

GRBs in the Swift and Fermi era

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RICAP-24
*Roma International
Conference on
Astroparticle Physics*

September 23rd – 27th, 2024 – Frascati, Roma
Hotel Villa Tuscolana

The 9th edition of the Roma International Conference on AstroParticle Physics will be organized by the INFN and the University of Roma Tor Vergata. The acronym stands for Roma International Conference on Astro-Particle Physics, the Conference is entirely dedicated to the study of high energy cosmic rays and it is organized by the three public Universities of Roma ("Sapienza" University, University "Tor Vergata" and University "Roma Tre"). These institutions provide both theoretical and experimental contributions and participate in major experimental projects in the field (AGILE, AMS, ANTARES, ARGO, Auger, CTA, Fermi, Virgo, Einstein Telescope, JEM-EUSO, KM3NeT, SWGO, ...)

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ARAP
Associazione Romana per le Astro-Particelle



For more information:
Email: Ricapsept2024@gmail.com
Web page: <https://agenda.infn.it/event/35353/>

link to the conference website

GRB studies through history

Seven eras

Adapted from L. Amati

Adapted from F. Longo

- 1) "Dark" era (1973-1991): **discovery**
Klebesadel, Strong & Olson's discovery (1973);
- 2) BATSE era (1992-1996): **spatial distribution**
Meegan & Fishman's discovery (1992),
detection rate: ~1 to 3 /day, ~3000 bursts;
- 3) BeppoSAX era (1997-2000): **afterglows**
van Paradijs, Costa, Frail's discoveries (1997);
- 4) HETE-2 era (2001-2004): **origin of long bursts**
Observations on GRB030329/SN2003dh
- 5) Swift era (2005-): **very early afterglows, short-GRB afterglow, GRB subclasses? GRB cosmology?**
- 6) Fermi era (2008-): **High energy emission component, GW counterparts! – origin of short GRB**
- 7) VHE era (2019-): **VHE emission component from GRB!**

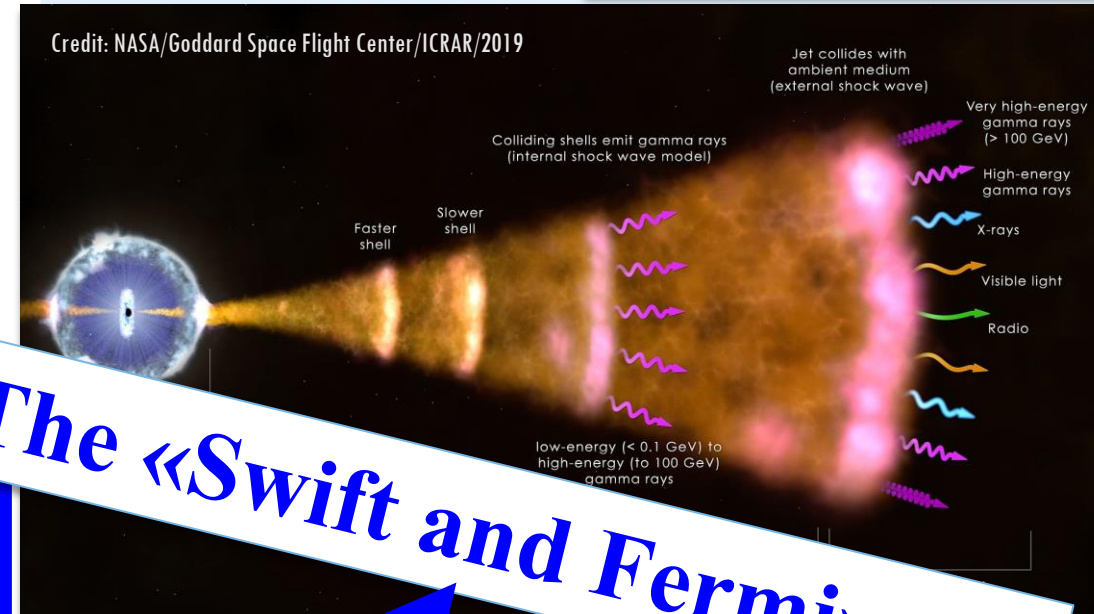
Long GRBs – Collapsars



Short GRBs – Binary mergers



Credit: NASA/Goddard Space Flight Center/ICRAR/2019



The «Swift and Fermi» era

The Swift Mission



Launched on November 20, 2004

Burst Alert Telescope (BAT)

Coded-aperture mask

15 – 150 keV

Localization: few arcmin

X-ray Telescope (XRT)

Wolter Type I X-ray telescope (12 nested mirrors)

0.3 – 10 keV

Localization: few arcsec

Ultraviolet/Optical Telescope (UVOT)

30 cm modified Ritchey-Chretien reflector

170 – 600 nm

Localization: 0.5 arcsec

Key features
superb
localization
multi-wavelength
fast repointing

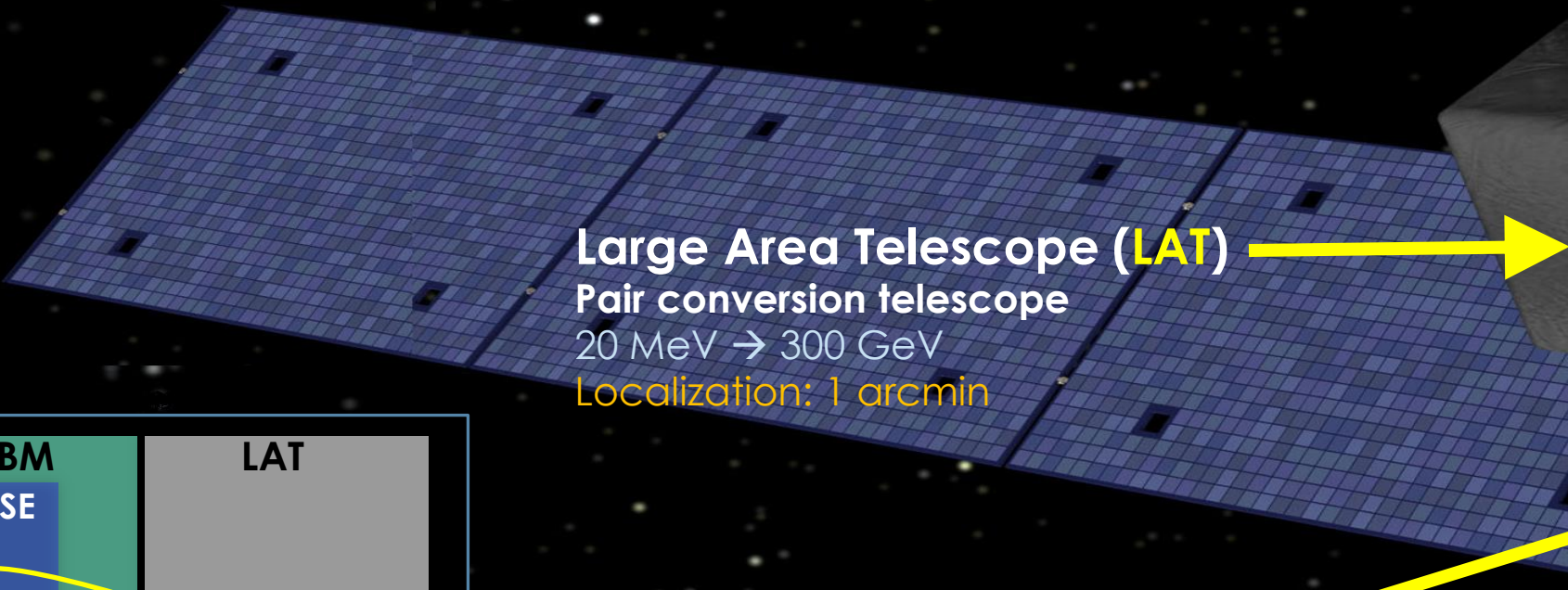
Part of NASA's MIDEX program
Instruments developed by an
international team from US, UK, Italy.
Additional scientific involvement in
France, Japan, Germany, Denmark,
Spain, and South Africa.

The Fermi Mission



Launched on June 11, 2008

Key features
huge FoV
&
large energy
range

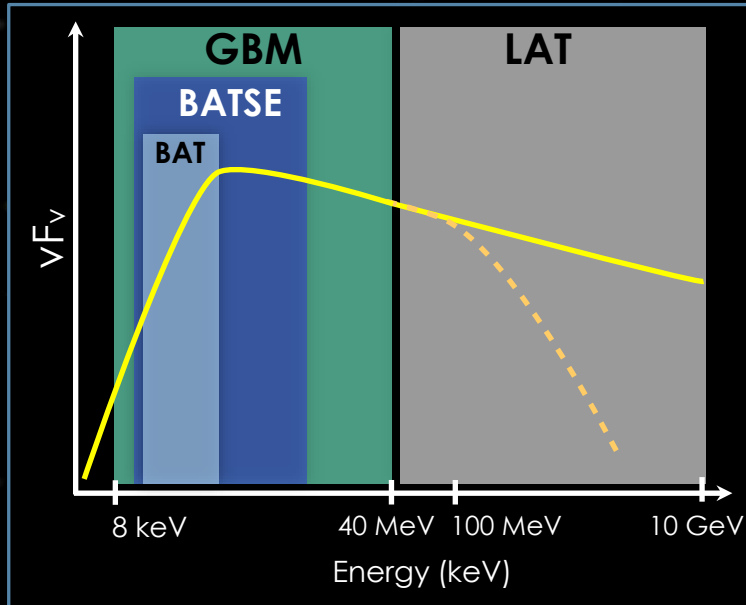
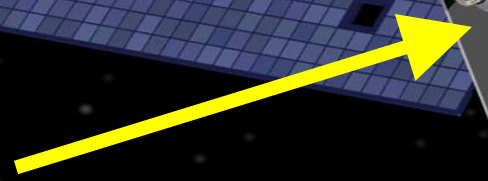


Large Area Telescope (LAT)

Pair conversion telescope

20 MeV \rightarrow 300 GeV

Localization: 1 arcmin



Gamma-ray Burst Monitor (GBM)

14 scintillator (NaI+BGO) detectors

8 keV – 40 MeV

Localization: few deg

GRB pillars of knowledge*

What we know now:

1. GRBs are **cosmological**
2. GRBs have large bulk Lorentz factors
3. 2 emission phases:
Prompt and **afterglow**
4. **Long** and **short** GRBs
5. Spikes have same **durations**
6. **Supernova** connection
7. **Common** behaviors and trends

Optical

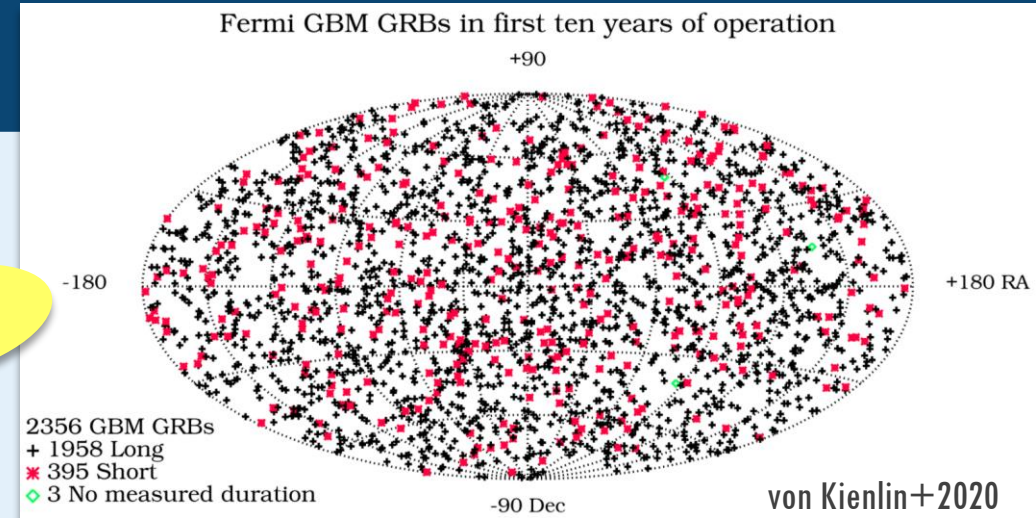
Radio/
GeV

Optical/
GeV

keV/MeV

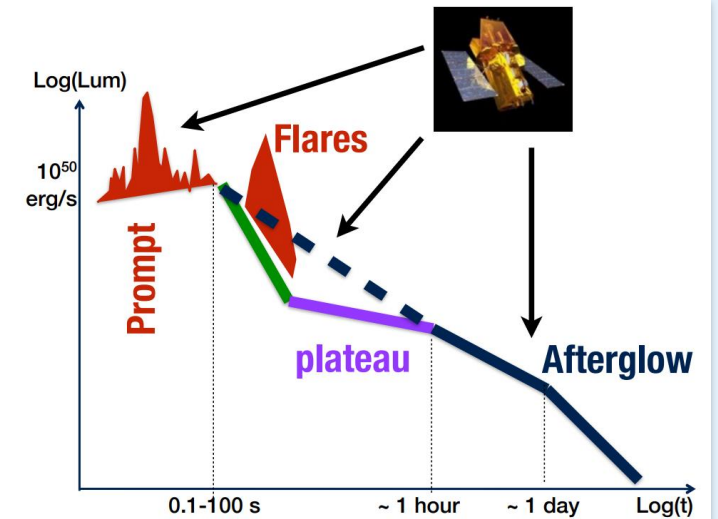
Optical

X-ray/keV



Credit: M.G. Bernardini

- + "canonical" X-ray light curve (steep-plateau-normal) in ~ 1/2 GRBs
- + X-ray flares in ~ 1/3 GRBs



Multi-Wavelength has always been the key!

