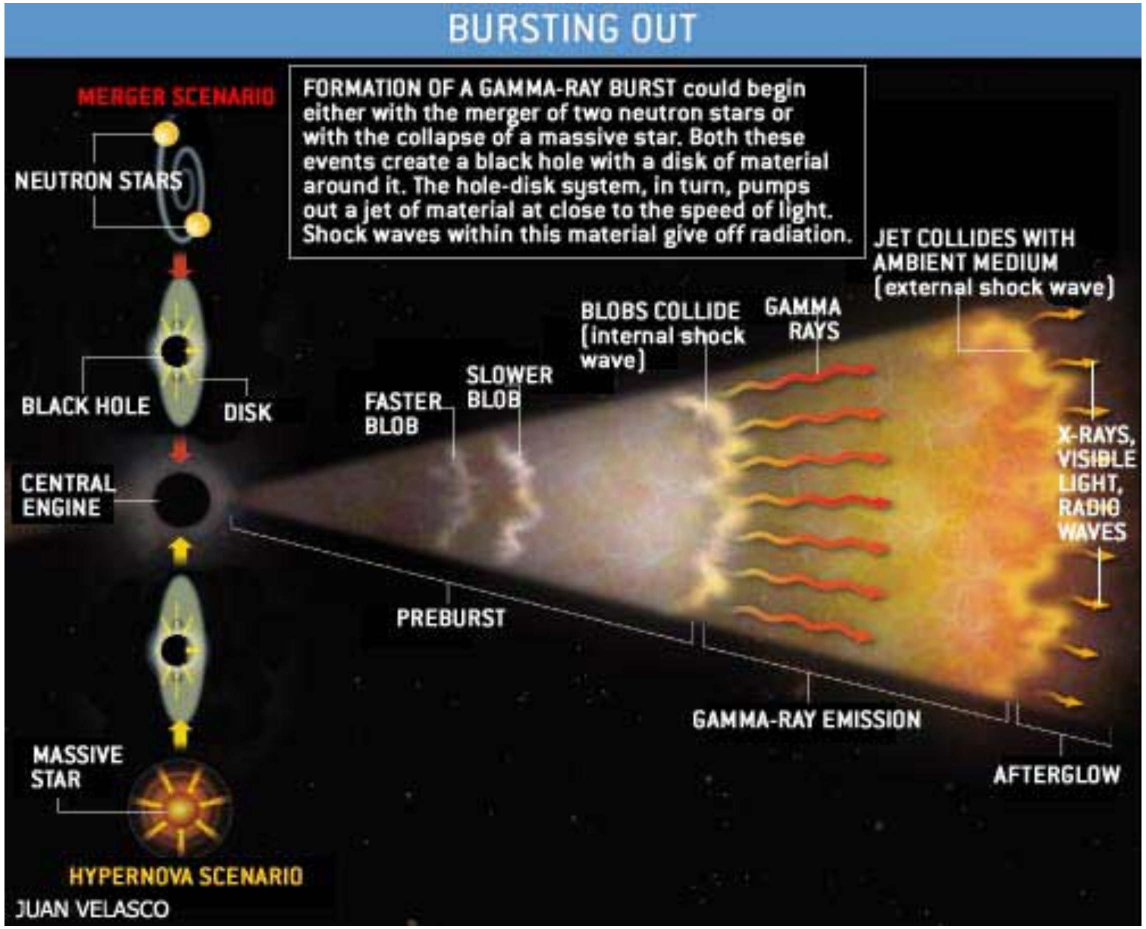
- in 1997, thanks to BeppoSAX observations, discovery of fading X-ray, optical, radio emission following the GRB

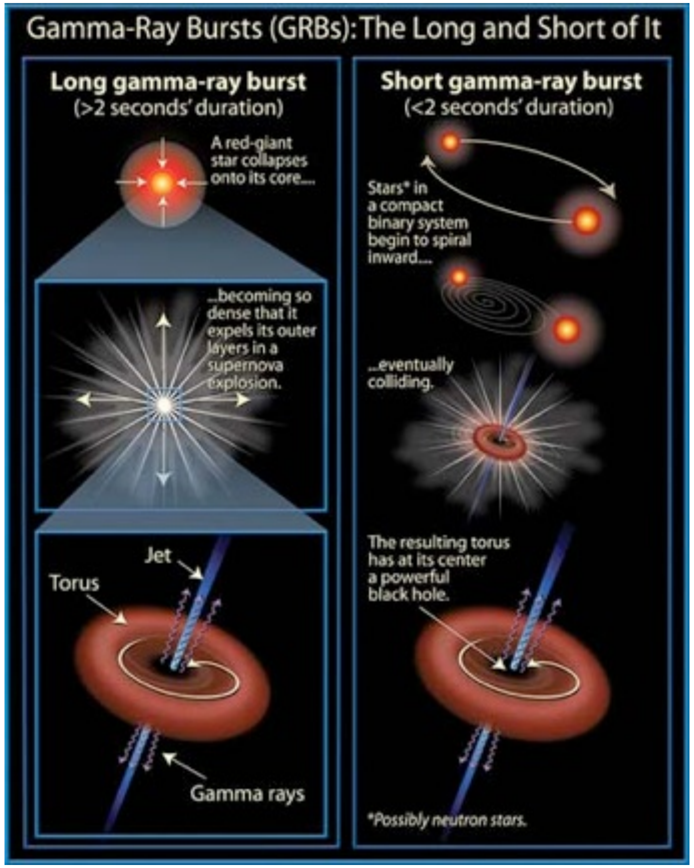
- photons received during the classical GRB phenomenon are then called "prompt emission" and the subsequent fading emission is called "afterglow emission"



Adapted from Maiorano et al., A&A, 2005

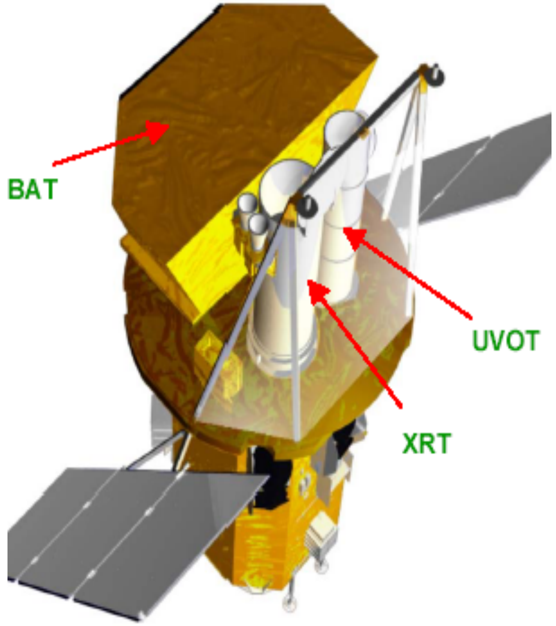
Gamma-ray Bursts





Adding pieces to the puzzle

- **Swift**: NASA mission dedicated to GRB studies launched 20 Nov. 2004 USA / Italy / UK consortium

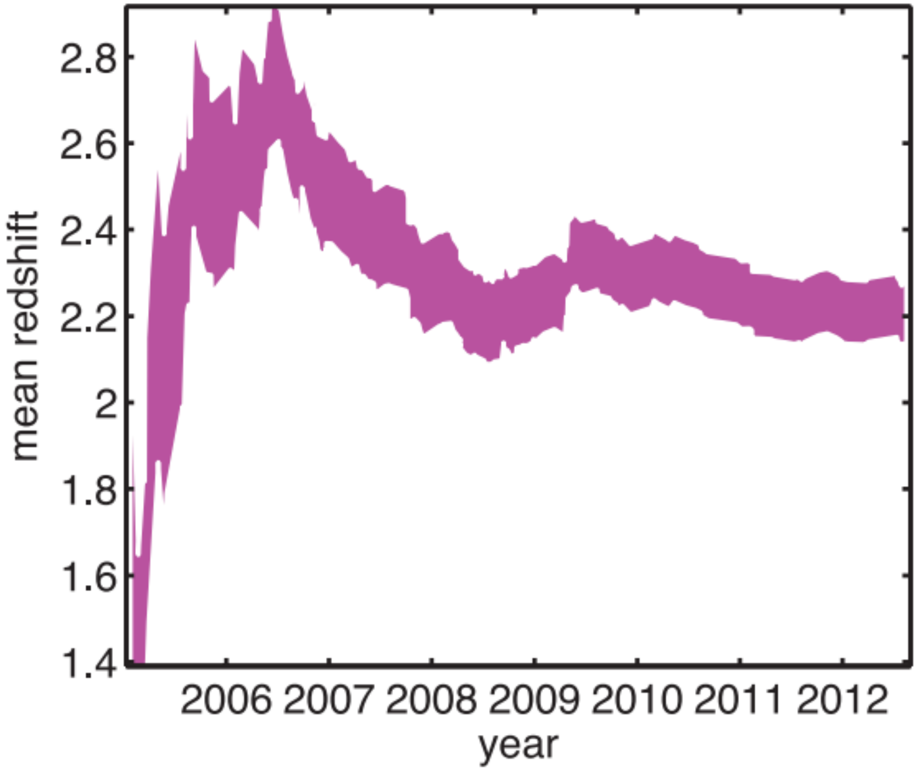


➢ main goals: afterglow onset, connection prompt-afterglow, substantially increase of conunterparts detection at all wavelengths (and thus of redshift estimates)

➢ payload: BAT (CZT+coded mask, 15-350 keV, wide FOV, arcmin ang. res.), XRT (X-ray optics, 0.3-10 keV, arcsec ang.res.), UVOT (sub-arcsec ang.res. mag 24 in 1000 s)

➢ spacecraft: automatic slew to target source in ~1 - 2 min.

Swift redshift distribution



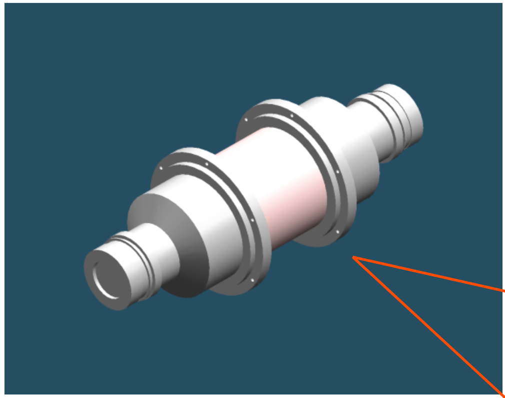
Coward et al. 2013

Towards the High z Universe
with Swift!

Record:
Z = 9.4 !!

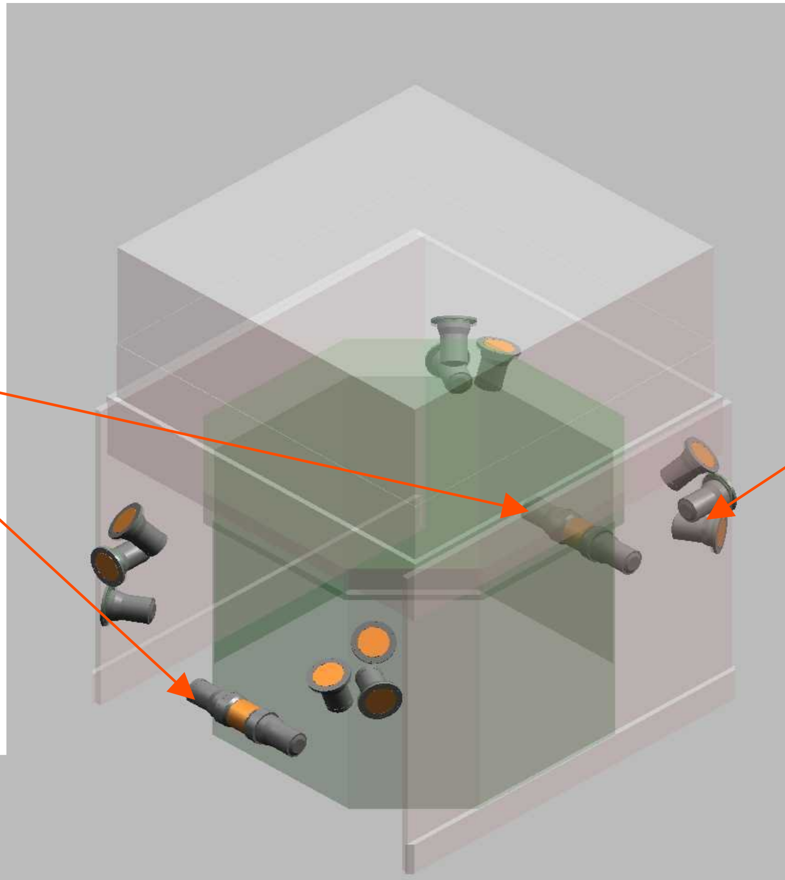
GBM Detectors

Bismuth Germanate (BGO) Scintillation Detector

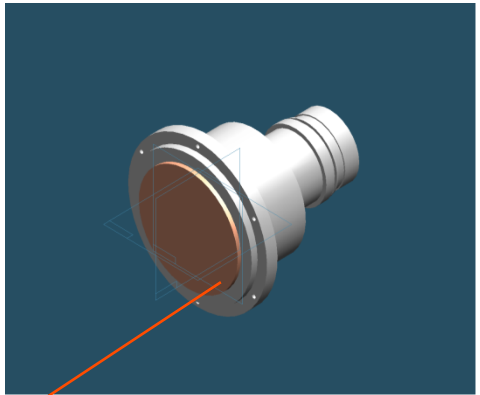


Major Purpose

- Provide high-energy spectral coverage (150 keV – 25 MeV) to overlap LAT range over a wide FoV



(12) Sodium Iodide (NaI) Scintillation Detectors



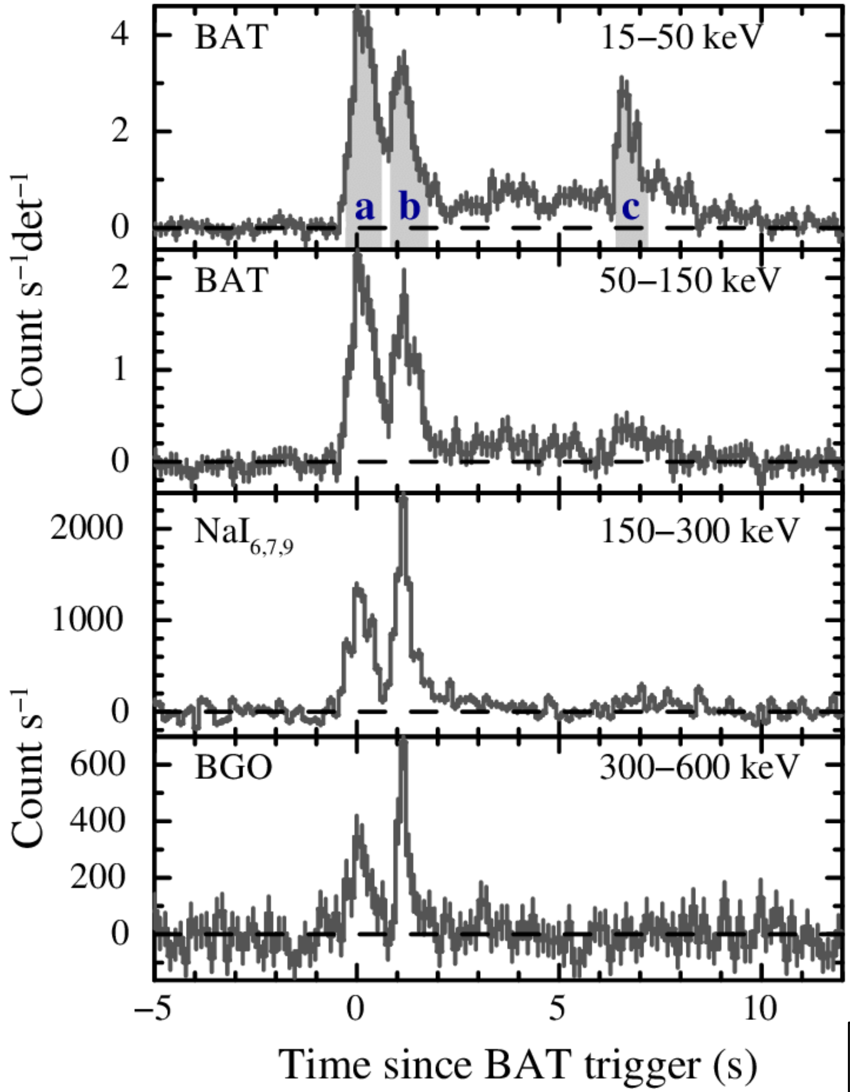
Major Purposes

- Provide low-energy spectral coverage in the typical GRB energy regime over a wide FoV (10 keV – 1 MeV)
- Provide rough burst locations over a wide FoV

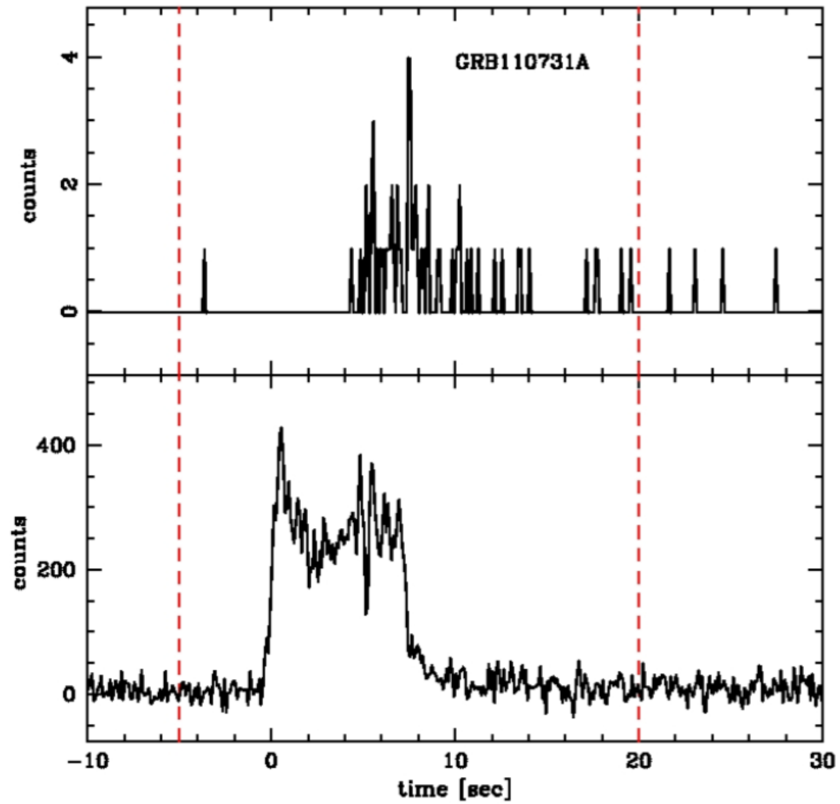
Provides spectra for GRB from 10 keV to 30 MeV.

Provides wide sky coverage (8 sr), enables autonomous repoints to allow for high energy afterglow observations with the LAT.

GBM light curves

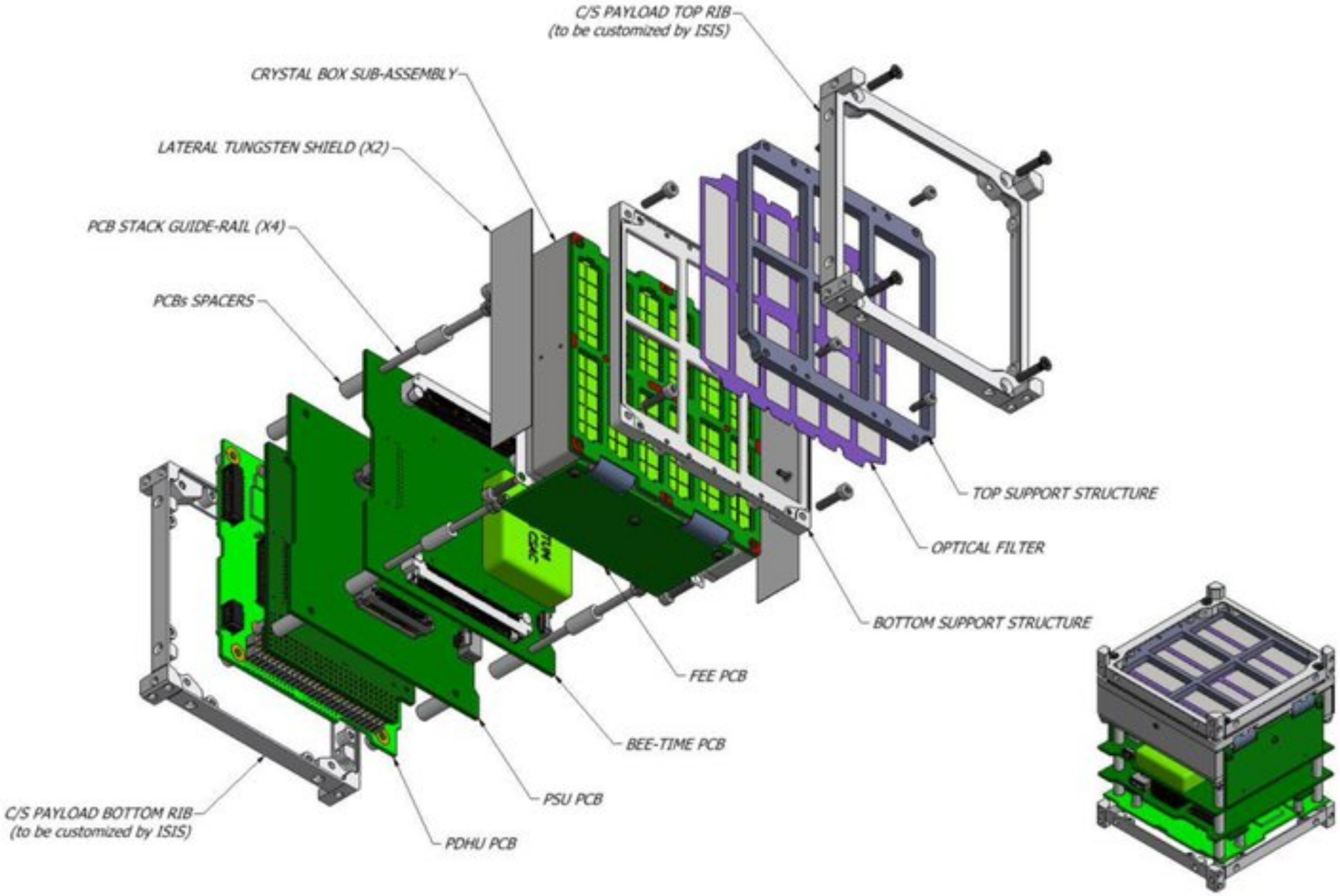


Troja et al 2012

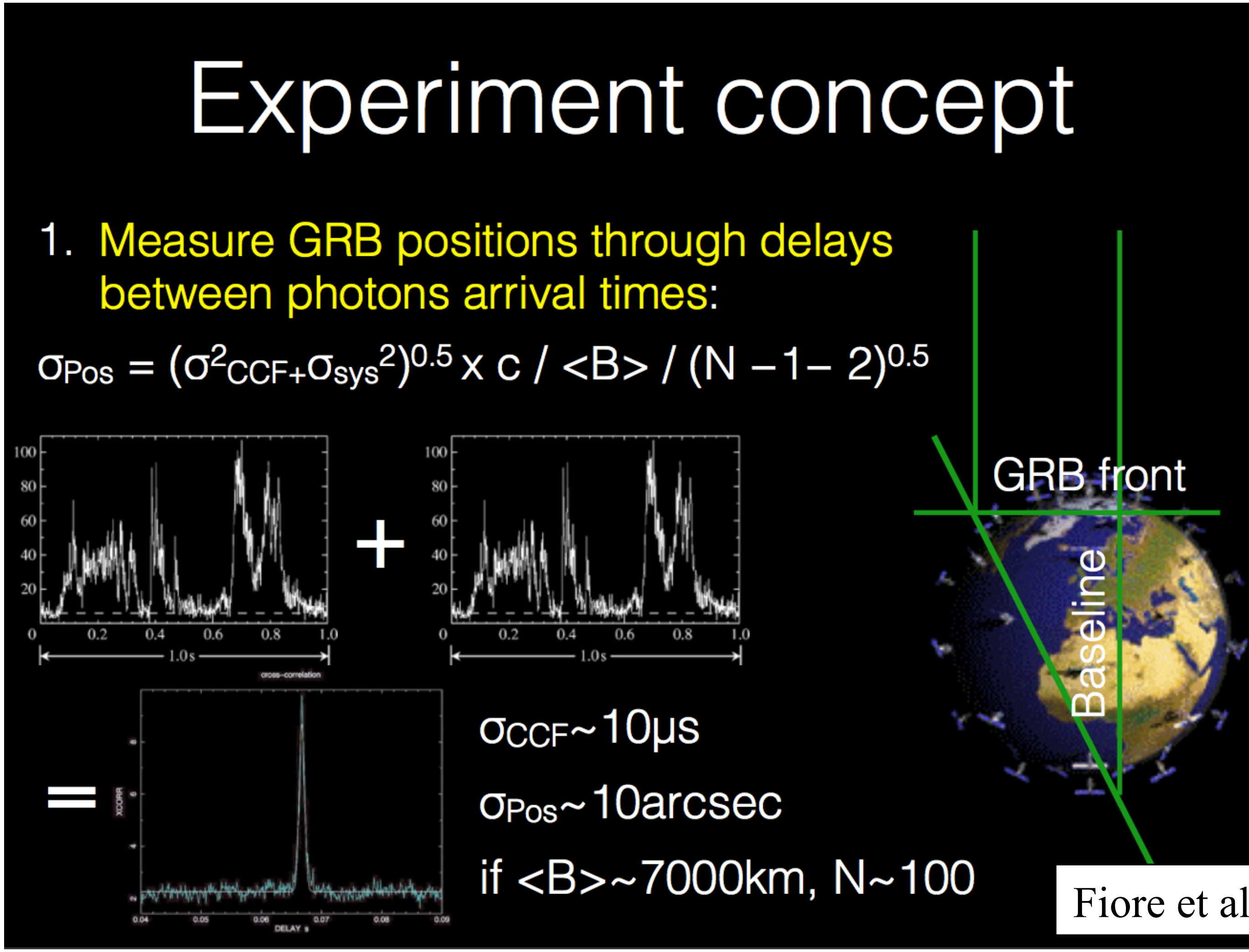


Castignani et al 2014

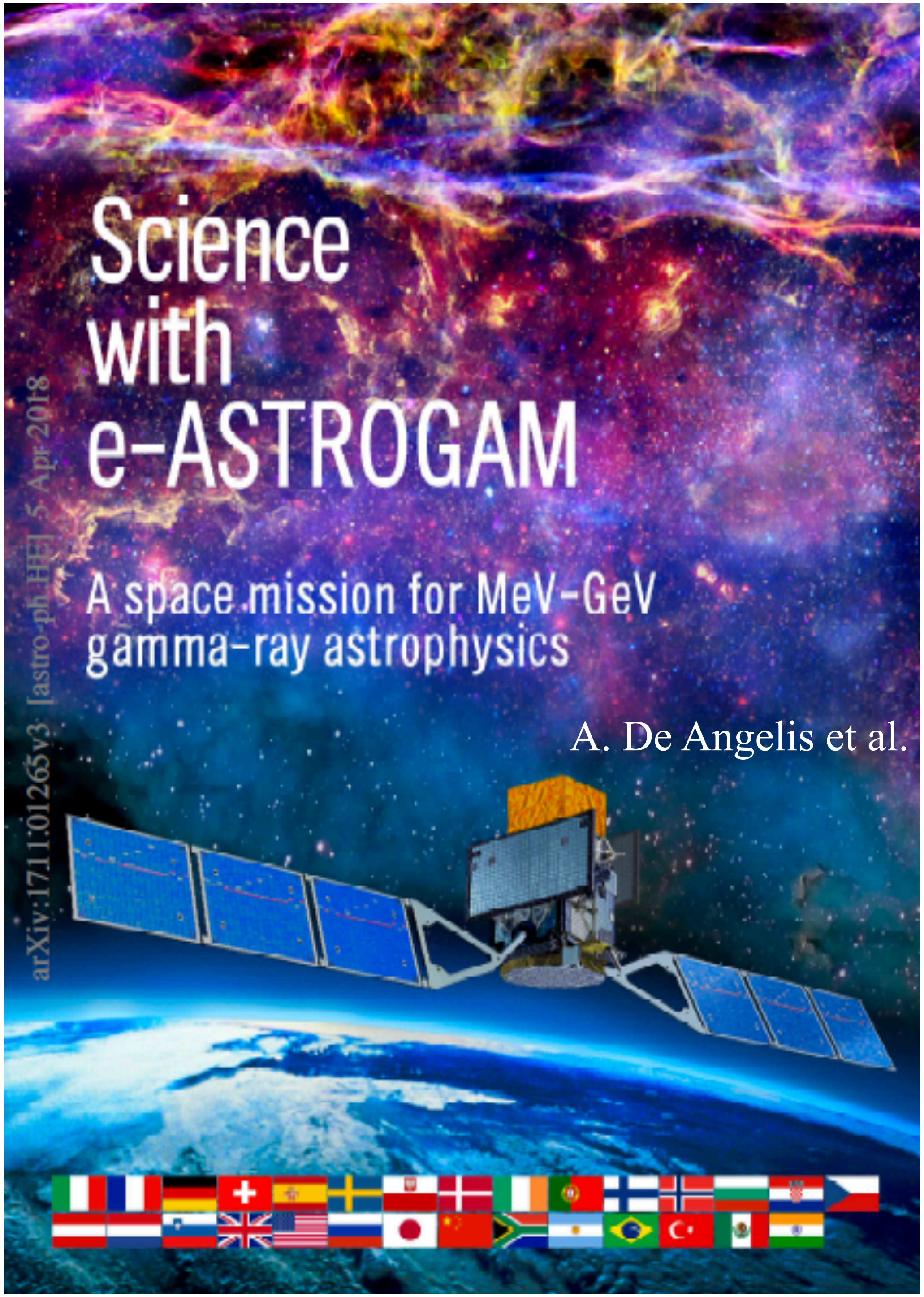
HERMES


C/S PAYLOAD TOP RIB (to be customized by ISIS)
CRYSTAL BOX SUB-ASSEMBLY
LATERAL TUNGSTEN SHIELD (X2)
PCB STACK GUIDE-RAIL (X4)
PCBs SPACERS
TOP SUPPORT STRUCTURE
OPTICAL FILTER
BOTTOM SUPPORT STRUCTURE
FEE PCB
BEE-TIME PCB
PSU PCB
PDHU PCB
C/S PAYLOAD BOTTOM RIB (to be customized by ISIS)

