GRBs in the Swift and Fermi era

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Affiliate member of the H.E.S.S. Collaboration

GRB studies through history

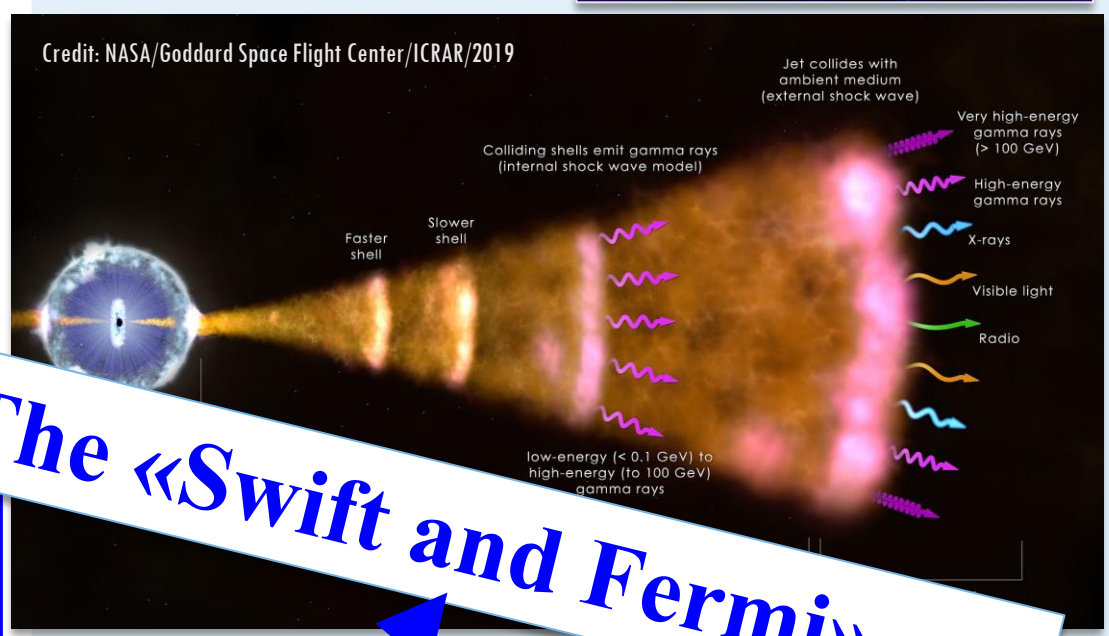
Seven eras

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!



The «Swift and Fermi» era

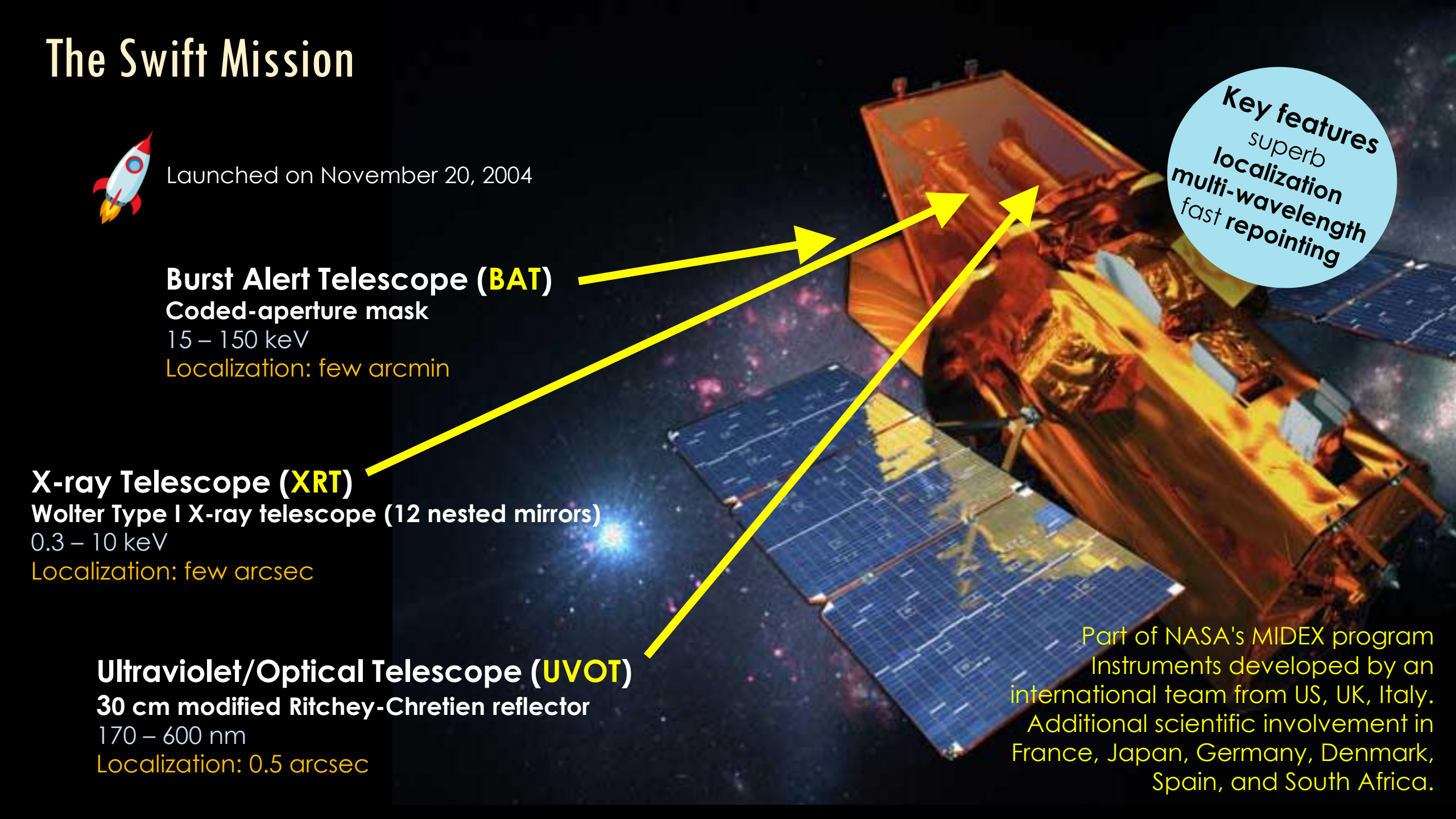
The Swift Mission

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.