Now also **Multi-Messenger!**

Synergy between instruments (and community!) is crucial

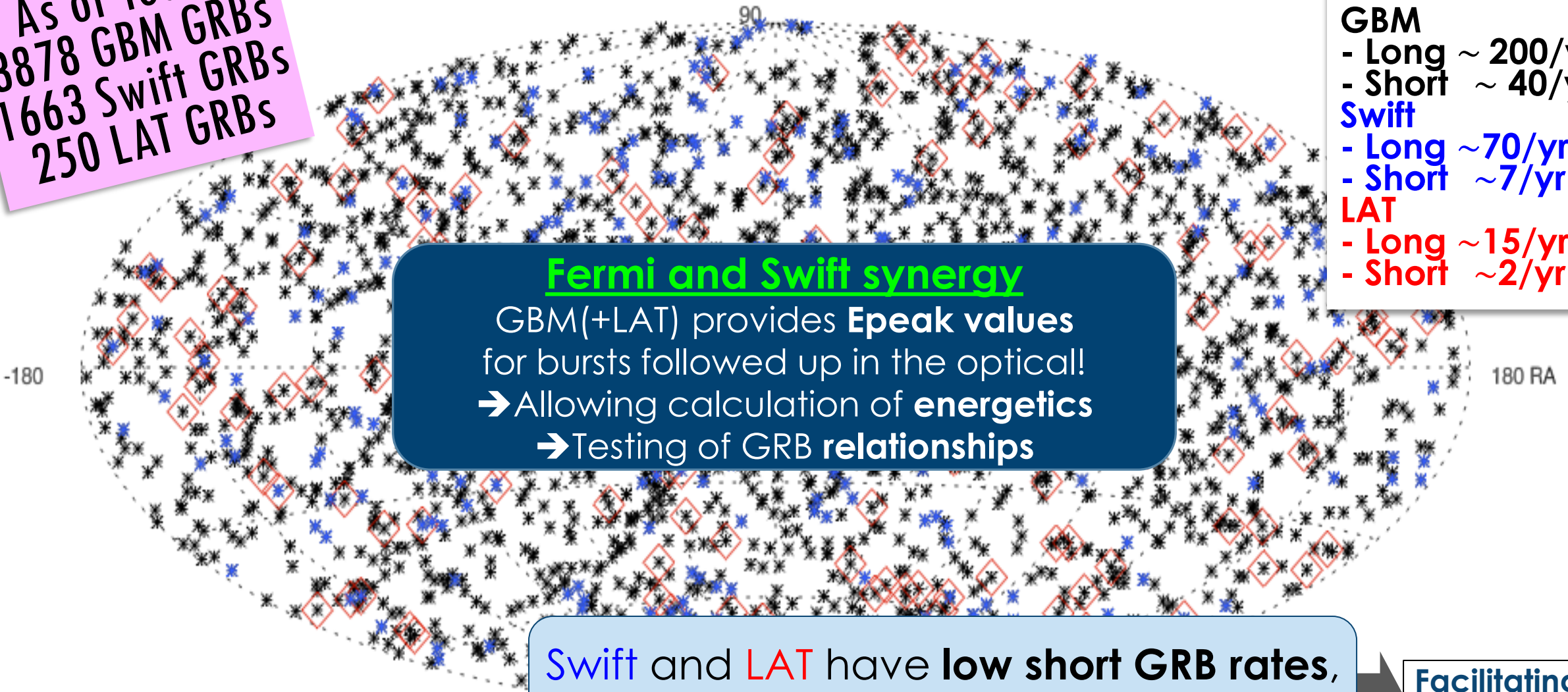
*from Ghisellini+2010

Fermi GRBs as of 171126

As of today
3878 GBM GRBs
1663 Swift GRBs
250 LAT GRBs

GRB rates

GBM	
- Long	~ 200/yr
- Short	~ 40/yr
Swift	
- Long	~ 70/yr
- Short	~ 7/yr
LAT	
- Long	~ 15/yr
- Short	~ 2/yr

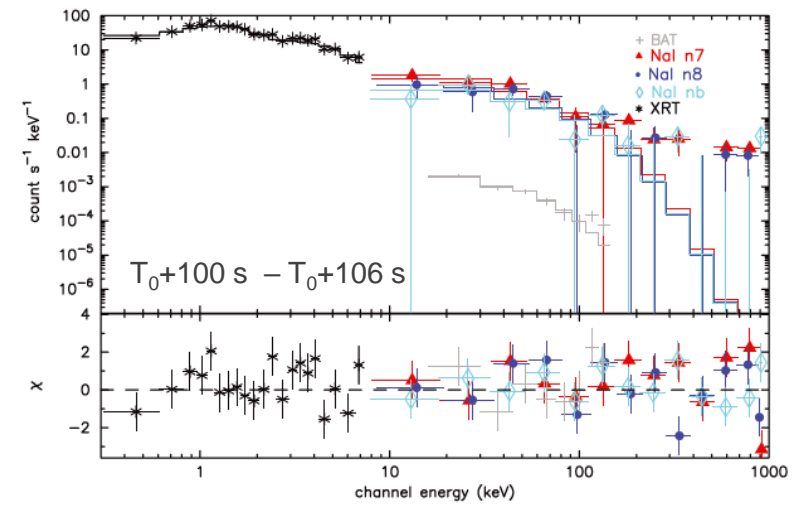
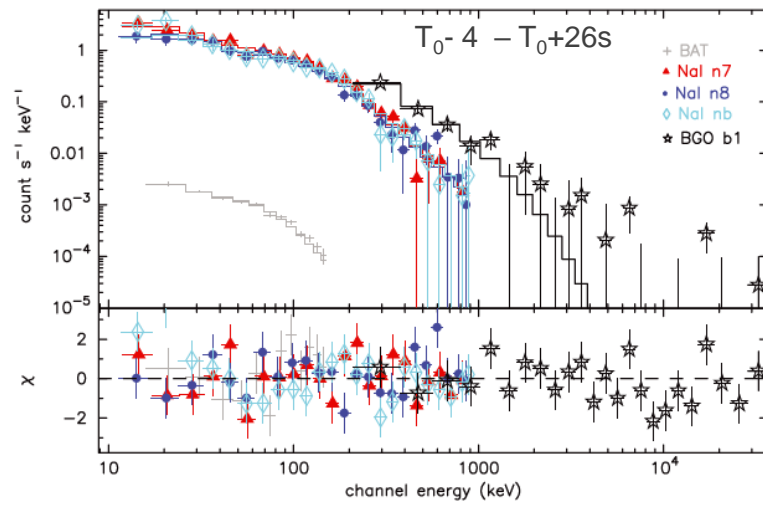
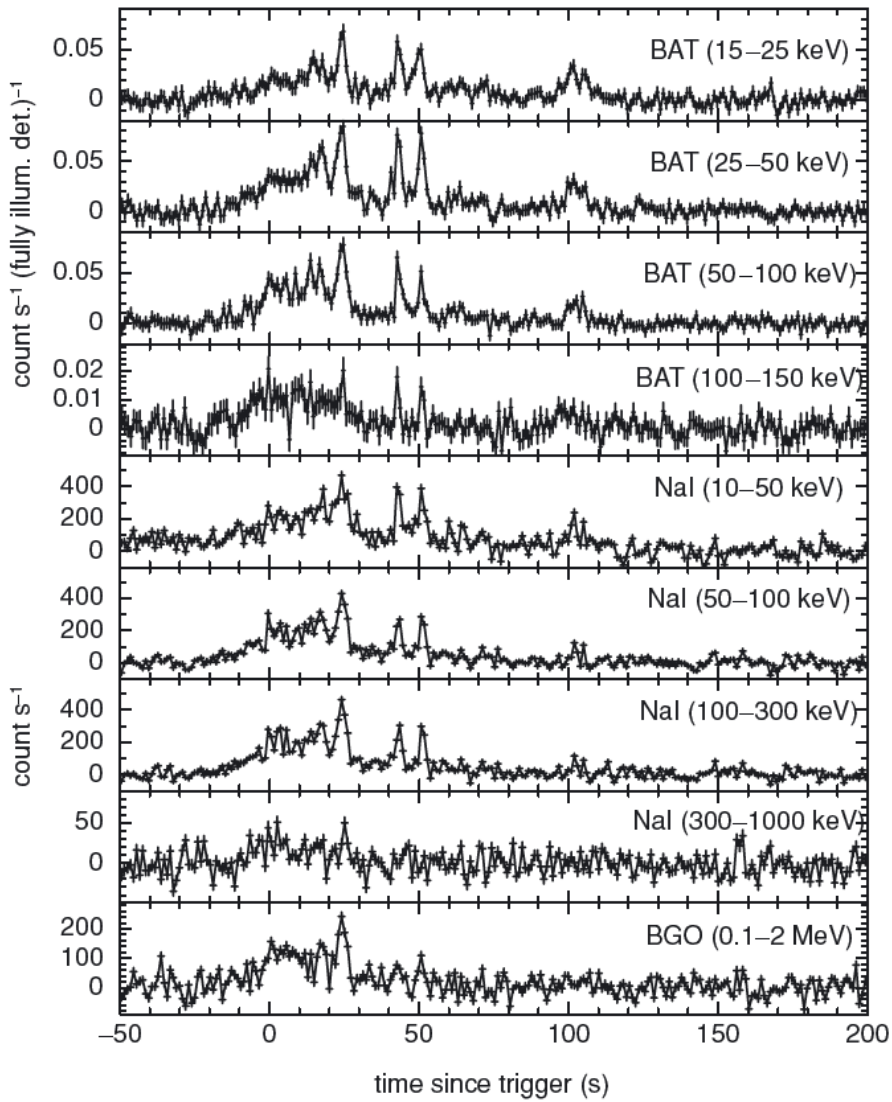


Fermi and Swift synergy
GBM(+LAT) provides **E_{peak}** values
for bursts followed up in the optical!
→ Allowing calculation of **energetics**
→ Testing of GRB **relationships**

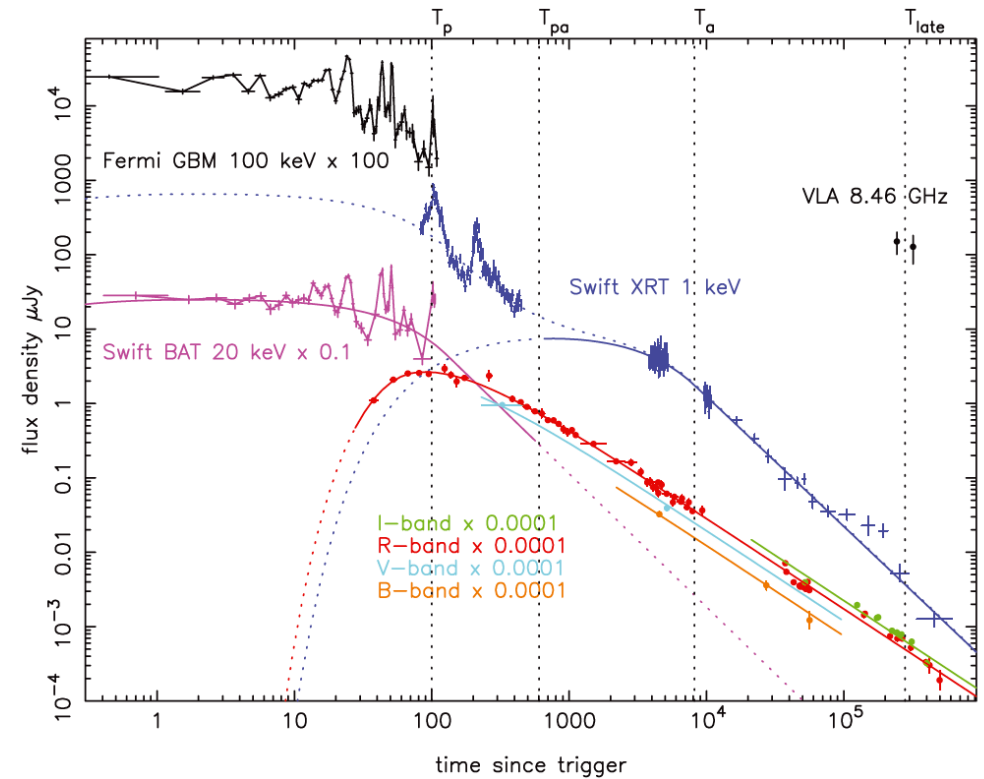
Swift and LAT have **low short GRB rates**,
but **small localizations!**

Facilitating
follow-up!

