An intergalactic magnetic field strength of 4×10^{-17} G inferred with GRB 221009A

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Intergalactic magnetic field (IGMF)

- The IGMF is a fundamental physical quantity broadly connects with many cosmological and astrophysical problems

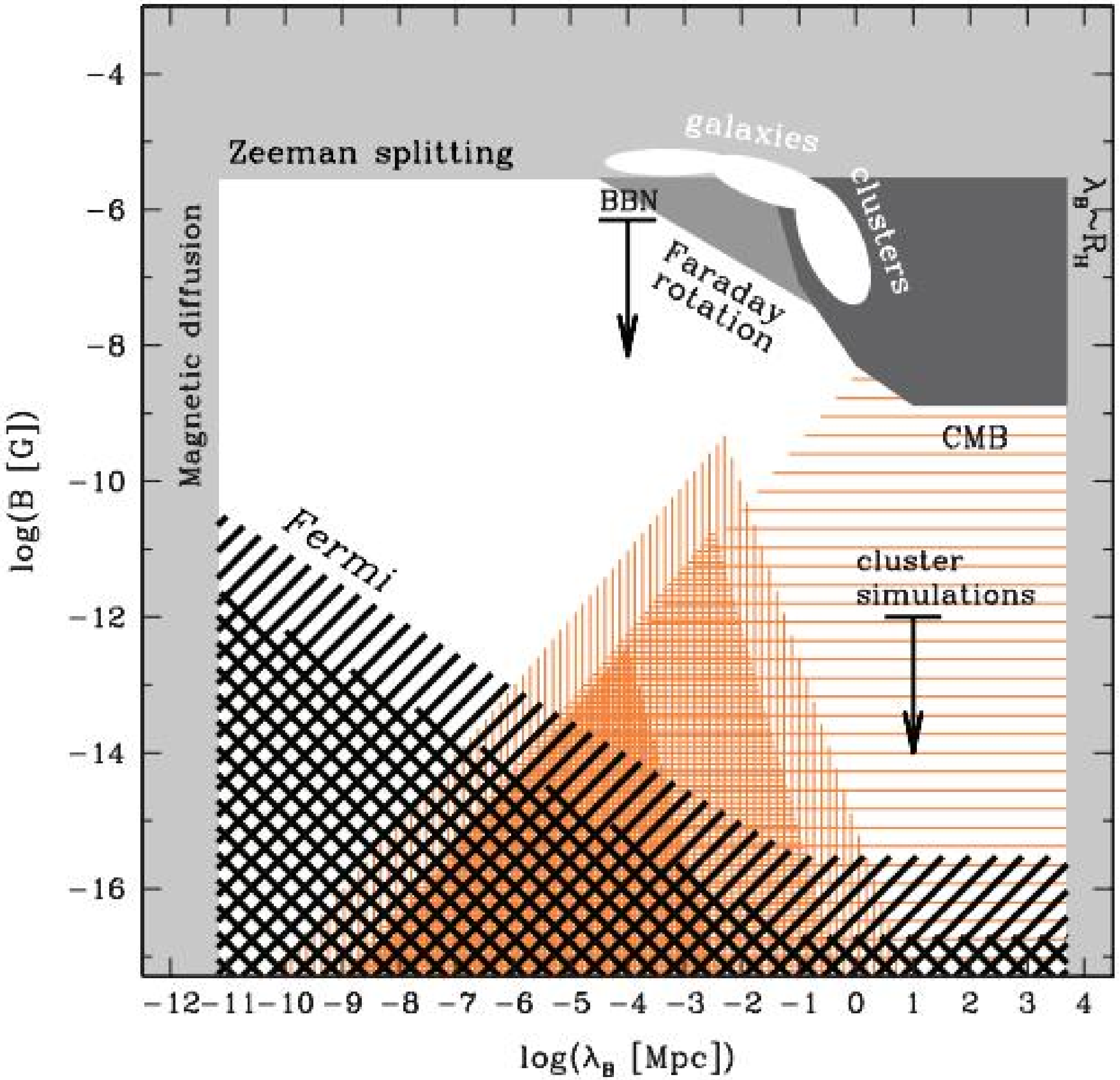
- The IGMF could be the seed magnetic field for galaxies and cluster of galaxies

- The IGMF affects the propagation of extragalactic ultrahigh energy photons and cosmic rays

- The IGMF affects also the detection of dark matter such as ALPs

The detection of IGMF is challenging, and only lower or upper limits were set.

Constraints on IGMF



2010, Science, 328, 73; 2013, A&AR, 21, 62

- Faraday rotation of linearly polarized radio emission
- Angular power spectrum, spectral distorsion, polarization of CMB
- Gravitational waves from magnetic stresses
- Deflection of ultra-high energy cosmic rays
- Cascade of very-high energy photons

IGMF with extragalactic gamma-rays

LETTERS TO NATURE

Detecting intergalactic magnetic fields using time delays in pulses of γ-rays

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INTERGALACTIC magnetic fields (IGMFs) can be produced by a number of mechanisms, but are expected to be weak and have not so far been detected. 'Primordial' magnetic fields might have been produced in the very early Universe, either by quantum fluctuations during the 'inflationary' period[1,2] or through the decoupling transitions of the fundamental forces[3,4]. The much later ejection of magnetized plasma into intergalactic space from galaxies and active galactic nuclei should also produce IGMFs, though it is possible that some fraction of the Universe retains its 'primordial' field[5]. Previous studies[6] have placed an upper limit of 10^{-9} gauss on the strength of an IGMF (with a coherence length of 1 Mpc), but the strength may be much less than this, posing a formidable challenge to current observational capabilities. Here I propose a highly sensitive method for probing weak IGMFs by exploiting their effect on the arrival times of γ-rays from extragalactic sources. The delay in arrival owing to the action of intergalactic magnetic fields on electron cascades caused by scattering of the γ-ray photons might be used to measure fields as weak as 10^{-24} gauss. I suggest that this effect may already have been seen in the arrival times of high-energy photons after the main burst of a γ-ray burster[7].

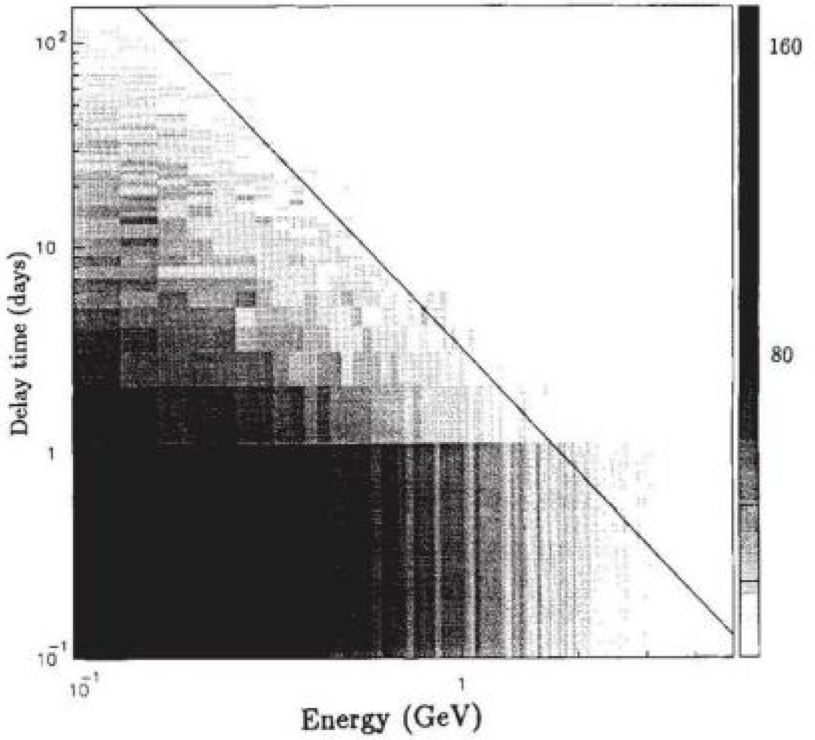
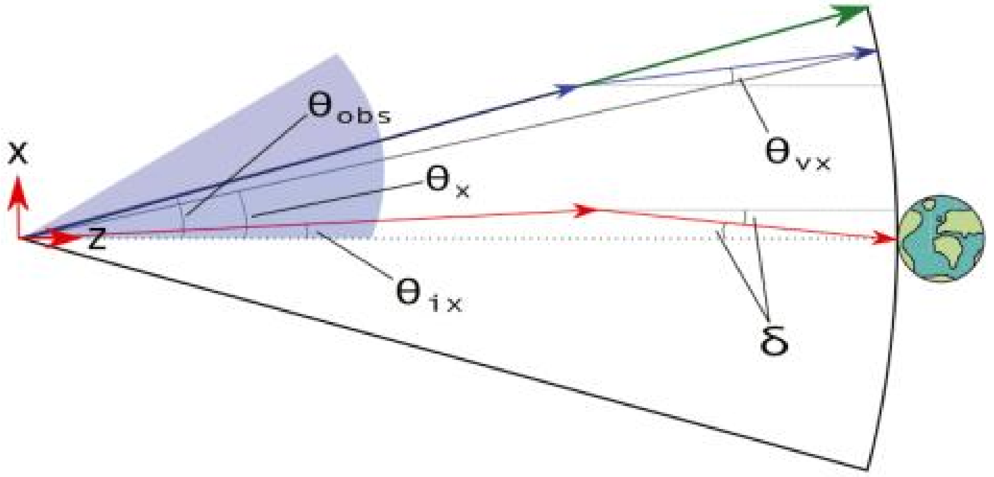