HERMES



Fiore et al. 2019



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G. Zaharijaš,[148] L. Zampieri,[2] S. Zane,[149] S. Zimmer,[150,13] A. Zoglauer,[151] and the e-ASTROGAM collaboration

White Book published in arXiv/JHEAP
Wide interest from the scientific community

https://arxiv.org/abs/1711.01265
JHEAP, 2018, 19, 1-106

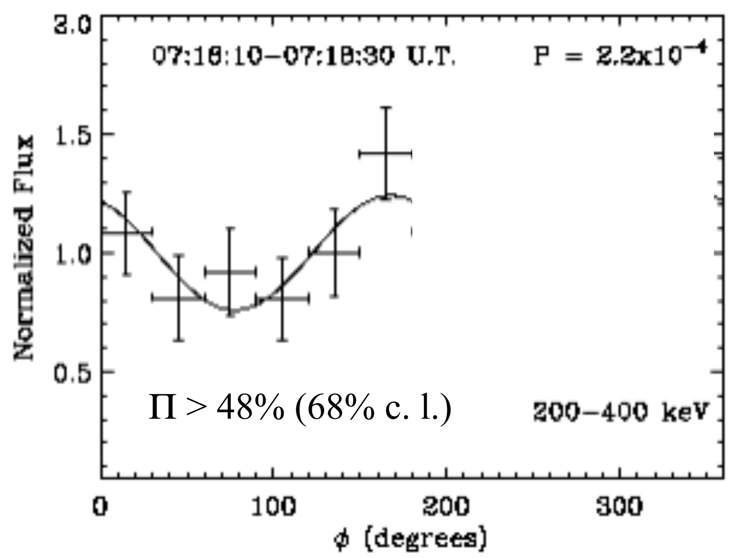
Gamma-ray polarization

- γ-ray polarization in **objects emitting jets** (GRBs, Blazars, X-ray binaries) or with **strong magnetic field** (pulsars, magnetars) ⇒ magnetization and content (hadrons, leptons, Poynting flux) of the outflows + radiation processes

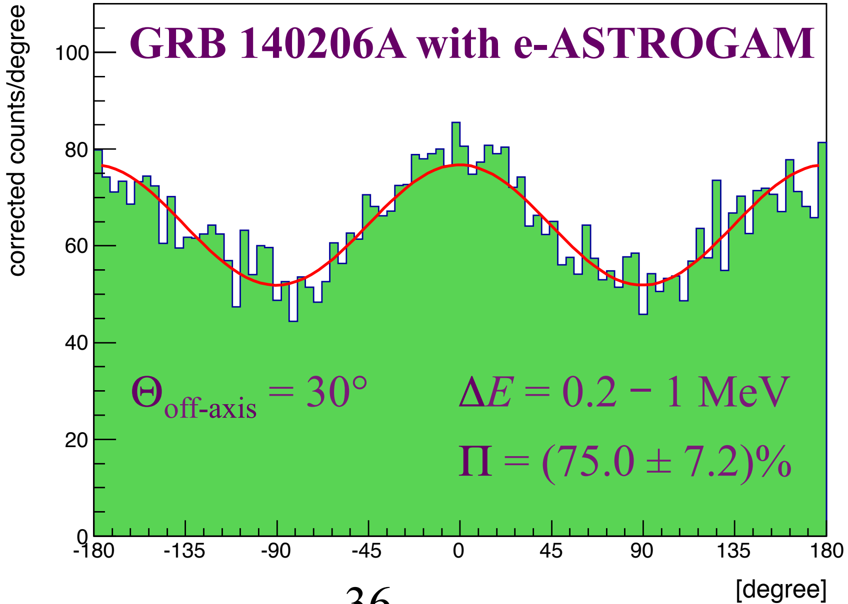
- γ-ray polarization from **cosmological sources** (GRBs, Blazars) ⇒ fundamental questions of physics related to Lorentz Invariance Violation (vacuum birefringence)

✓ e-ASTROGAM will measure the γ-ray polarization of ~ **200 GRBs per year** (promising candidates for highly γ-ray polarized sources)

INTEGRAL/IBIS – GRB 140206A (z = 2.74)



Götz et al. (2014)

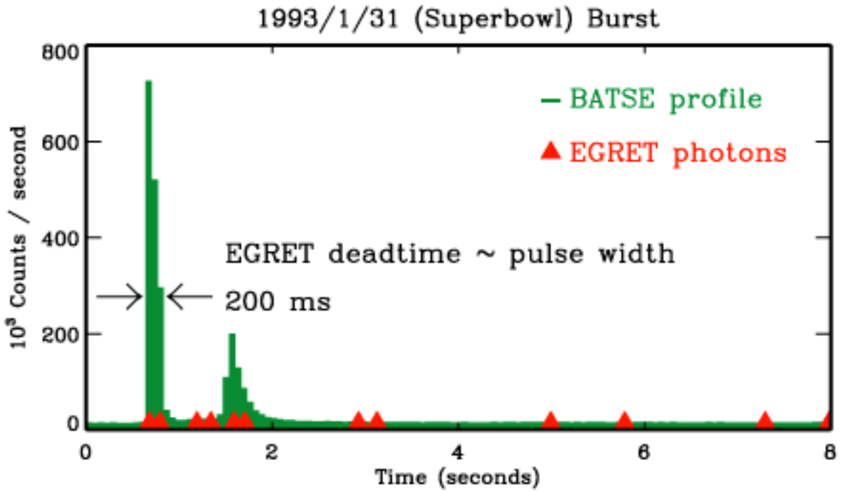


GeV Gamma-ray Astrophysics

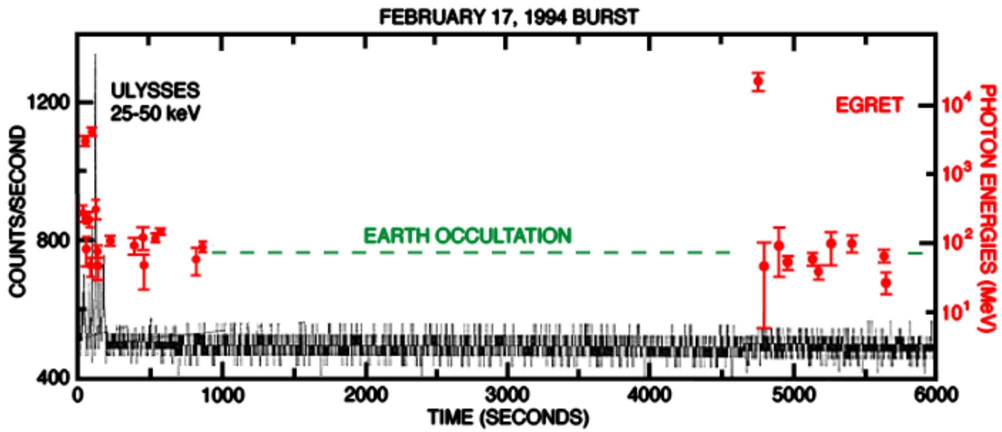
GRB physics

- **Fast timing for gamma-ray detection in prompt phase. High energy photons**

Prompt Emission (GRB 930131)

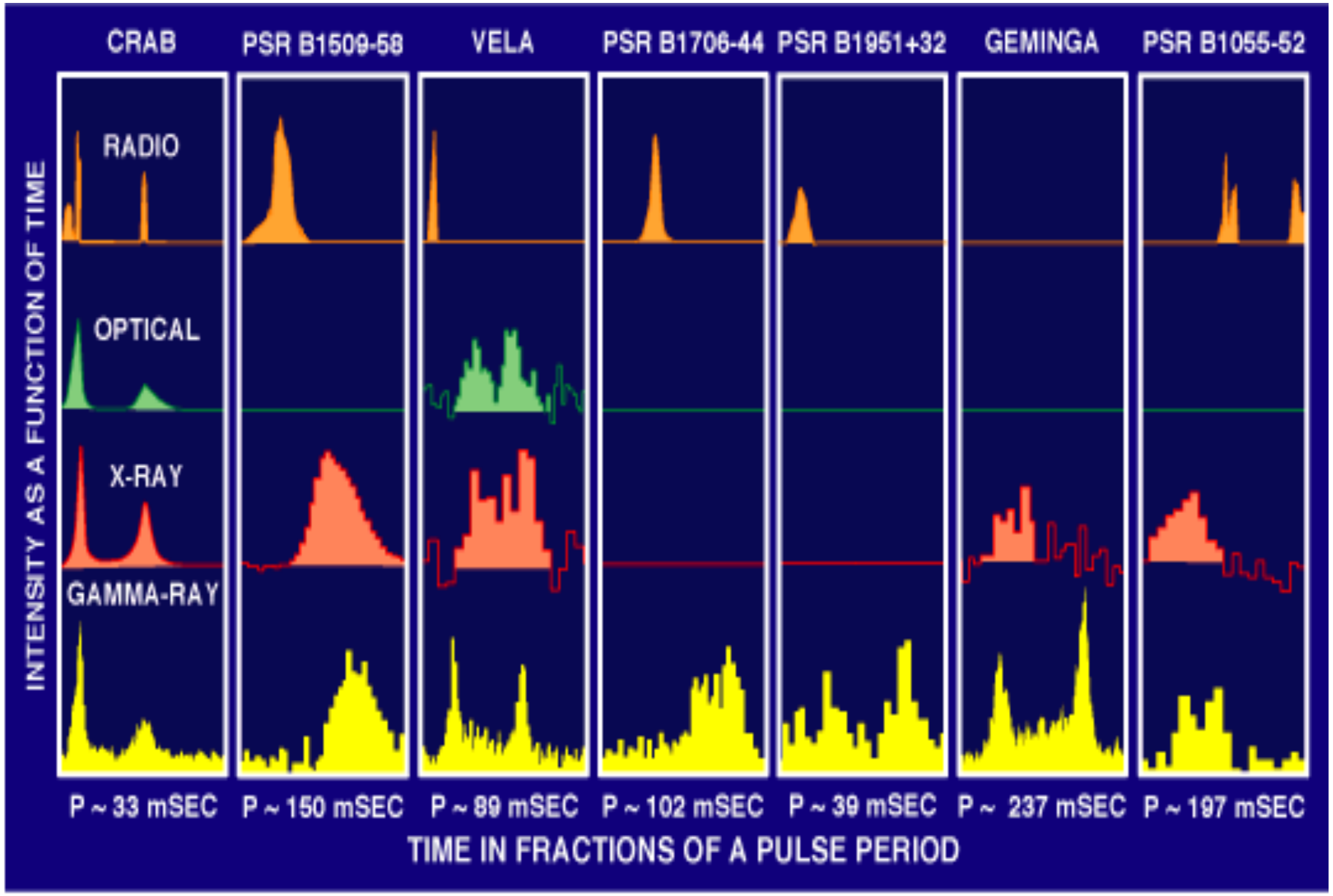


Delayed Emission (GRB 940217)

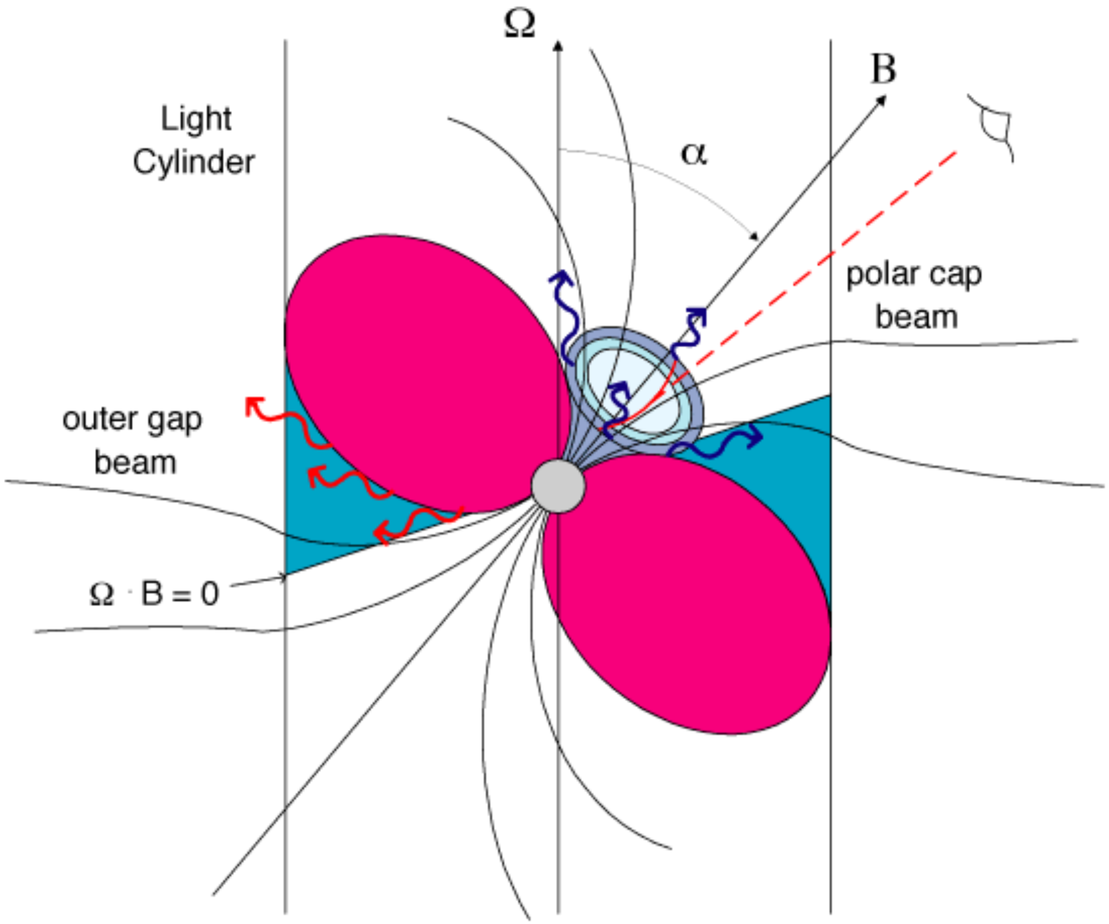


Pulsars Physics

- Wide variety of PSR profiles.

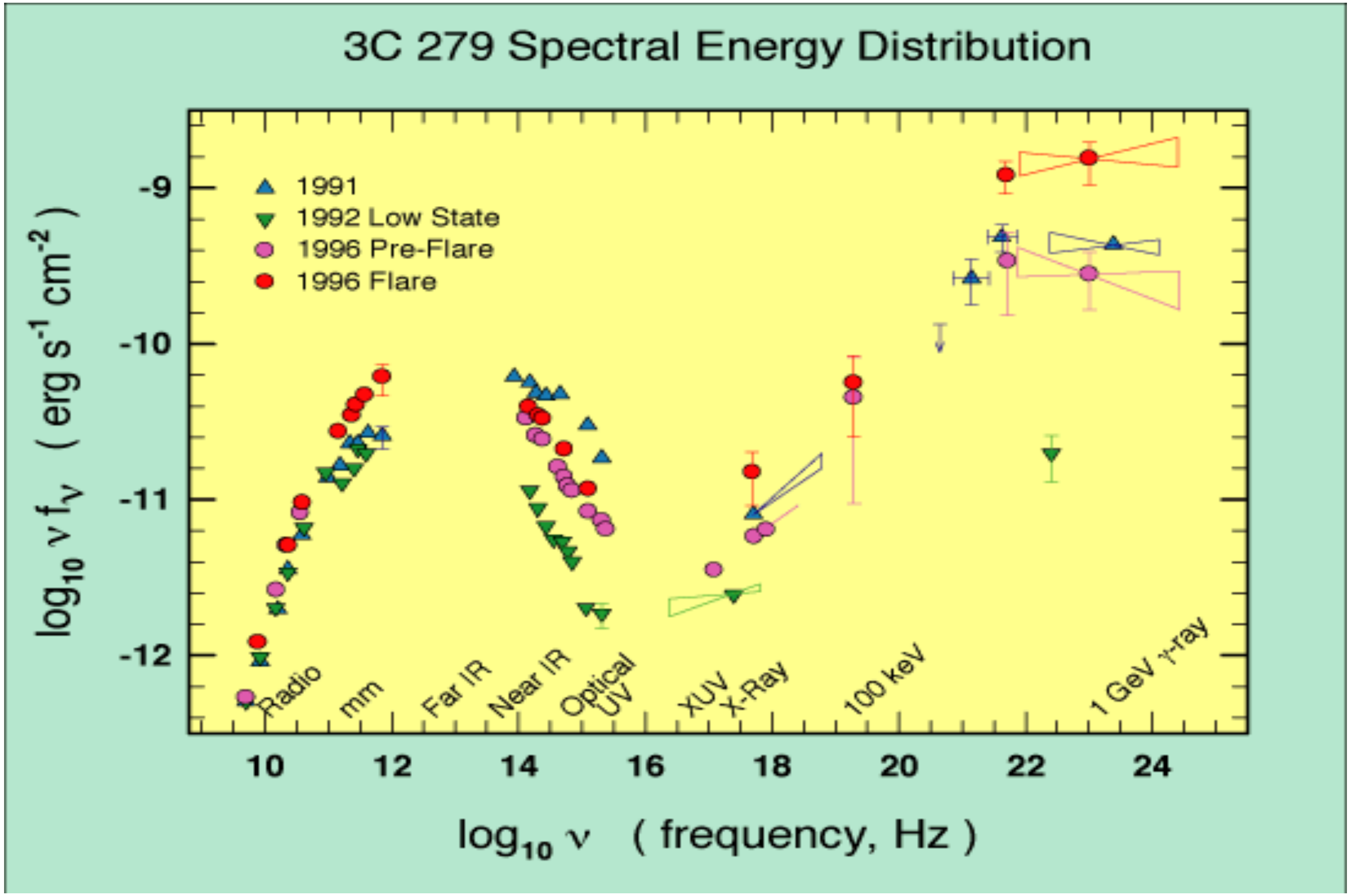


Pulsars

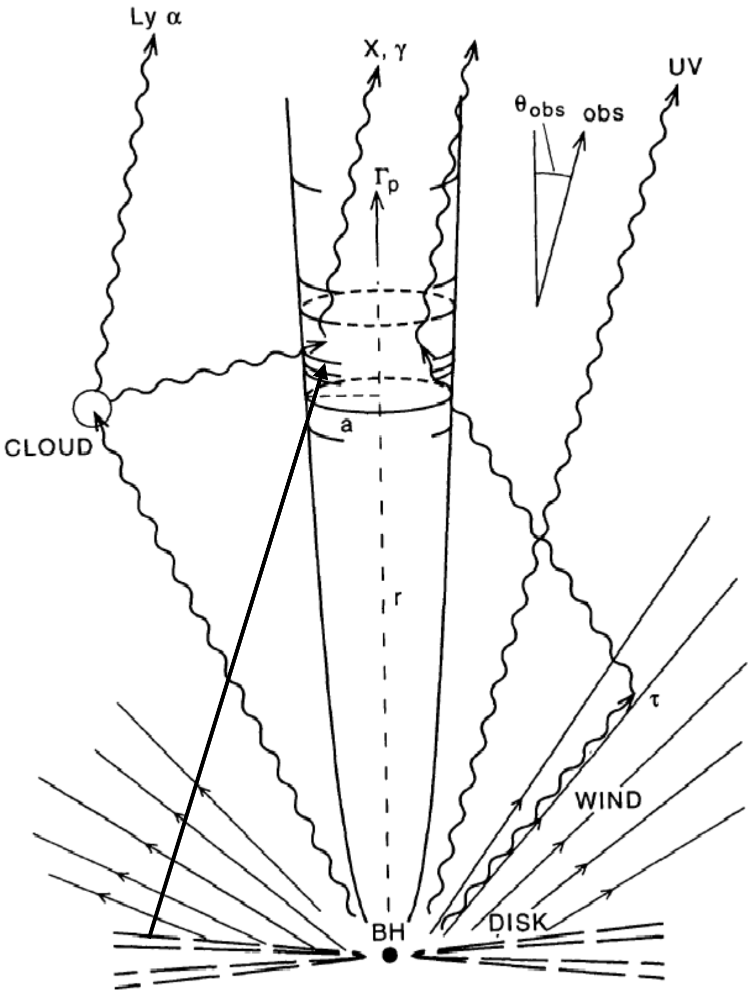


AGN physics

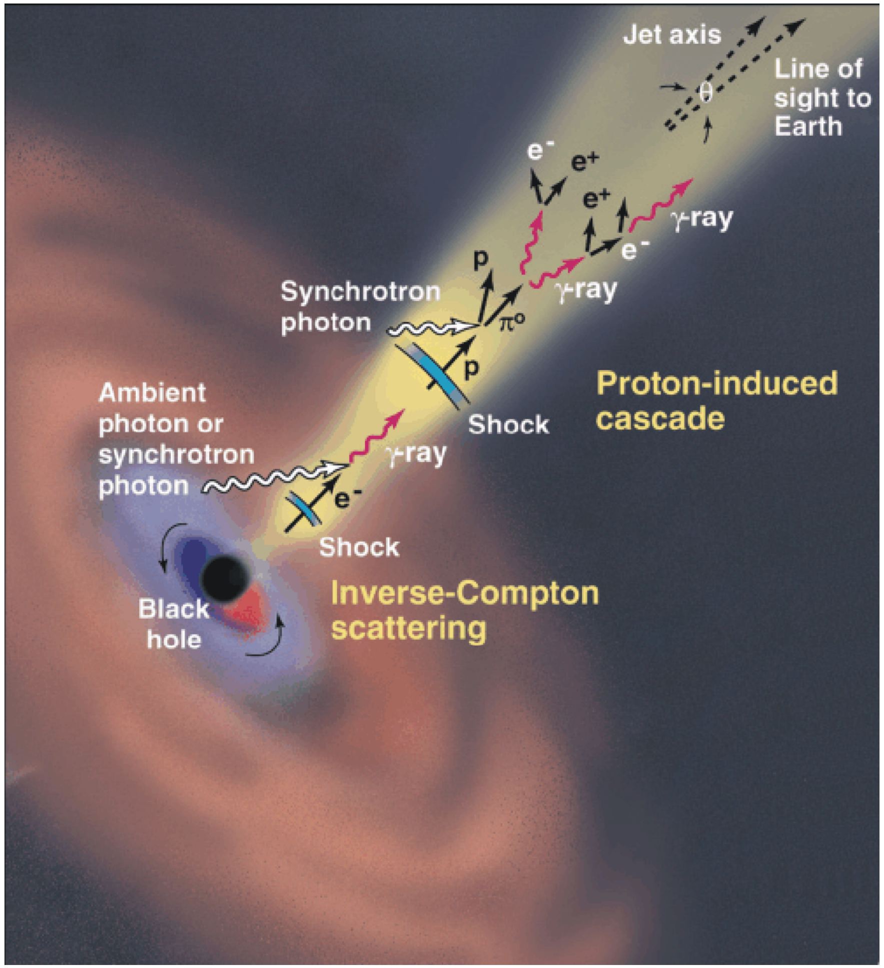
- **Simultaneous multiwavelength data to study variability and emission processes**



Models of AGN Gamma-ray Production



(from Sikora, Begelman, and Rees (1994))



(credit:J. Buckley)

AGN and the Extragalactic Background Light (EBL)

Look for roll-offs in blazar spectra due to attenuation:

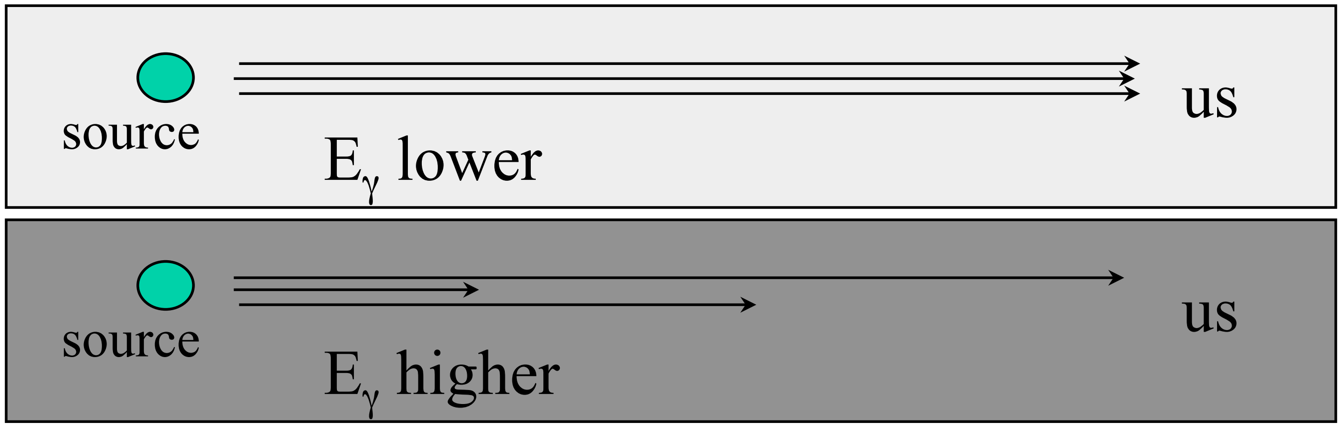
(Stecker, De Jager & Salamon; Madau & Phinney; Macminn & Primack)

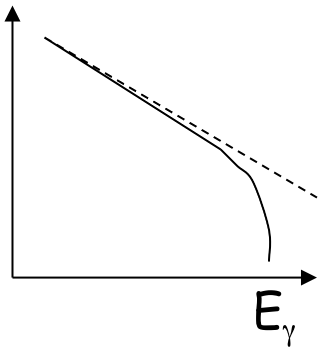
the start: A.I. Nikishov, Sov. Phys. JETP 14 (1962) 393.

If γγ c.m. energy > $2m_e$, pair creation will attenuate flux. For a flux of γ -rays with energy, E, this cross-section is maximized when the partner, ε, is

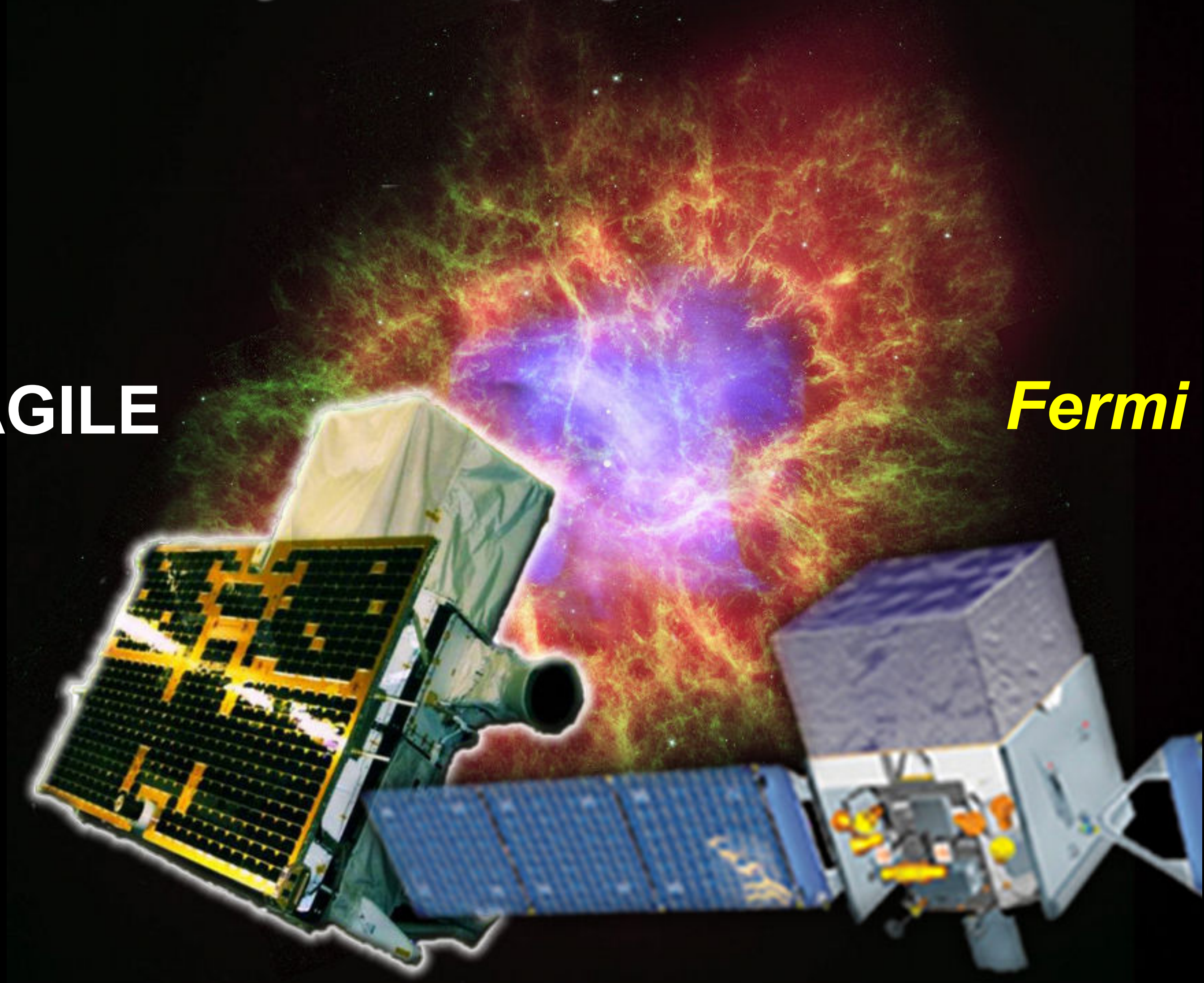
$$\epsilon \sim \frac{1}{3}(\frac{1TeV}{E})eV$$

For 10 GeV- 100 GeV γ - rays, this corresponds to a partner photon energy in the optical - UV range. Density is sensitive to time of galaxy formation.