GBM+Swift GRBs (13%, ~30/yr)
GBM+LAT GRBs (6%, ~15/yr)
[52% within LAT FoV]

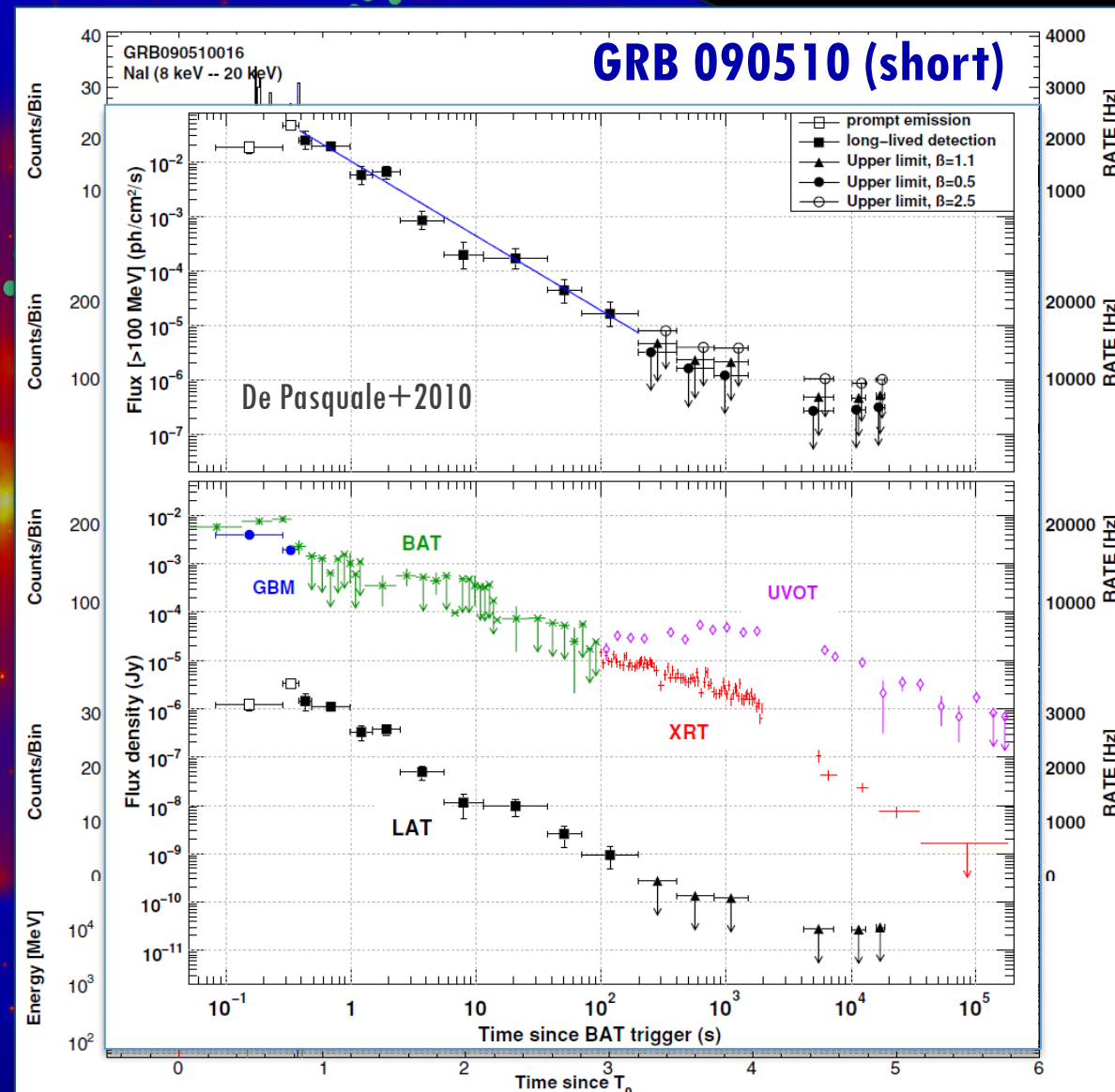
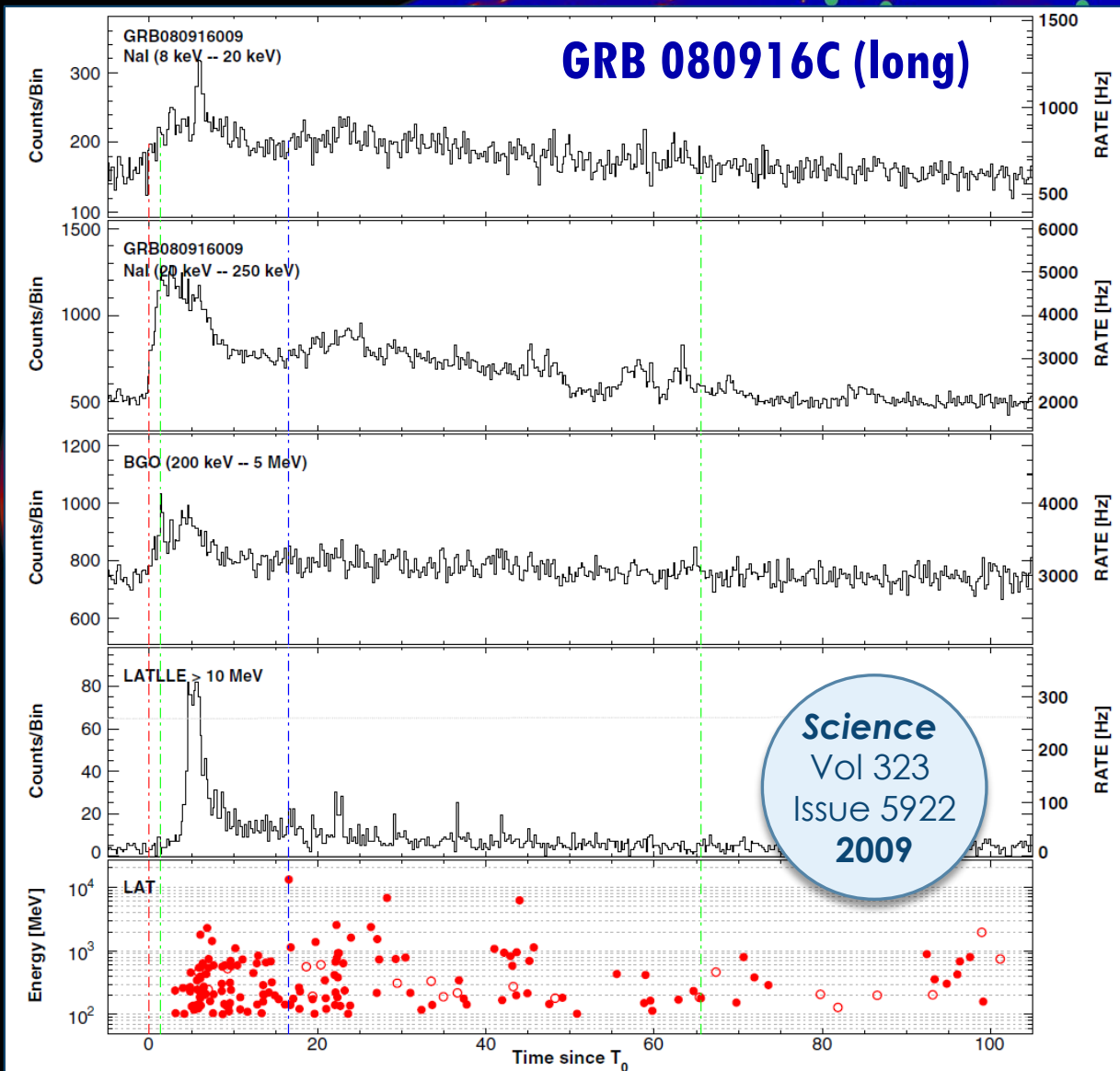


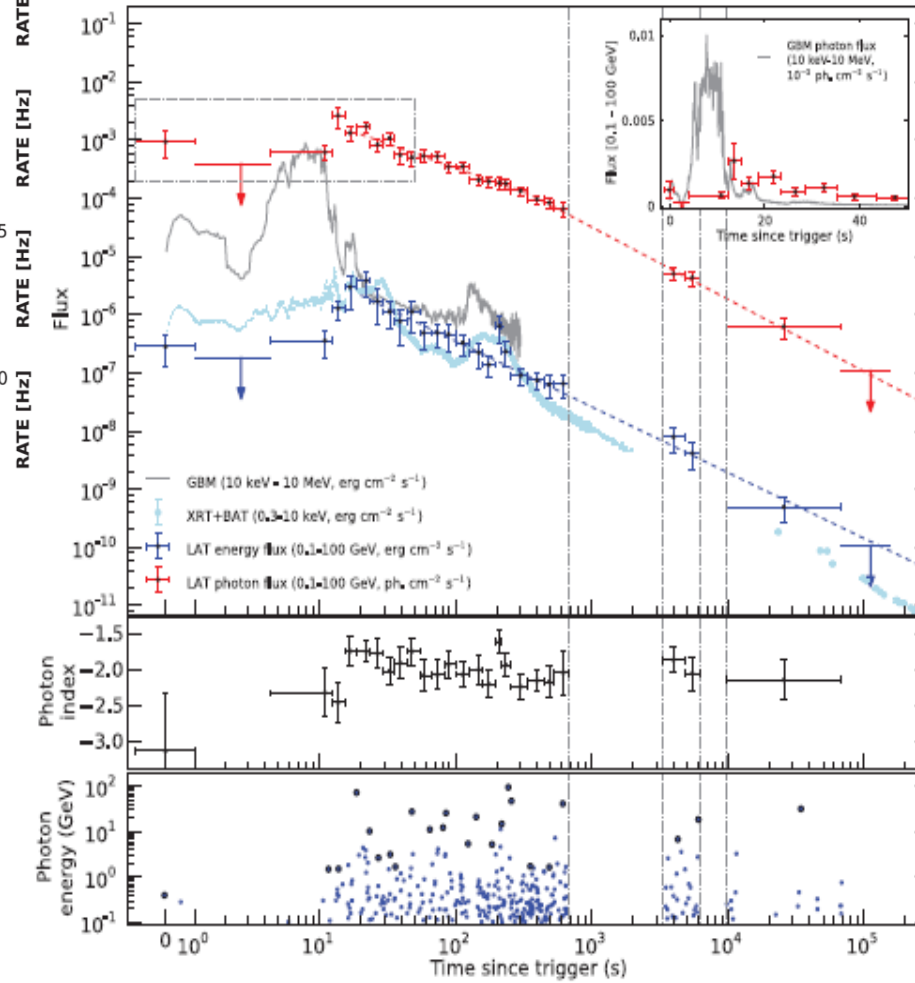
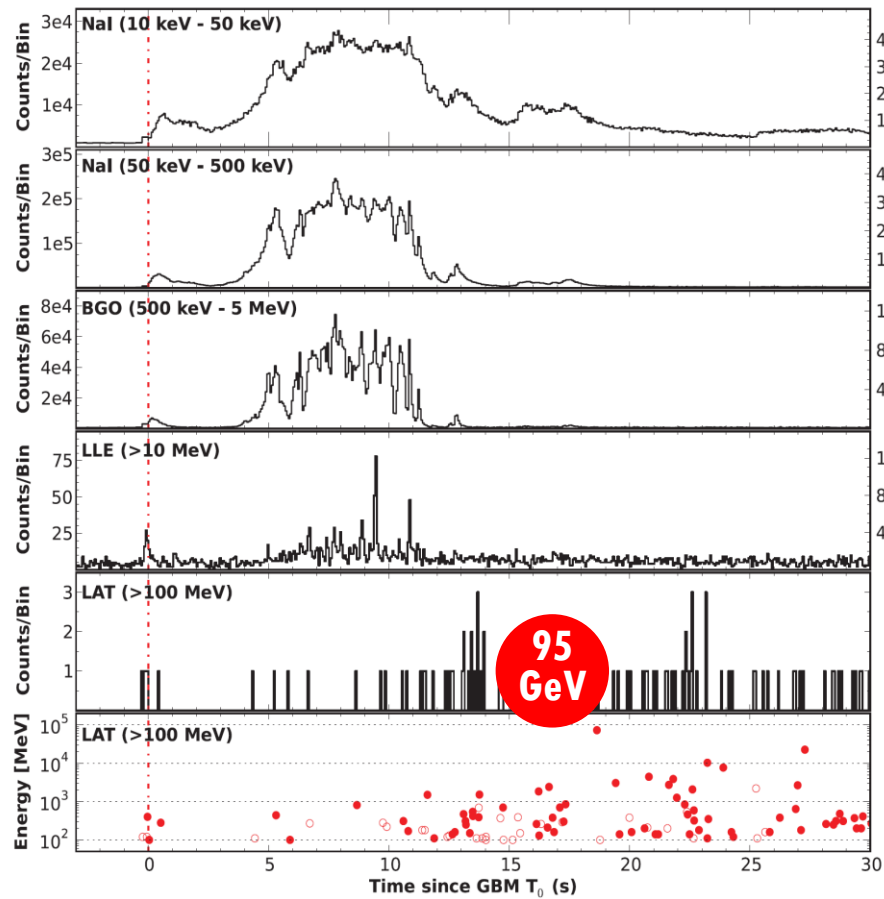
GBM's first published GRB!
Meegan et al., 2008, GCN 8100



Multiwavelength observations of the energetic GRB 080810: detailed mapping of the broad-band spectral evolution — Page, Willingale, Bissaldi+2009