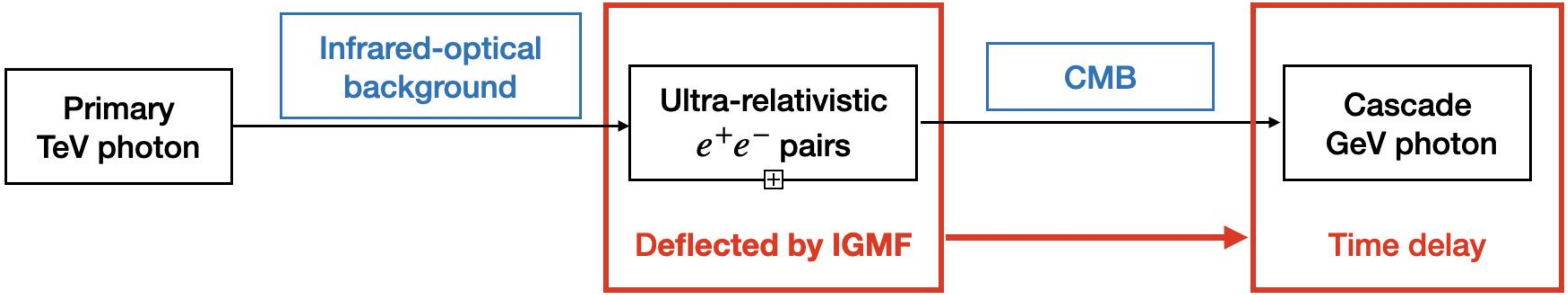
FIG. 1 Number of Monte Carlo events from a pair–photon cascade in an IGMF of 2×10^{-21} G as a function of energy and delay time. Photons of 1 TeV energy were injected at a distance of 1 Gpc. The depth of shading is proportional to the number of events in a bin (see bar at right-hand side of figure). The bin widths are 32.7 MeV in energy and 1 d in time. The straight line is a result of a linear least-squares fit to the bins which have the highest energy at a given time and more than five events per bin.

IGMF will result in delayed emission of very-high-energy photons when they produce cascades in the extragalactic radiation field

Delayed cascade emission

- Primary TeV photons will be absorbed by infrared-optical background and produce high-energy e+e- pairs, which scatter off background radiation to produce gamma-ray emission again (cascade)
- If there is IGMF, e+e- pairs get deflected, resulting in extended halo and delayed secondary emission



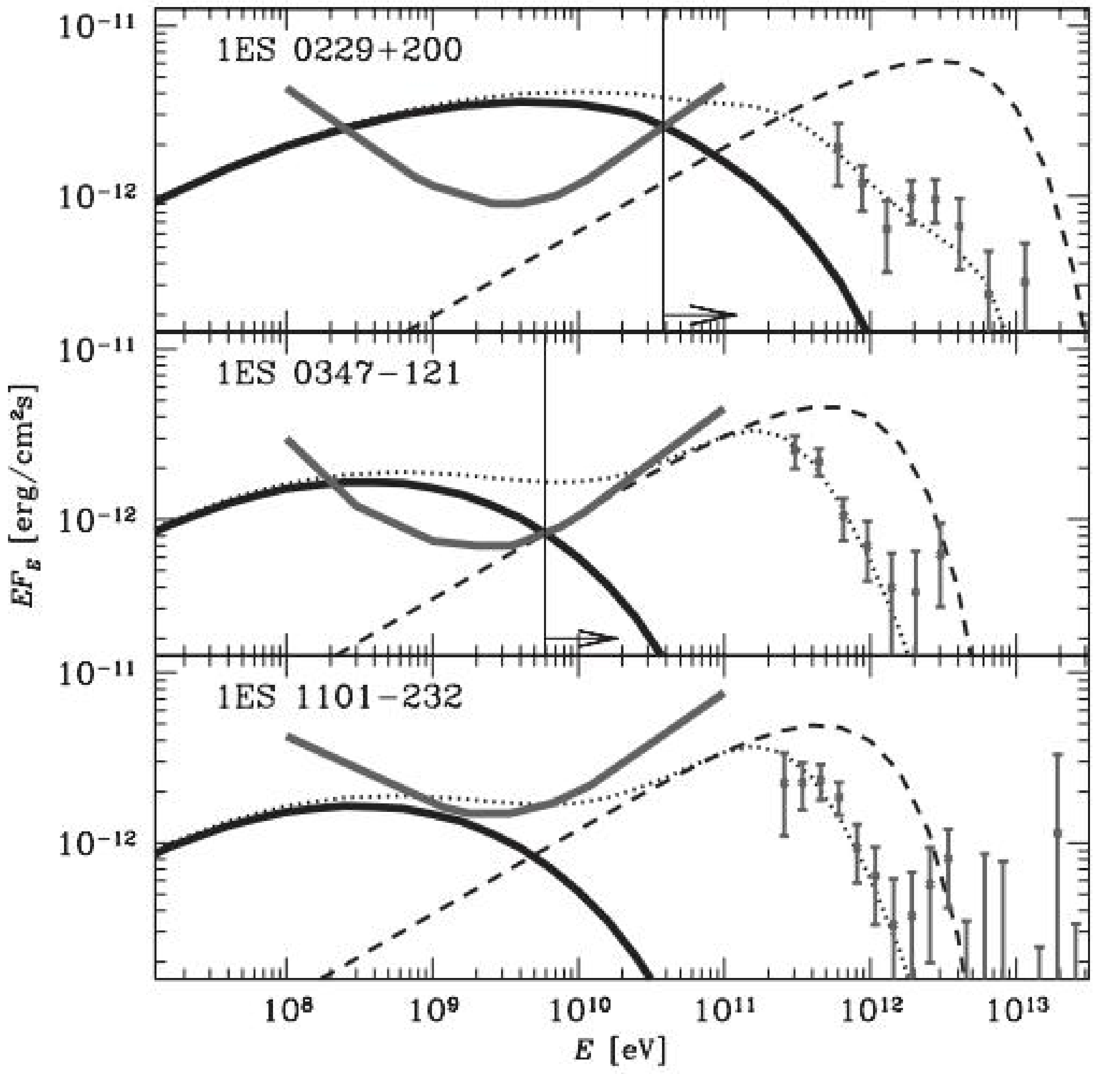


Constraints from Fermi blazar observations

Evidence for Strong Extragalactic Magnetic Fields from Fermi Observations of TeV Blazars