Gamma-ray astrophysics above 100 MeV



Picture of the day, Feb. 28, 2011, NASA-HEASARC

AGILE

agenzia spaziale italiana

INAF

INFN

CARLO GAVAZZI
Carlo Gavazzi Space SpA

OERLIKON CONTRAVES

ALCATEL ALENIA SPACE
An Alcatel/Finmeccanica company

telespazio
A Finmeccanica/Alcatel company

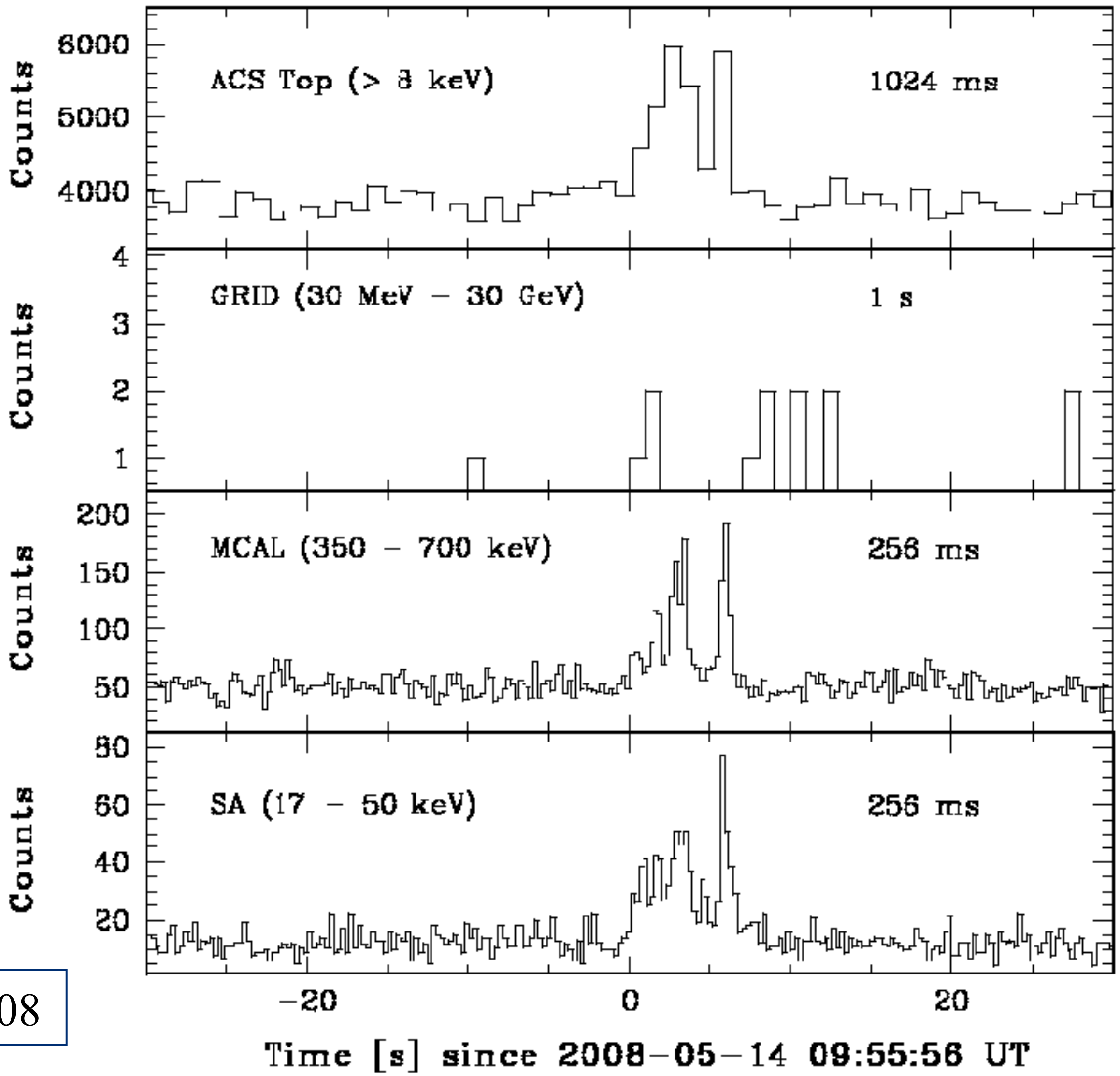
Galileo Avionica

MIPOT

ENEA

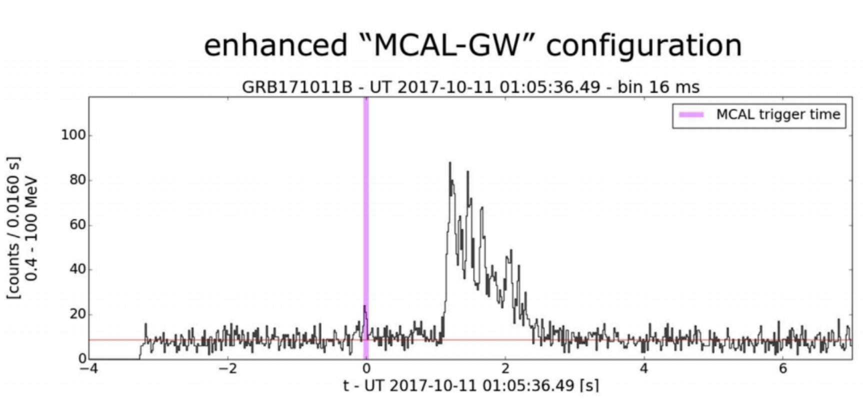

AGILE: inside the cube…
HARD X-RAY IMAGER (SUPER-AGILE)
INAF-IASF-Rm (E.Costa, M. Feroci)
GAMMA-RAY IMAGER
SILICON TRACKER
INFN-Trieste
(G.Barbiellini, M. Prest)
ANTICOINCIDENCE
INAF-IASF-Mi (F.Perotti)
(MINI) CALORIMETER
INAF-IASF-Bo, Thales-Alenia Space (LABEN)
(G. Di Cocco, C. Labanti)

GRB analysis

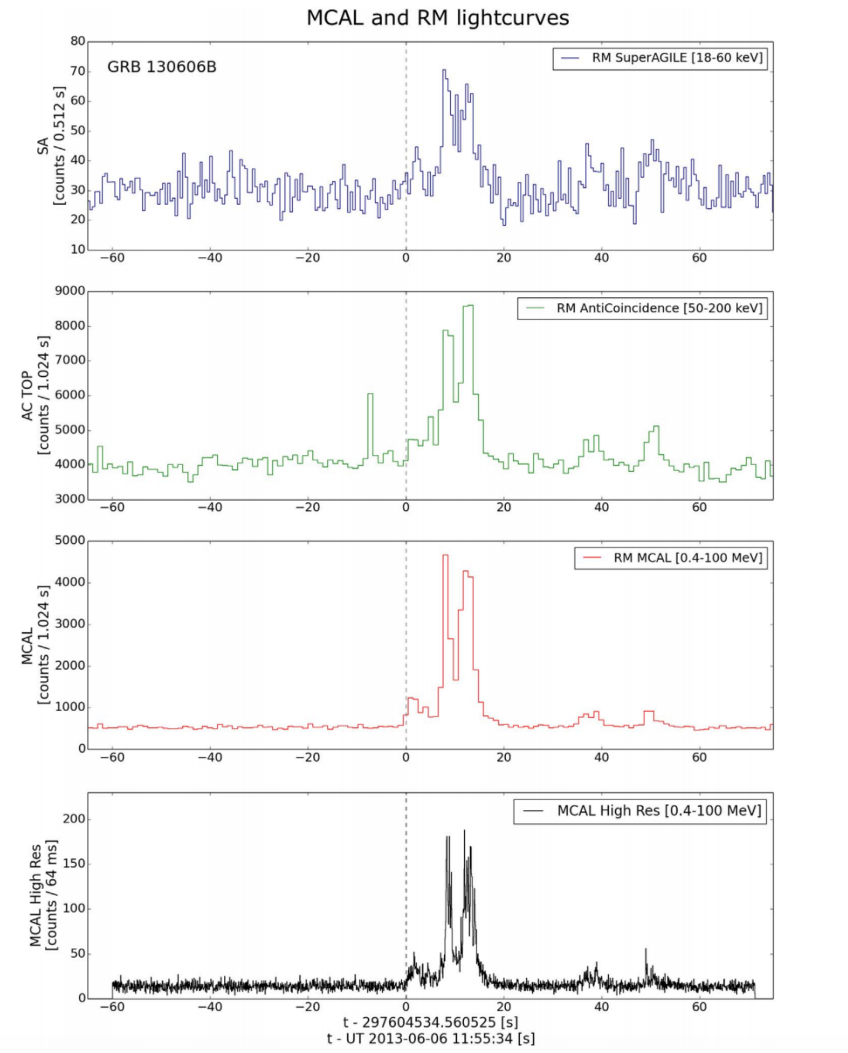


Giuliani et al. 2008

GRB analysis



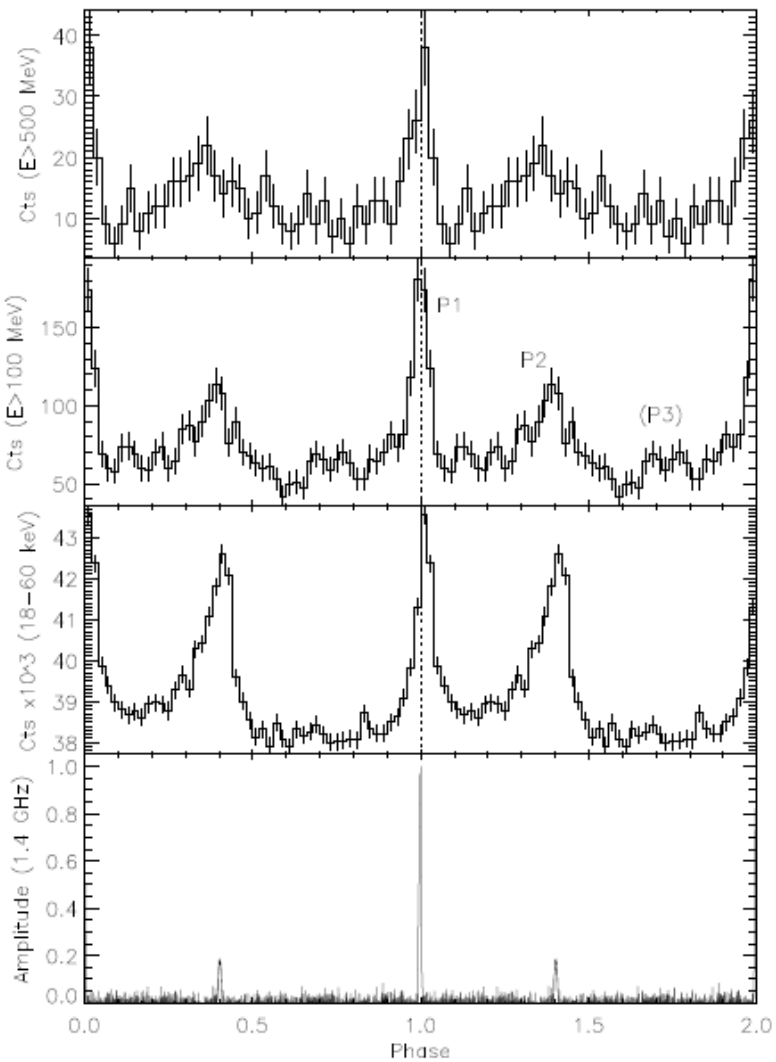
Ursi et al. 2019



Ursi et al. 2022

Pulsar timing

High Precision Timing (eg. Crab PSR)



Pellizzoni et al. 2009

AGILE

Space Science Data Center

Home | About SSDC | News and Communication | Quick Look | Missions | Multimission Archive | Catalogs | Tools | Links | Bibliographic services | Helpdesk | Privacy

AGILE Science Data Center

AGILE Home | About AGILE | ASI HQ AGILE | AGILE News | AGILE Data Archive | Public Software | AGILE Pointings | AGILE Catalogs | Restricted Area | Guest Observer Program | User Feedback Form | AGILE Workshops | Agile Helpdesk

Welcome to the AGILE Data Center Home Page at SSDC

These pages provide updated information and services in support to the general scientific community for the mission AGILE, which is a small Scientific Mission of the Italian Space Agency (ASI) with participation of INFN, IASF/INAF and CIFS .

AGILE is devoted to gamma-ray astrophysics and it is a first and unique combination of a gamma-ray (AGILE-GRID) and a hard X-ray (SuperAGILE) instrument, for the simultaneous detection and imaging of photons in the 30 MeV - 50 GeV and in the 18 - 60 keV energy ranges. After more than 13 years of operations, AGILE is working nominally, providing valuable data and important scientific results.

AGILE operations:
Launch date 23 April, 2007
Planned Nominal Phase: 2 + 2 extended years
Elapsed: 13 years in orbit completed on 23 April, 2020
Current Extended Phase: ASI extended AGILE operations up to 31 May, 2022

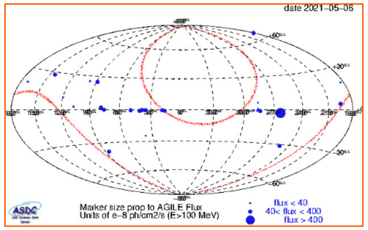
The AGILE Mission Board (AMB) has executive power overseeing all the scientific matters of the AGILE Mission and is composed of:

- AGILE Principal Investigator: Marco Tavani, INAF Rome (Chair)
- ASI Project Scientist: Paolo Giommi, ASI
- ASI Mission Director: Fabio D'Amico, ASI
  (Former ASI Mission Directors: Luca Salotti, up to September 20, 2010 and Giovanni Valentini up to January 22, 2015)
- AGILE Co-Principal Investigator: Guido Barbiellini, INFN Trieste
- 1 ASI representative: Elisabetta Tommasi di Vignano
  (Former ASI representative: Sergio Colafrancesco up to June, 2010)

- INAF Project Scientist: Carlotta Pittori (from November 10, 2020)

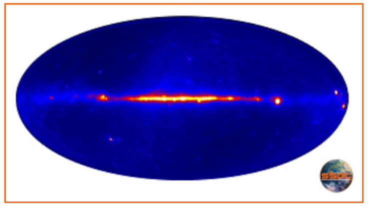
AGILE current spinning sky view

(Click here for previous pointing details)



Click here to access the AGILE Spinning FOV plotter

Click here to access the AGILE Real Data FOV Plotter

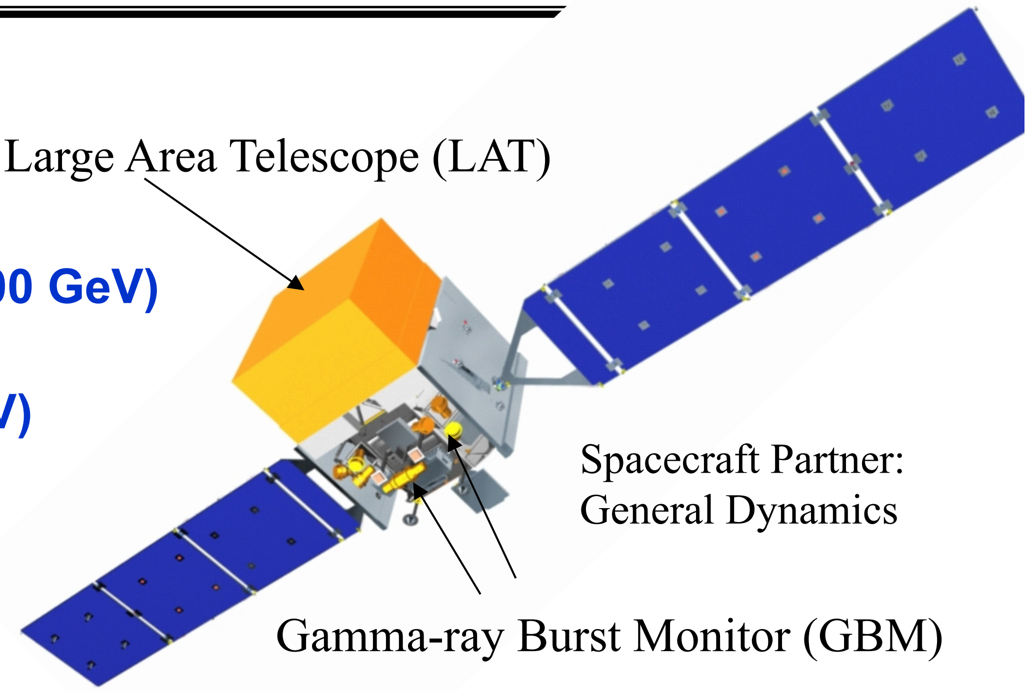


AGILE total intensity map up to Sep. 30, 2017.

https://agile.ssdc.asi.it/

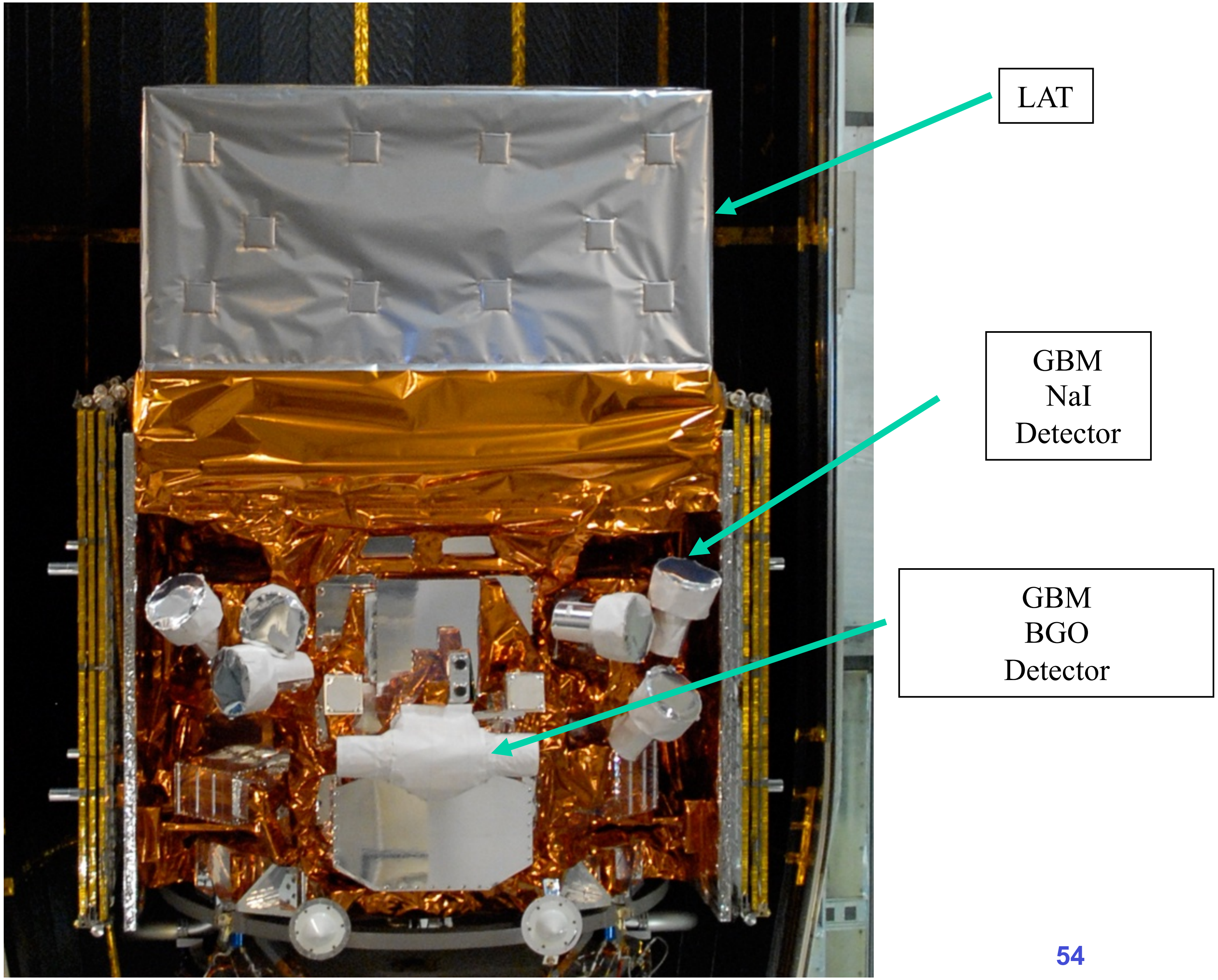
Fermi Key Features

- **Two instruments:**
  - **LAT:**
    - **high energy (20 MeV – >300 GeV)**
  - **GBM:**
    - **low energy (8 keV – 40 MeV)**



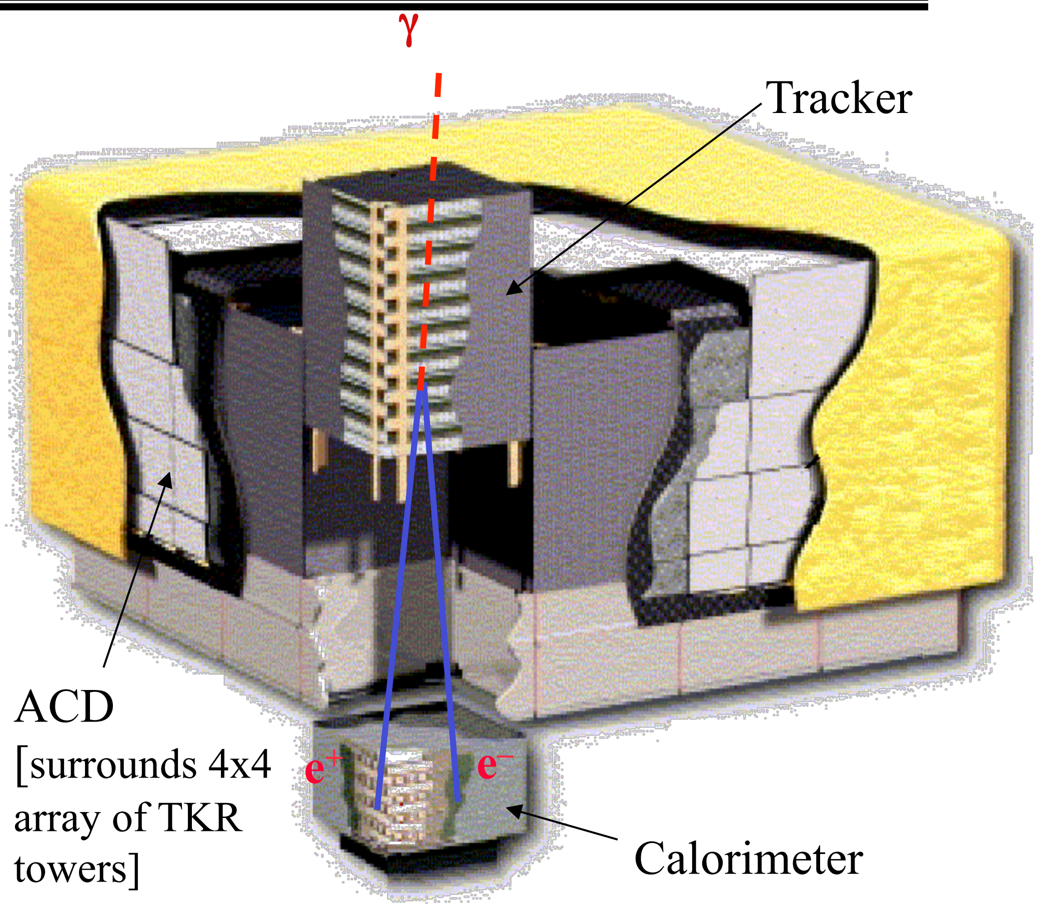
- **Huge field of view**
  - **LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV**
- **Large leap in all key capabilities. Great discovery potential.**

Fermi mission



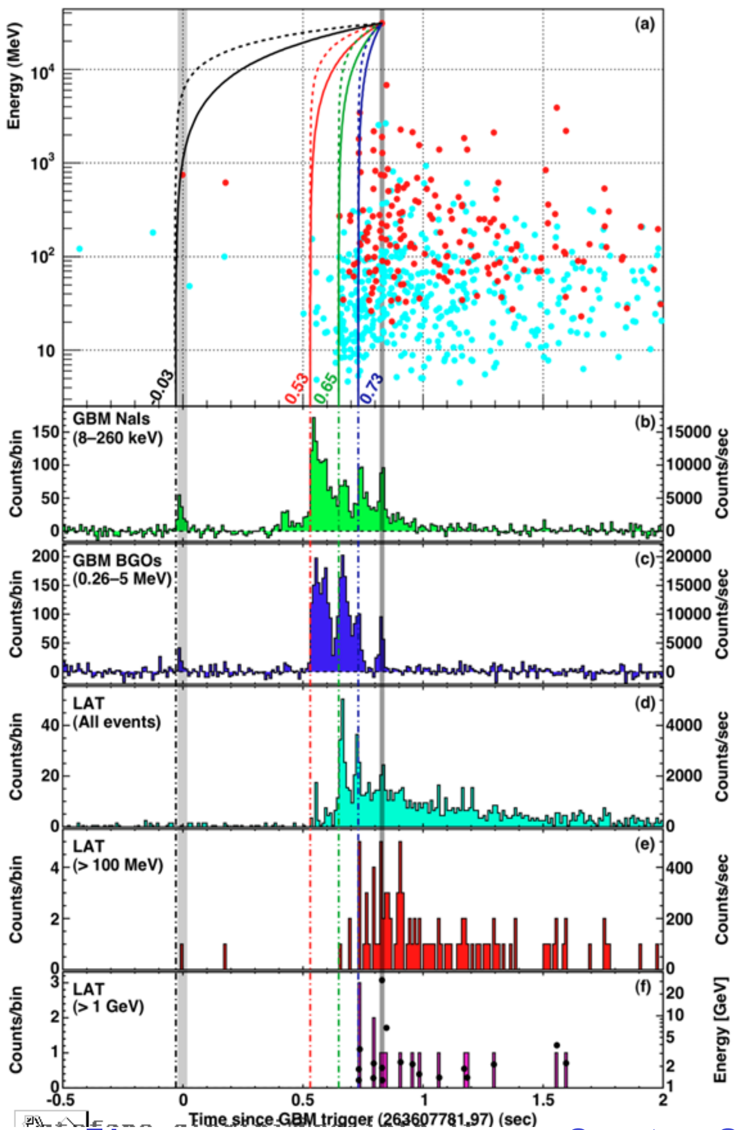
Overview of Fermi/LAT

- **<u>Precision Si-strip Tracker (TKR)</u>** **18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.**
- **<u>Hodoscopic CsI Calorimeter(CAL)</u>** **Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.**
- **<u>Segmented Anticoincidence Detector (ACD)</u>** **89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.**
- **<u>Electronics System</u>** **Includes flexible, robust hardware trigger and software filters.**



Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

GRB with Fermi/LAT

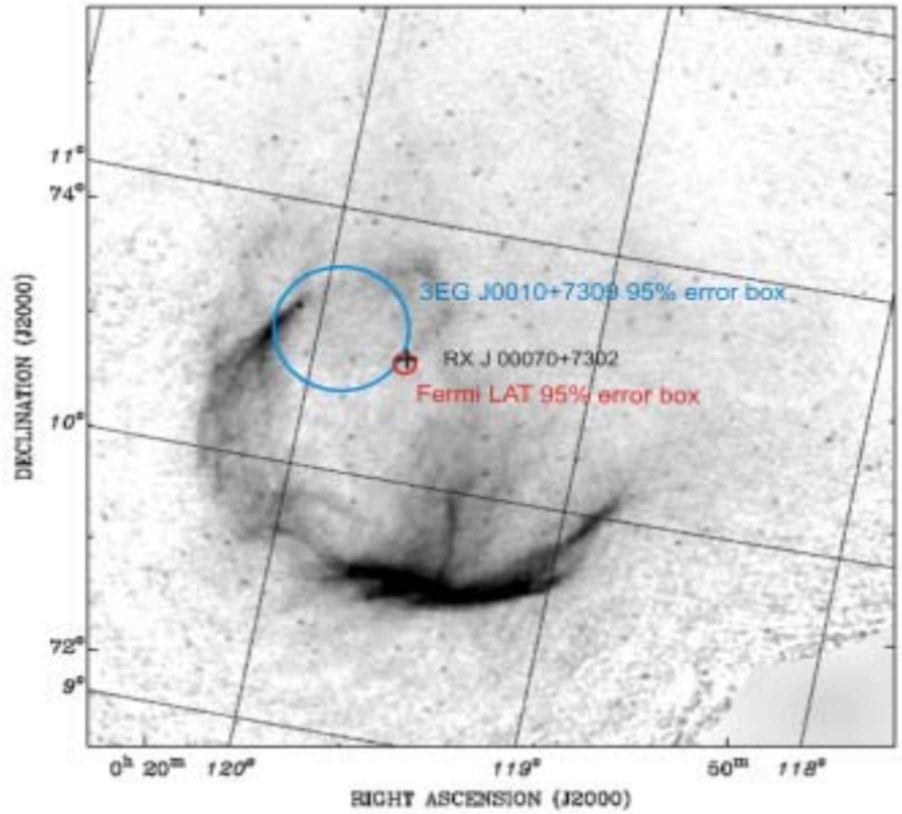


- This GRB is a perfect case for studying Lorentz Invariance Violation
  - z = 0.9 (5.381 Gyr)
  - Emission of 31 GeV photon after 859 ms since the trigger
- Only conservative assumption!
  - the HE photon is not emitted *before* the LE photons, at different events.