FFF-GRBs (Famous First Fermi bursts) ^{081102B}





Fermi-LAT Observations of the Gamma-Ray Burst GRB 130427A — Ackermann+2014

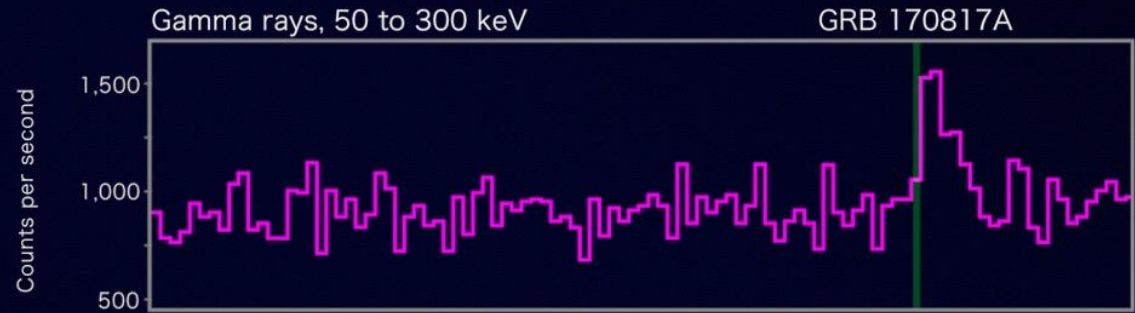


Breakthrough #1

Joint GW-GRB observation

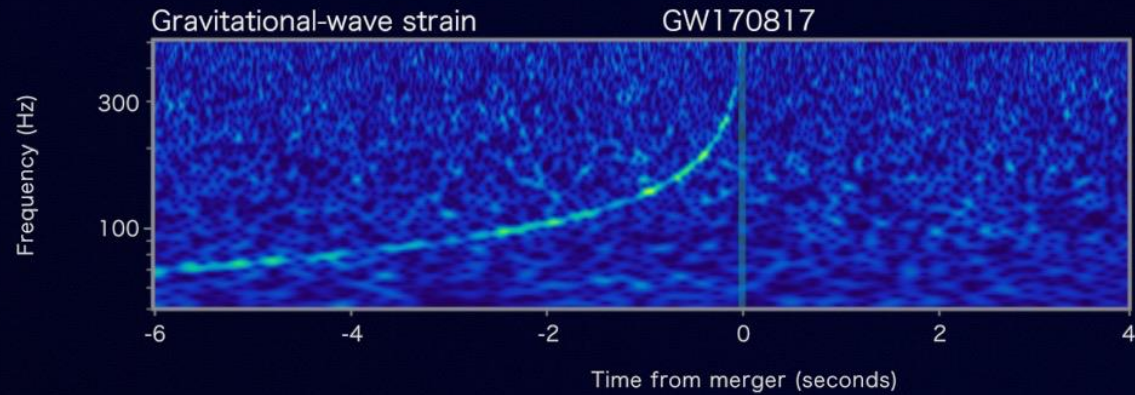
Fermi

Reported 16 seconds
after detection



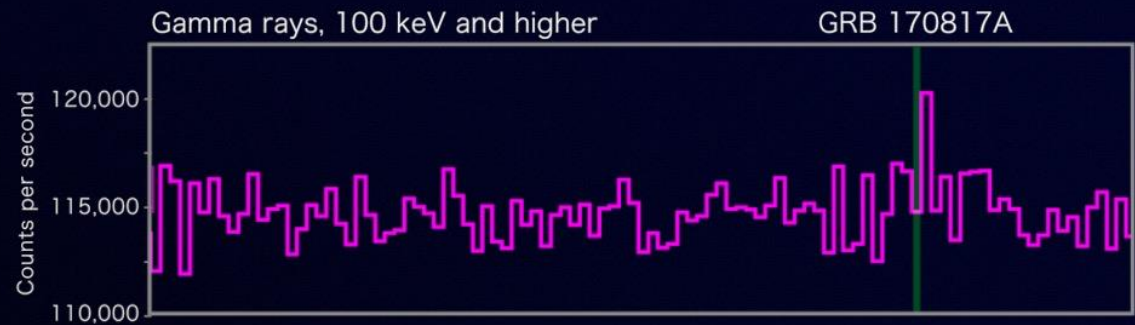
LIGO-Virgo

Reported 27 minutes after detection



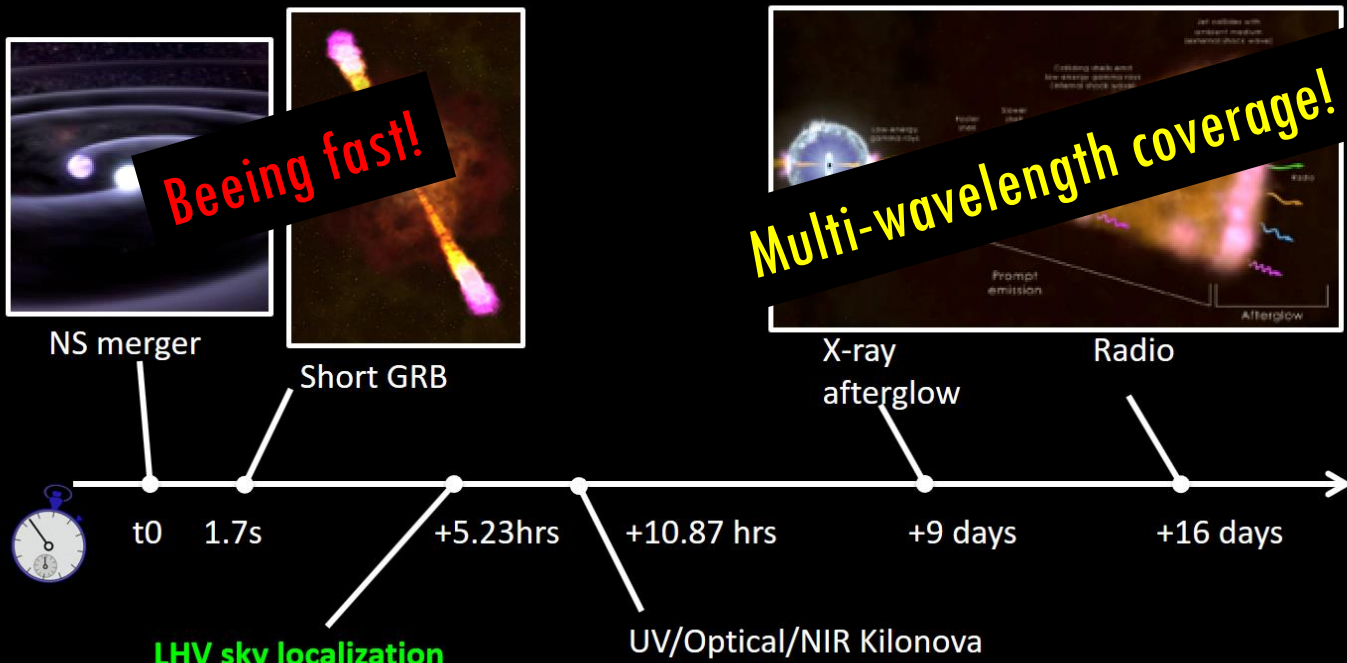
INTEGRAL

Reported 66 minutes
after detection

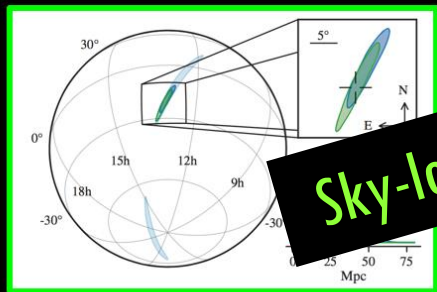


Credit: NASA GSFC & Caltech/MIT/LIGO Lab

<https://www.youtube.com/watch?v=-Yt5EmEgz2w>



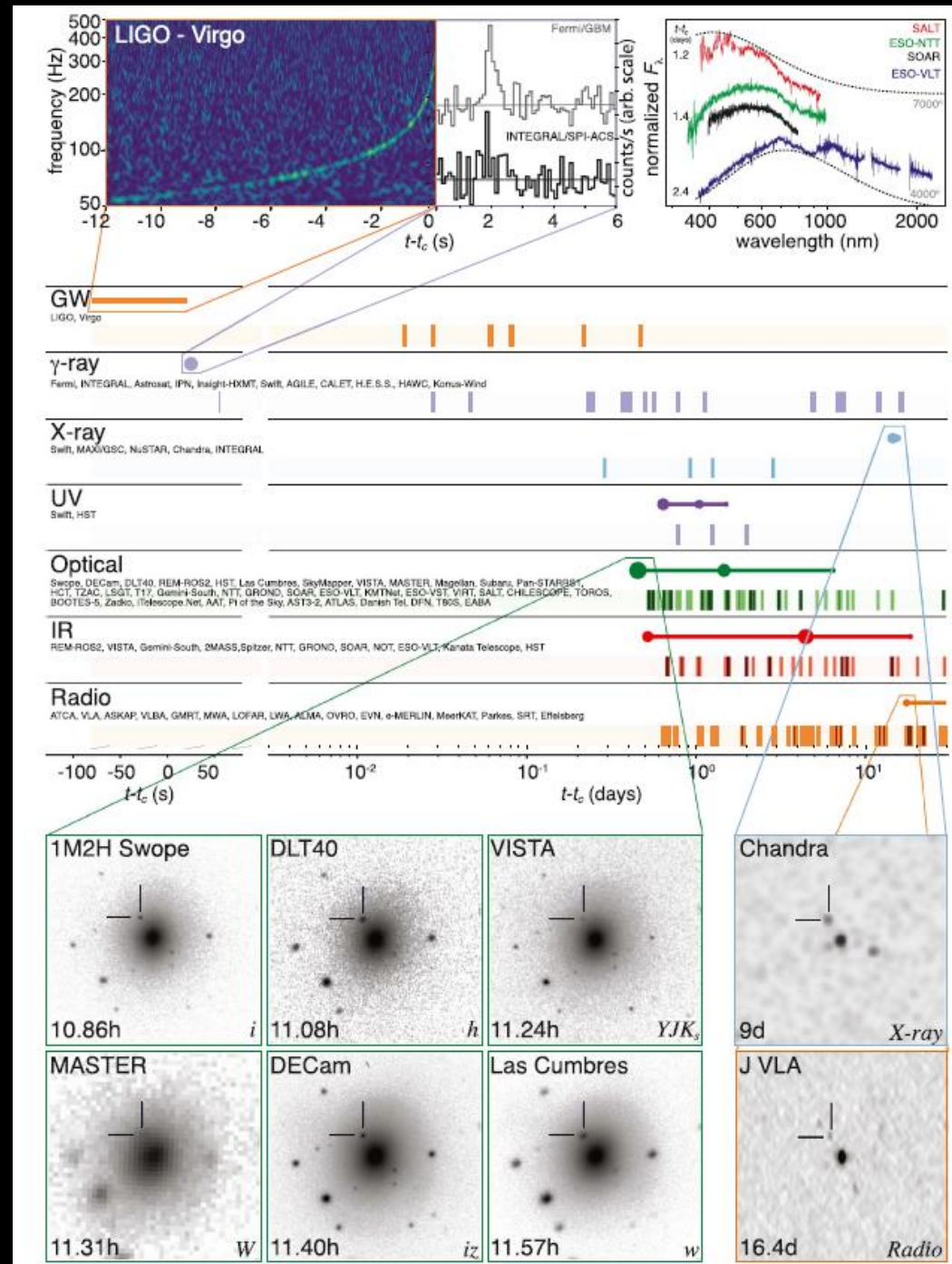
LHV sky localization



Sky-localization!



LVC + astronomers, ApJL, 848, L12



Multi-messenger Observations of a Binary Neutron Star Merger — Abbott+2017

The image is a composite of three panels. The top-left panel shows a satellite in space with a large, fan-shaped burst of yellow and white particles emanating from a central point. The top-right panel shows a bright blue gamma-ray burst against a starry night sky. The bottom panel shows several radio telescope dishes on Earth, with a red and blue aurora-like glow in the background. A central text box is overlaid on the image.