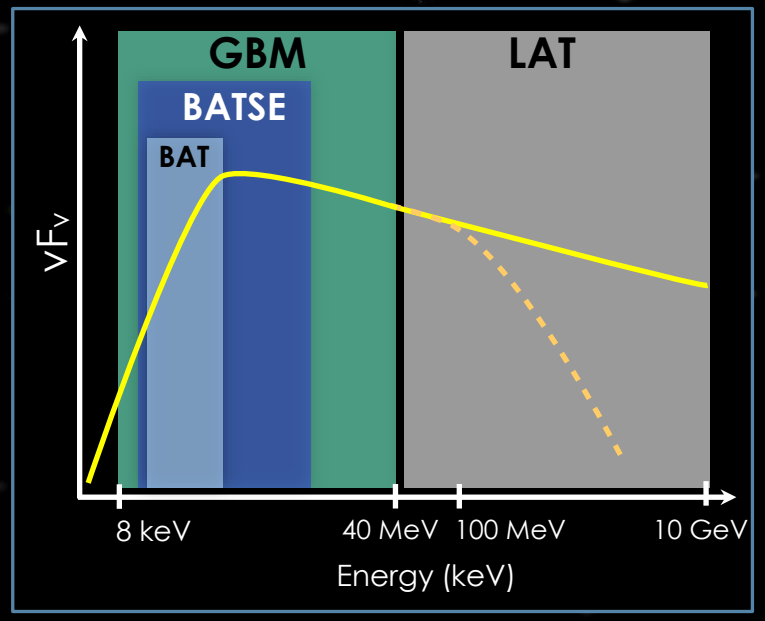
The Fermi Mission

Launched on June 11, 2008

Key features
huge **FoV**
&
large **energy range**

Large Area Telescope (LAT)
Pair conversion telescope
20 MeV → 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