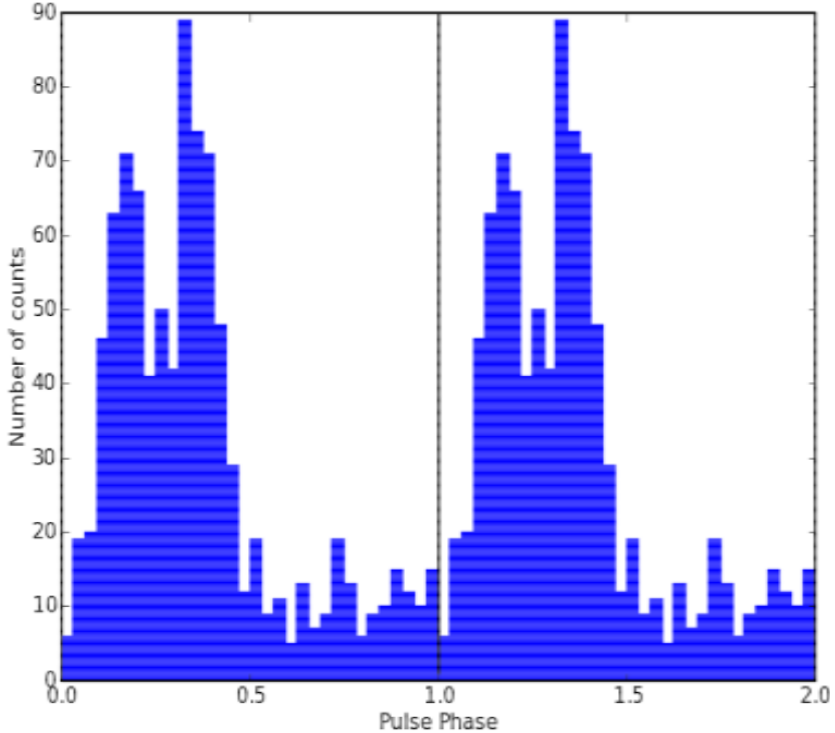
Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (ms)	Limit on $\lvert\Delta t\rvert$ (ms)	Reasoning for choice of t_{start} or limit on Δt or $\lvert\Delta t/\Delta E\rvert$	E_l† (MeV)	Valid for s_n*	Lower limit on $M_{QG,1}/M_{Planck}$
(a)✧	−30	< 859	start of any < 1 MeV emission	0.1	1	> 1.19
(b)✧	530	< 299	start of main < 1 MeV emission	0.1	1	> 3.42
(c)✧	*648*	< 181	start of main > 0.1 GeV emission	100	1	> 5.63
(d)✧	730	< 99	start of > 1 GeV emission	1000	1	> 10.0
(e)♦	—	< 10	association with < 1 MeV spike	0.1	± 1	> 102
(f)♦	—	< 19	If 0.75 GeV‡ γ-ray from 1st spike	0.1	− 1	> 1.33
(g)♠	$\lvert\Delta t/\Delta E\rvert$ < 30 ms/GeV		lag analysis of > 1 GeV spikes	—	± 1	> 1.22

LAT discovers a radio-quiet pulsar!



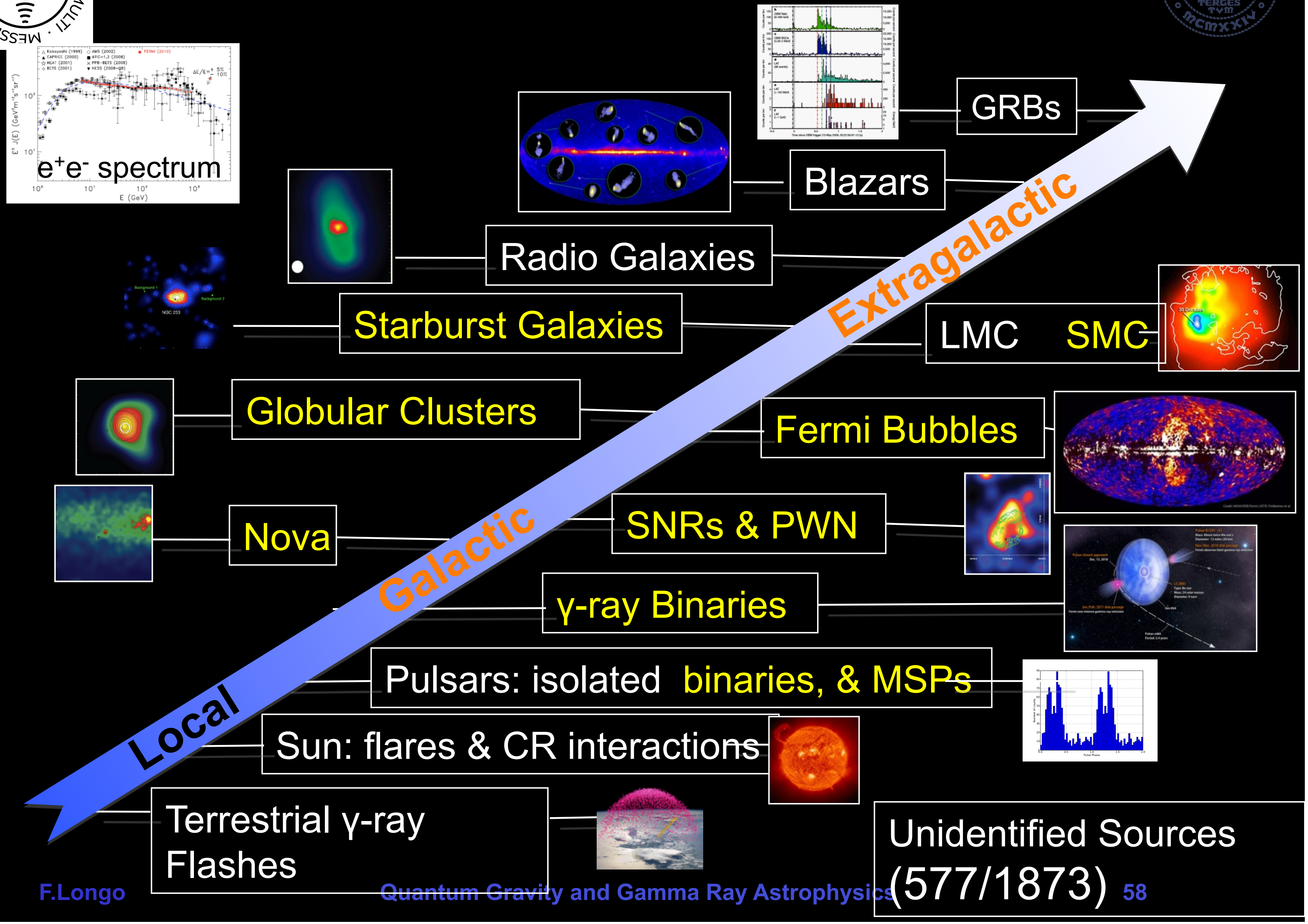
P ~ 317 ms
Pdot ~ 3.6E-13
Characteristic age ~ 10,000 yrs



Location of EGRET source 3EG J0010+7309, the Fermi-LAT source, and the central X-ray source RX J0007.0+7303

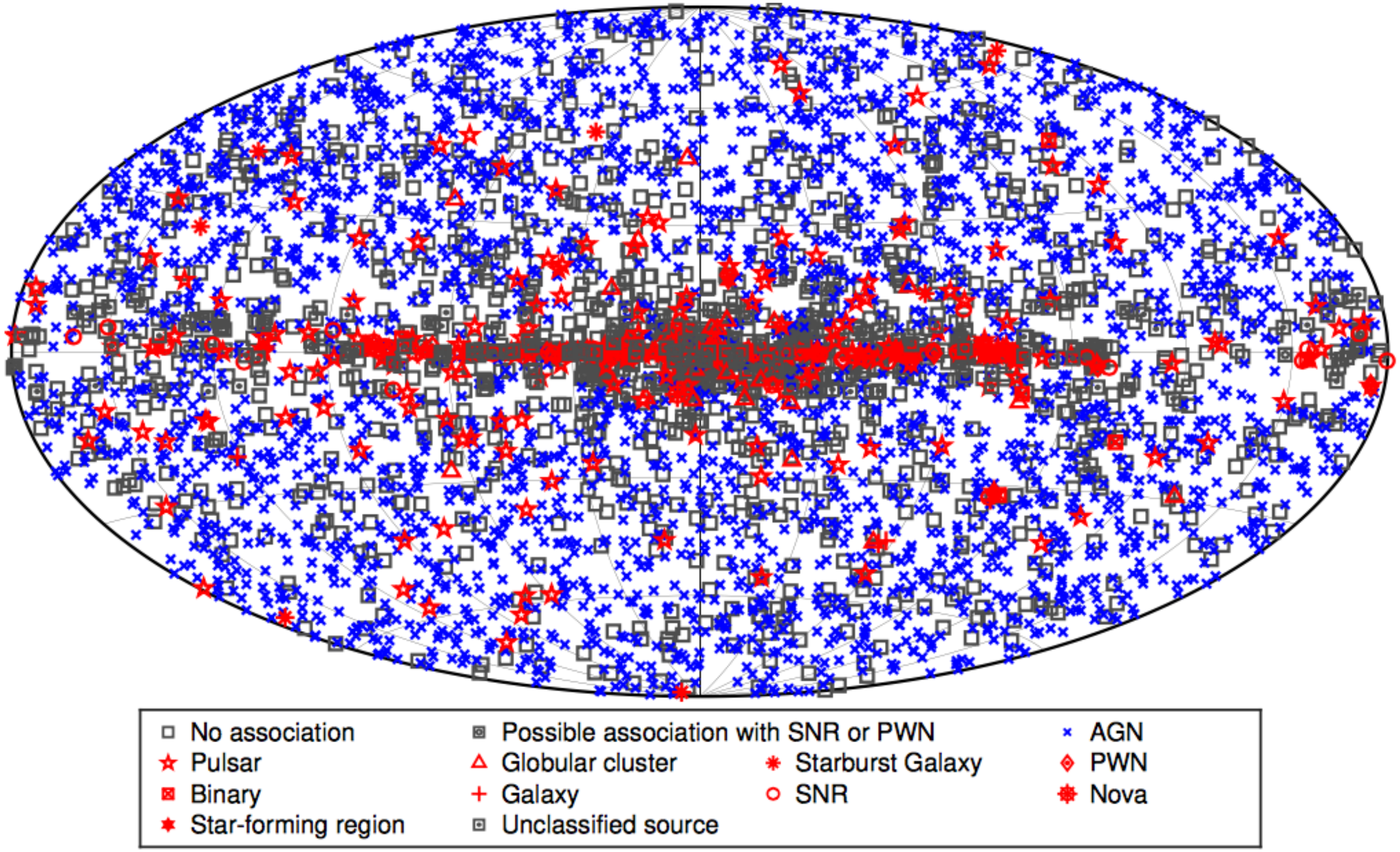
Published in Science Express October 16, 2008

Fermi Reveals the Very High Energy Universe

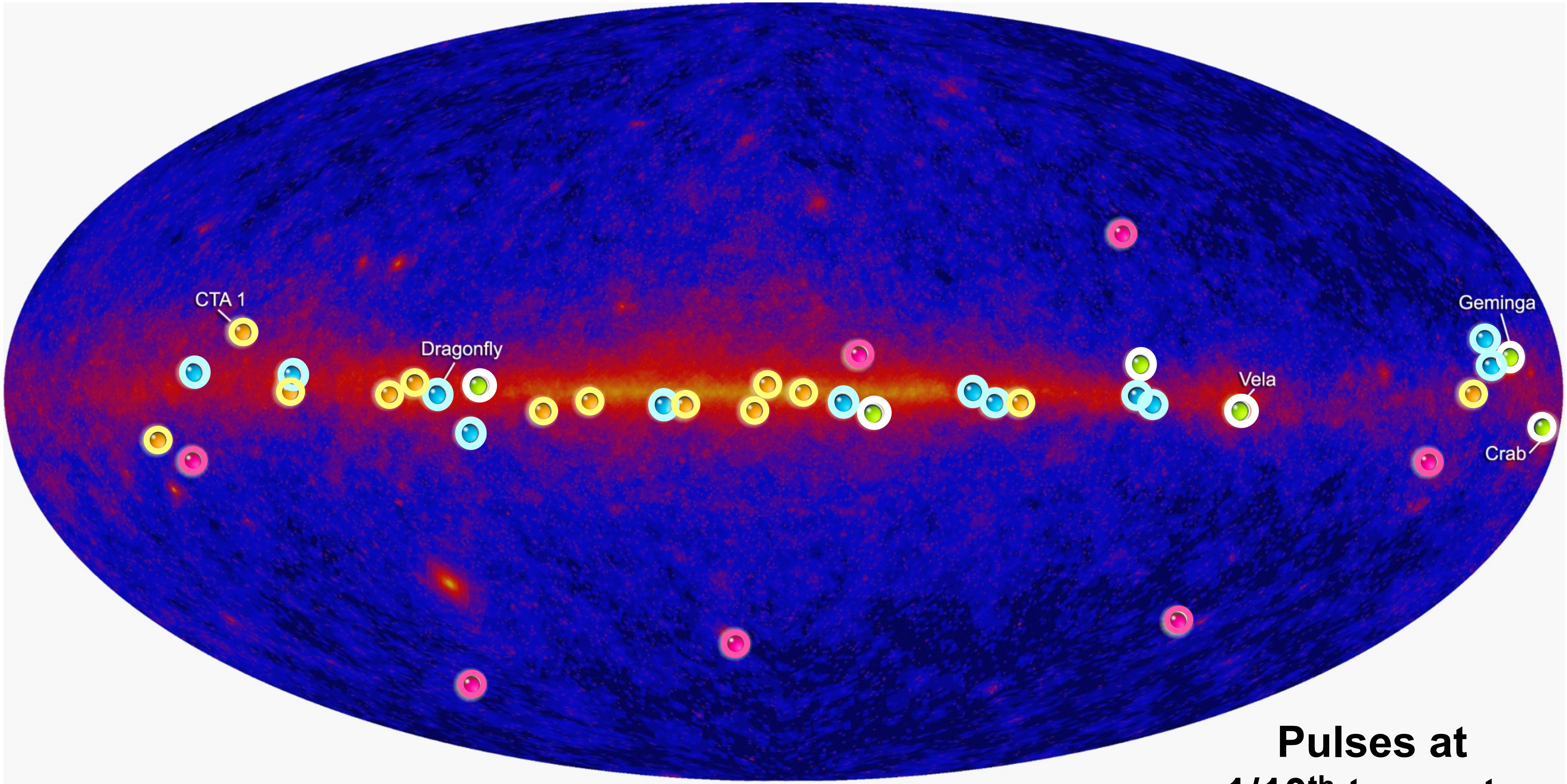


4FGL catalog

ApJ Supplement Series, Volume 247, Issue 1, id.33, 37 pp. (2020)



Pulsars with Fermi/LAT



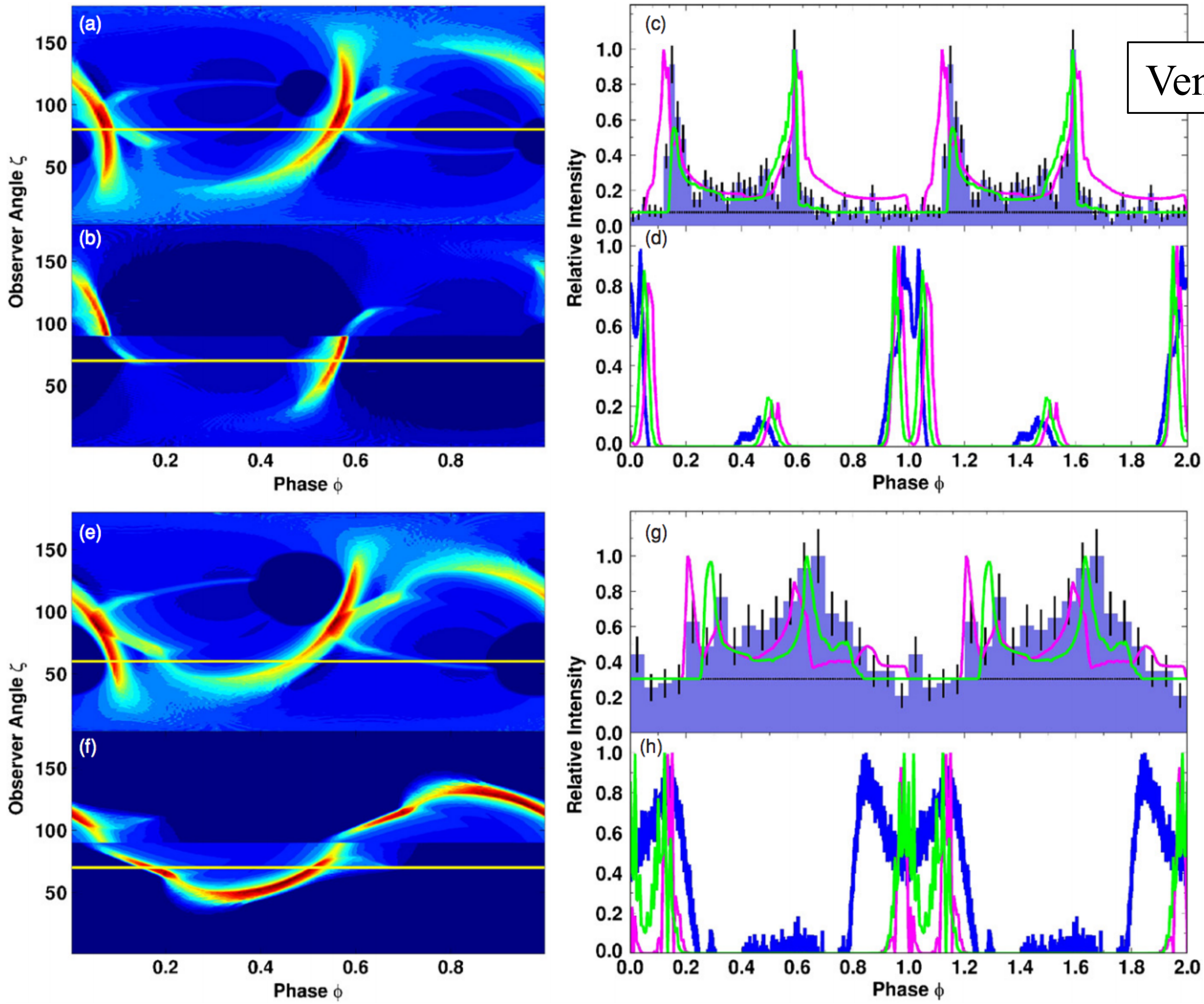
Pulses at 1/10th true rate

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Confirmed pulsars seen by Compton Observatory EGRET instrument

Fermi Pulsar Detections

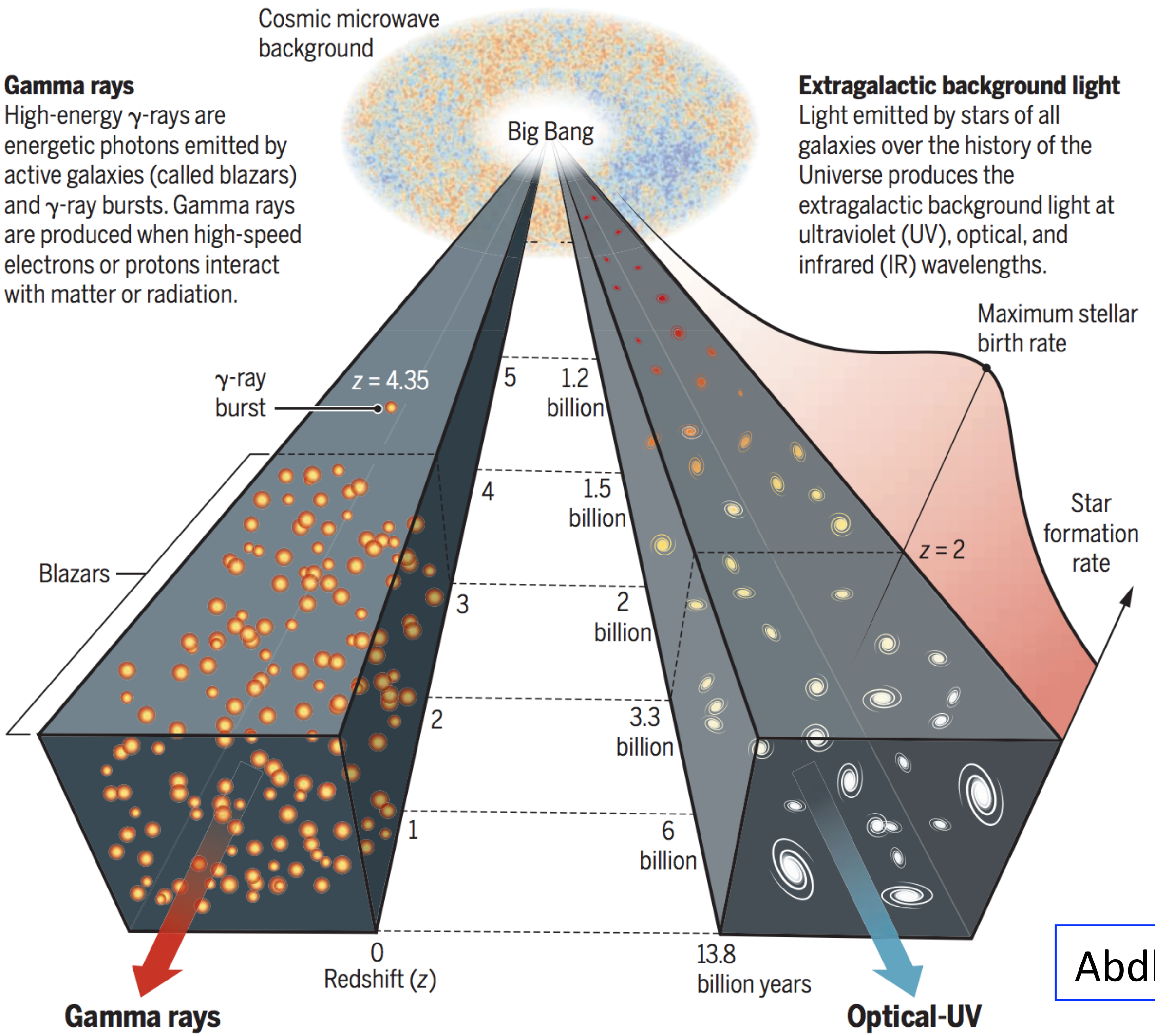
Abdo et al..2010

PSR light curves



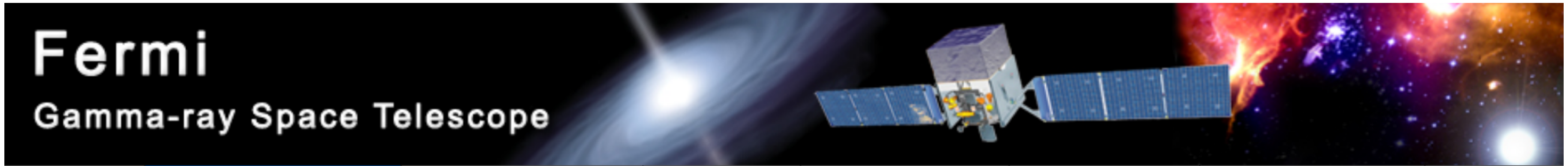
Venter et al. 2009

The Extragalactic Background Light



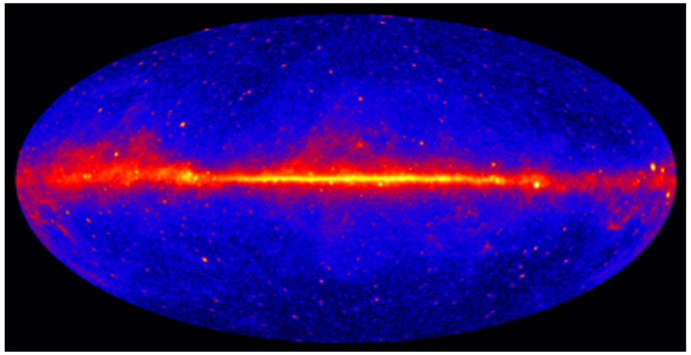
Abdhollai et al 2018

Fermi/LAT



Home | Support Center | Observations | Data | Proposals | Library | HEASARC | Help

The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



This view shows the entire sky at energies greater than 1 GeV based on five years of data from the LAT instrument on NASA's Fermi Gamma-ray Space Telescope. Brighter colors indicate brighter gamma-ray sources.
Image Credit: NASA/DOE/Fermi LAT Collaboration

Look into the "Resources" section for finding schedules, publications, useful links etc. The "Proposals" section is where you will be able to find the relevant information and tools to prepare and submit proposals for guest investigator projects. At "Data" you will be able to access the Fermi databases and find the software to analyse them. Address all questions and requests to the helpdesk in "Help".

Fermi Observations for MW 675

Mission week 675 starts with a continuation of the asymmetric rocking +50/-60 profile from the previous week. On day of year 126 (2021-05-06) at 01:59 there is a 10 minute freeze observation during which an updated asymmetric profile is loaded. This profile continues until DOY 129 (2021-05-09) at 03:01 when there is a 10 minute freeze observation during which a symmetric +/-50 deg. profile is loaded. This profile continues until the end of the week. Note that positive rock angles are south, and negative angles are north.