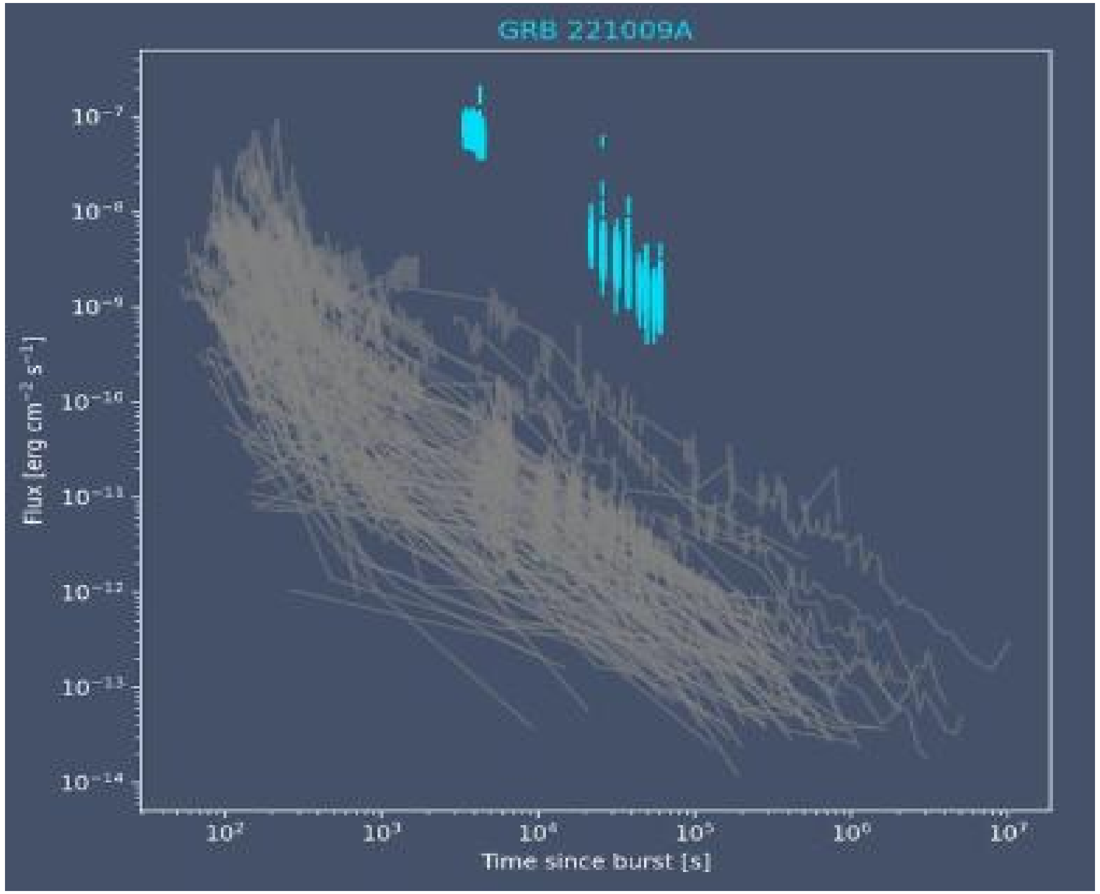
Andrii Neronov* and Ievgen Vovk

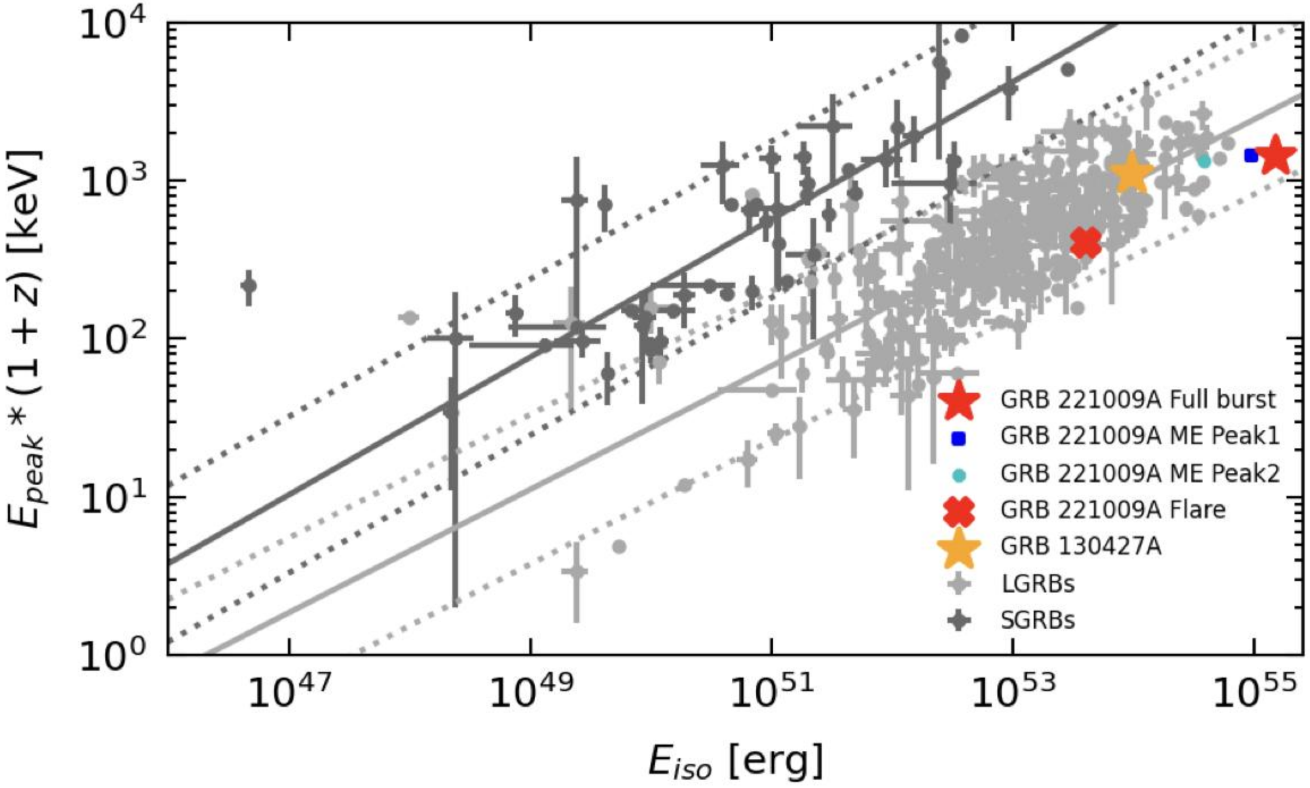
Magnetic fields in galaxies are produced via the amplification of seed magnetic fields of unkn nature. The seed fields, which might exist in their initial form in the intergalactic medium, were never detected. We report a lower bound $B \geq 3 \times 10^{-16}$ gauss on the strength of intergal magnetic fields, which stems from the nonobservation of GeV gamma-ray emission from electromagnetic cascade initiated by tera–electron volt gamma rays in intergalactic medium. The bound improves as $\lambda_B^{-1/2}$ if magnetic field correlation length, λ_B, is much smaller than a megaparsec. This lower bound constrains models for the origin of cosmic magnetic fields.



2010, Science, 328, 73

GRB 221009A: the most powerful event every 10^4 yr!