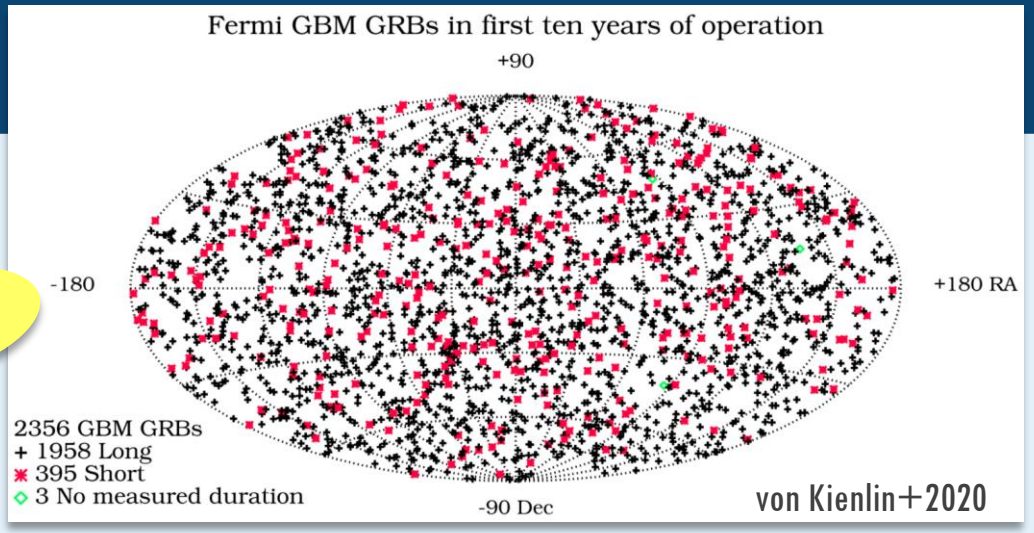
Radio/ GeV

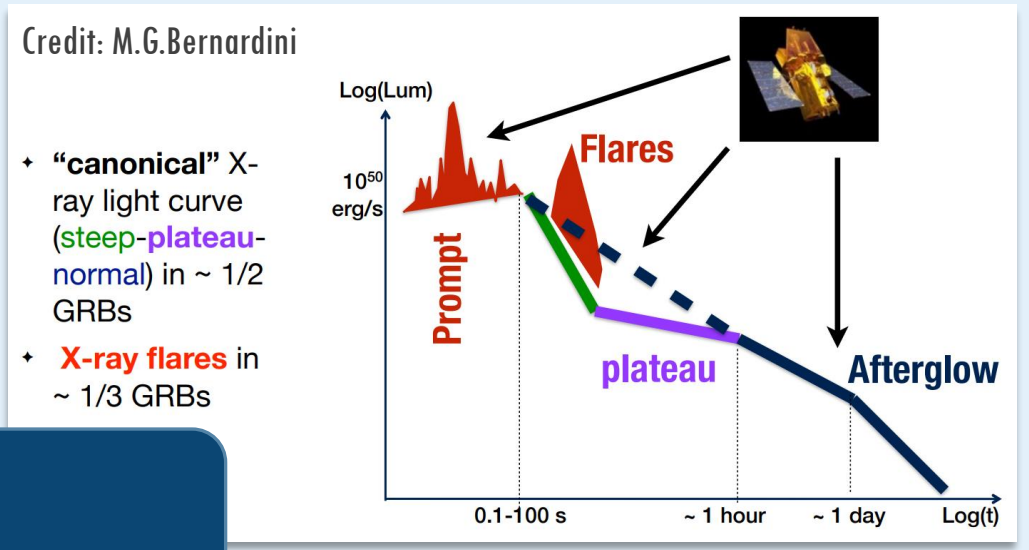
Optical/ GeV

keV/MeV

Optical

X-ray/keV

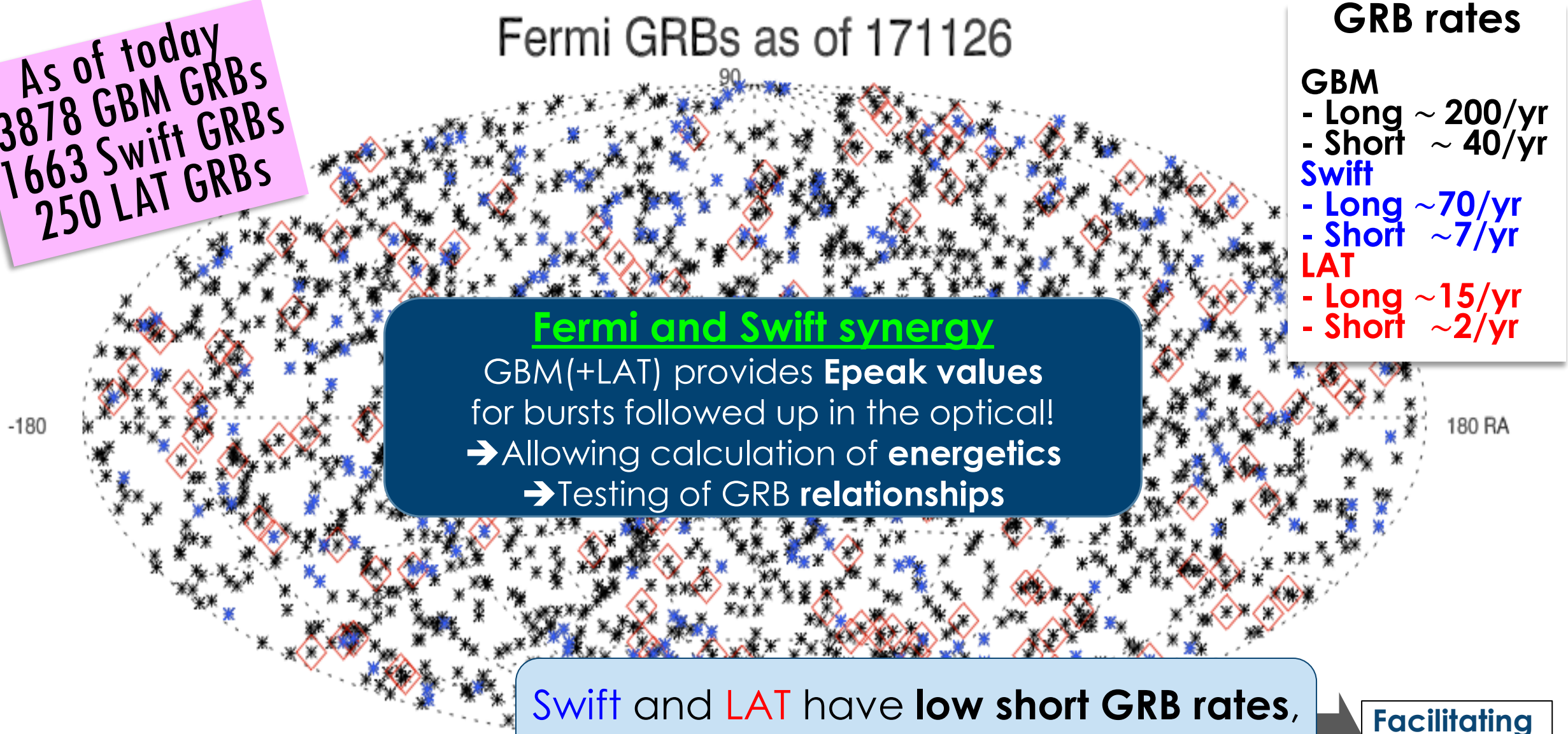




Multi-Wavelength has always been the key!
Now also **Multi-Messenger**!
Synergy between instruments (and community!) is crucial

*from Ghisellini+2010

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 **Epeak values** for bursts followed up in the optical!

➔Allowing calculation of **energetics**

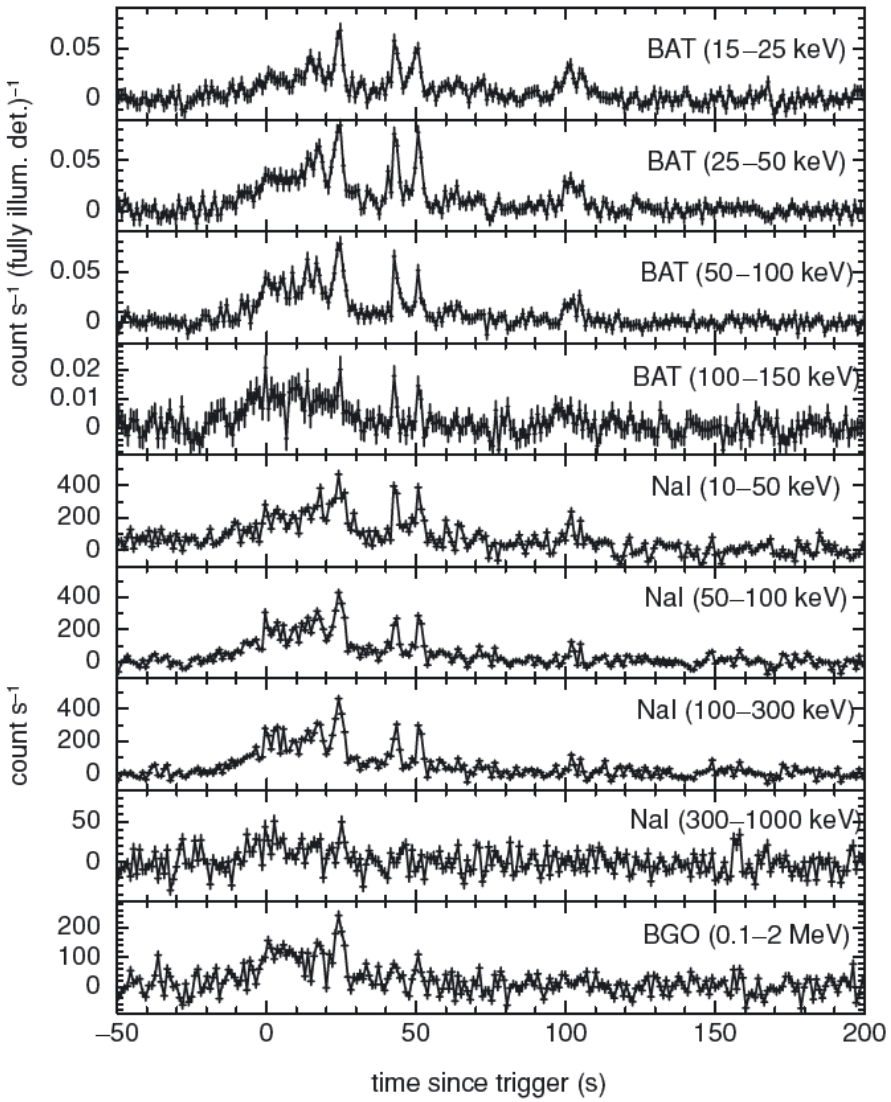
➔Testing of GRB **relationships**

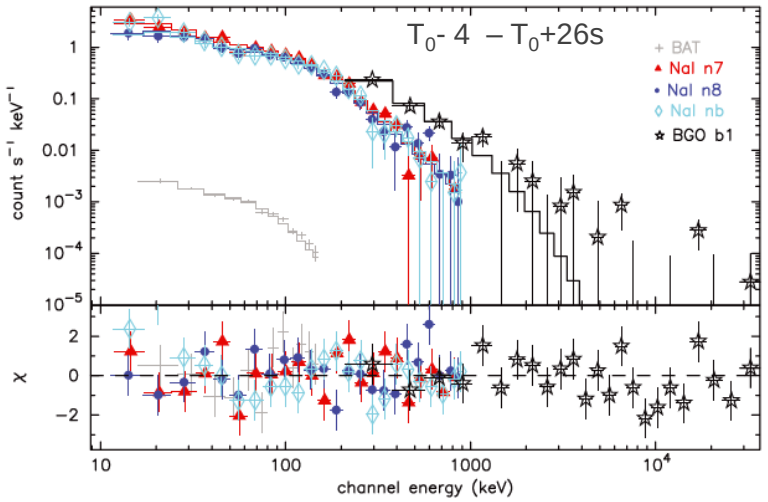
Swift and LAT have **low short GRB rates**, but **small localizations**!