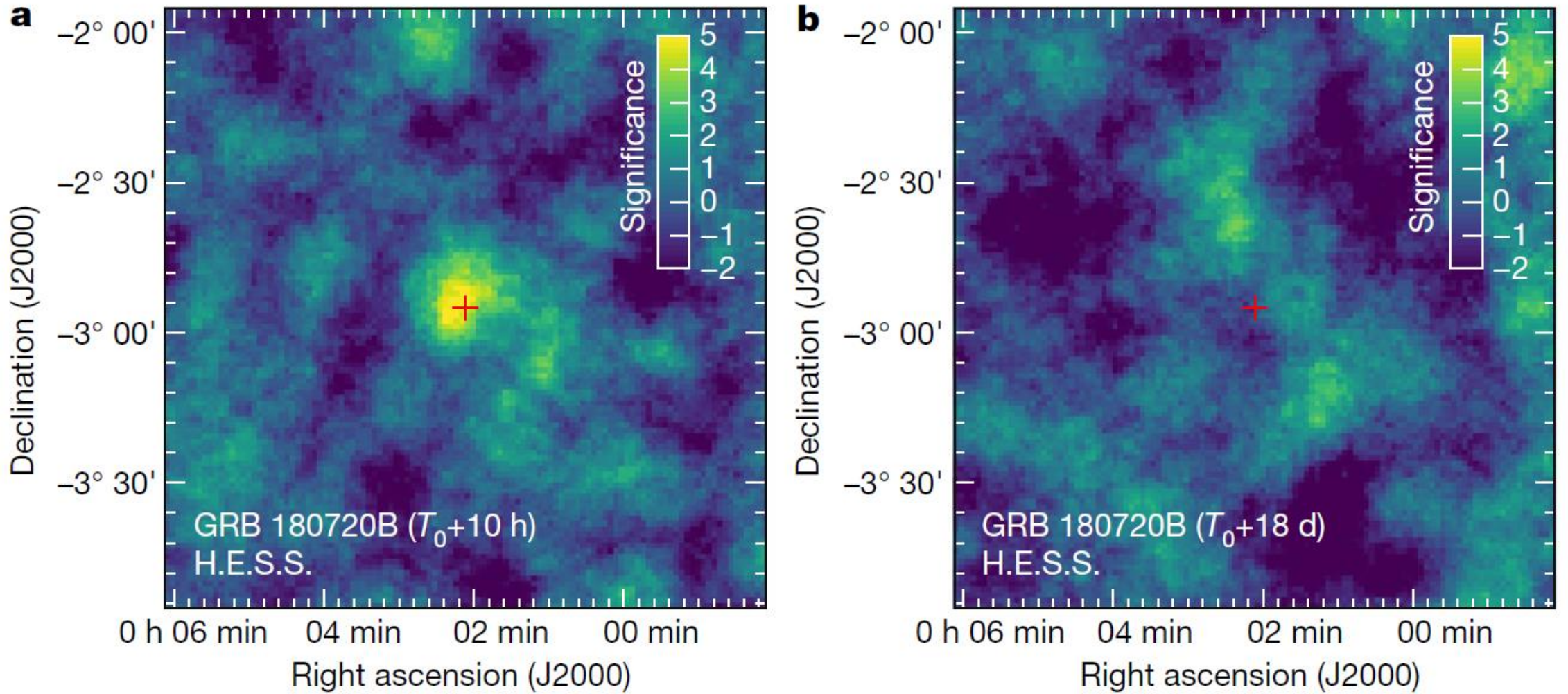
Breakthrough #2

GRBs at TeV energies

Credit: NASA/Fermi and Aurore Simonnet, Sonoma State University

Credit: DESY, Science Communication Lab

GRB 180720B



$z = 0.653$

A very-high-energy component deep in the γ -ray burst afterglow — Abdalla+2019

Multiwavelength observations of GRB 180720B

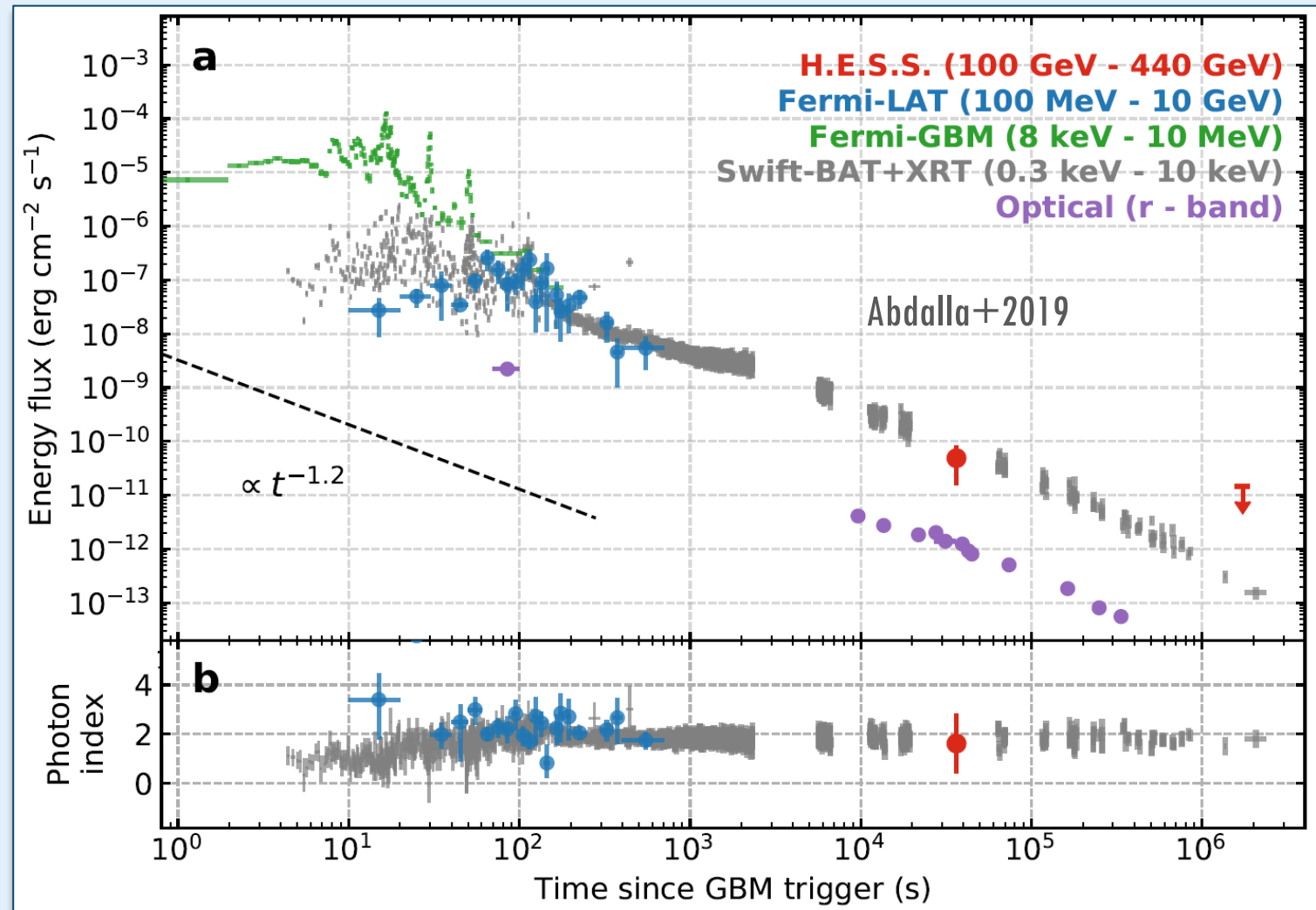
2 radiation processes most plausible dominant contributors:

1. **Synchrotron emission** of an electron population in the local magnetic field

- **Favours** the **similar temporal decay** in all bands
- **Difficulty** in explaining VHE emission (would require $\Gamma > 1000$)

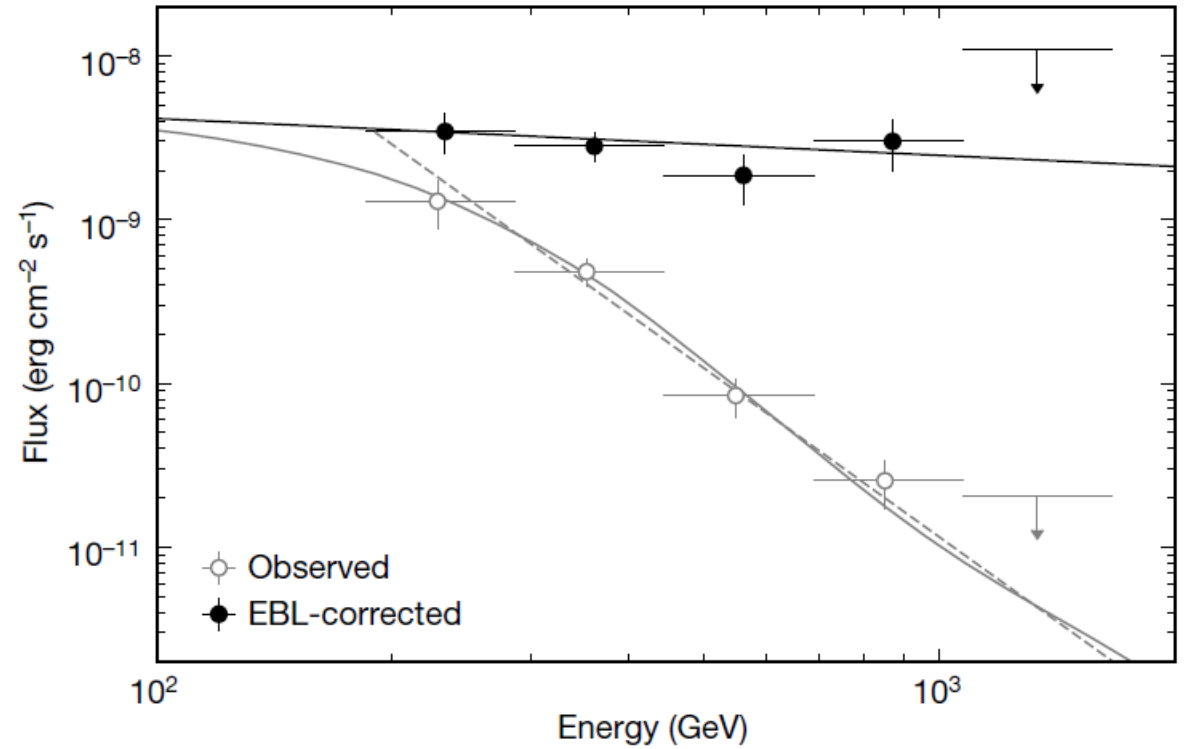
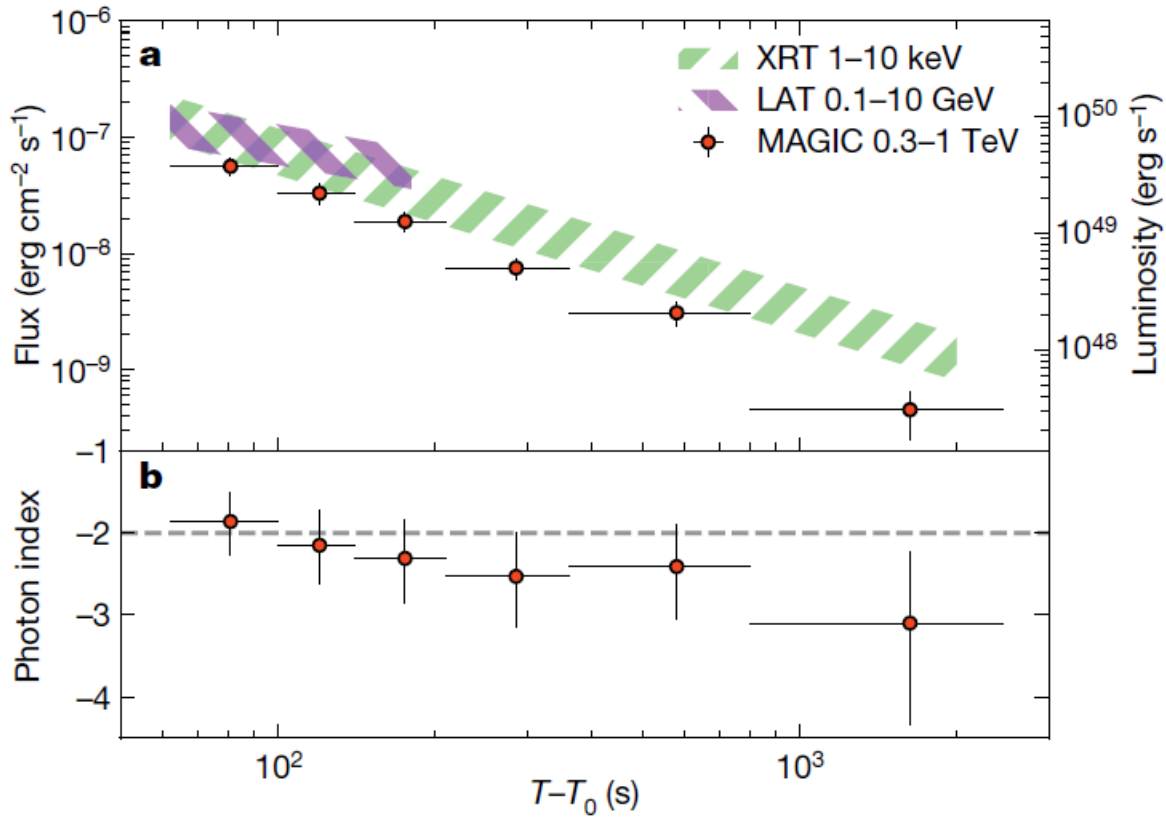
2. **Synchrotron self-Compton (SSC)** scattering

- VHE at late times is energetically much more easily achievable



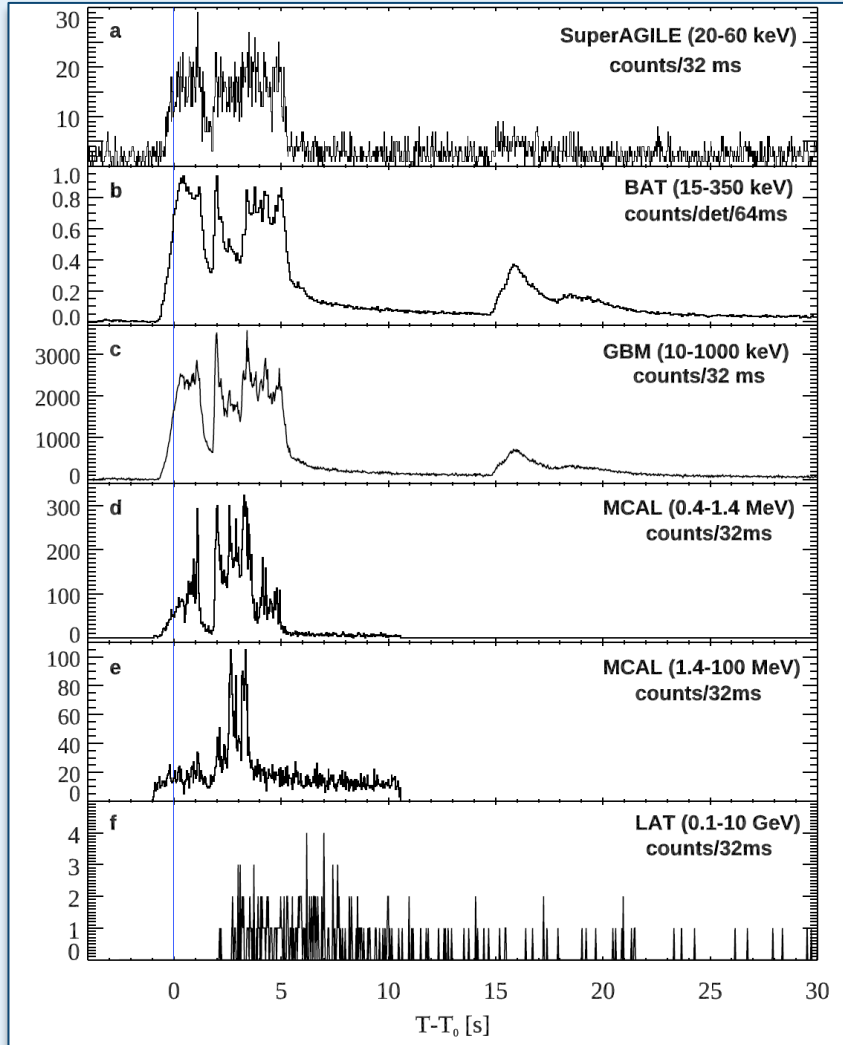
Energy flux lightcurves at different wavelengths