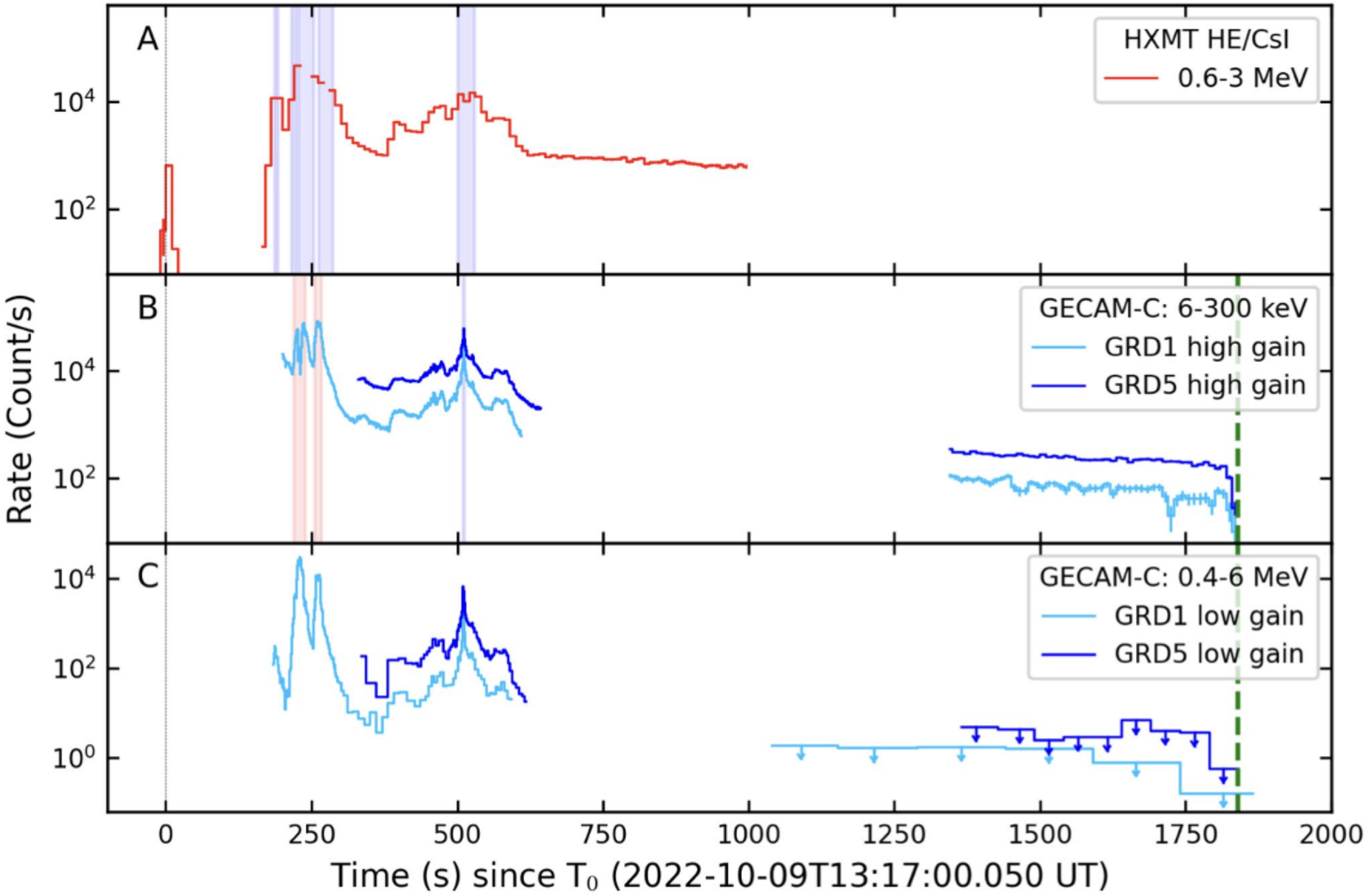
GRB 221009A: the most powerful event every 10^4 yr!

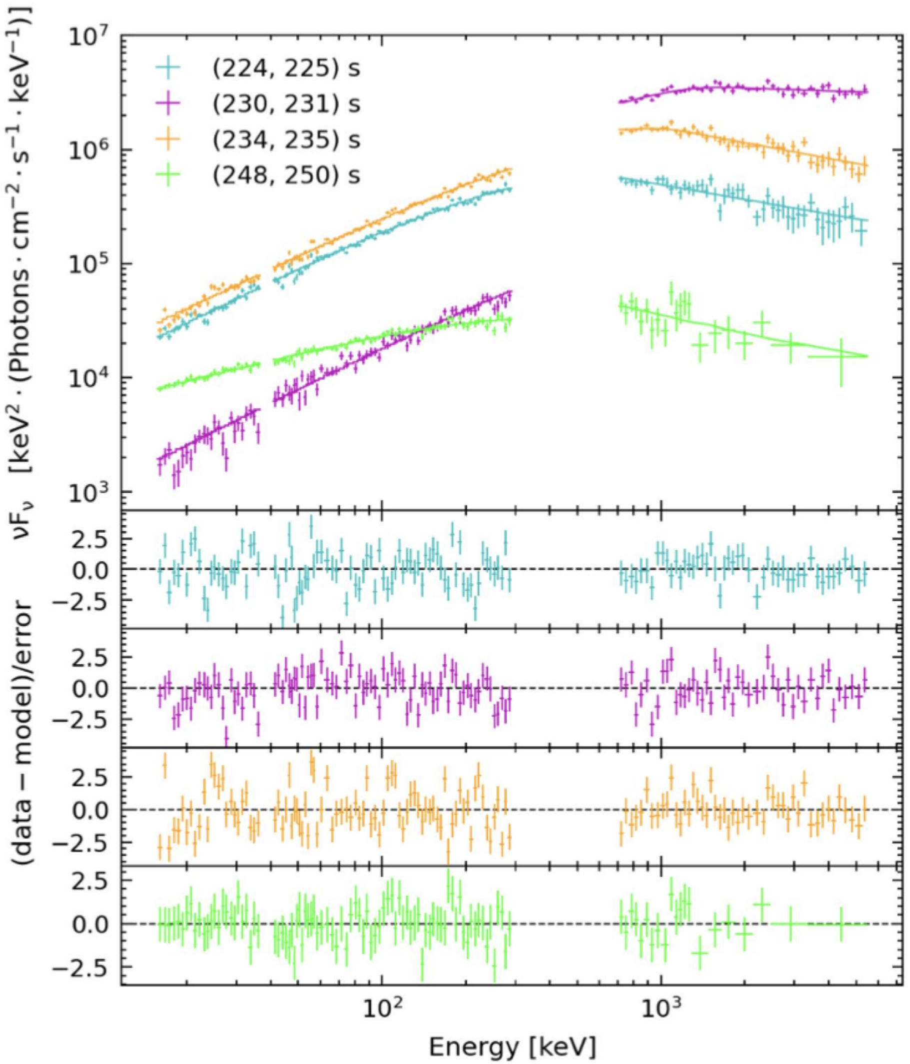
GRB 221009A: GCN Circ archive: MASTER-Net, Swift, Fermi GBM, IPN, BOOTES, Nanshan/NEXT, VLT, Swift-XRT, REM, AMI, Swift/UVOT, Fermi-LAT, BGO, IceCube, Lulin, Konus-Wind, Lick, Swift/XRT, NOEMA, HAWC, CrAO, GTC, INTEGRAL, COATLI, LCOGT, NICER, Konkoly Obs, GMG, MITSuME, LDT, MeerKAT, Gemini, MAXI/GSC, VLA, Pan-STARRS, ALMA, ATCA, Assy, GRANDMA, TNG, LBT, DFOT

Multi-wavelength observations for GRB 221009A from Radio to Gamma-ray.