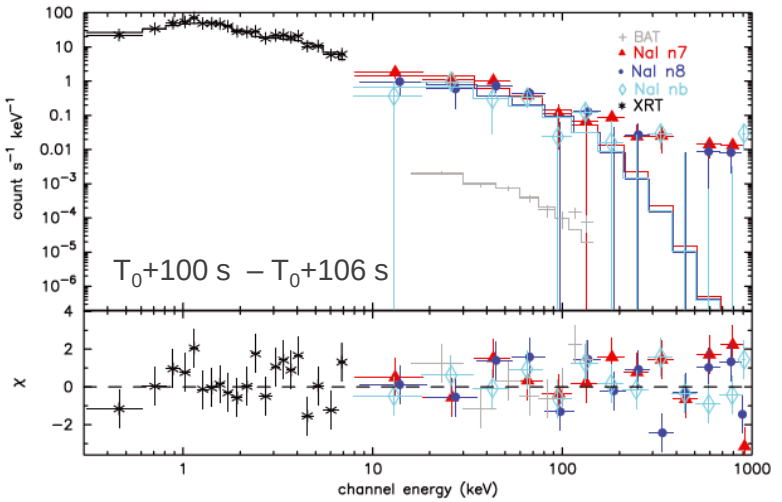
➡ **Facilitating follow-up!**

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

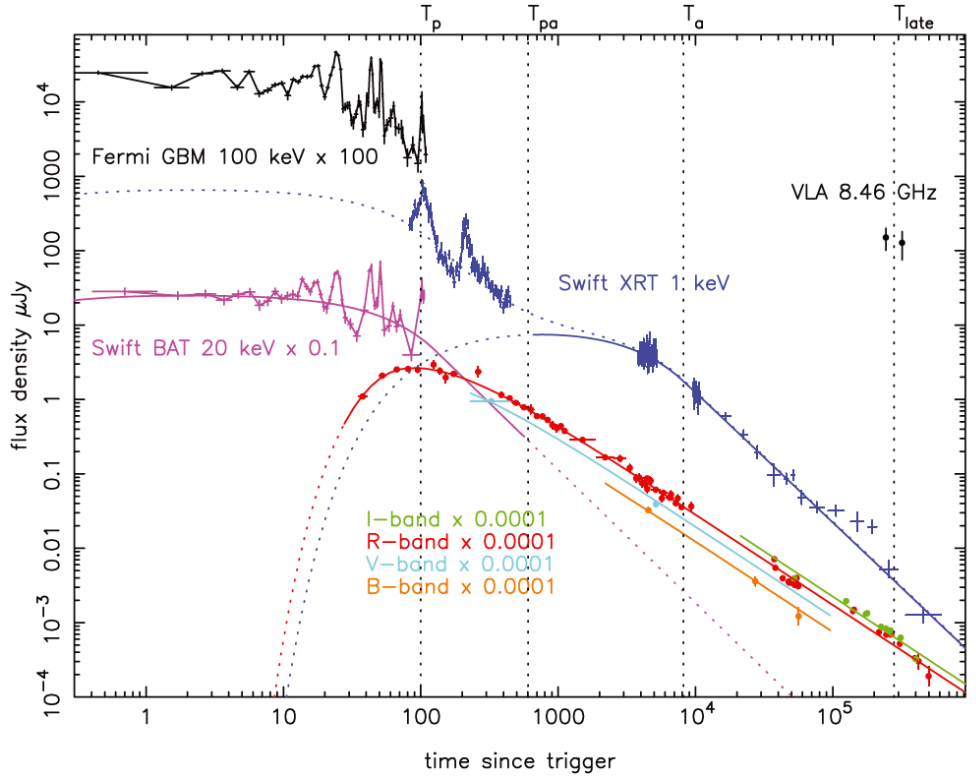
Fermi-GBM 9.5-year GRB map ©Connaughton/Fermi GBM Collaboration