» More Timeline Info

Latest News

» Fermi Sky Blog
» Fermi Blog

Apr 20, 2021

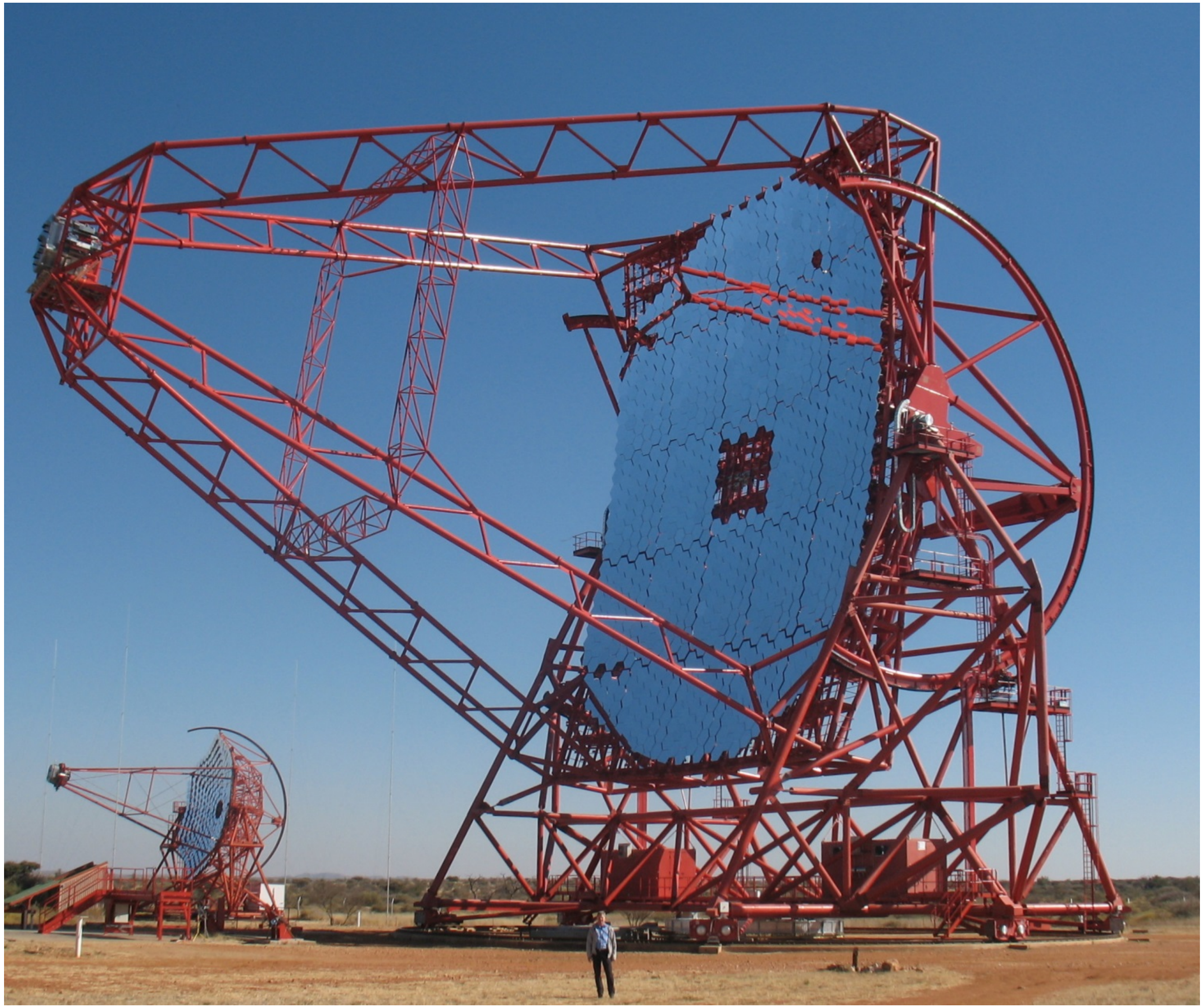
Updated Spacecraft Position and History Files Available

The updated files include the addition of the SC_VELOCITY column. This column contains a vector with the spacecraft velocity in meters per

https://fermi.gsfc.nasa.gov/ssc/

TeV Gamma-ray Astrophysics

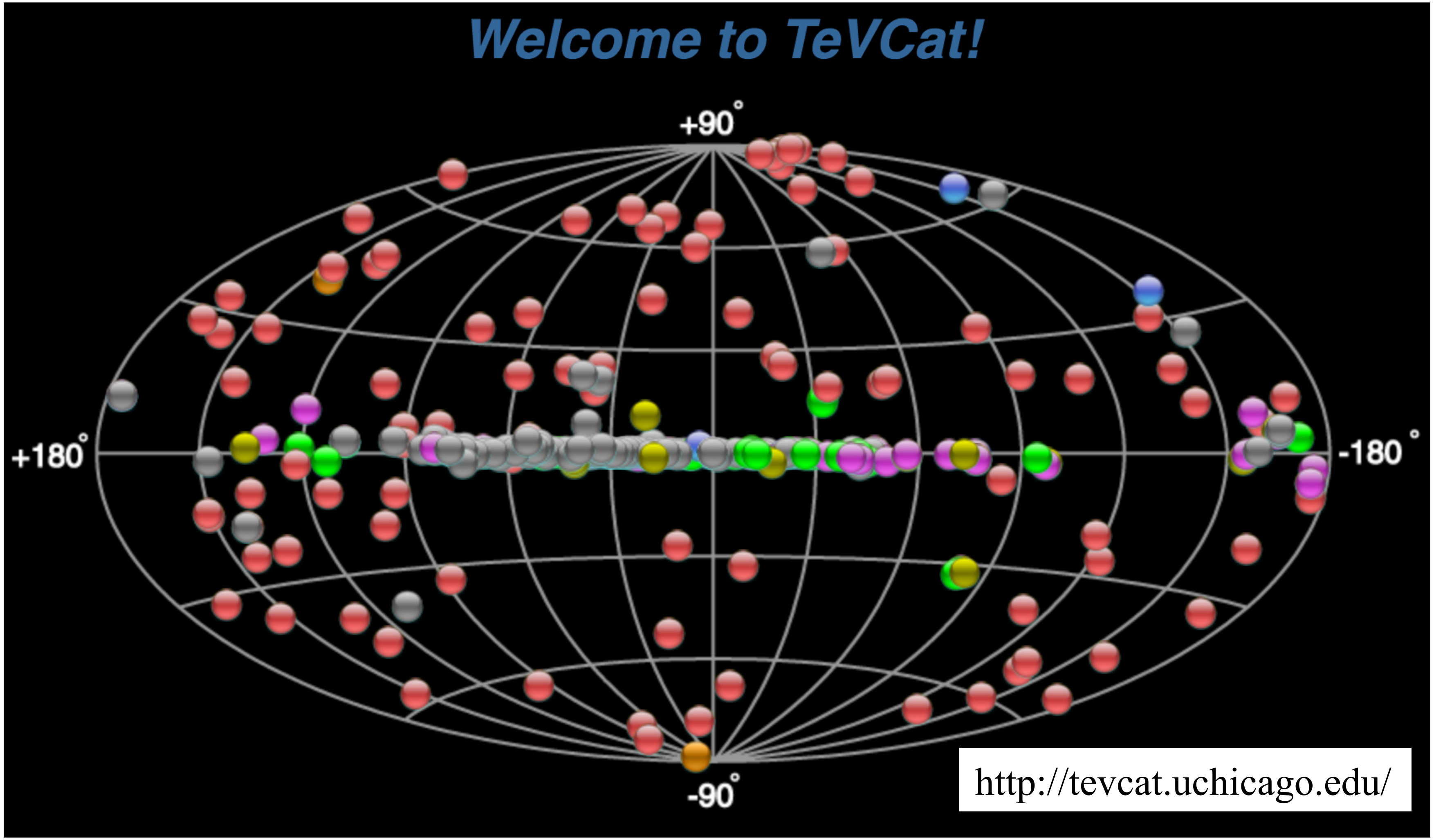
HESS



MAGIC

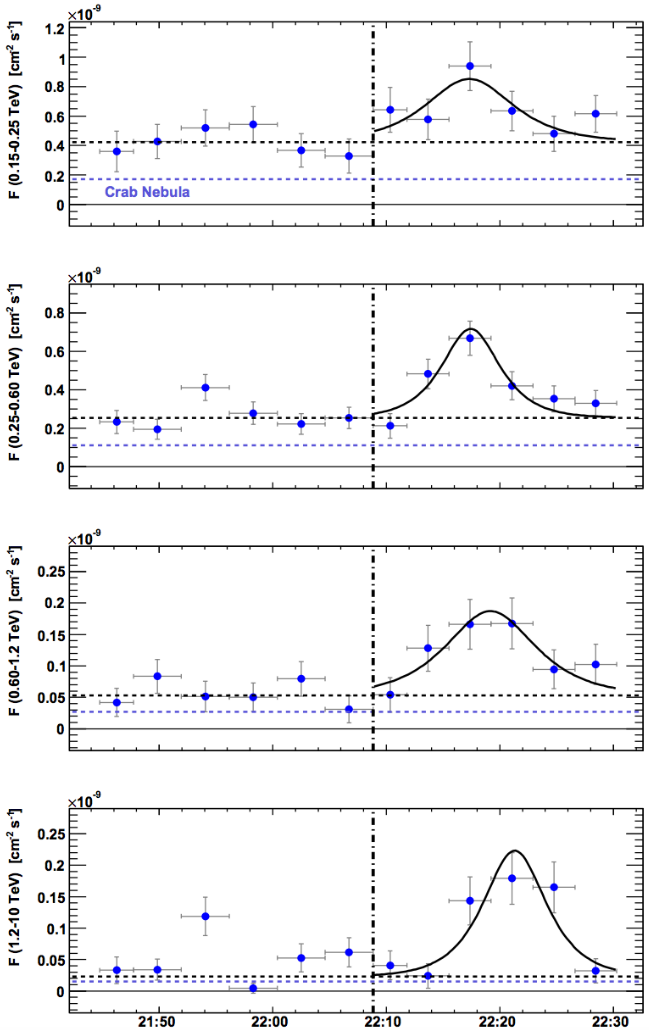
VERITAS

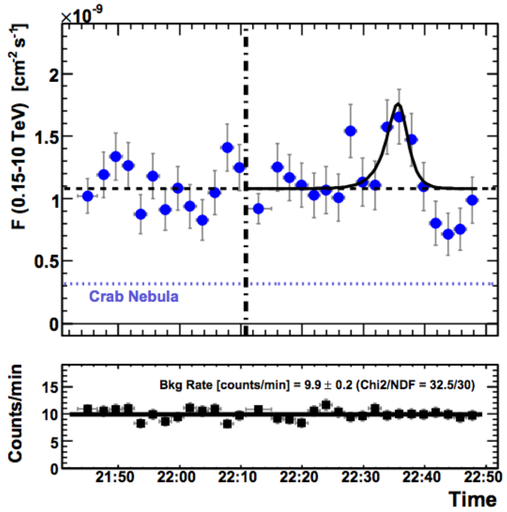
The TeV Catalog

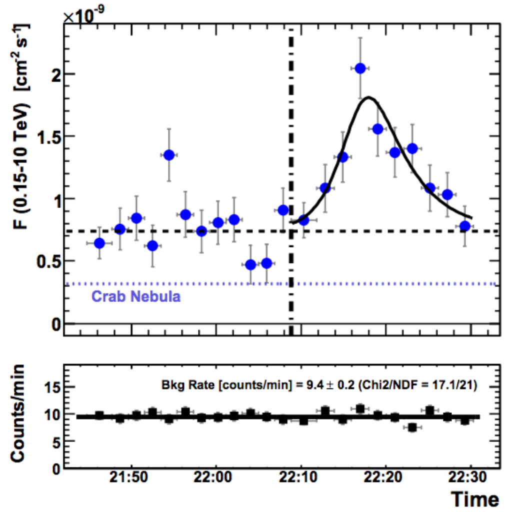


AGN physics

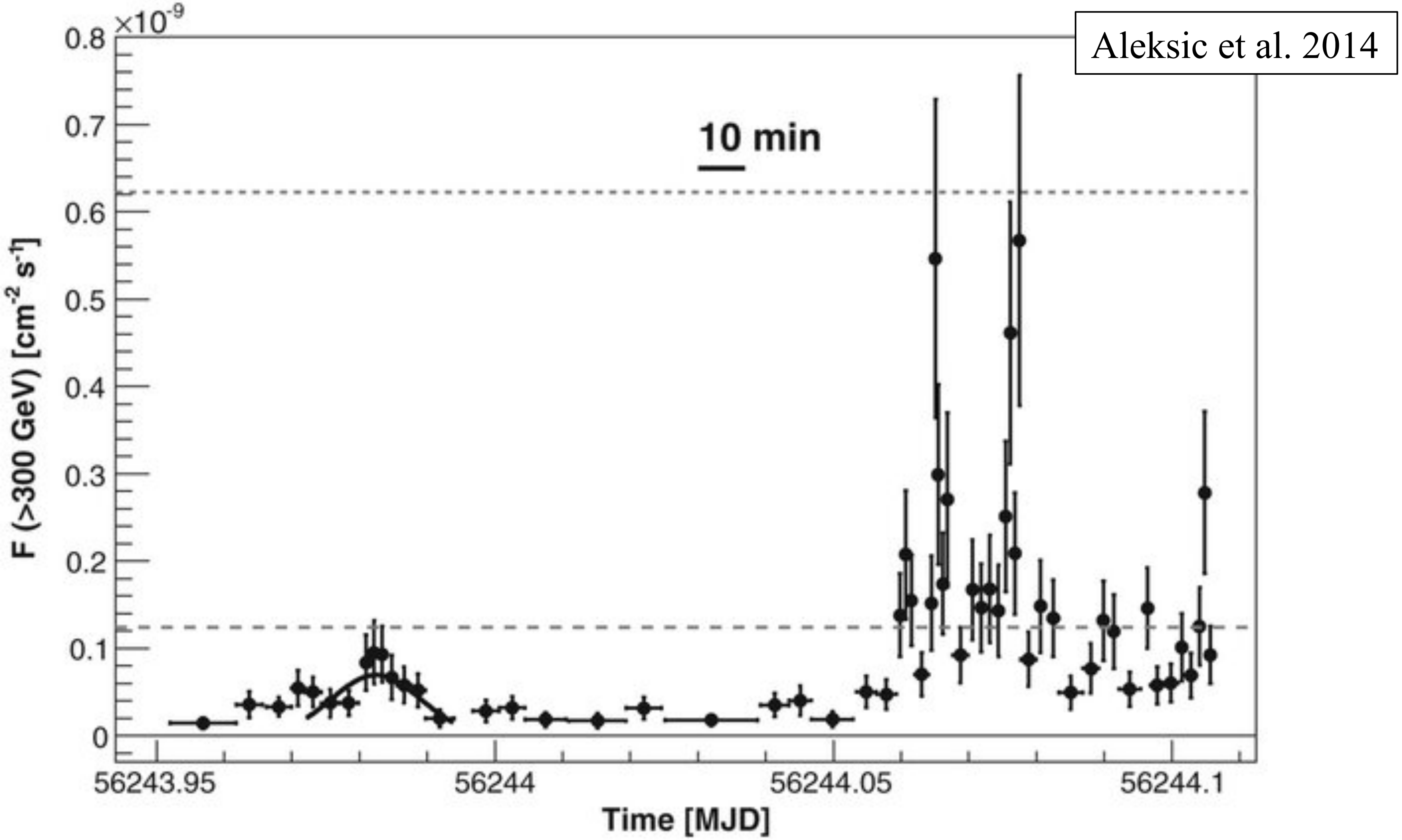
Albert et al. 2007



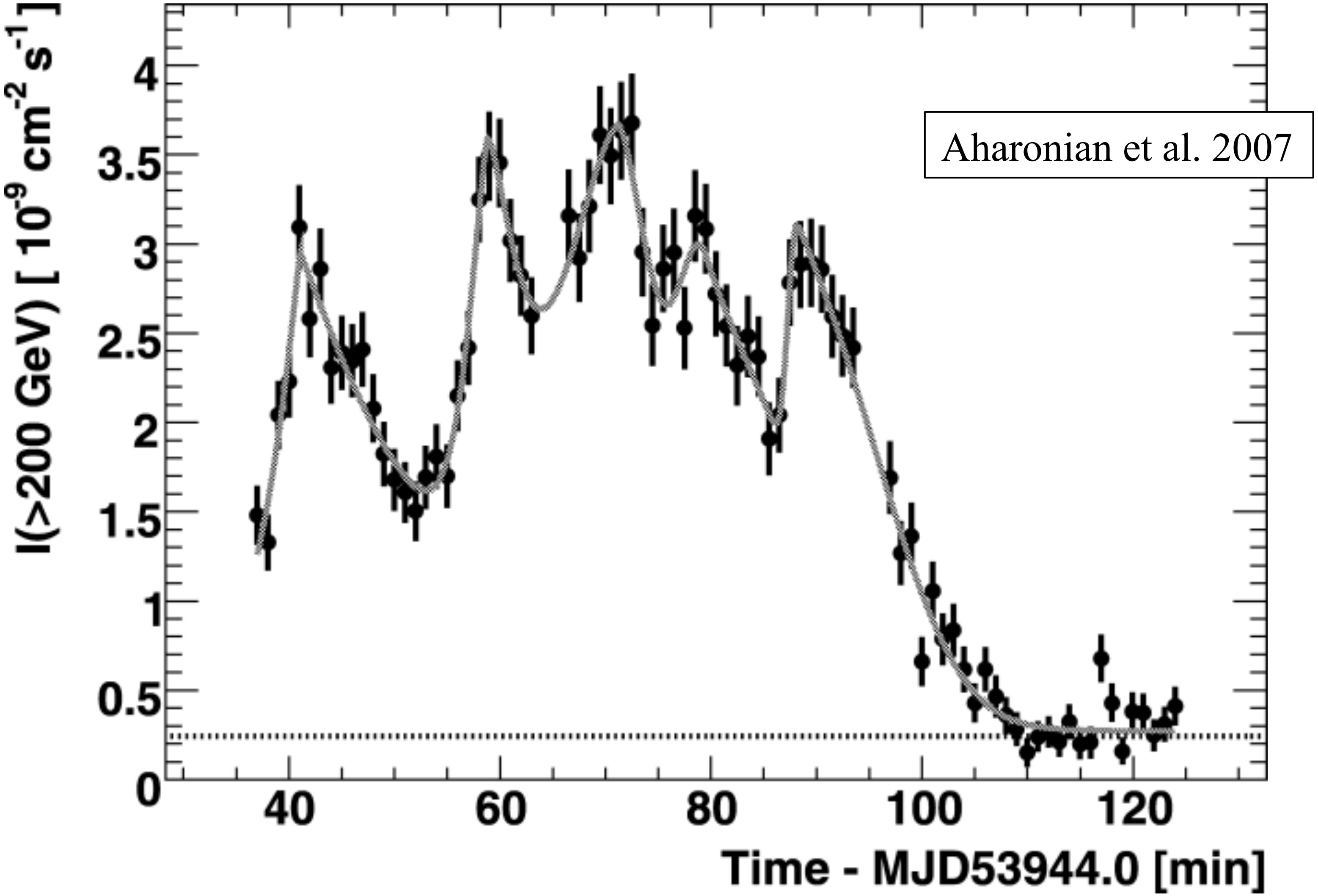




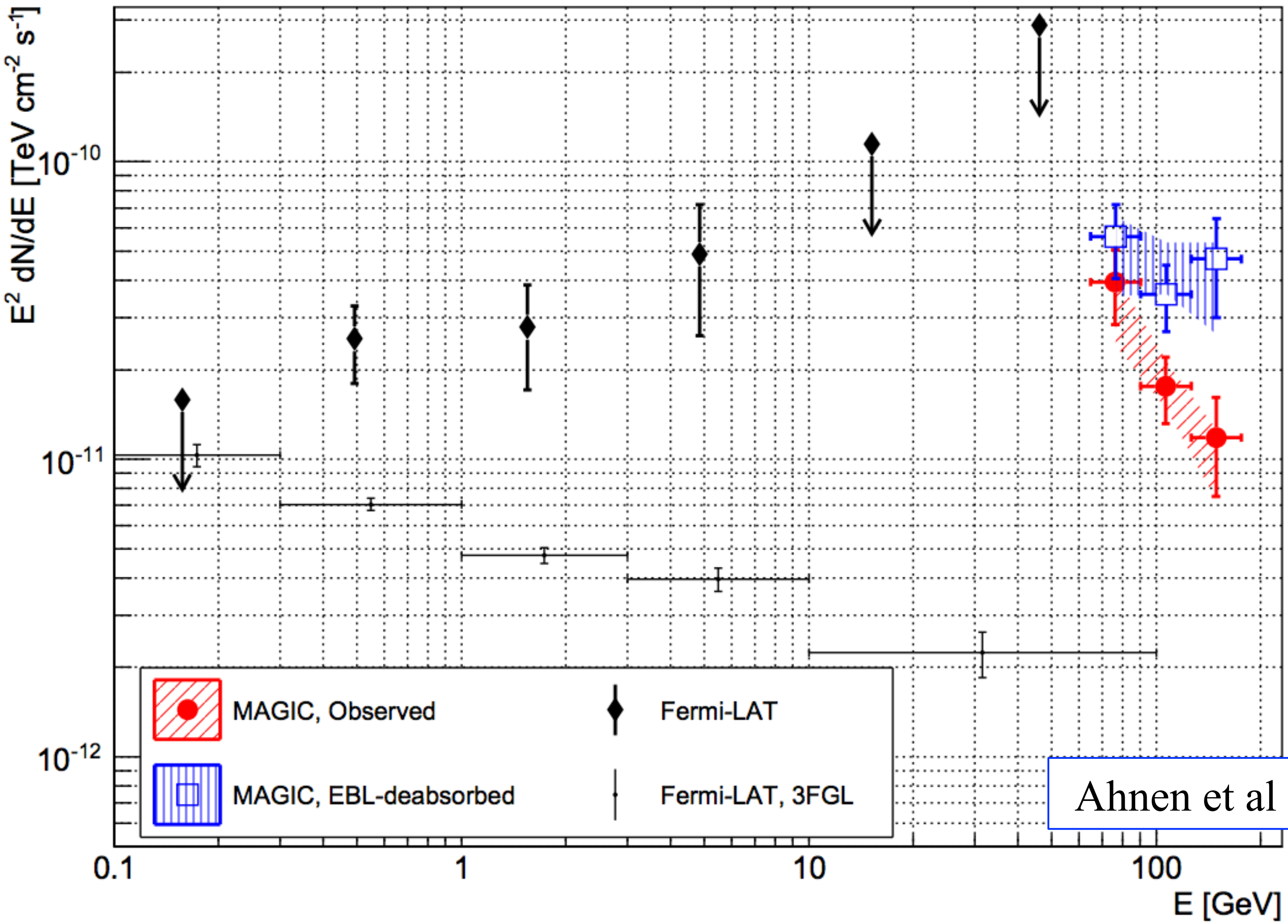
AGN physis


Aleksic et al. 2014
10 min
×10^-9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
F (>300 GeV) [cm^-2 s^-1]
56243.95
56244
56244.05
56244.1
Time [MJD]

AGN physics

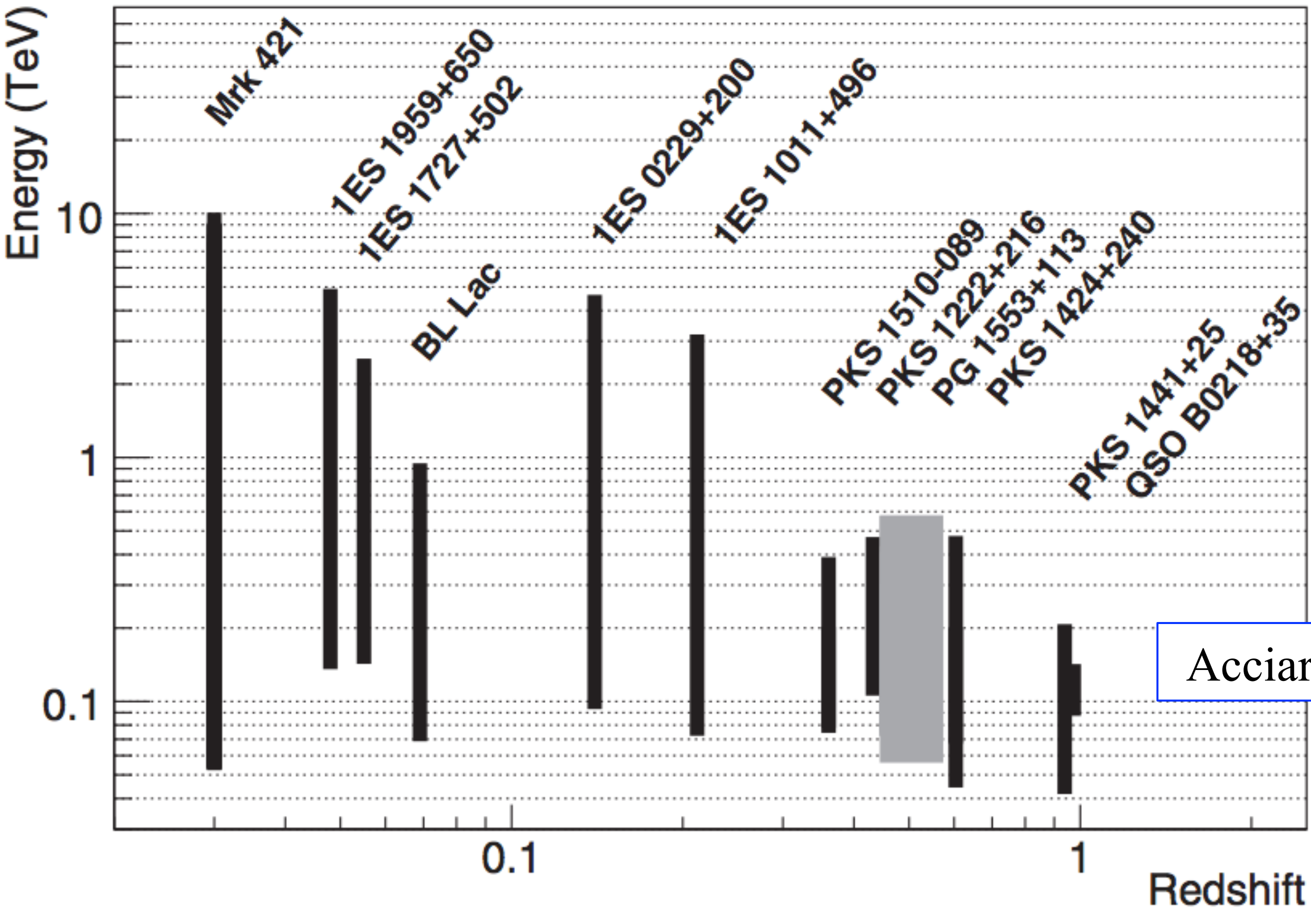

Aharonian et al. 2007
I(>200 GeV) [10^-9 cm^-2 s^-1]
Time - MJD53944.0 [min]
0
0.5
1
1.5
2
2.5
3
3.5
4
40
60
80
100
120

EBL measurements



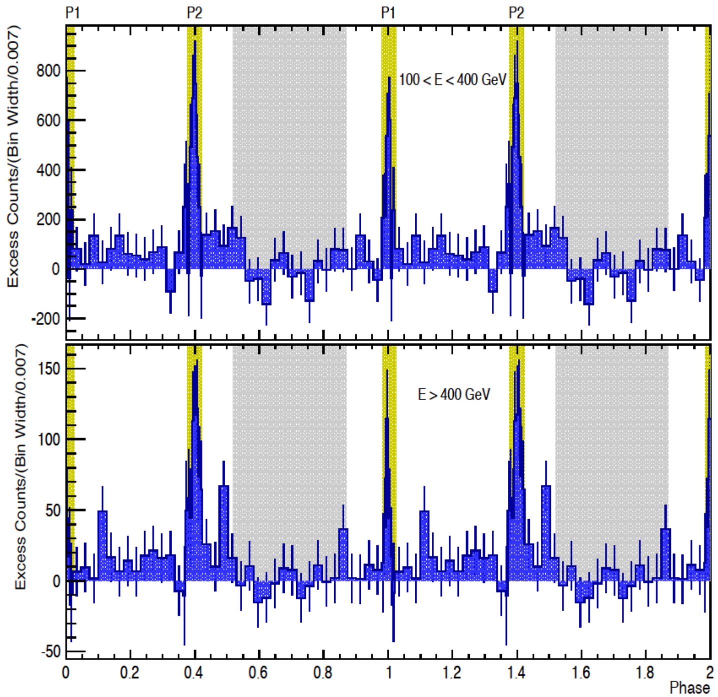
Ahnen et al 2016

EBL measurements

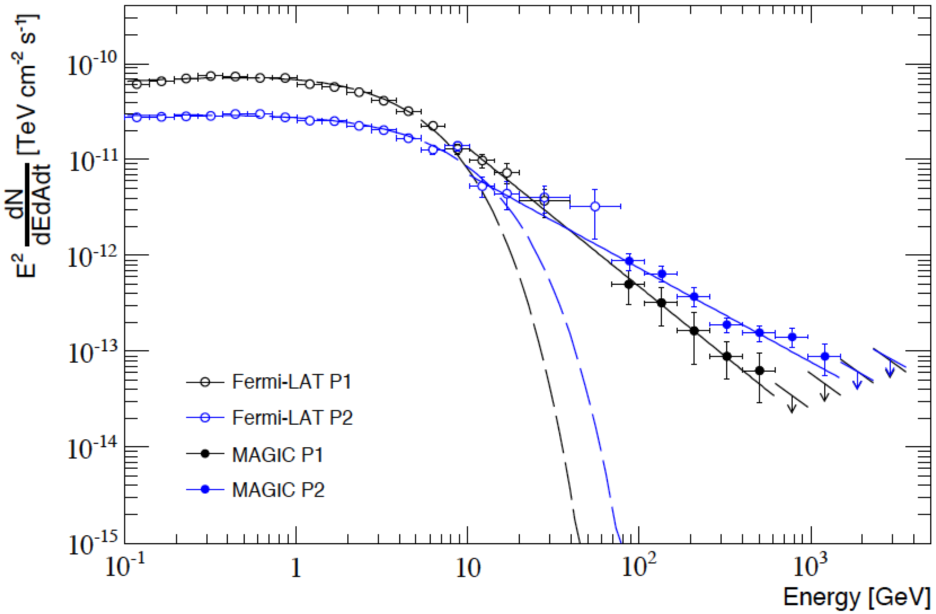


Acciari et al 2019

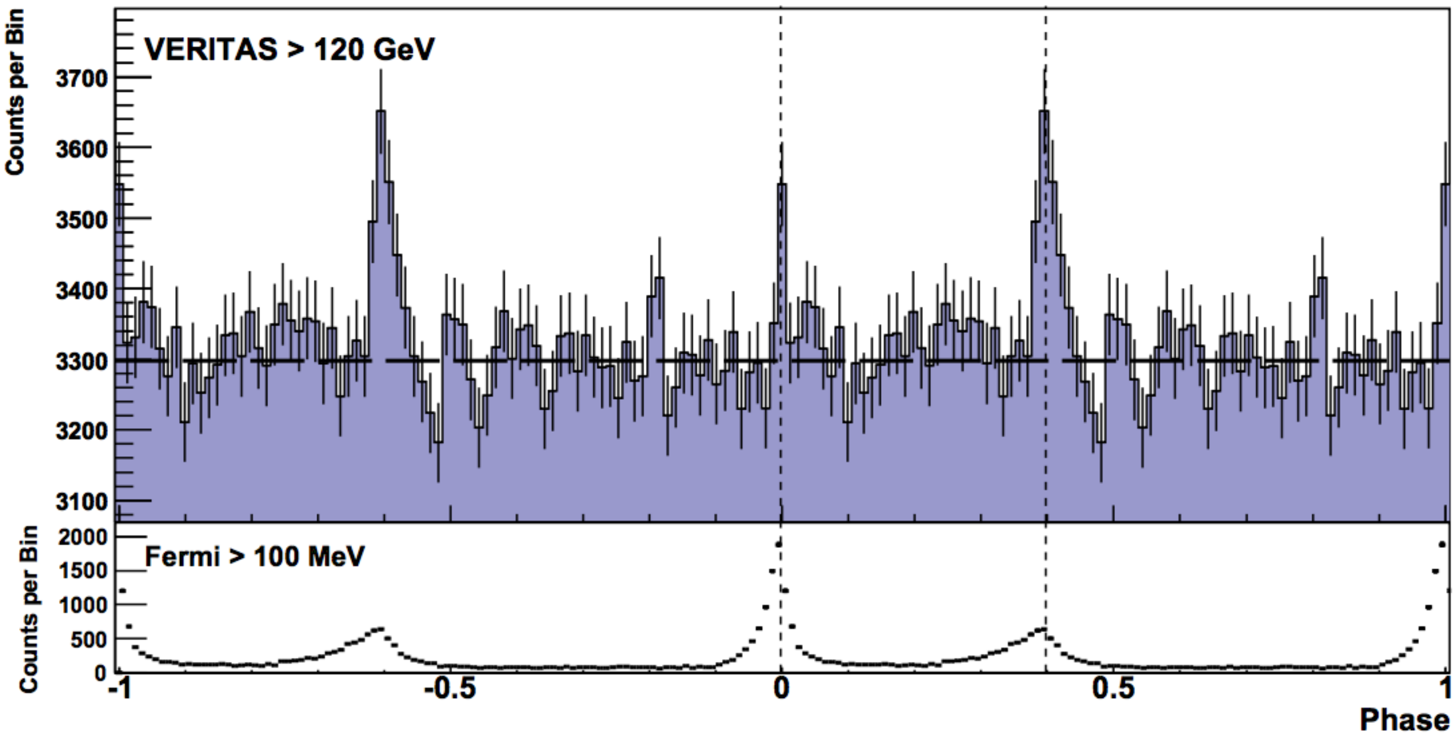
Pulsar physics with IACTs



Ansoldi et al. 2016



Pulsar physics with IACTs



Aliu et al. 2011

GRBs

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)