GRB 221009A: Insight-HXMT and GECAM

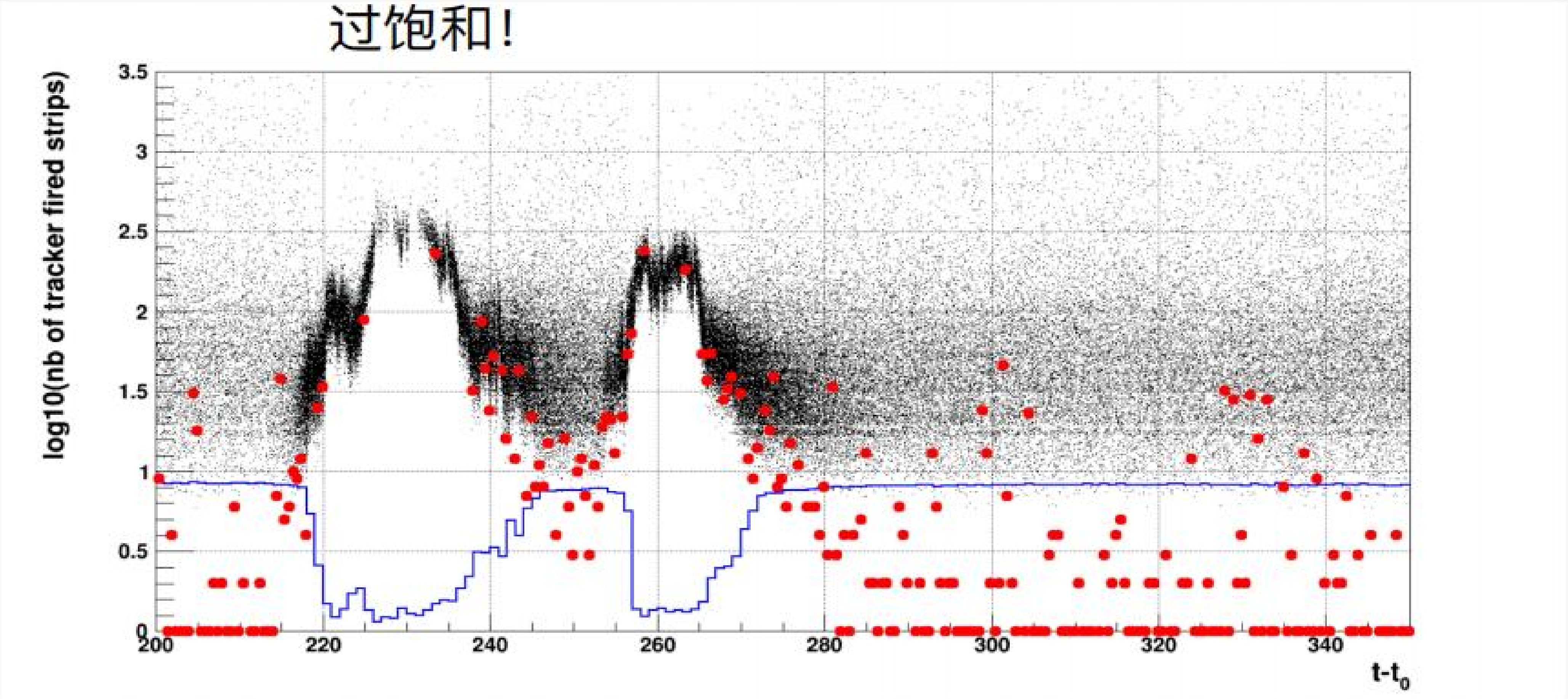
arXiv:2303.01203





Insight-HXMT and GECAM-C observations of the brightest-of-all-time GRB 221009A

GRB 221009A: Fermi-LAT

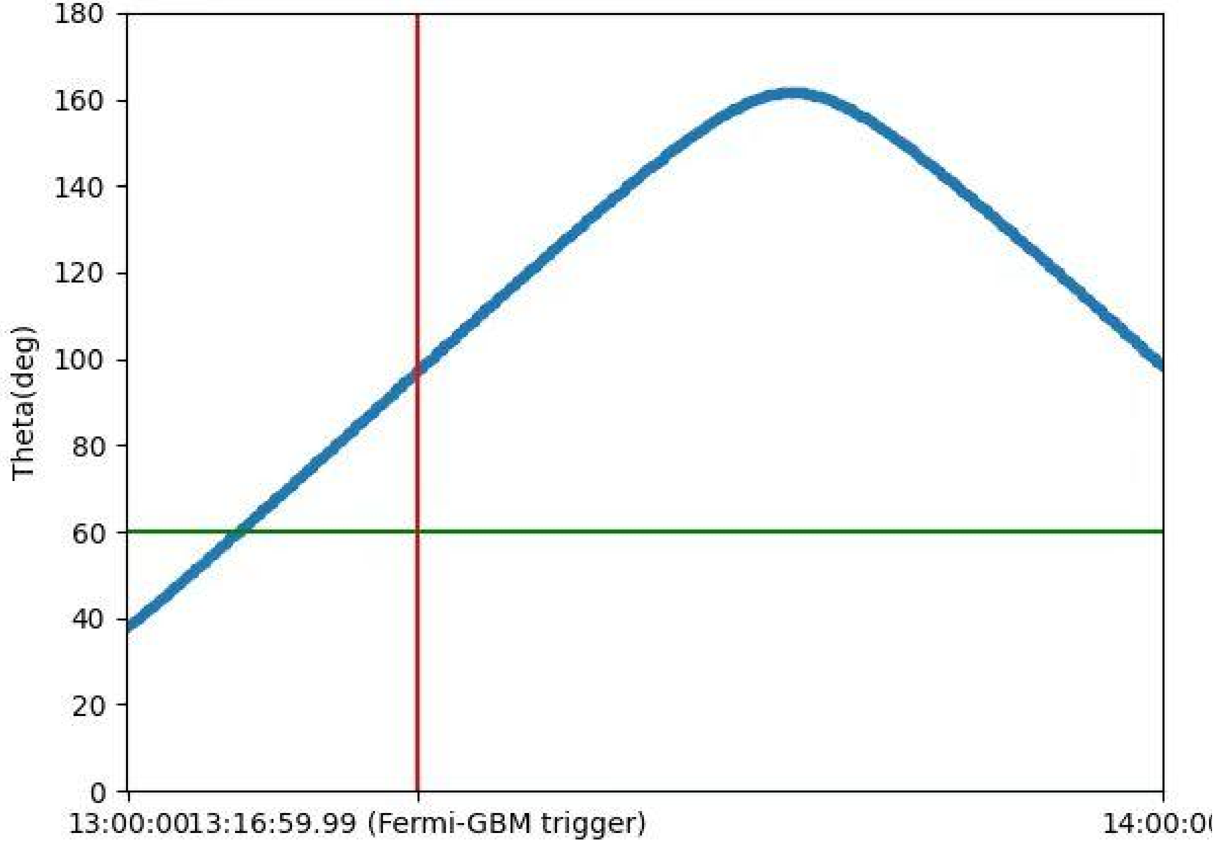


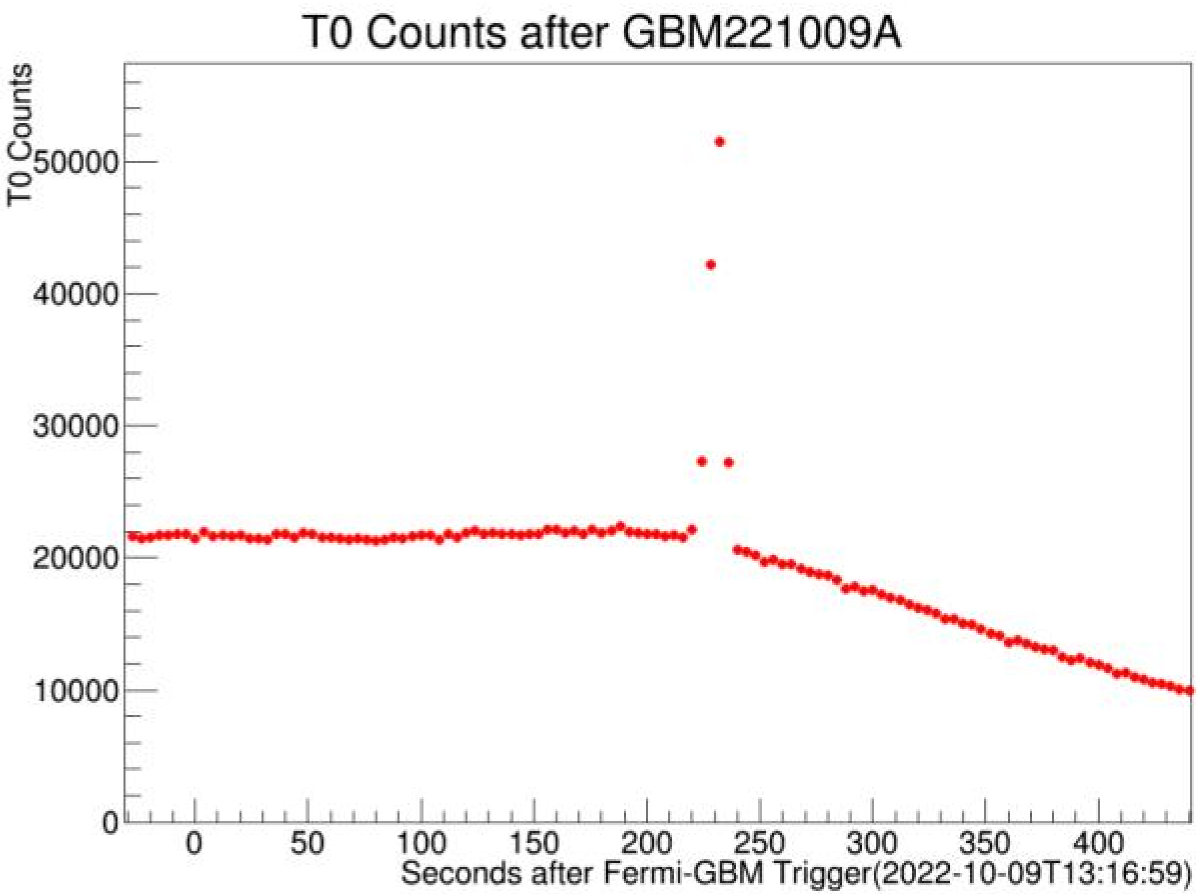
Caption: *Number of tracker fired strips in the recorded events with at least one track that passes the gamma-ray main trigger and on-board filter as a function of time since the GBM trigger (black dots). The red dots correspond to the events triggered with a 2Hz cadence to monitor the noise in the instrument. The blue histogram shows the livetime recorded in the 1sec spacecraft file.*

https://fermi.gsfc.nasa.gov/ssc/data/analysis/grb221009a.html

GRB 221009A: DAMPE

GCN #32973





GRB 221009A is out of DAMPE's FoV at the outburst. DAMPE recorded enhanced T_0 counts due to side-entrance events

GRB 221009A: LHAASO

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//////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32677
SUBJECT: LHAASO observed GRB 221009A with more than 5000 VHE photons up to around 18 TeV
DATE:    22/10/11 09:21:54 GMT
FROM:    Judith Racusin at GSFC  <judith.racusin@nasa.gov>

Yong Huang, Shicong Hu, Songzhan Chen,  Min Zha, Cheng Liu, Zhiguo Yao and
Zhen Cao report on behalf of the LHAASO experiment

We report the observation of GRB 221009A, which was detected by Swift (Kennea
et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636, Lesage et al. GCN #32642),
Fermi-LAT (Bissaldi et al. GCN #32637), IPN (Svinkin et al. GCN #32641) and so on.

GRB 221009A is detected by LHAASO-WCDA at energy above 500 GeV, centered at
RA = 288.3, Dec = 19.7 within 2000 seconds after T0, with the significance above
100 s.d., and is observed as well by LHAASO-KM2A with the significance about 10 s.d.,
where the energy of the highest photon reaches 18 TeV.

This represents the first detection of photons above 10 TeV from GRBs.