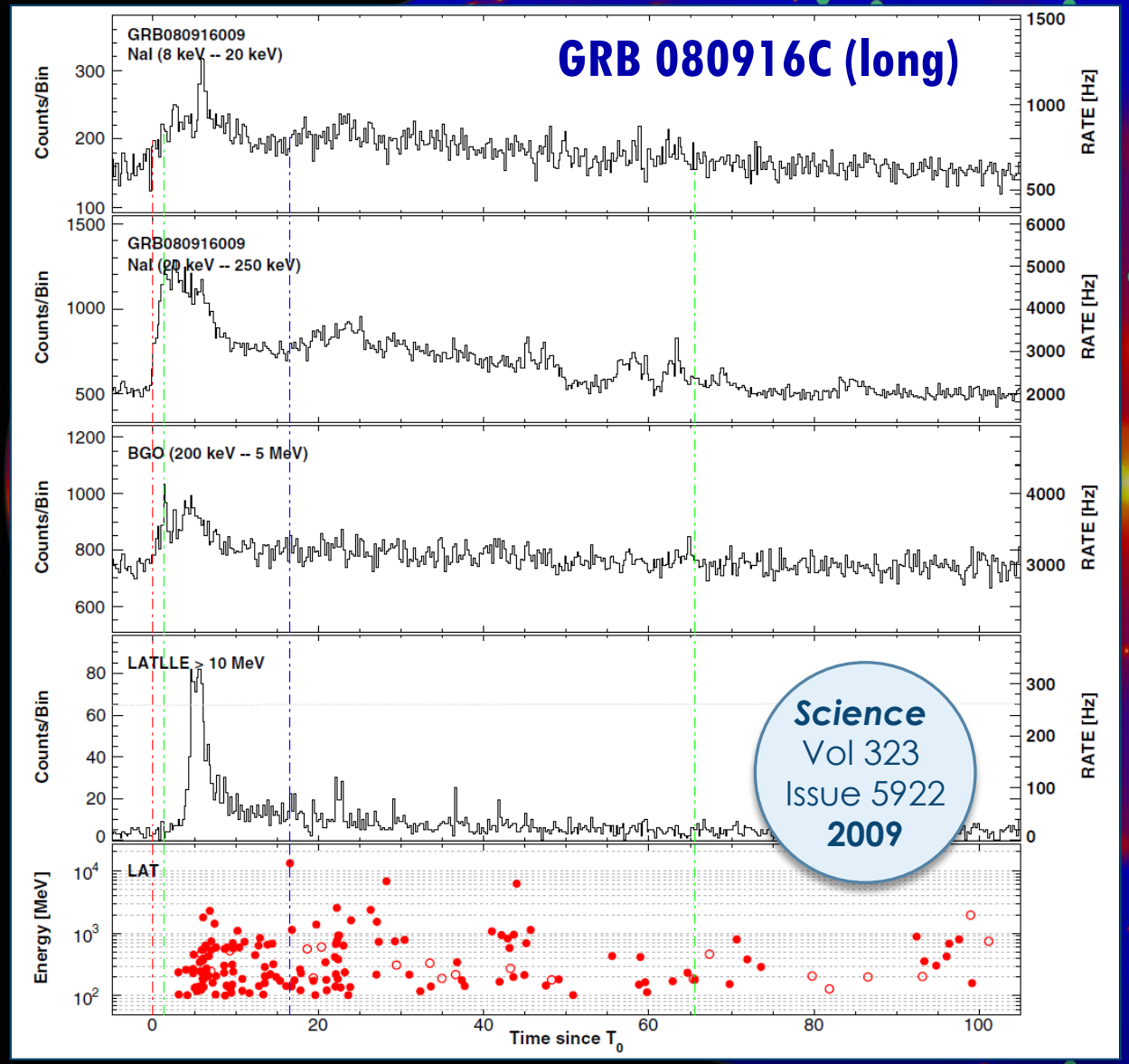


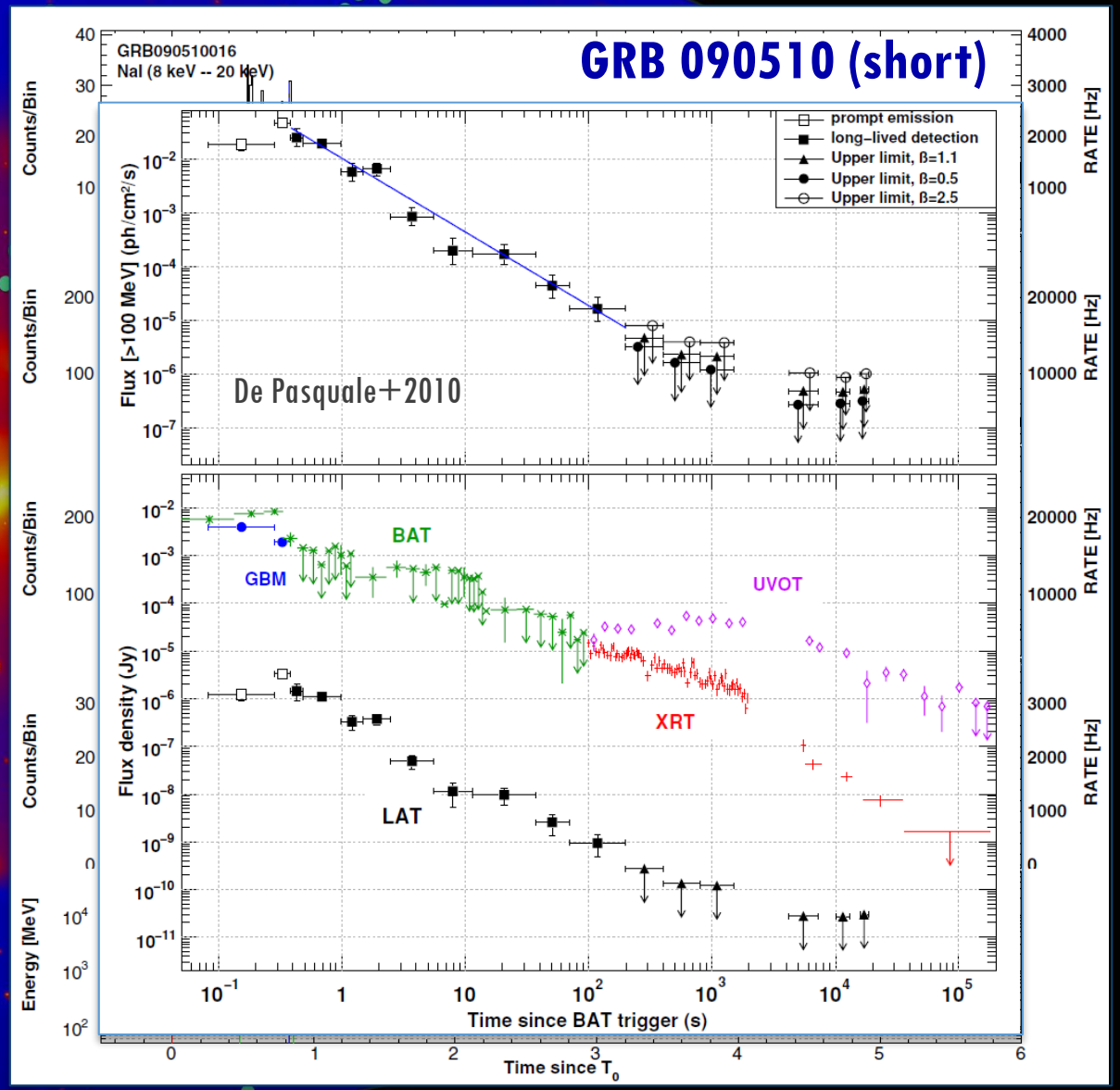
GBM's first published GRB!
Meegan et al., 2008, GCN 8100



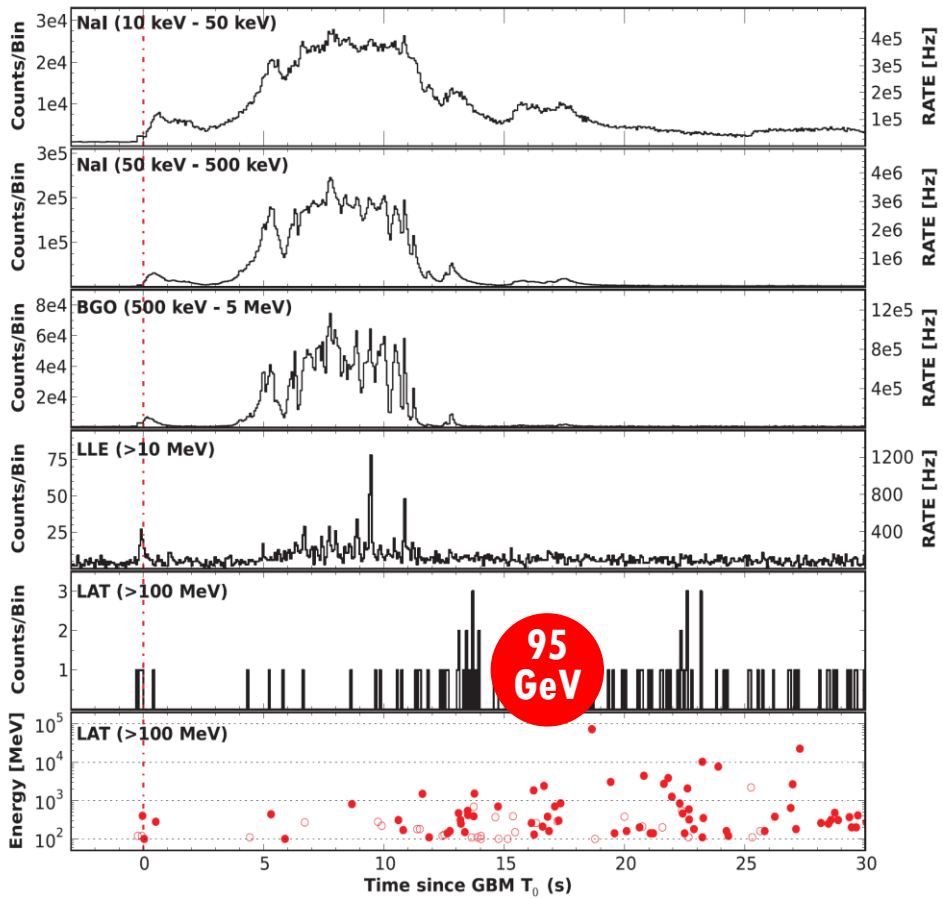
Multiwavelength observations of the energetic GRB 080810:
detailed mapping of the broad-band spectral evolution – Page,Willingale,Bissaldi+2009