GRB 190114C



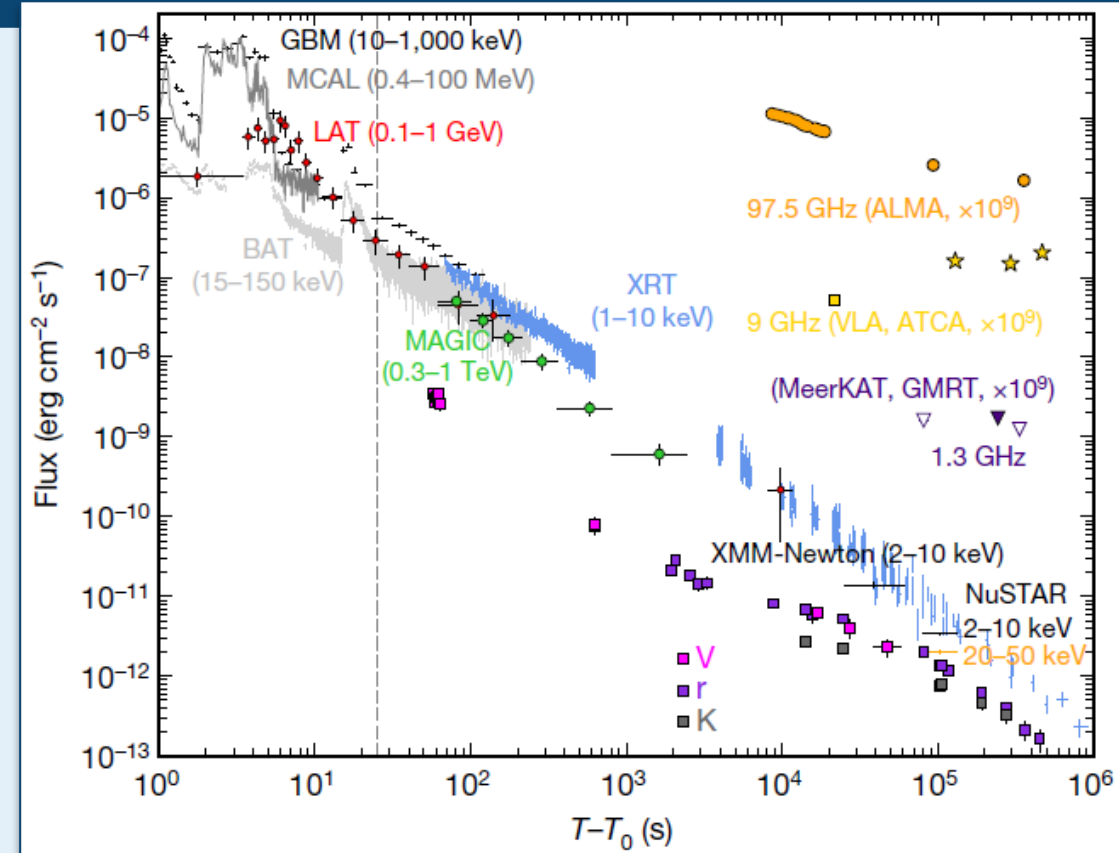
$z = 0.4245$

Multiwavelength observations of GRB 190114C



Prompt-emission lightcurves from different detectors

MAGIC Collaboration+2019

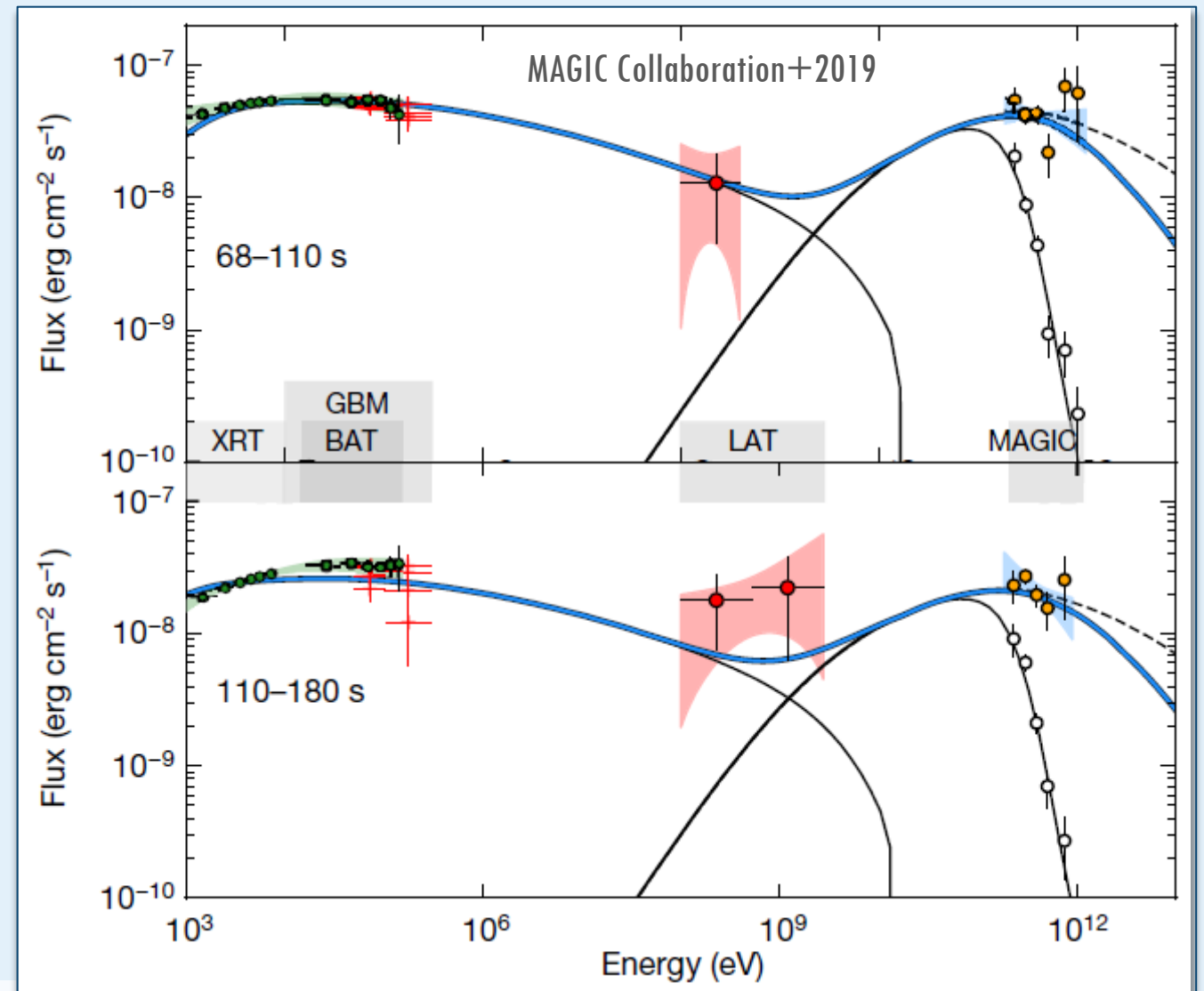


Energy flux lightcurves at different wavelengths from radio to gamma-rays

→ Vertical dashed line: end of the prompt-emission phase, identified as the end of the last flaring episode

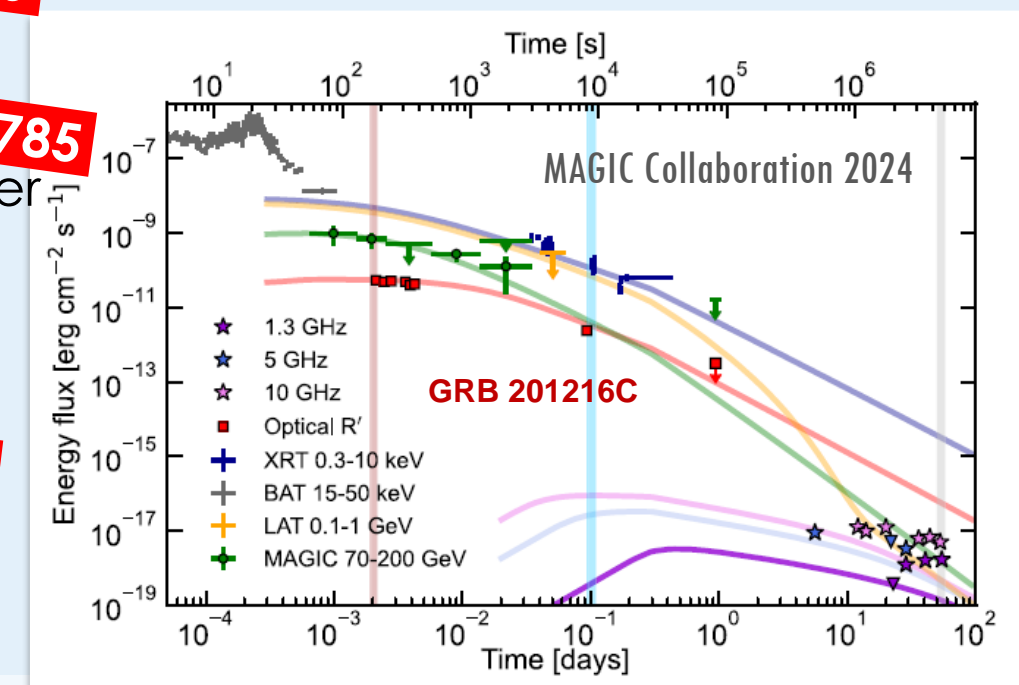
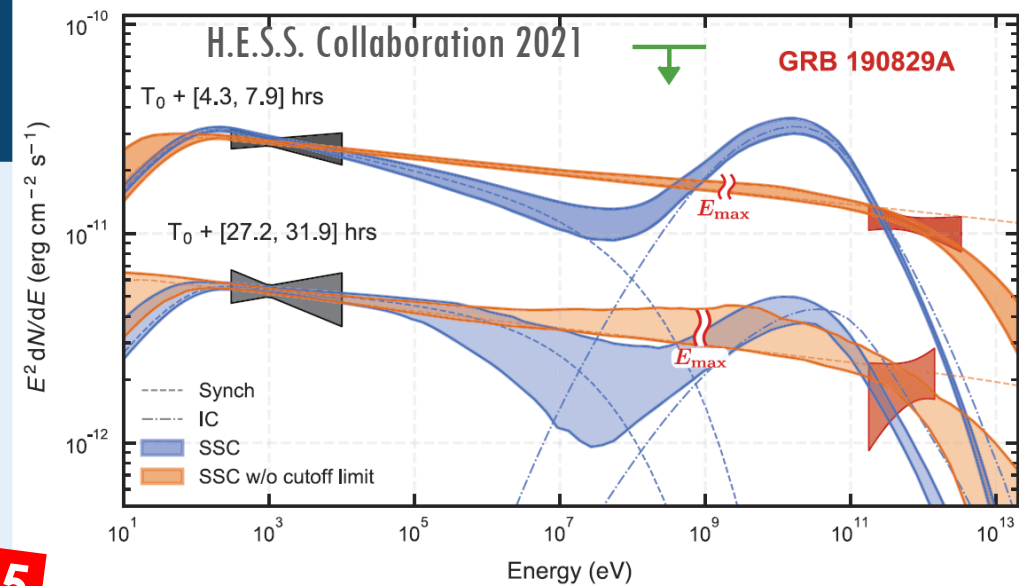
Multiwavelength observations of GRB 190114C