The LHAASO is a multi-purpose experiment for gamma-ray astronomy (in the energy
band between 10^11 and 10^15 eV) and cosmic ray measurements.
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First LHAASO paper about the structured jet of this GRB will be published soon

GRB 221009A: HAWC

GCN #32683

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//////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32683
SUBJECT: GRB 221009A: Upper limits from HAWC 8 hours after trigger
DATE:    22/10/11 12:04:14 GMT
FROM:    Hugo Ayala at Pennsylvania State University  <hgayala@psu.edu>

Hugo Ayala  (PSU) reports on behalf of the HAWC
collaboration (http://www.hawc-observatory.org/collaboration)
reports observations of GRB 221009A which was detected by
Swift (Kennea et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636,
Lesage et al. GCN #32642), Fermi-LAT (Bissaldi et al. GCN #32637),
and the IPN (Svinkin et al. GCN #32641).

We use the position measured by Fermi LAT (GCN #32658), located at:
RA = 288.282, Dec = 19.495 (0.027 deg 90% containment radius)

This position started transiting over HAWC at 21:19:57 UTC on 2022/10/09
(~8 hours after the trigger time)  and ended at 03:42:07 UTC on 2022/10/10.
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Upper limit

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Assuming a power law spectra with index of -2.0 we found no significant
detection in the region. We proceeded to calculate the 95% upper limit on
the flux at 1 TeV: 4.16e-12 (TeV cm2 s)^-1
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HAWC is a very-high-energy gamma-ray observatory operating in Central
Mexico at latitude 19 deg. north. Operating day and night with over
95% duty cycle, HAWC has an instantaneous field of view of 3.14 sr and
surveys <5/6 of the sky every day. It is sensitive to gamma rays from
300 GeV to 100 TeV.
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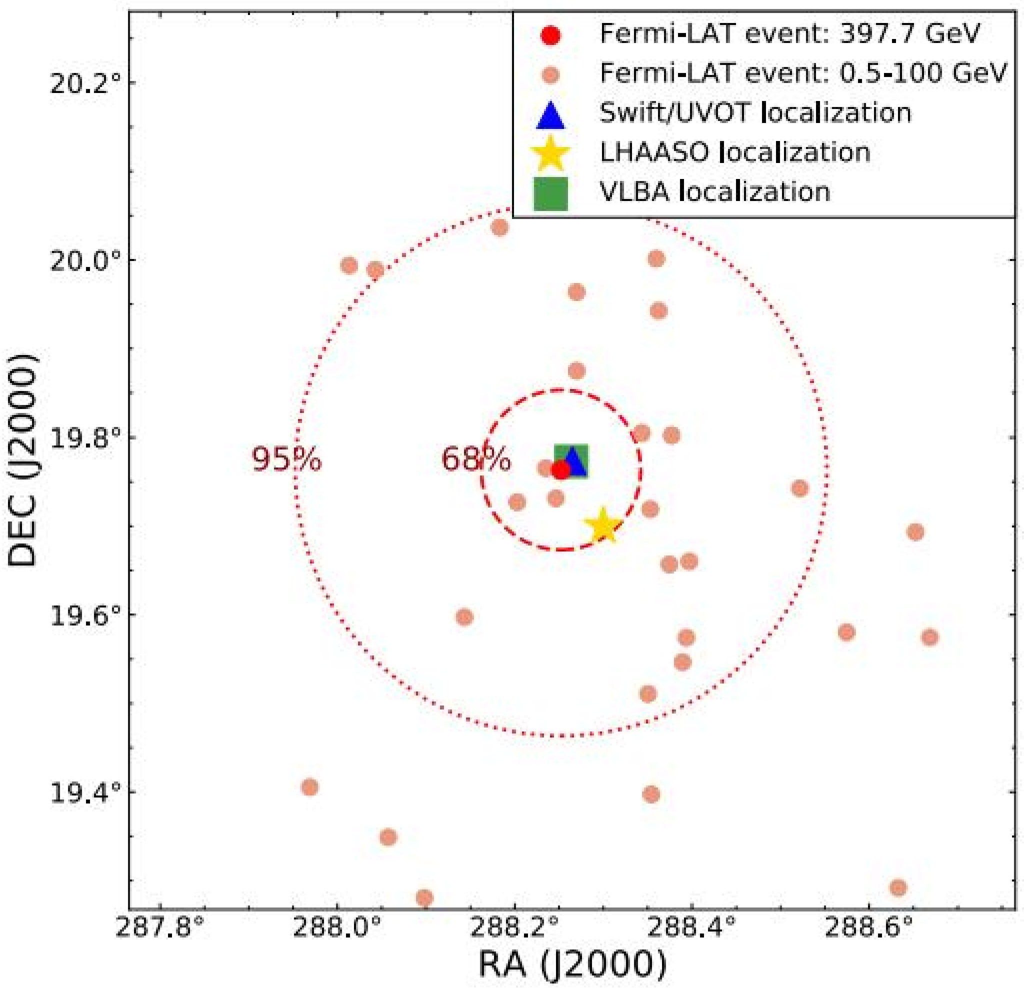
A 400 GeV photon from GRB 221009A by Fermi-LAT