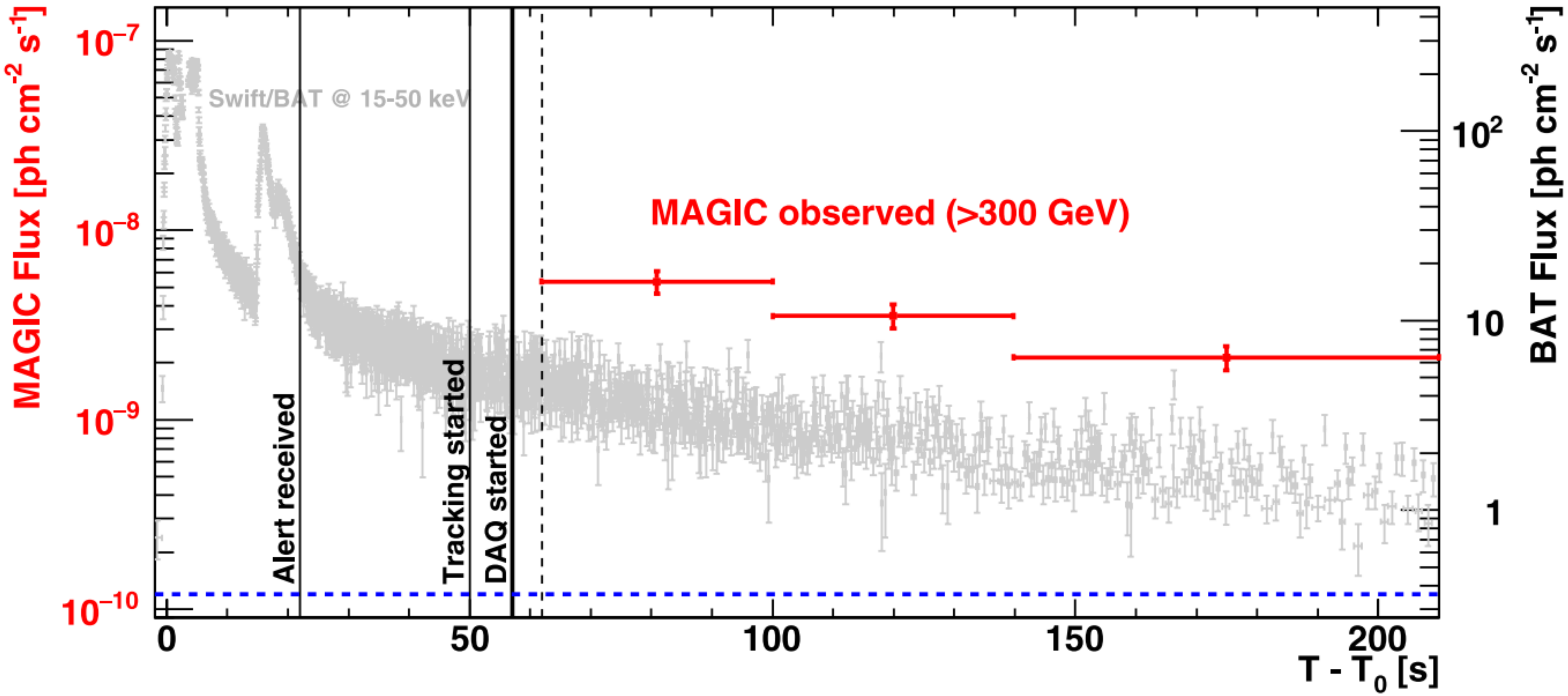
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

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.

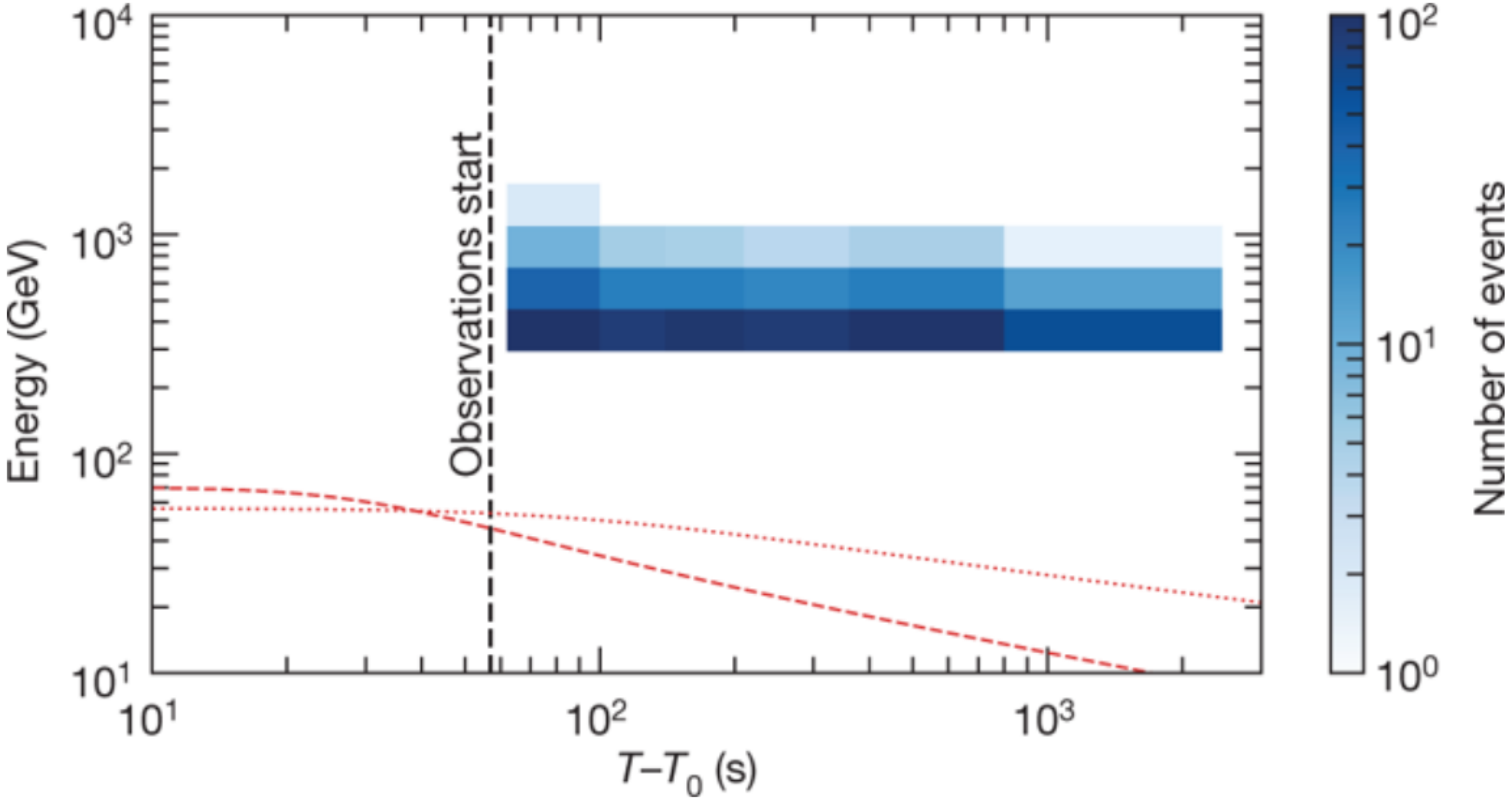
MAGIC detection



GRB 190114C

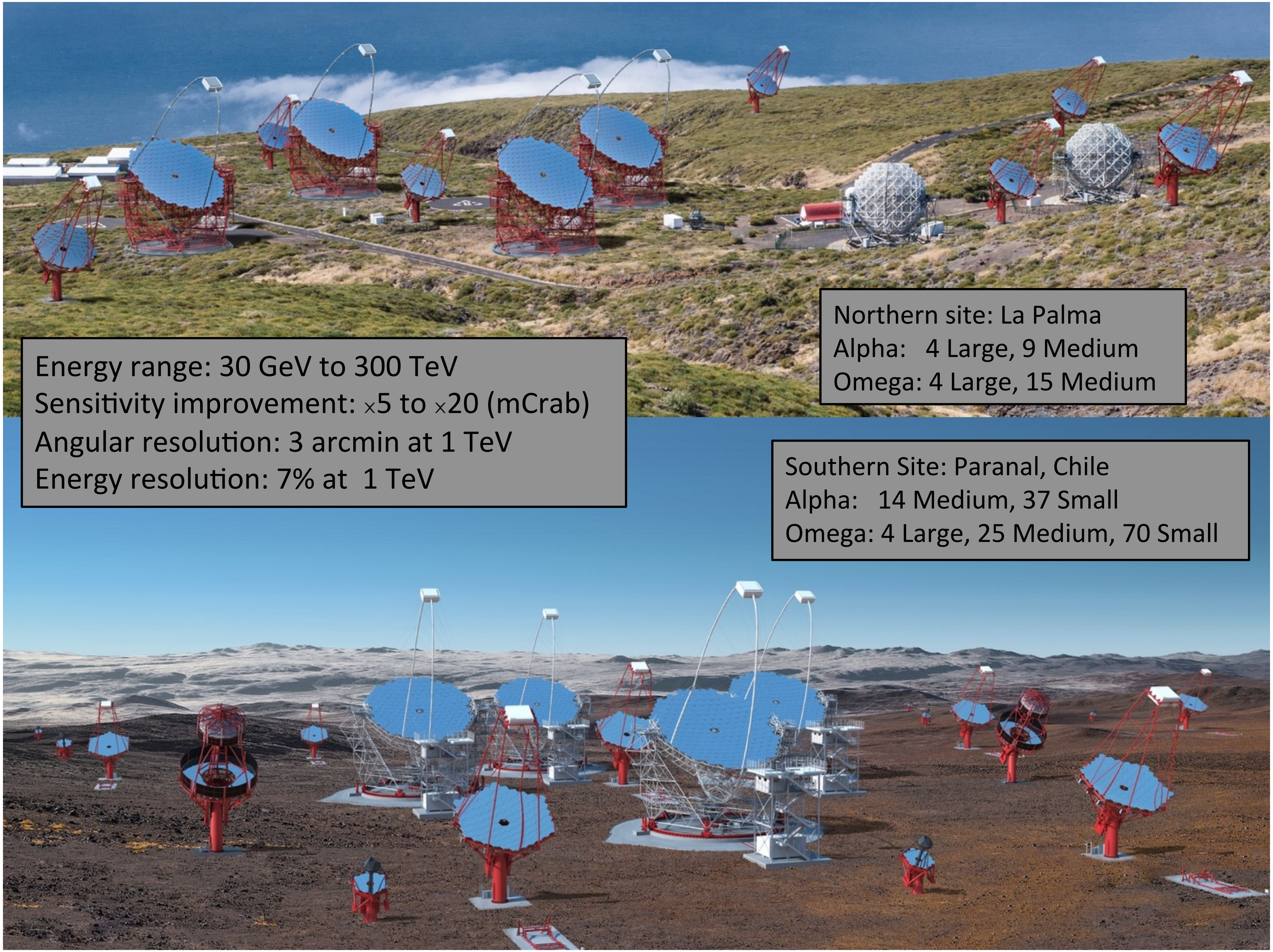
Acciari et al. 2019a

MAGIC detection



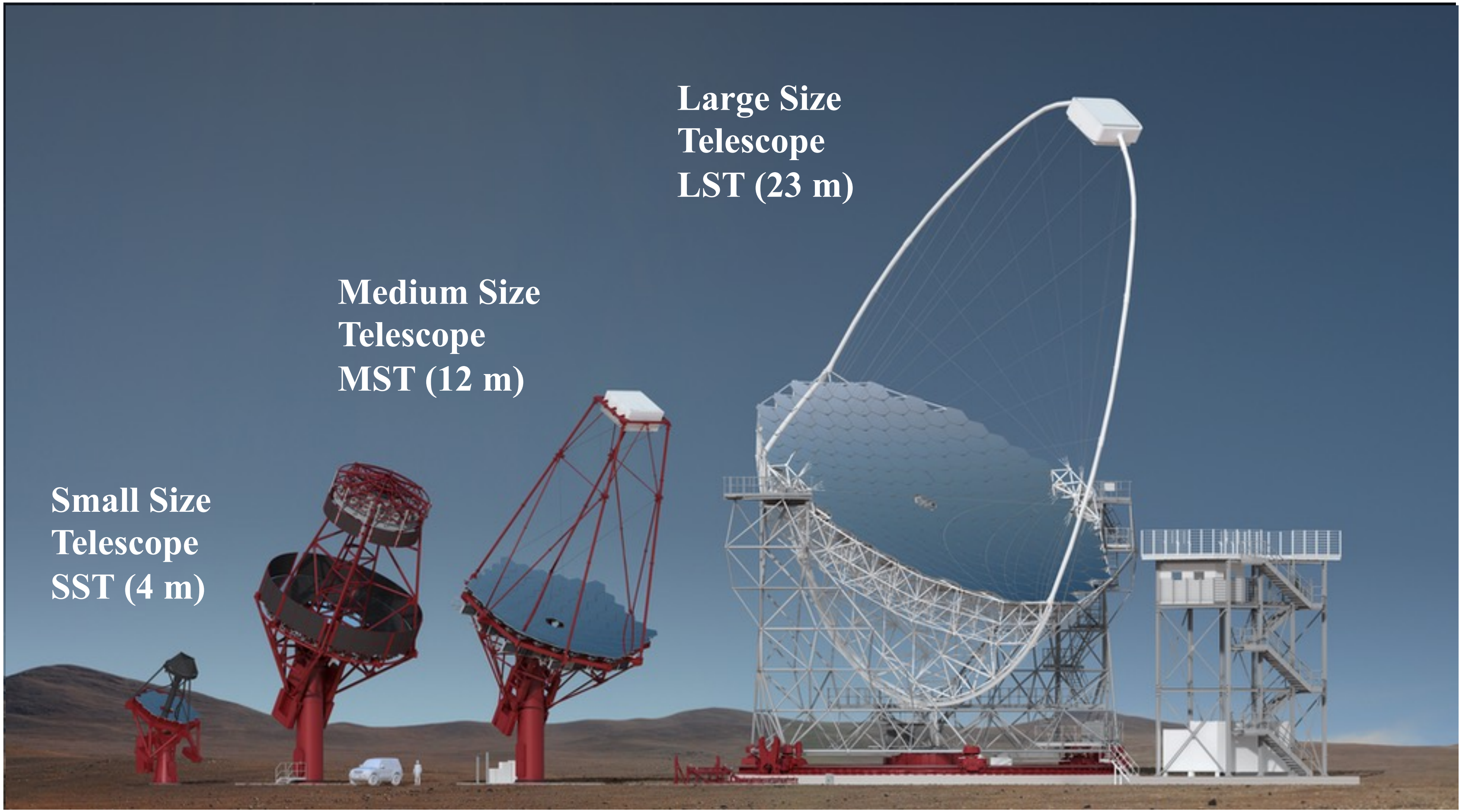
GRB 190114C

Acciari et al. 2019a

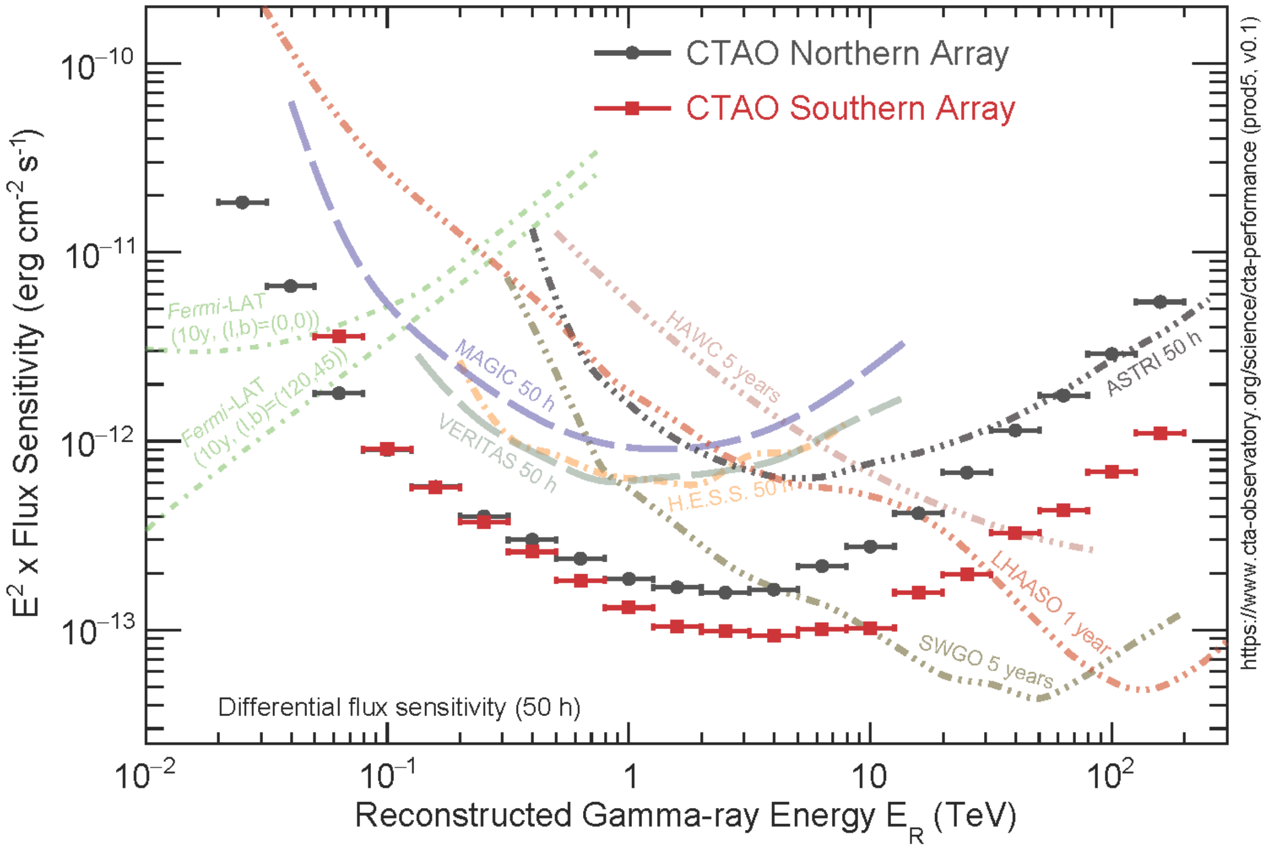

Northern site: La Palma
Alpha: 4 Large, 9 Medium
Omega: 4 Large, 15 Medium
Energy range: 30 GeV to 300 TeV
Sensitivity improvement: ×5 to ×20 (mCrab)
Angular resolution: 3 arcmin at 1 TeV
Energy resolution: 7% at 1 TeV
Southern Site: Paranal, Chile
Alpha: 14 Medium, 37 Small
Omega: 4 Large, 25 Medium,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

The CTA Telescopes

A Hybrid Observatory…



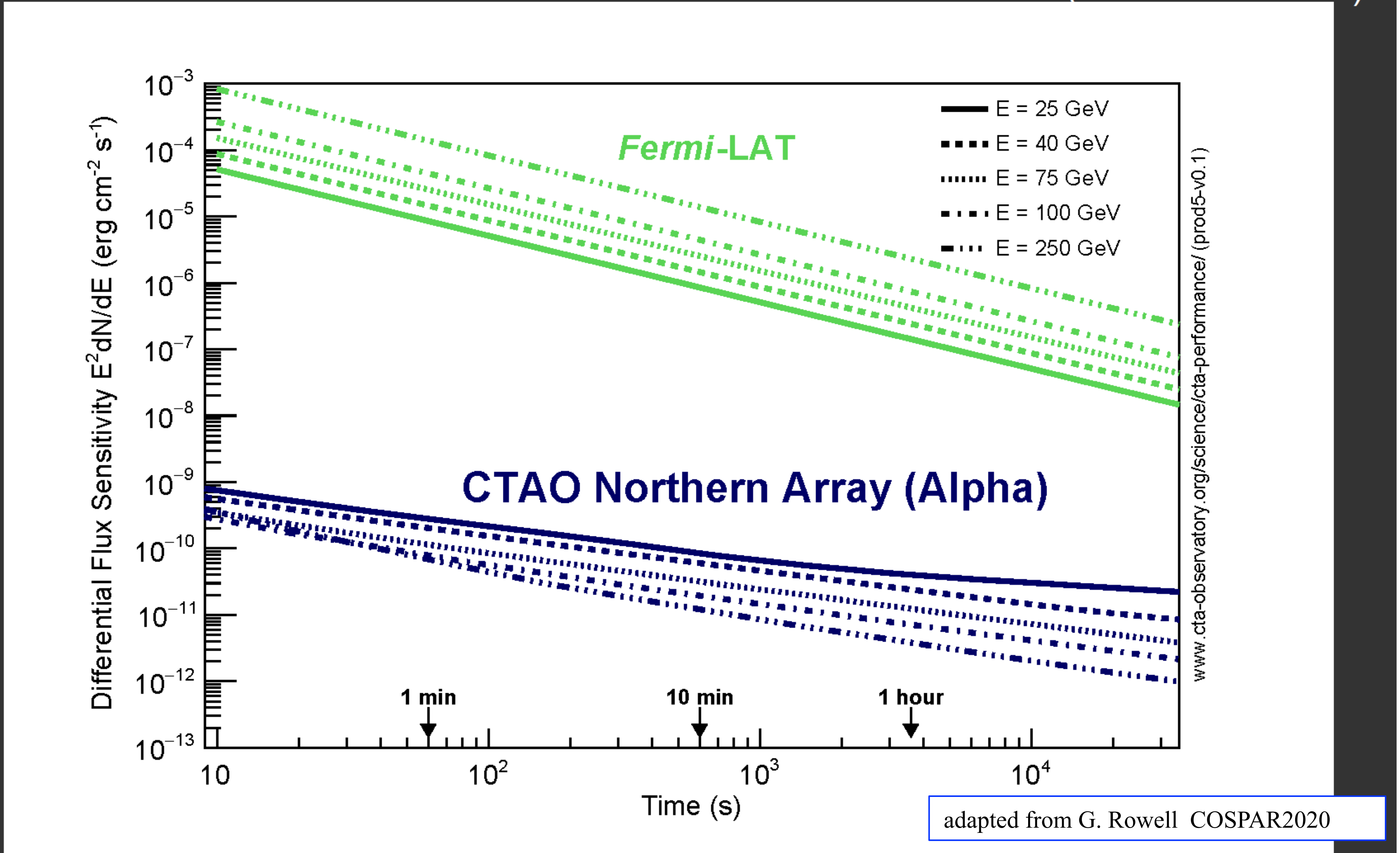
CTA performance



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

Transients & Variable Sources: CTA Sensitivity vs. Time

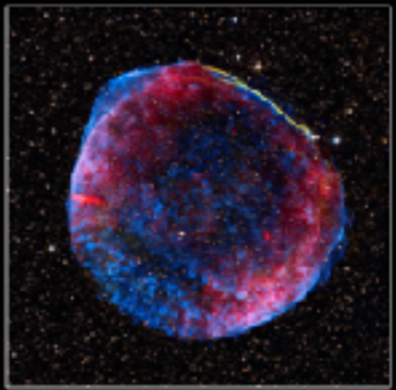
(CTA Collab 2019)

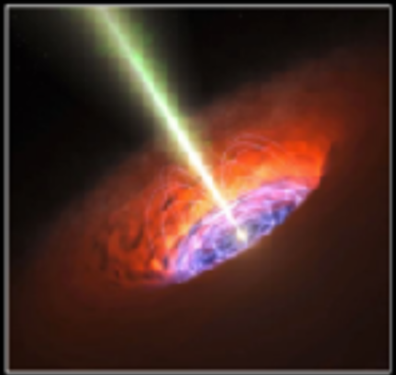


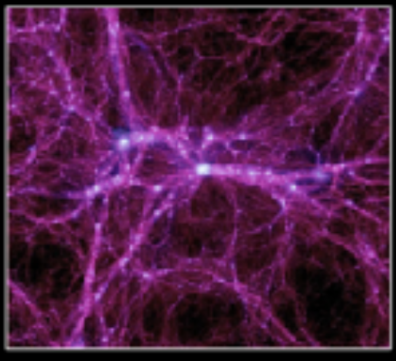
CTA >10,000 times more sensitive than Fermi-LAT in multi-GeV range

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

Astrophysics with IACTs







- **COSMIC PARTICLE ACCELERATION**

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

- **EXTREME ASTROPHYSICAL ENVIRONMENTS**

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

- **FUNDAMENTAL PHYSICS FRONTIERS**

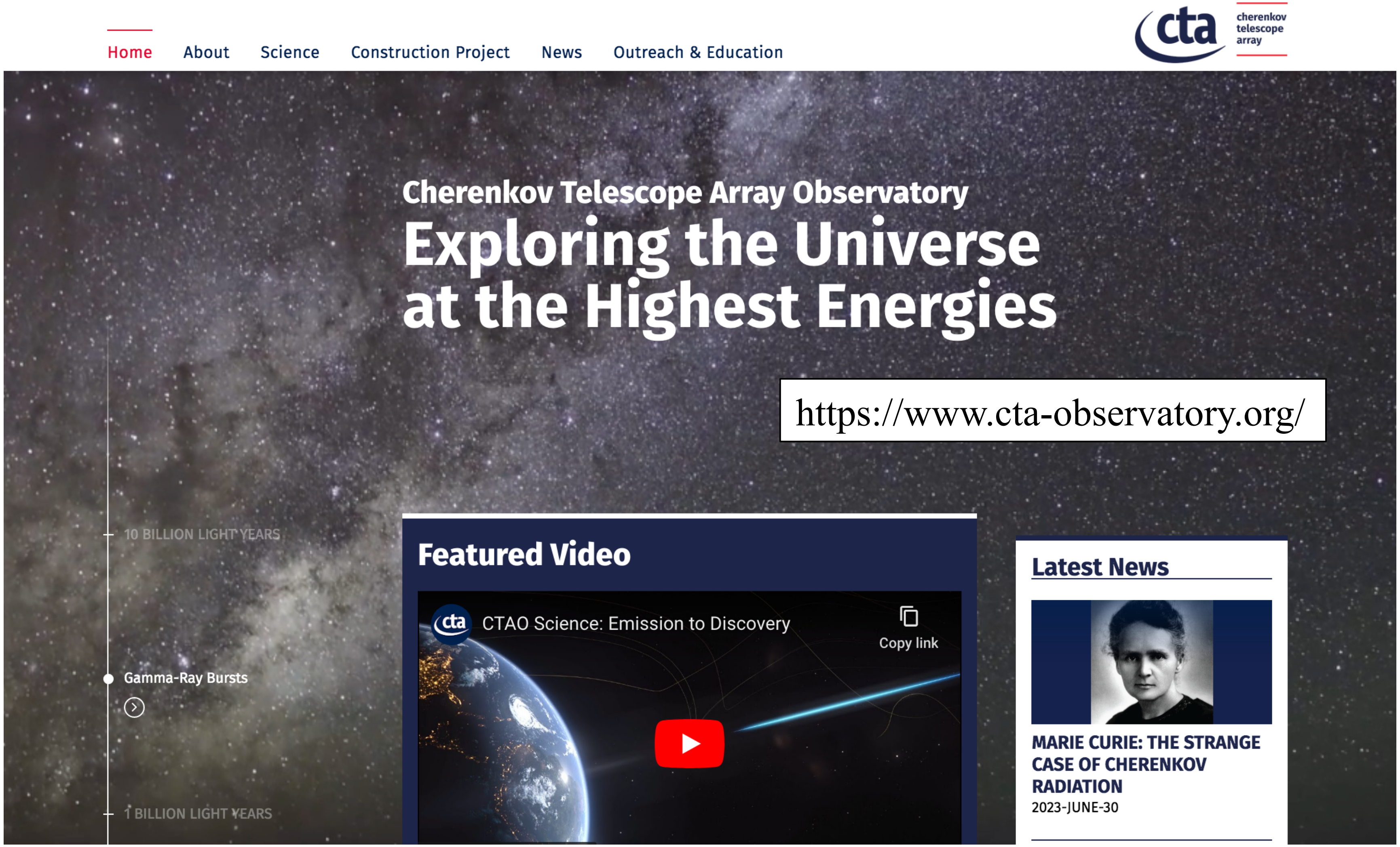
Probing the nature of Dark Matter, the existence of axion-like particles, and Lorentz invariance violation