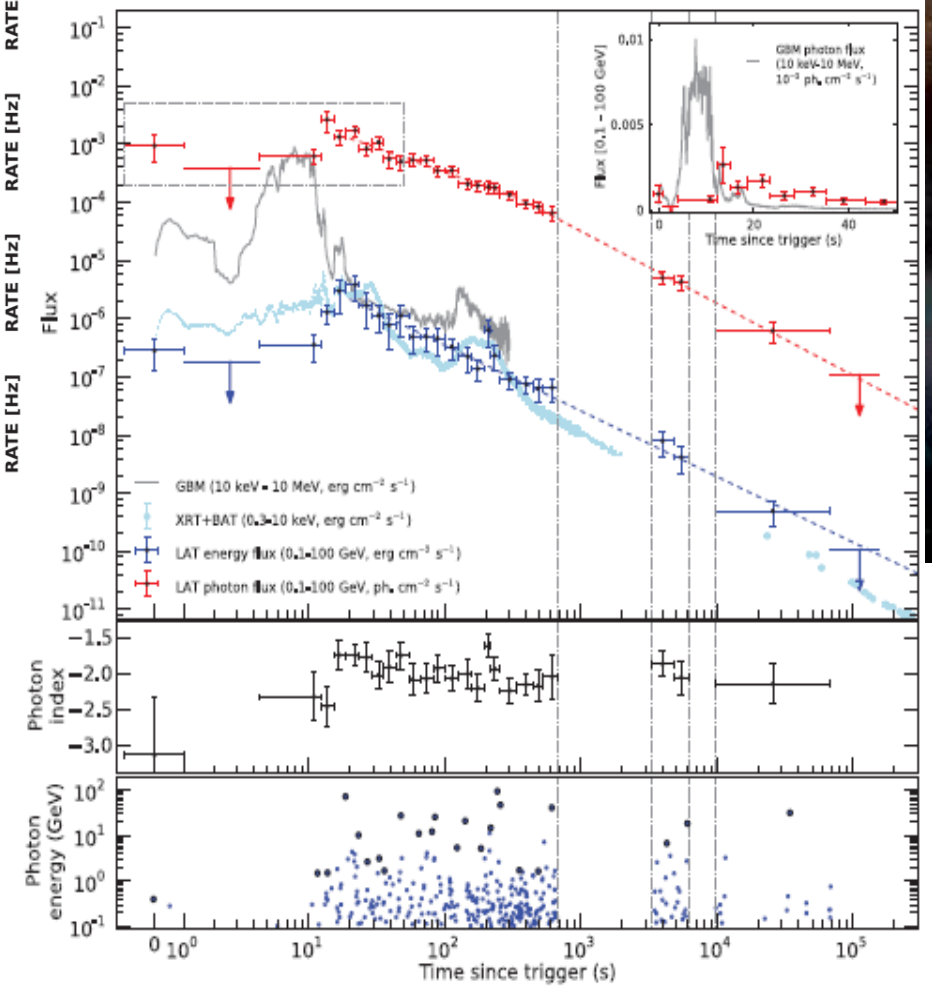
FFF-GRBs (Famous First Fermi bursts)





Credit: NASA/DOE/Fermi LAT Collaboration





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

Breakthrough #1
Joint GW-GRB observation

Credit: Dana Berry/SkyWorks Digital, Inc./Harvard-Smithsonian Center for Astrophysics