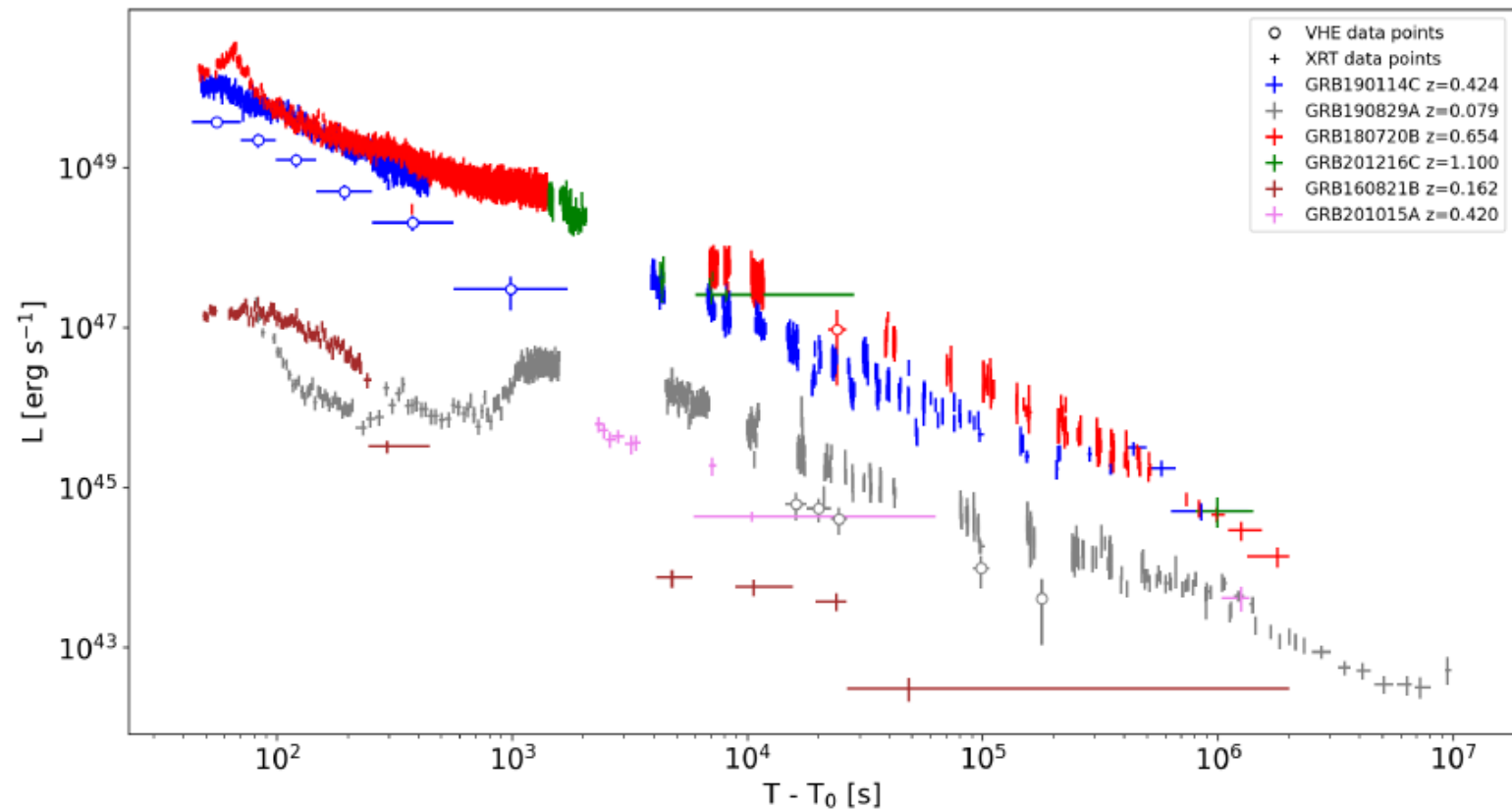
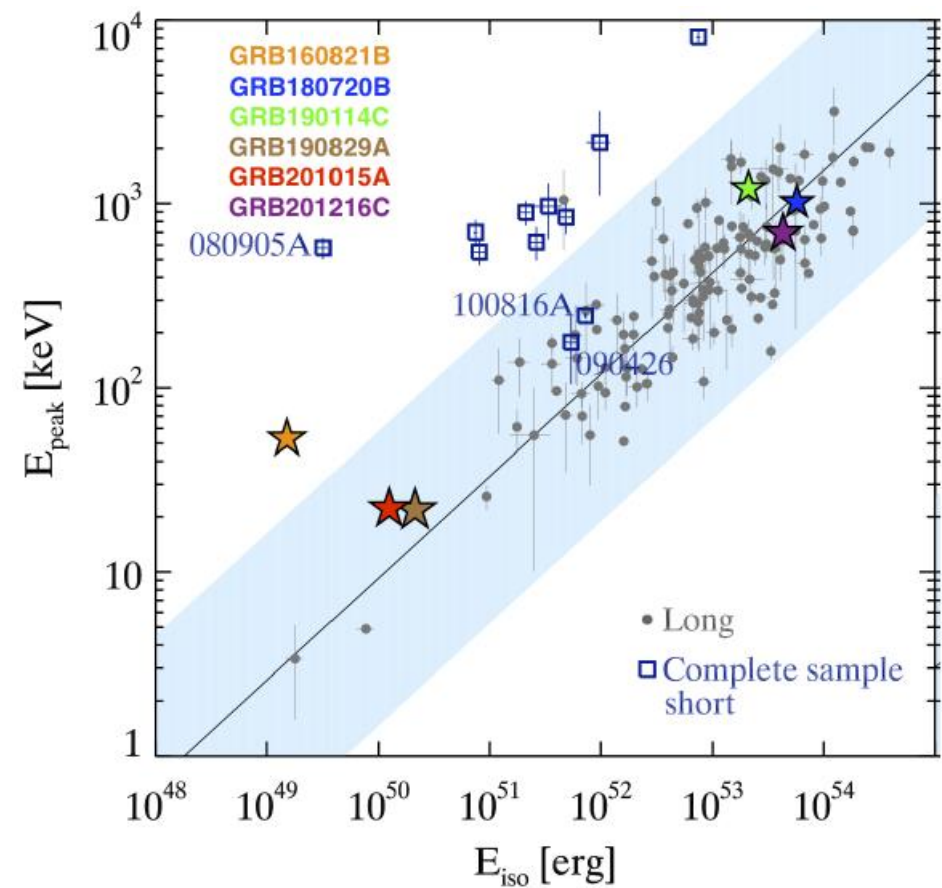
- The spectra from **X-ray to TeV** show the need for an **extra spectral component** to explain the flux increase at the **highest energies**
 - ➔ Same forward shock, but **different emission processes**
- Extra component generated by **Synchrotron Self-Compton**
 - Synchrotron photons are Compton up-scattered by the same electrons accelerated in the shocks



More GRBs @ TeV energies

- **GRB 160821B**
 - 3σ detection – **short** GRB, >0.5 TeV, **4h** post trigger (MAGIC+2021) **$z = 0.162$**
- **GRB 180720B**
 - 5σ detection – long GRB, >0.1 TeV, **10h** post trigger (HESS+2019 *Nature*) **$z = 0.653$**
- **GRB 190114C**
 - 50σ detection – long GRB, >0.2 TeV, **60s** post trigger (MAGIC+2019 *Nature*) **$z = 0.4245$**
- **GRB 190829A**
 - 20σ detection – long GRB, >0.18 TeV, **4-50h** post trigger (HESS+2021 *Science*) **$z = 0.0785$**
- **GRB 201015A**
 - 3σ detection – long GRB, **40s** post trigger (MAGIC+2022) **$z = 0.43$**
- **GRB 201216C**
 - 6σ detection – long GRB >70 GeV, **57s** post trigger (MAGIC+2024 *MNRAS*) **$z = 1.1$**





The «BOAT» GRB 221009A

Astronomy Picture of the Day

15 October 2022



https://apod.nasa.gov/apod/ap221015.html?fbclid=IwAR0dtOruG18ZOg9a-AhjcLkfPfvsoK_C5Dvn-sjK7YpBQB5Pt_g_RShYsUE

Image Credit: NASA, DOE, Fermi LAT Collaboration, R.Pillera

GRB 221009A – Timeline of events

■ Oct.9 2022

- 13:16:60 UT (T_0) Fermi-GBM trigger 221009553 (no prompt GCN notices)
- 14:10:17 UT ($T_0+3200s$) Swift trigger ([GCN](#) after 20min - [Swift J1913.1+1946](#))
- 20:54:36 UT Fermi-GBM [reports](#) that trigger 221009553 is superbright+long **GRB 221009A**
→ location consistent with Swift → **same event!!!**
- 21:45:05 UT Fermi-LAT [reports](#) HE emission (E_{max} : **8 GeV** @766 s post Swift trigger)

■ Oct.10, 2022

- X-shooter/VLT [reports](#) redshift **$z = 0.151$**
- Fermi-LAT [reports](#) refined analysis (Duration **>25ks** and E_{max} : **99 GeV** @ T_0+240s)
- IceCube [reports](#) neutrino UL (no detection)
- Konus/WIND [reports](#) highest GRB fluence in 28 years of operation

■ Oct.11, 2022

- LHAASO [reports](#) **>500 GeV** emission within $T_0+2000s$ ($>100\sigma$) + **18 TeV photon** (10σ)
- Swift/XRT [reports](#) complex system of **bright expanding dust-scattering rings**
- HAWC [reports](#) upper limits 8 hours after trigger

■ Oct.12, 2022

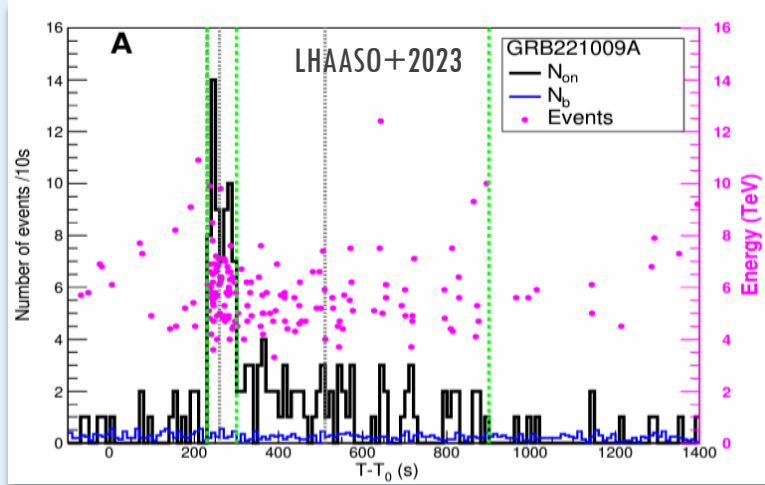
- Carpet-2 [reports](#) **250 TeV photon-like** air shower

■ Oct.14, 2022

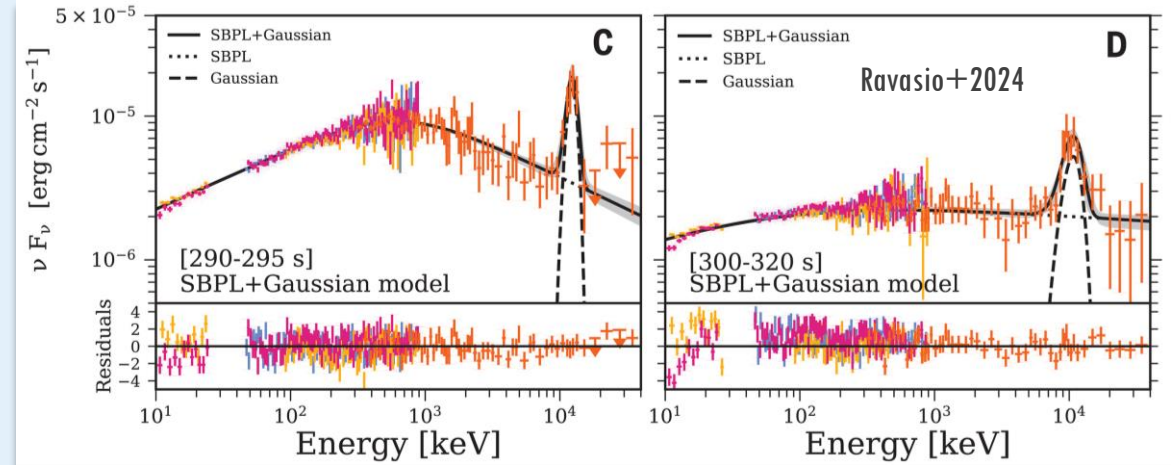
- Xia et al. [report](#) **400 GeV photon** observed by Fermi-LAT at $T_0+0.4 d$