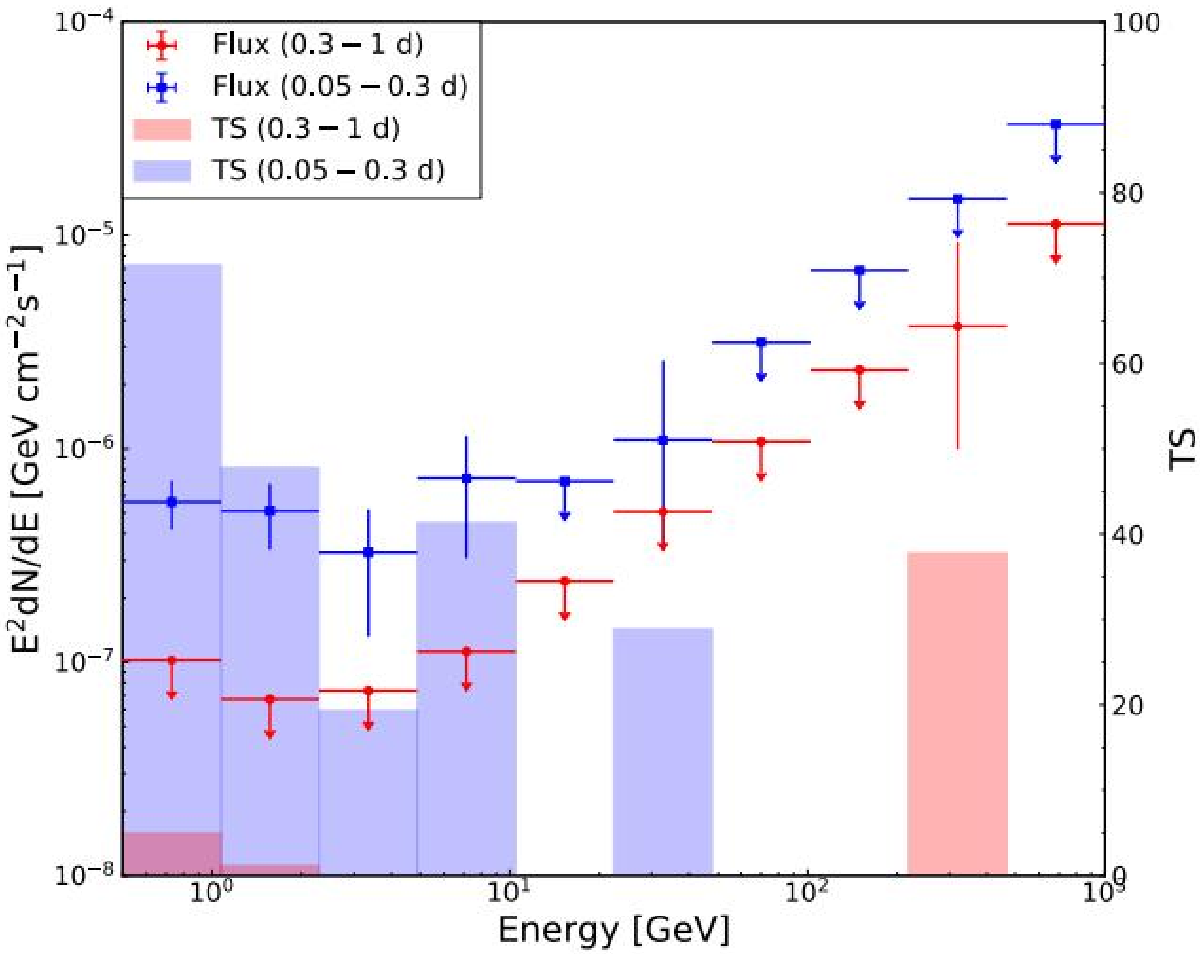
- 33554 s (0.4 day) after the Fermi-GBM trigger
- Energy ~ 397.7 GeV
- 0.02 deg from the Swift/UVOT localization
- The highest energy photon from GRBs by Fermi-LAT

99.99937% belong to GRB 221009A



Spectrum from Fermi-LAT

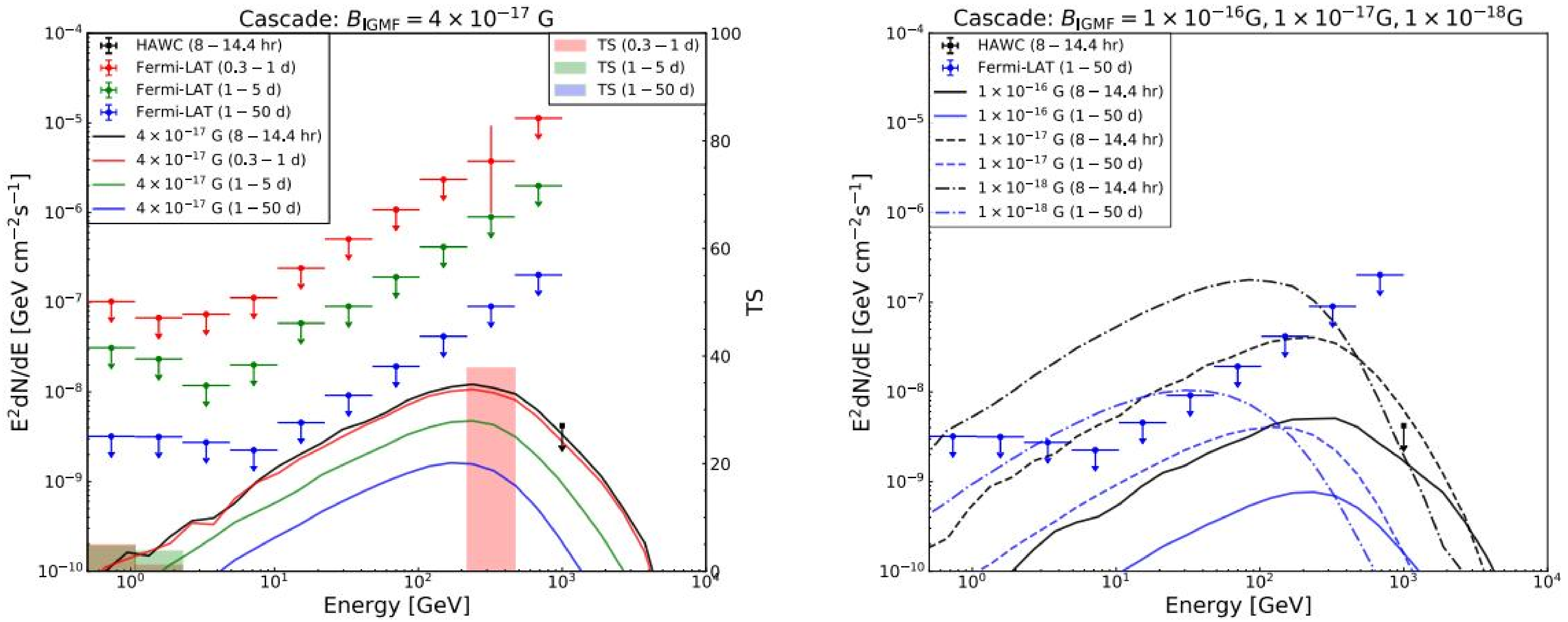
Time	0.05-0.3d	0.3-1d
Index	2.08	1.32 (hard)
Model	Synchrotron-Self-Compton model	Delayed Cascade?