Fermi

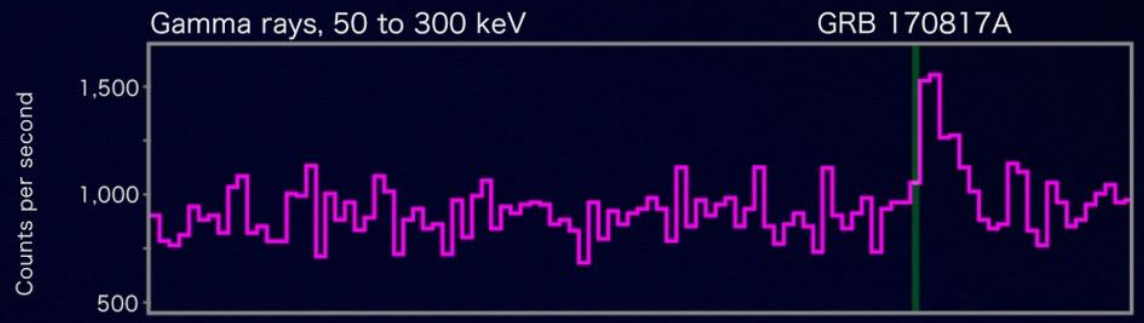
Reported 16 seconds after detection

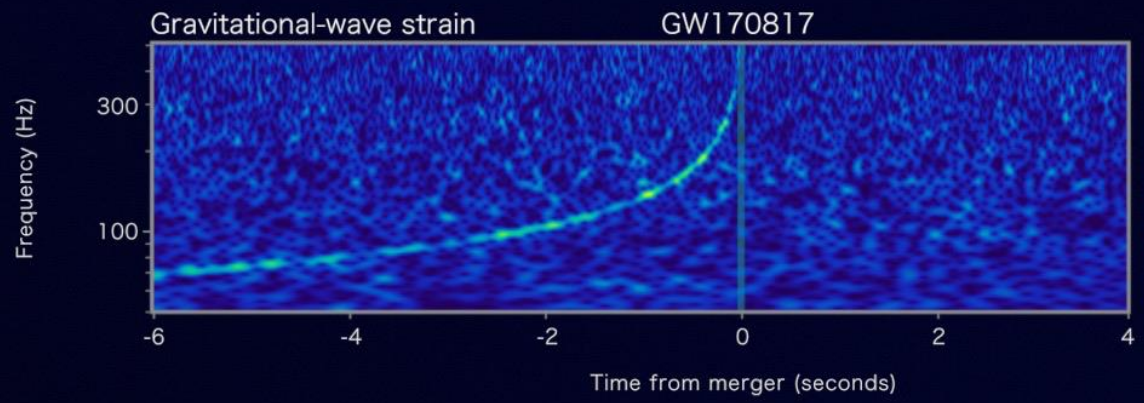
LIGO-Virgo

Reported 27 minutes after detection

INTEGRAL

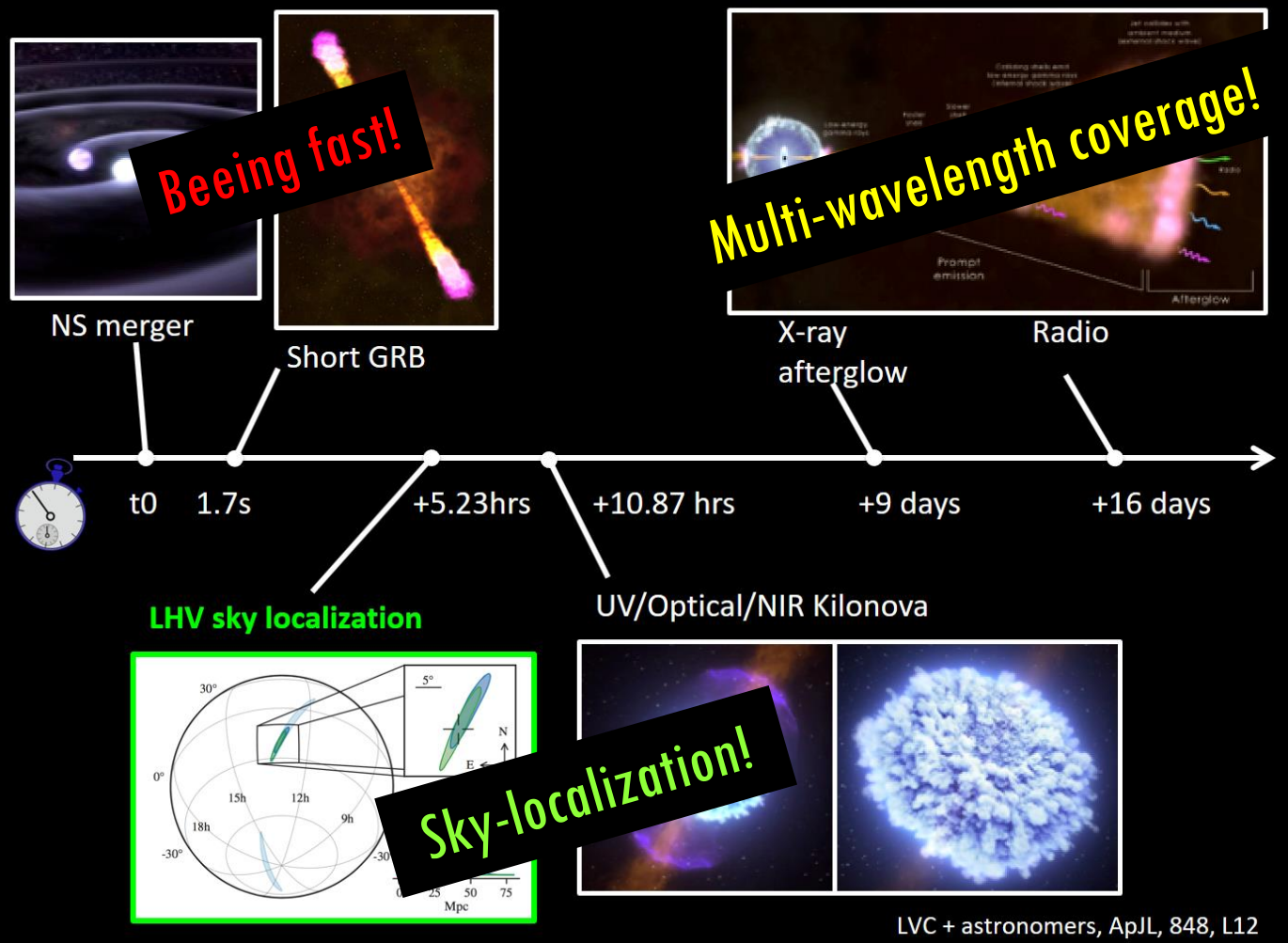
Reported 66 minutes after detection



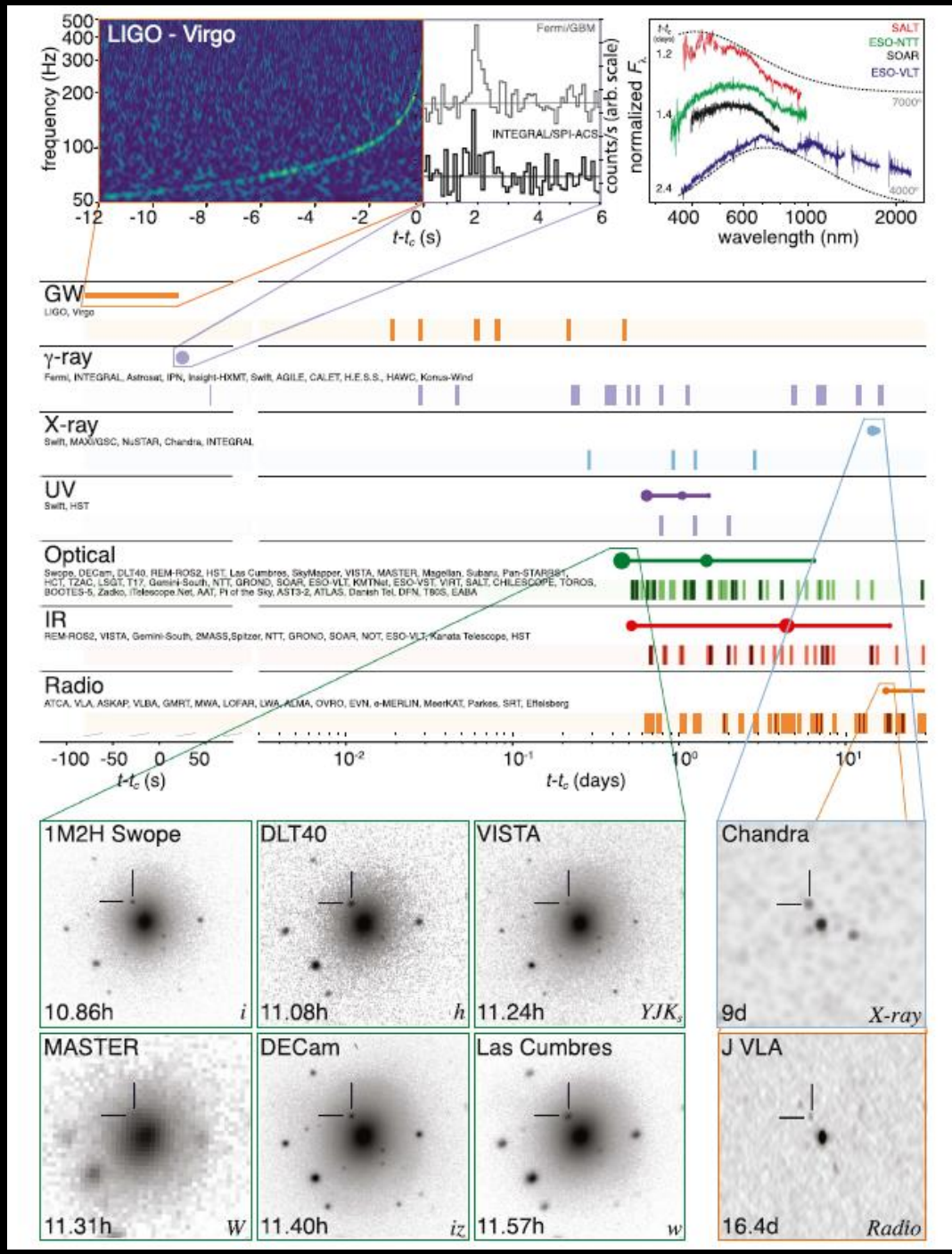


Credit: NASA GSFC & Caltech/MIT/LIGO Lab

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