GRB 221009A – Remarkable observations

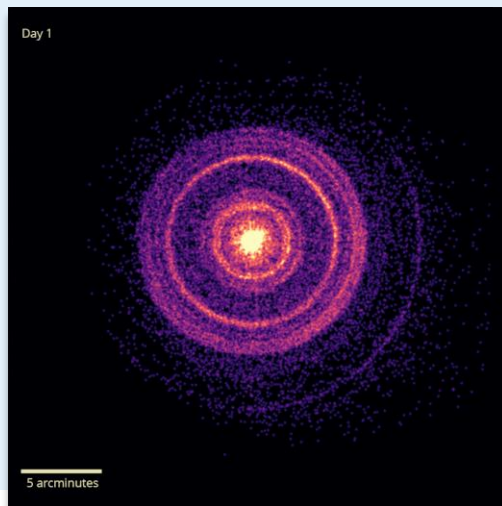
LHAASO detection of the TeV afterglow



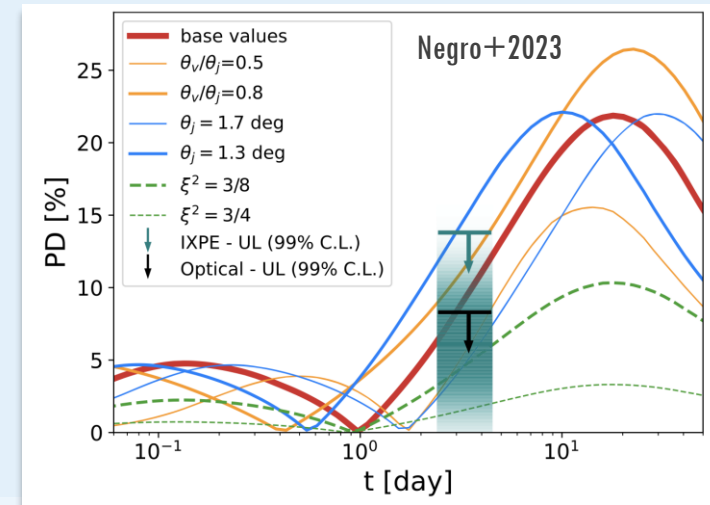
An MeV emission line in its spectrum

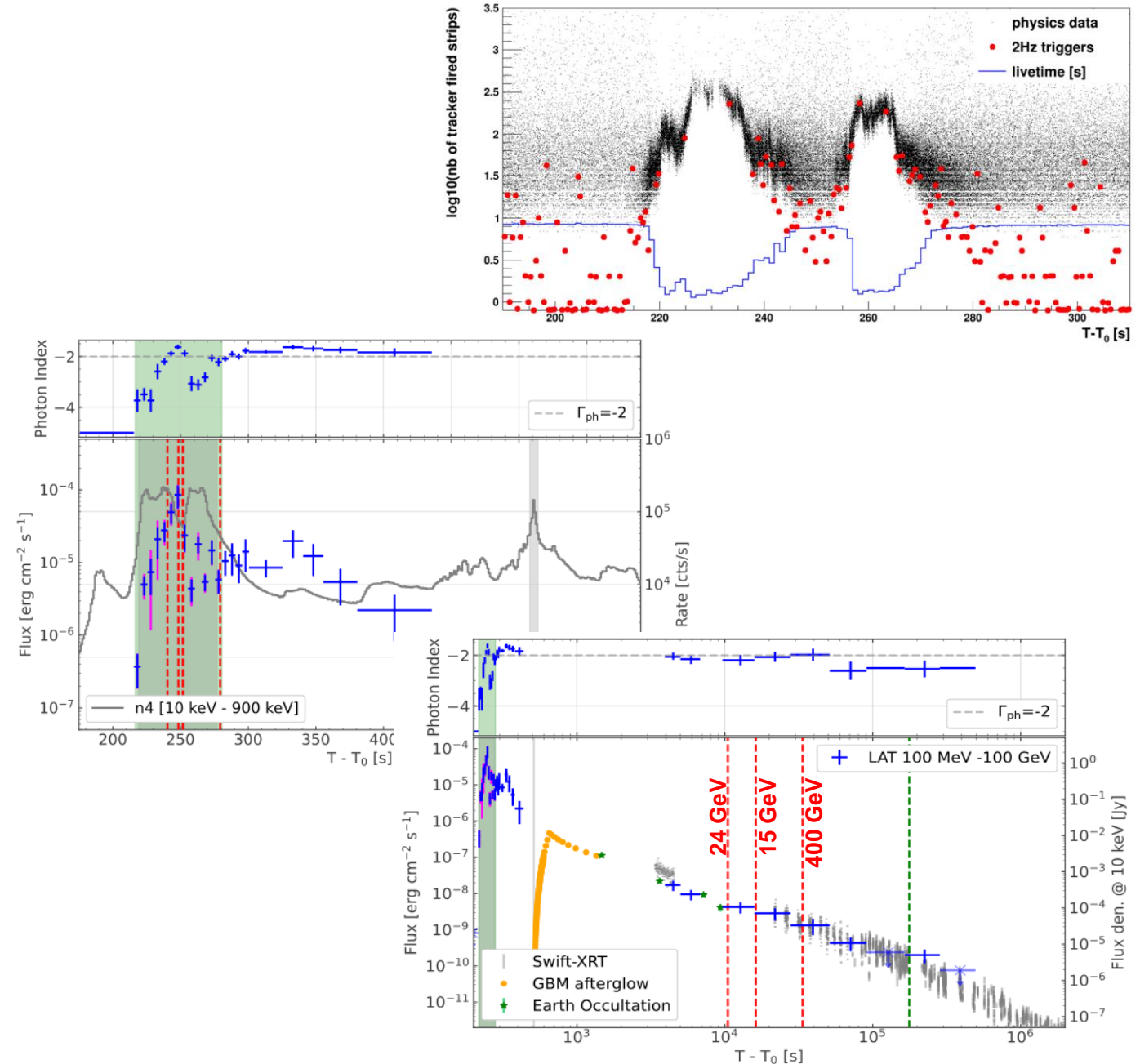
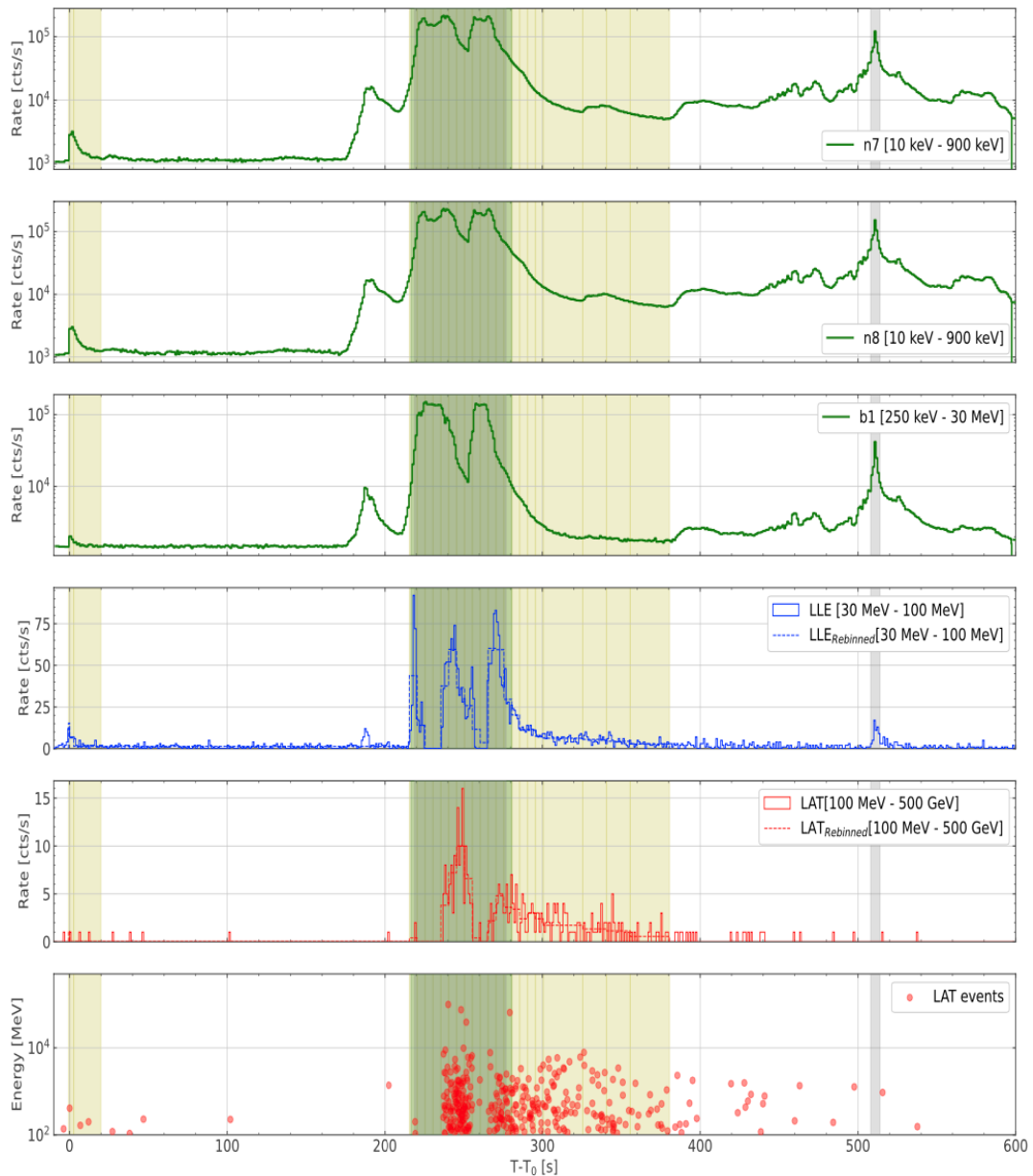


Dust scattering rings visible in Swift and XMM



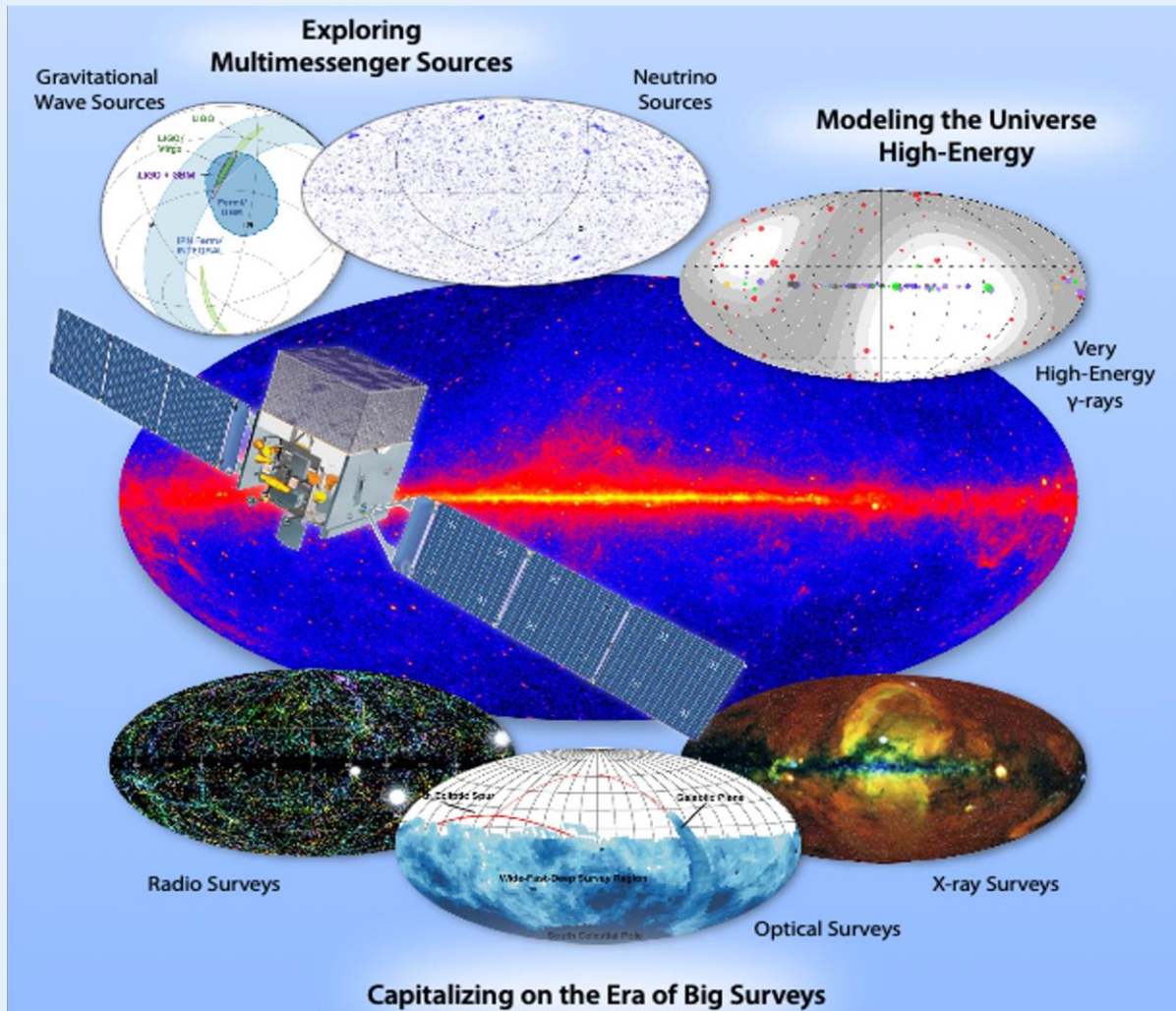
X-ray polarization UL on both prompt and afterglow





GRB 221009A: the B.O.A.T Burst that Shines in Gamma Rays — Axelsson+2024 [<https://arxiv.org/abs/2409.04580>]

Fermi and Swift mission status and prospects



- Last NASA Senior Review (SR) in 2022
 - “**Fermi and Swift** provide constant watch on the sky for high-energy transient events, discovering and localizing Gamma ray, X-ray, and UV emission from a variety of sources, including multi-messenger sources like gravitational wave and neutrino events”
 - Fermi and Swift extended mission lifetime: 2025
 - End of Operations: No specific requirement (no consumables, no significant degradation)
- ➔ **Next SR coming up in 2025**
- Fermi spacecraft and instrument performance is **excellent at 16 years**
 - 2 maneuvers (2013 and 2024) to avoid close approaches to other spacecraft
 - Lifetime of orbit extends into the **mid-2030s**

Thank you!

Elisabetta Bissaldi

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September 23rd – 27th, 2024 – Frascati, Roma
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For more information:
Email: Ricapsept2024@gmail.com
Web page: <https://agenda.infn.it/event/35353/>

link to the conference website