IGMF inferred from 400 GeV delayed photon

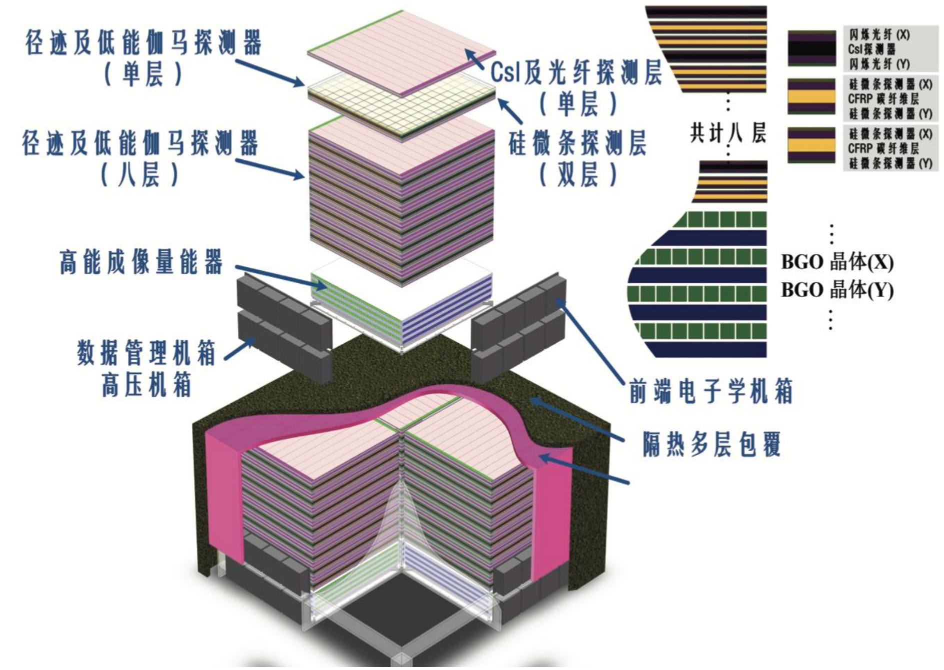
- The primary photon: $$\epsilon_\gamma \approx 12 \left(\frac{\epsilon_{\gamma,\mathrm{2nd}}}{400\,\mathrm{GeV}}\right)^{1/2} \left(\frac{1+z}{1.151}\right)^{-1} \ \mathrm{TeV}.$$
- Time delay: $$\Delta t_\mathrm{B} \sim 7\times 10^5 \left(\frac{\epsilon_\gamma}{10\ \mathrm{TeV}}\right)^{-5} \left(\frac{B_\mathrm{IGMF}}{10^{-16}\,\mathrm{G}}\right)^{2} \left(\frac{1+z}{1.151}\right)^{-16} \ \mathrm{s},$$
- The strength of IGMF: $$B_\mathrm{IGMF} \approx 4\times 10^{-17}\ \mathrm{G} \times \left(\frac{\epsilon_{\gamma,\mathrm{2nd}}}{400\,\mathrm{GeV}}\right)^{5/4} \left(\frac{\Delta t_\mathrm{B}}{0.4\ \mathrm{days}}\right)^{1/2} \left(\frac{1+z}{1.151}\right)^{11/2}.$$

Monte Carlo simulation with ELMAG



- ➢ **Simulations give consistent results with the analytical estimate**
- ➢ **The detection of the 400 GeV event has a relatively low probability of ~1%**

Very Large Area gamma-ray Space Telescope (VLAST)



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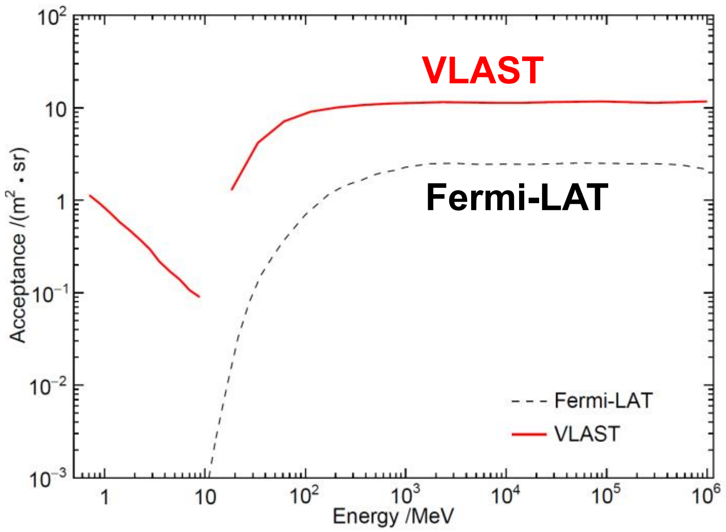
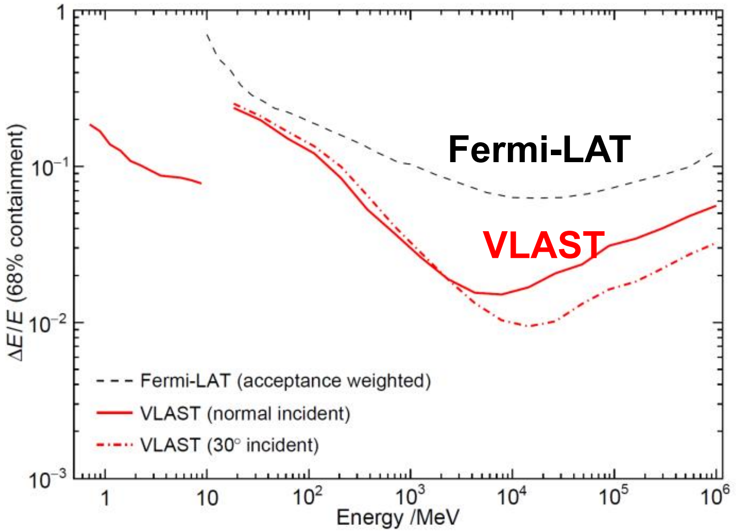
甚大面积伽马射线空间望远镜计划*

范一中[1,2,3†] 常 进[1,2,3,8‡] 郭建华[1,2,3] 袁 强[1,2,3] 胡一鸣[1,2] 李 翔[1,2,3]
岳 川[1,2] 黄光顺[4,5] 刘树彬[4,5] 封常青[4,5] 张云龙[4,5] 魏逸丰[4,5]

Improve by a factor of ~10 than Fermi-LAT





国内外正在运行或提议的一些相关空间探测项目

探测设施	主要探测对象	峰值接受度 (m^2 sr)	目前阶段	备注
Fermi-LAT	伽马射线	~ 2	在轨	量能器
悟空号	宇宙线、伽马	~ 0.3	在轨	
AMS-100	宇宙线、伽马	~100	初步概念	磁谱仪
先进粒子天文望远镜APT	伽马射线、宇宙线	~20	关键技术攻关	量能器
HERD	宇宙线	~4	关键技术攻关	
VLAST	伽马射线	~10	关键技术攻关	

A 400 GeV photon from the direction of GRB 221009A was found ~0.4 days after the outburst. If interpreted as delayed emission from cascade of TeV photons, the inferred IGMF strength is about 4×10^{-17} G

Thank you!