Science with CTA

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

https://arxiv.org/abs/1709.07997

CTAO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2023-JUNE-30

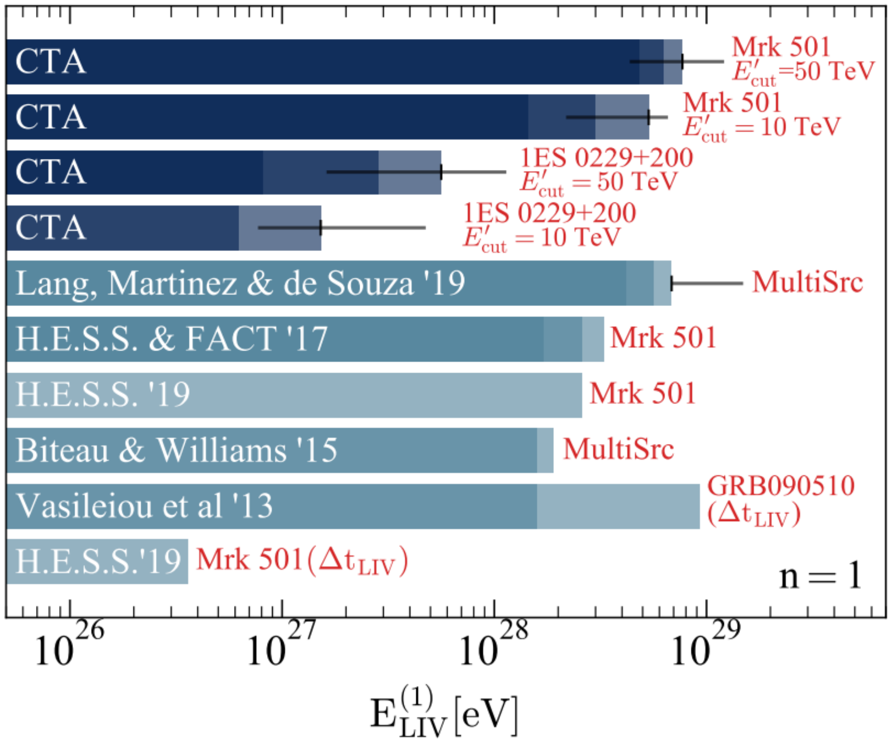
Cosmology and Fundamental Physics

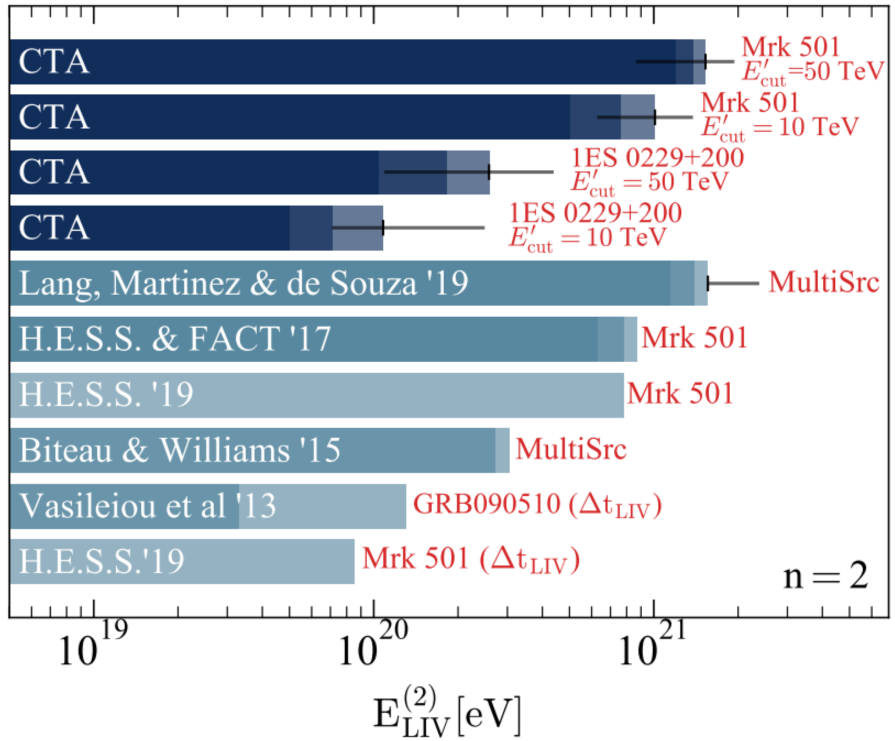
Sensitivity of the Cherenkov Telescope Array for probing cosmology and fundamental physics with gamma-ray propagation

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

https://arxiv.org/abs/2010.01349

Cosmology and Fundamental Physics



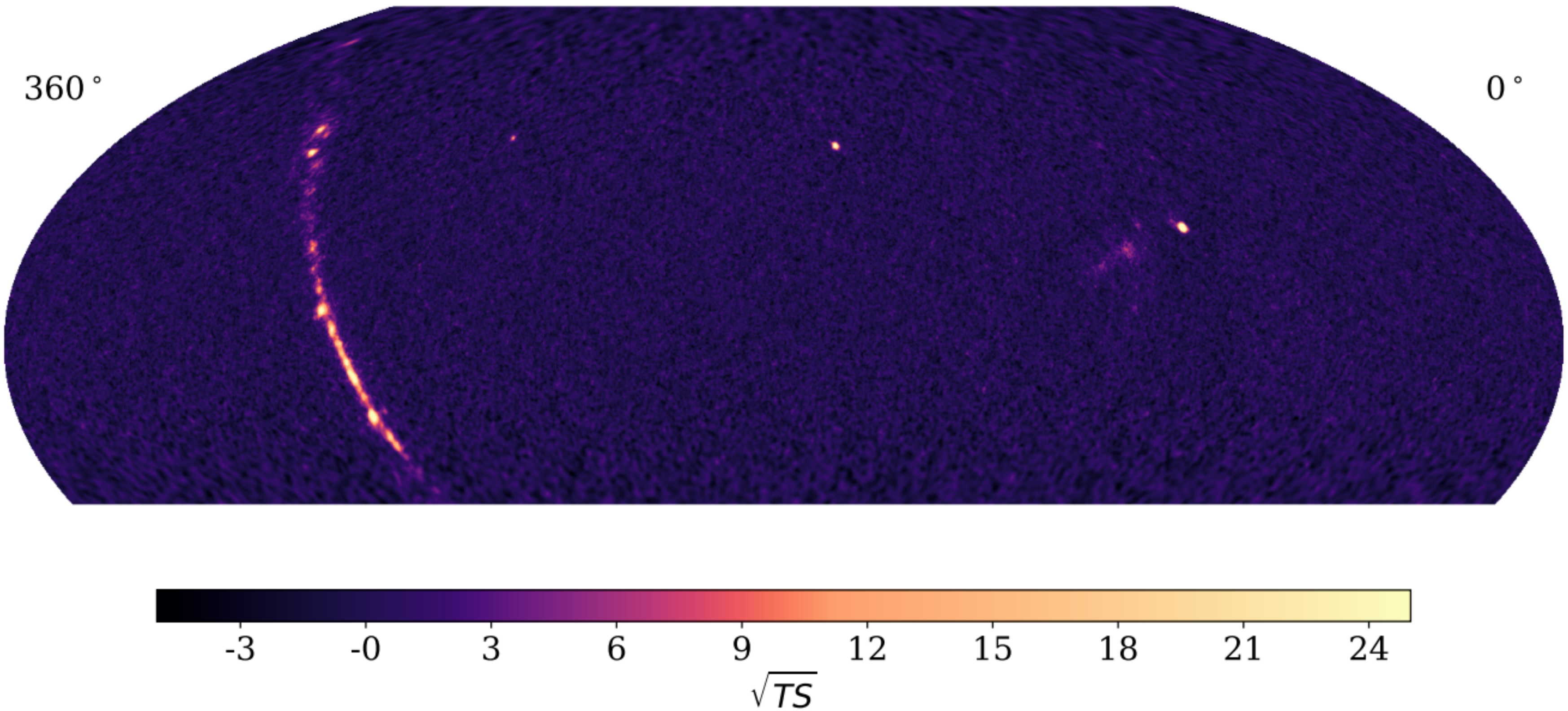


https://arxiv.org/abs/2010.01349

HAWC inauguration

HAWC Sky Survey

- **HAWC 3rd catalog of Gamma Ray sources**



Albert et al. 2021

HAWC

HAWC
High Altitude Water Cherenkov

HAWC Observatory | Publications | **Public Datasets** | Resources

- **Intro**
- 3HWC Survey
- Geminga Paper
- IC170922 neutrino followup
- Lightcurves
- SS-433
- Crab Dataset
- Crab Event Lists

Public Datasets

HAWC is a wide-field detector with an instantaneous field-of-view of nearly 2 sr and a daily exposure of more than 8 sr of the sky. HAWC is uniquely suited, in the multi-TeV band, for all-sky survey and detection of transients. One of the core goals of HAWC is public release of data to facilitate multi-wavelength, mult-messenger follow-up by other instruments.

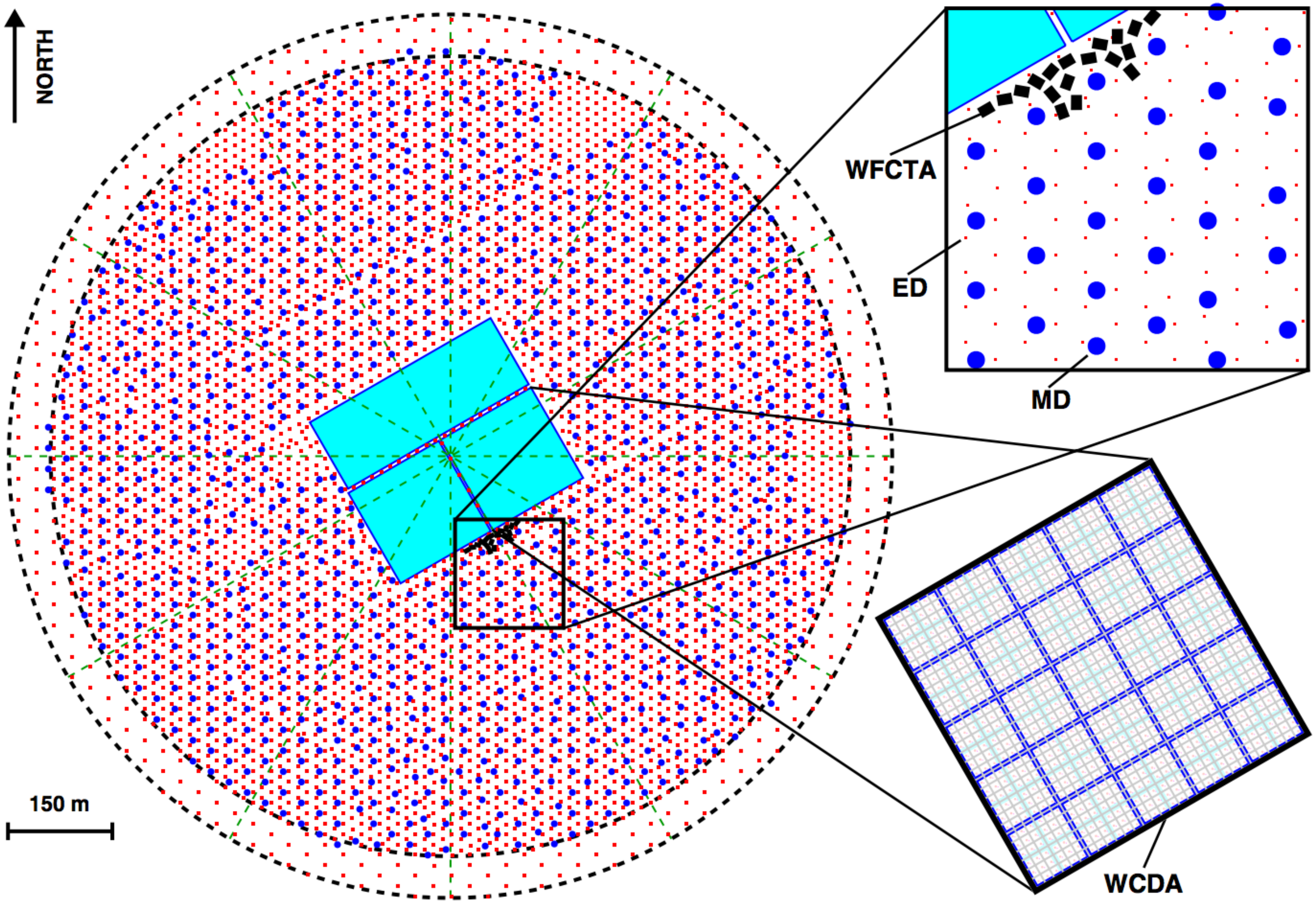
Other Data

Making the full HAWC dataset available is prohibitive. Analysis requires dedicated computing infrastructure and custom tools. Nevertheless, specific analyses of specific events or sky locations may be done with help from a member of the HAWC team. If the data you are interested in is not included in one of the public datasets, you can contact one of the relvant leaders of the HAWC working groups below who can facilitate your analysis.

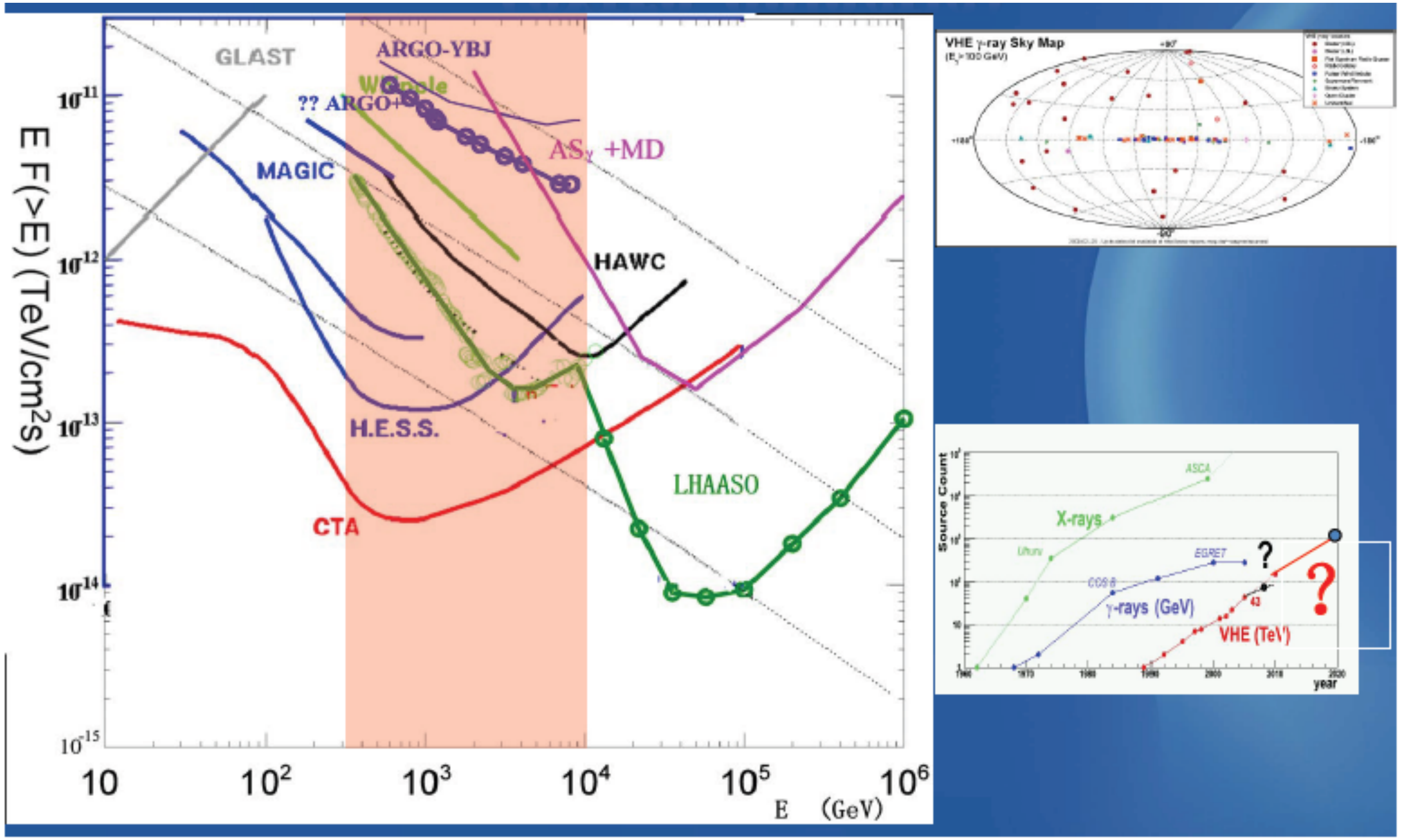
- Science Coordinator: Andrea Albert
- Galactic Cordinator: Kelly Malone
- Extra-galactic Astrophysics: Hugo Ayala
- Particle Physics: Mehr Un Nisa
- Cosmic-Ray Physics: Juan Carlos Arteaga

https://data.hawc-observatory.org/

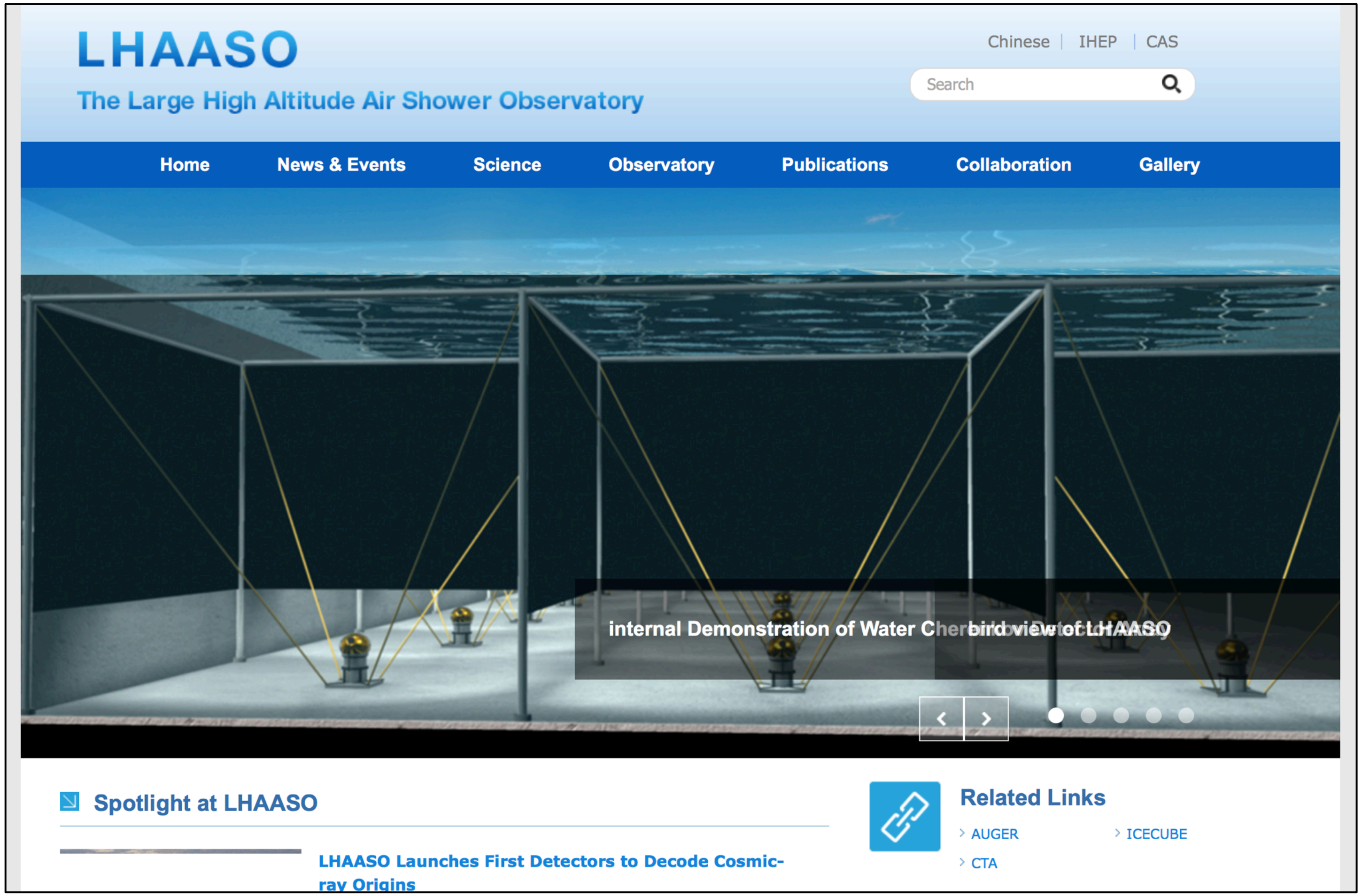
LHAASO



LHAASO

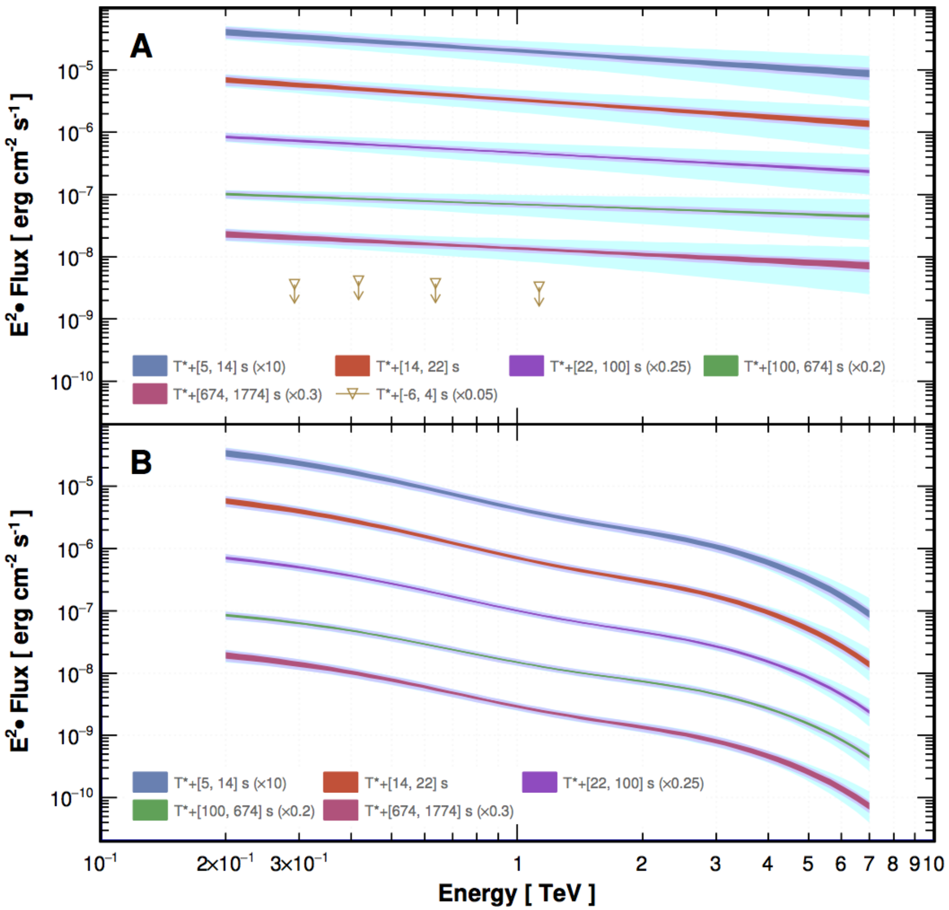

GLAST
ARGO-YBJ
Whipple
?? ARGO+
ASγ +MD
MAGIC
HAWC
H.E.S.S.
CTA
LHAASO
E F(>E) (TeV/cm²s)
E (GeV)
VHE γ-ray Sky Map
X-rays
γ-rays (GeV)
VHE (TeV)
Source Count
year

LHAASO



http://english.ihep.cas.cn/lhaaso/

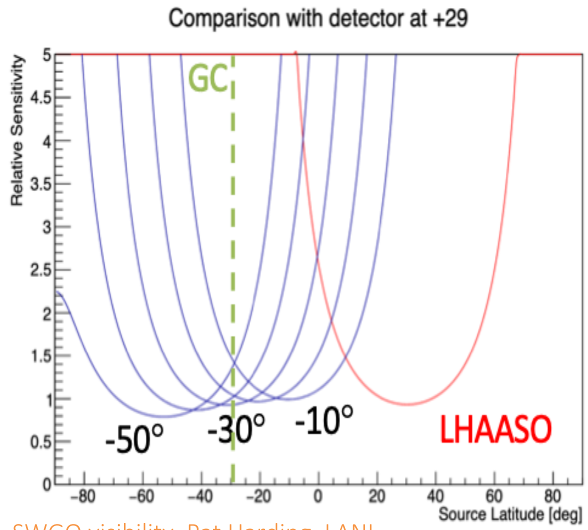
LHAASO GRB



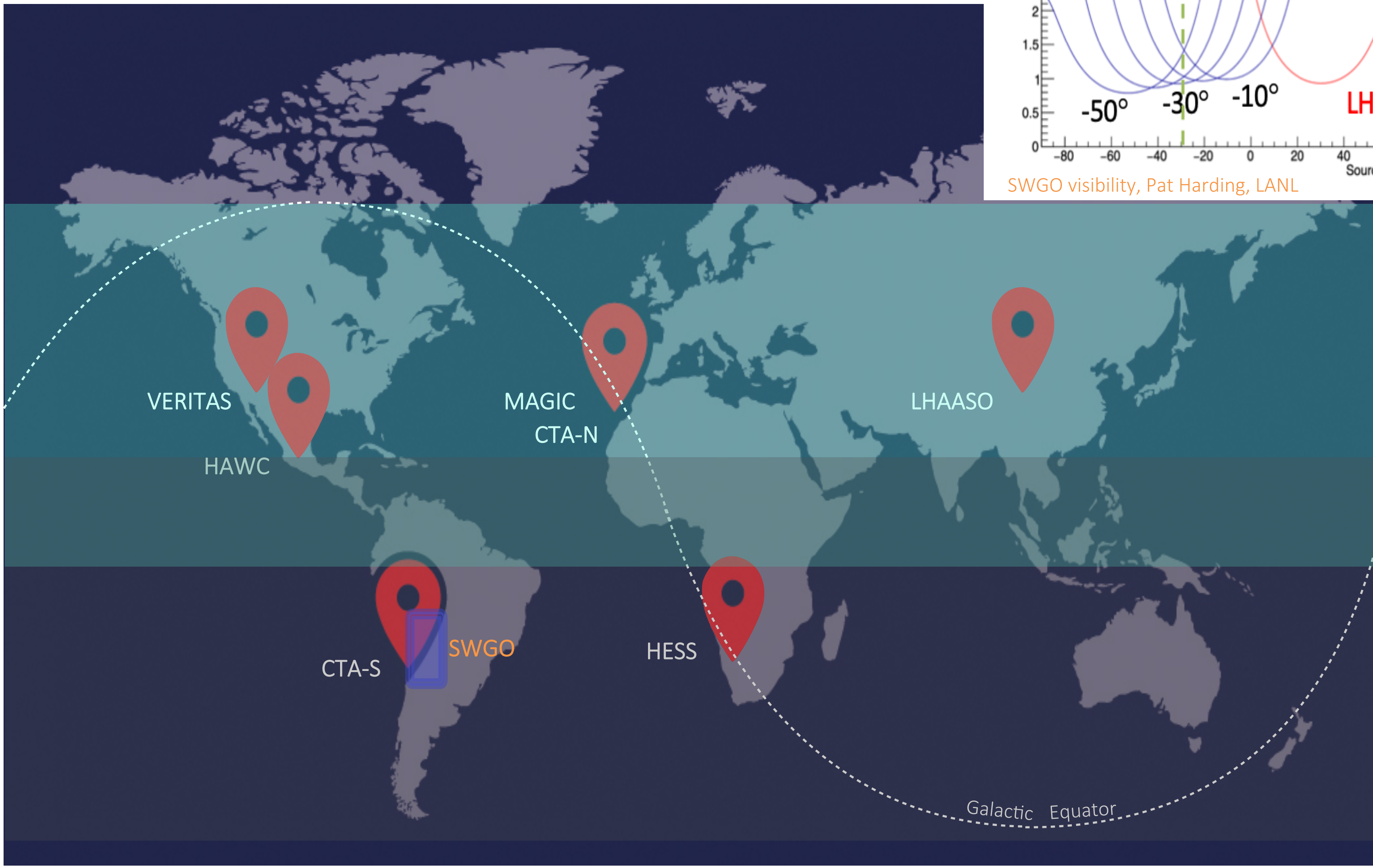
https://arxiv.org/abs/2306.06372

University of Trieste and INFN

Geographic distribu



SWGO visibility, Pat Harding, LANL



Examples of search of QG with the different types of sources

GRB with BATSE

A SEARCH IN GAMMA-RAY BURST DATA FOR NONCONSTANCY OF THE VELOCITY OF LIGHT

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V. A. MITSOU
Department of Physics, University of Athens, Panepistimioupolis Zografou GR 157 71 Athens, Greece; and Experimental Physics Division, CERN
AND
D. V. NANOPOULOS
Department of Physics, Texas A & M University, College Station, TX 77843-4242; Astroparticle Physics Group, Houston Advanced Research Center; and Academy of Athens, Chair of Theoretical Physics, Division of Natural Sciences

ABSTRACT

We discuss possible tests of the constancy of the velocity of light using distant astrophysical sources such as gamma-ray bursters (GRBs), active galactic nuclei (AGNs), and pulsars. This speculative quest may be motivated by some models of quantum fluctuations in the spacetime background, and we discuss explicitly how an energy-dependent variation in photon velocity $\delta c/c \sim -E/M$ arises in one particular quantum-gravitational model. We then discuss how data on GRBs may be used to set limits on variations in the velocity of light, which we illustrate using BATSE and OSSE observations of the GRBs that have recently been identified optically and for which precise redshifts are available. We show how a regression analysis can be performed to look for an energy-dependent effect that should correlate with redshift. The present data yield a limit $M \gtrsim 10^{15}$ GeV for the quantum gravity scale. We discuss the prospects for improving this analysis using future data, and how one might hope to distinguish any positive signal from astrophysical effects associated with the sources.

The Astrophysical Journal, Volume 535, Issue 1, pp. 139-151, 2000

GRB with Swift

Limits on quantum gravity effects from *Swift* short gamma-ray bursts

M. G. Bernardini[1,2], G. Ghirlanda[2], S. Campana[2], P. D'Avanzo[2], J.-L. Atteia[3,4], S. Covino[2], G. Ghisellini[2], A. Melandri[2], F. Piron[1], R. Salvaterra[5], and G. Tagliaferri[2]

ABSTRACT

The delay in arrival times between high and low energy photons from cosmic sources can be used to test the violation of the Lorentz invariance (LIV), predicted by some quantum gravity theories, and to constrain its characteristic energy scale E_{QG} that is of the order of the Planck energy. Gamma-ray bursts (GRBs) and blazars are ideal for this purpose thanks to their broad spectral energy distribution and cosmological distances: at first order approximation, the constraints on E_{QG} are proportional to the photon energy separation and the distance of the source. However, the LIV tiny contribution to the total time delay can be dominated by intrinsic delays related to the physics of the sources: long GRBs typically show a delay between high and low energy photons related to their spectral evolution (spectral lag). Short GRBs have null intrinsic spectral lags and are therefore an ideal tool to measure any LIV effect. We considered a sample of 15 short GRBs with known redshift observed by *Swift* and we estimate a limit on $E_{QG} \gtrsim 1.5 \times 10^{16}$ GeV. Our estimate represents an improvement with respect to the limit obtained with a larger (double) sample of long GRBs and is more robust than the estimates on single events because it accounts for the intrinsic delay in a statistical sense.

Key words. gamma-ray burst: general

A&A 607, A121 (2017)

GRBs in Fermi/LAT

Robust Constraint on Lorentz Violation Using *Fermi*-LAT Gamma-Ray Burst Data

John Ellis[a,b], Rostislav Konoplich[c,d], Nikolaos E. Mavromatos[a,e], Linh Nguyen[d], Alexander S. Sakharov[c,d,f], Edward K. Sarkisyan-Grinbaum[f,g],

Abstract

Models of quantum gravity suggest that the vacuum should be regarded as a medium with quantum structure that may have non-trivial effects on photon propagation, including the violation of Lorentz invariance. *Fermi* Large Area Telescope (LAT) observations of gamma-ray bursts (GRBs) are sensitive probes of Lorentz invariance, via studies of energy-dependent timing shifts in their rapidly-varying photon emissions. In this paper we analyze the *Fermi*-LAT measurements of high-energy gamma rays from GRBs with known redshifts, allowing for the possibility of energy-dependent variations in emission times at the sources as well as a possible non-trivial refractive index *in vacuo* for photons. We use statistical estimators based on the irregularity, kurtosis and skewness of bursts that are relatively bright in the 100 MeV to multi-GeV energy band to constrain possible dispersion effects during propagation. We find that the energy scale characterizing a linear energy dependence of the refractive index should exceed a few $\times 10^{17}$ GeV, and we estimate the sensitivity attainable with additional future sources to be detected by *Fermi*-LAT.

Physical Review D, Volume 99, Issue 8, id.083009, 2019

GRBs in Fermi/LAT

Constraints on Lorentz Invariance Violation from *Fermi*-Large Area Telescope Observations of Gamma-Ray Bursts

V. Vasileiou,[1,*] A. Jacholkowska,[2,†] F. Piron,[1] J. Bolmont,[2] C. Couturier,[2]
J. Granot,[3] F. W. Stecker,[4,5] J. Cohen-Tanugi,[1] and F. Longo[6,7]

We analyze the MeV/GeV emission from four bright Gamma-Ray Bursts (GRBs) observed by the *Fermi*-Large Area Telescope to produce robust, stringent constraints on a dependence of the speed of light *in vacuo* on the photon energy (vacuum dispersion), a form of Lorentz invariance violation (LIV) allowed by some Quantum Gravity (QG) theories. First, we use three different and complementary techniques to constrain the total degree of dispersion observed in the data. Additionally, using a maximally conservative set of assumptions on possible source-intrinsic spectral-evolution effects, we constrain any vacuum dispersion solely attributed to LIV. We then derive limits on the "QG energy scale" (the energy scale that LIV-inducing QG effects become important, $E_{\rm QG}$) and the coefficients of the Standard Model Extension. For the subluminal case (where high energy photons propagate more slowly than lower energy photons) and without taking into account any source-intrinsic dispersion, our most stringent limits (at 95% CL) are obtained from GRB 090510 and are $E_{\rm QG,1} > 7.6$ times the Planck energy ($E_{\rm Pl}$) and $E_{\rm QG,2} > 1.3 \times 10^{11}$ GeV for linear and quadratic leading order LIV-induced vacuum dispersion, respectively. These limits improve the latest constraints by *Fermi* and H.E.S.S. by a factor of ~ 2. Our results disfavor any class of models requiring $E_{\rm QG,1} \lesssim E_{\rm Pl}$.

Physical Review D, vol. 87, Issue 12, id. 122001 (2013)

GRBs in Fermi/LAT

Light speed variation from gamma-ray bursts

Haowei Xu[a], Bo-Qiang Ma[a,b,c,d,*]

Abstract

The effect of quantum gravity can bring a tiny light speed variation which is detectable through energetic photons propagating from gamma ray bursts (GRBs) to an observer such as the space observatory. Through an analysis of the energetic photon data of the GRBs observed by the Fermi Gamma-ray Space Telescope (FGST), we reveal a surprising regularity of the observed time lags between photons of different energies with respect to the Lorentz violation factor due to the light speed energy dependence. Such regularity suggests a linear form correction of the light speed $v(E) = c(1 - E/E_{\rm LV})$, where E is the photon energy and $E_{\rm LV} = (3.60 \pm 0.26) \times 10^{17}$ GeV is the Lorentz violation scale measured by the energetic photon data of GRBs. The results support an energy dependence of the light speed in cosmological space.

Astroparticle Physics, Volume 82, p. 72-76, 2016.

PSR in VHE detectors

Constraining Lorentz Invariance Violation Using the Crab Pulsar Emission Observed up to TeV Energies by MAGIC

(MAGIC Collaboration),
M. L. Ahnen[1], S. Ansoldi[2,3], L. A. Antonelli[4], C. Arcaro[5], A. Babić[6], B. Banerjee[7], P. Bangale[8], U. Barres de Almeida[8],
J. A. Barrio[9], J. Becerra González[10], W. Bednarek[11], E. Bernardini[12,13], A. Berti[14], W. Bhattacharyya[12], B. Biasuzzi[2],
A. Biland[1], O. Blanch[15], S. Bonnefoy[9], G. Bonnoli[16], R. Carosi[16], A. Carosi[4], A. Chatterjee[7], S. M. Colak[15], P. Colin[8],
. Colombo[10], J. L. Contreras[9], J. Cortina[15], S. Covino[4], P. Cumani[15], P. Da Vela[16], F. Dazzi[4], A. De Angelis[5], B. De Lotto[2],
. de Oña Wilhelmi[17], F. Di Pierro[5], M. Doert[18], A. Domínguez[9], D. Dominis Prester[6], D. Dorner[19], M. Doro[5], S. Einecke[18],
D. Eisenacher Glawion[19], D. Elsaesser[18], M. Engelkemeier[18], V. Fallah Ramazani[20], A. Fernández-Barral[15], D. Fidalgo[9],
M. V. Fonseca[9], L. Font[21], C. Fruck[8], D. Galindo[22], R. J. García López[10], M. Garczarczyk[12], D. Garrido[21], M. Gaug[21],
. Giammaria[4], N. Godinović[6], D. Gora[12], D. Guberman[15], D. Hadasch[3], A. Hahn[8], T. Hassan[15], M. Hayashida[3], J. Herrera[10],
J. Hose[8], D. Hrupec[6], T. Inada[3], K. Ishio[8], Y. Konno[3], H. Kubo[3], J. Kushida[3], D. Kuveždić[6], D. Lelas[6], E. Lindfors[20],
S. Lombardi[4], F. Longo[14], M. López[9], C. Maggio[21], P. Majumdar[7], M. Makariev[23], G. Maneva[23], M. Manganaro[10],
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. Noda[15], L. Nogués[15], S. Paiano[5], J. Palacio[15], D. Paneque[8], R. Paoletti[16], J. M. Paredes[22], G. Pedaletti[12], M. Peresano[2],
L. Perri[4], M. Persic[2,4], P. G. Prada Moroni[24], E. Prandini[5], I. Puljak[6], J. R. Garcia[8], I. Reichardt[5], W. Rhode[18], M. Ribó[22],
J. Rico[15], C. Righi[4], T. Saito[3], K. Satalecka[12], S. Schroeder[18], T. Schweizer[8], S. N. Shore[24], J. Sitarek[11], I. Šnidarić[6],
D. Sobczynska[11], A. Stamerra[4], M. Strzys[8], T. Surić[6], L. Takalo[20], F. Tavecchio[4], P. Temnikov[23], T. Terzić[6], D. Tescaro[5],
M. Teshima[3,8], D. F. Torres[25], N. Torres-Albà[22], A. Treves[2], G. Vanzo[10], M. Vazquez Acosta[10], I. Vovk[8], J. E. Ward[15],
M. Will[8], and D. Zarić[6]

ApJ Supplement Series, 232, 1, article id. 9, 17 pp. (2017).

Spontaneous breaking of Lorentz symmetry at energies on the order of the Planck energy or lower is predicted by many quantum gravity theories, implying non-trivial dispersion relations for the photon in vacuum. Consequently, gamma-rays of different energies, emitted simultaneously from astrophysical sources, could accumulate measurable differences in their time of flight until they reach the Earth. Such tests have been carried out in the past using fast variations of gamma-ray flux from pulsars, and more recently from active galactic nuclei and gamma-ray bursts. We present new constraints studying the gamma-ray emission of the galactic Crab Pulsar, recently observed up to TeV energies by the Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) collaboration. A profile likelihood analysis of pulsar events reconstructed for energies above 400 GeV finds no significant variation in arrival time as their energy increases. Ninety-five percent CL limits are obtained on the effective Lorentz invariance violating energy scale at the level of $E_{QG_1} > 5.5 \times 10^{17}$ GeV (4.5×10^{17} GeV) for a linear, and $E_{QG_2} > 5.9 \times 10^{10}$ GeV (5.3×10^{10} GeV) for a quadratic scenario, for the subluminal and the superluminal cases, respectively. A substantial part of this study is dedicated to calibration of the test statistic, with respect to bias and coverage properties. Moreover, the limits take into account systematic uncertainties, which are found to worsen the statistical limits by about 36%–42%. Our constraints would have been much more stringent if the intrinsic pulse shape of the pulsar between 200 GeV and 400 GeV was understood in sufficient detail and allowed inclusion of events well below 400 GeV.

AGN in VHE detectors

Probing quantum gravity using photons from a flare of the active galactic nucleus Markarian 501 observed by the MAGIC telescope

MAGIC Collaboration

J. Albert[a], E. Aliu[b], H. Anderhub[c], L.A. Antonelli[d], P. Antoranz[e], M. Backes[f], C. Baixeras[g], J.A. Barrio[e], H. Bartko[h], D. Bastieri[i], J.K. Becker[f], W. Bednarek[j], K. Berger[a], E. Bernardini[k], C. Bigongiari[i], A. Biland[c], R.K. Bock[h,i], G. Bonnoli[l], P. Bordas[m], V. Bosch-Ramon[m], T. Bretz[a], I. Britvitch[c], M. Camara[e], E. Carmona[h], A. Chilingarian[n], S. Commichau[c], J.L. Contreras[e], J. Cortina[b], M.T. Costado[o,p], S. Covino[d], V. Curtef[f], F. Dazzi[i], A. De Angelis[q], E. De Cea del Pozo[r], C. Delgado Mendez[o], R. de los Reyes[e], B. De Lotto[q], M. De Maria[q], F. De Sabata[q], A. Dominguez[s], D. Dorner[a], M. Doro[i], M. Errando[b], M. Fagiolini[l], D. Ferenc[t], E. Fernández[b], R. Firpo[b], M.V. Fonseca[e], L. Font[g], N. Galante[h], R.J. García López[o,p], M. Garczarczyk[h], M. Gaug[o], F. Goebel[h], M. Hayashida[h], A. Herrero[o,p], D. Höhne[a], J. Hose[h], C.C. Hsu[h], S. Huber[a], T. Jogler[h], D. Kranich[c], A. La Barbera[d], A. Laille[t], E. Leonardo[l], E. Lindfors[u], S. Lombardi[i], F. Longo[q], M. López[i], E. Lorenz[c,h], P. Majumdar[k], G. Maneva[v], N. Mankuzhiyil[q], K. Mannheim[a], L. Maraschi[d], M. Mariotti[i], M. Martínez[b], D. Mazin[b], M. Meucci[l], M. Meyer[a], J.M. Miranda[e], R. Mirzoyan[h], M. Moles[s], A. Moralejo[b], D. Nieto[e], K. Nilsson[u], J. Ninkovic[h], N. Otte[h,w,1], I. Oya[e], M. Panniello[o,✠], R. Paoletti[l], J.M. Paredes[m], M. Pasanen[u], D. Pascoli[i], F. Pauss[c], R.G. Pegna[l], M.A. Perez-Torres[s], M. Persic[q,x], L. Peruzzo[i], A. Piccioli[l], F. Prada[s], E. Prandini[i], N. Puchades[b], A. Raymers[n], W. Rhode[f], M. Ribó[m], J. Rico[y,b], M. Rissi[c], A. Robert[g], S. Rügamer[a], A. Saggion[i], T.Y. Saito[h], M. Salvati[d], M. Sanchez-Conde[s], P. Sartori[i], K. Satalecka[k], V. Scalzotto[i], V. Scapin[q], R. Schmitt[a], T. Schweizer[h], M. Shayduk[h], K. Shinozaki[h], N. Sidro[b], A. Sierpowska-Bartosik[r], A. Sillanpää[u], D. Sobczynska[j], F. Spanier[a], A. Stamerra[l], L.S. Stark[c], L. Takalo[u], F. Tavecchio[d], P. Temnikov[v], D. Tescaro[b], M. Teshima[h], M. Tluczykont[k], D.F. Torres[y,r], N. Turini[l], H. Vankov[v], A. Venturini[i], V. Vitale[q], R.M. Wagner[h,*], W. Wittek[h], V. Zabalza[m], F. Zandanel[s], R. Zanin[b], J. Zapatero[g]

and

John Ellis[z], N.E. Mavromatos[aa], D.V. Nanopoulos[ab,ac,ad], A.S. Sakharov[c,z], E.K.G. Sarkisyan[z,ae,2]

Physics Letters B 668, 4, 2008, 253-257

A B S T R A C T

We analyze the timing of photons observed by the MAGIC telescope during a flare of the active galactic nucleus Mkn 501 for a possible correlation with energy, as suggested by some models of quantum gravity (QG), which predict a vacuum refractive index $\simeq 1 + (E/M_{QGn})^n$, $n = 1, 2$. Parametrizing the delay between γ-rays of different energies as $\Delta t = \pm\tau_l E$ or $\Delta t = \pm\tau_q E^2$, we find $\tau_l = (0.030 \pm 0.012)$ s/GeV at the 2.5-σ level, and $\tau_q = (3.71 \pm 2.57) \times 10^{-6}$ s/GeV^2, respectively. We use these results to establish lower limits $M_{QG1} > 0.21 \times 10^{18}$ GeV and $M_{QG2} > 0.26 \times 10^{11}$ GeV at the 95% C.L. Monte Carlo studies confirm the MAGIC sensitivity to propagation effects at these levels. Thermal plasma effects in the source are negligible, but we cannot exclude the importance of some other source effect.

AGN spectra in VHE detectors

LORENTZ INVARIANCE VIOLATION EFFECTS ON GAMMA-GAMMA ABSORPTION AND COMPTON SCATTERING

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ABSTRACT

In this paper, we consider the impact of Lorentz Invariance Violation (LIV) on the $\gamma - \gamma$ opacity of the Universe to VHE-gamma rays, compared to the effect of local under-densities (voids) of the Extragalactic Background Light, and on the Compton scattering process. Both subluminal and superluminal modifications of the photon dispersion relation are considered. In the subluminal case, LIV effects may result in a significant reduction of the $\gamma - \gamma$ opacity for photons with energies $\gtrsim 10$ TeV. However, the effect is not expected to be sufficient to explain the apparent spectral hardening of several observed VHE γ-ray sources in the energy range from 100 GeV – a few TeV, even when including effects of plausible inhomogeneities in the cosmic structure. Superluminal modifications of the photon dispersion relation lead to a further enhancement of the EBL $\gamma\gamma$ opacity. We consider, for the first time, the influence of LIV on the Compton scattering process. We find that this effect becomes relevant only for photons at ultra-high energies, $E \gtrsim 1$ PeV. In the case of a superluminal modification of the photon dispersion relation, both the kinematic recoil effect and the Klein-Nishina suppression of the cross section are reduced. However, we argue that the effect is unlikely to be of astrophysical significance.

ApJ, 865, 159, 2019

GRB with VHE detectors

Bounds on Lorentz Invariance Violation from MAGIC Observation of GRB 190114C

On January 14, 2019, the Major Atmospheric Gamma Imaging Cherenkov telescopes detected GRB 190114C above 0.2 TeV, recording the most energetic photons ever observed from a gamma-ray burst. We use this unique observation to probe an energy dependence of the speed of light in vacuo for photons as predicted by several quantum gravity models. Based on a set of assumptions on the possible intrinsic spectral and temporal evolution, we obtain competitive lower limits on the quadratic leading order of speed of light modification.

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GRBs at VHE

Light speed variation from GRB 221009A

Jie Zhu[a], Bo-Qiang Ma[a,b,c,*]

Abstract

It is postulated in Einstein's relativity that the speed of light in vacuum is a constant for all observers. However, the effect of quantum gravity could bring an energy dependence of light speed, and a series of studies on high-energy photon events from gamma-ray bursts (GRBs) and active galactic nuclei (AGNs) suggest a light speed variation $v(E) = c\,(1 - E/E_{\mathrm{LV}})$ with $E_{\mathrm{LV}} = 3.6 \times 10^{17}$ GeV or a bound $E_{\mathrm{LV}} \geq 3.6 \times 10^{17}$ GeV. From the newly observed gamma-ray burst GRB 221009A, we find that a 99.3 GeV photon detected by Fermi-LAT is coincident with the sharp spike in the light curves detected by both Fermi-GBM and HEBS under the above scenario of light speed variation, suggesting an option that this high-energy photon was emitted at the same time as a sharp spike of low-energy photon emission at the GRB source. Thus this highest energy photon event detected by Fermi-LAT during the prompt emission of gamma-ray bursts might be considered as an optional signal for the linear form modification of light speed in cosmological space.

Journal of Physics G: Nuclear and Particle Physics, Volume 50, Issue 6, id.06LT01

GRBs at VHE

Revisiting Lorentz invariance violation from GRB 221009A

Hao Li[1,*] and Bo-Qiang Ma[1,2,3,†]

As a potential consequence of Lorentz invariance violation (LIV), threshold anomalies open a window to study LIV. Recently the Large High Altitude Air Shower (LHAASO) observatory reported that more than 5000 photons from GRB 221009A have been observed with energies above 500 GeV and up to 18 TeV. In the literature, it is suggested that this observation may have tension with the standard model result because extragalactic background light (EBL) can prevent photons around 18 TeV photons from reaching the earth and that LIV induced threshold anomalies might be able to explain the observation. In this work we further study this proposal with more detailed numerical calculation for different LIV scales and redshifts of the sources. We find that GRB 221009A is a rather unique opportunity to search LIV, and a LIV scale $E_{\rm LIV} \lesssim E_{\rm Planck} \approx 1.22 \times 10^{19}$ GeV is feasible to the observation of GRB 221009A on 9 October, 2022.

eprint arXiv:2306.02962

Take home messages

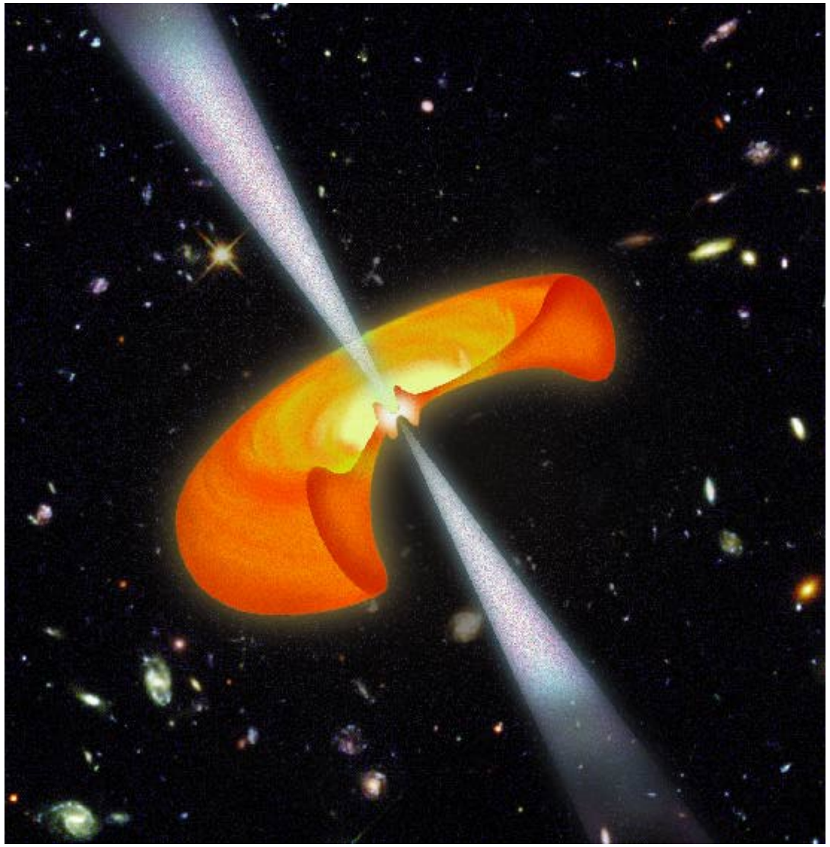
If dispersion were to be detected it would need to be present in a wide variety of sources to be sure it was due to LIV.

object	fast	far	High Energy	comments
GRBs	Y	Y	GeV + TeV	serendipity required
AGN flares	Y	N	TeV	still serendipitous, but know where to look
AGN Monitoring	N	Y	TeV	good redshift coverage
gamma-ray horizon	N	-	TeV++	hard spectrum AGN required
pulsars	Y	N	?	better for higher order effects

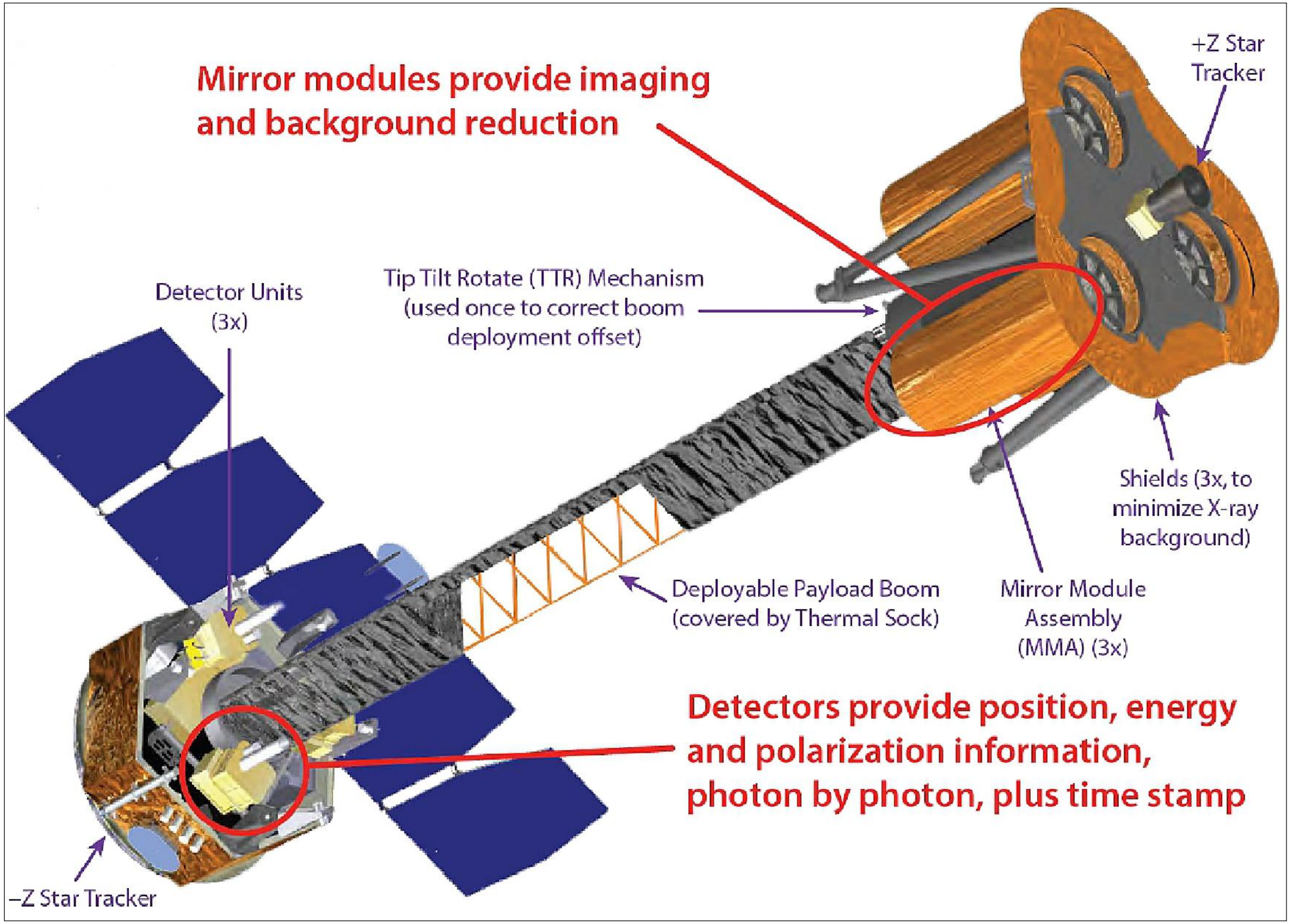
Daniel – NOW 2014

Outline

- HE and VHE gamma astrophysics
  - Introduction to Gamma Astrophysics
  - Few Science Topics
  - Experiment types
- MeV Gamma Ray experiments
  - BATSE - Swift/BAT - Fermi GBM – AGILE/MCAL
  - GRB physics
  - eASTROGAM - HERMES
- GeV Gamma Ray experiments
  - AGILE/GRID – Fermi/LAT
  - PSR physics
- TeV gamma Astrophysics
  - MAGIC, HESS, VERITAS
  - HAWC – LHAASO
  - AGN physics
  - CTAO – SWGO
- Quantum Gravity searches
  - GRB , PSR, AGN …
  - Other channels ? What about polarimetry -- IXPE?



IXPE – Xray polarimetry



Conclusions

- At the dawn of Quantum Gravity Phenomenology
- The future of GeV experiments !
- Joint work of theoreticians and experimental physicists