LVC + astronomers, ApJL, 848, L12



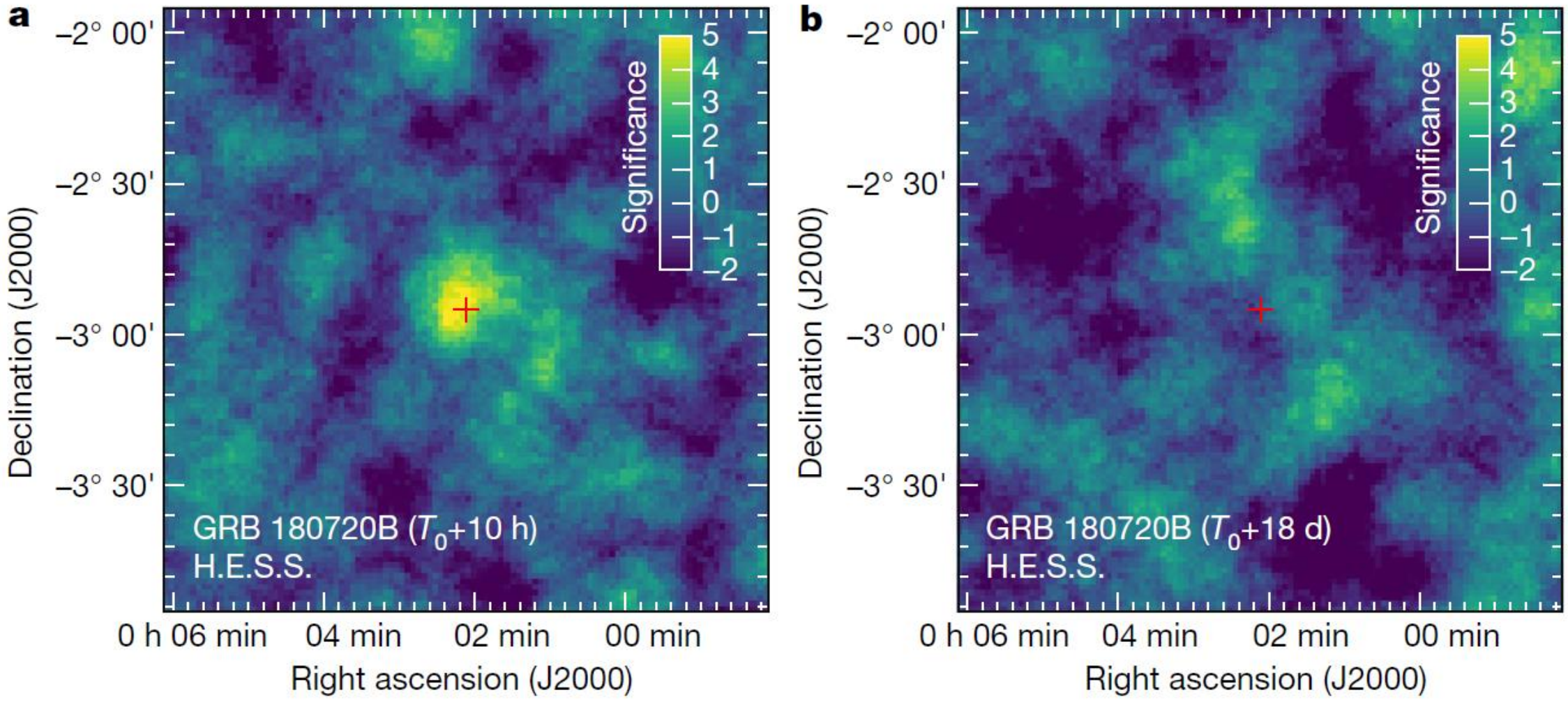
Multi-messenger Observations of a Binary Neutron Star Merger – Abbott+2017

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

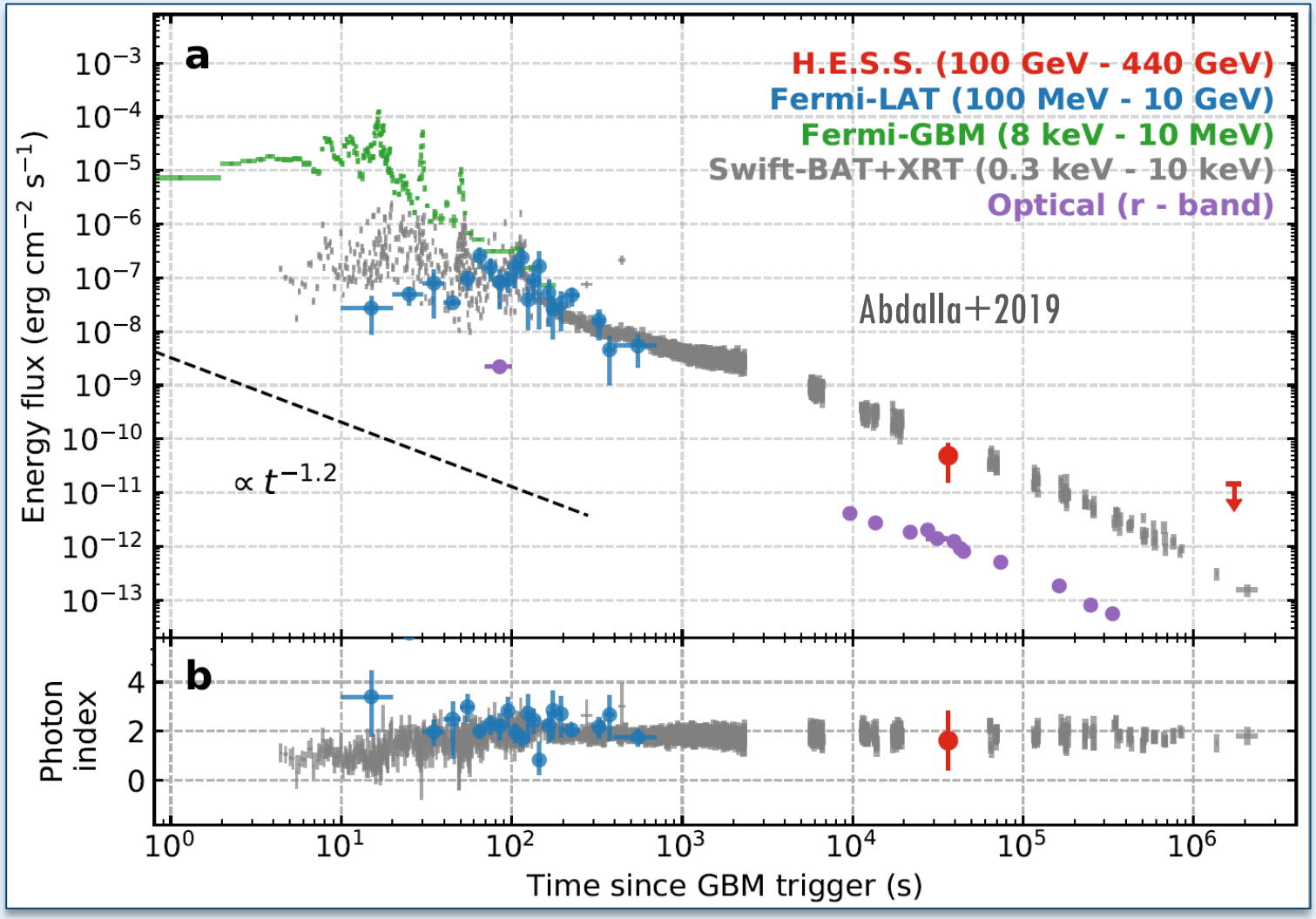
A very-high-energy component deep in the γ-ray burst afterglow – Abdalla+2019

Multiwavelength observations of GRB 180720B

2 radiation processes most plausible dominant contributors:

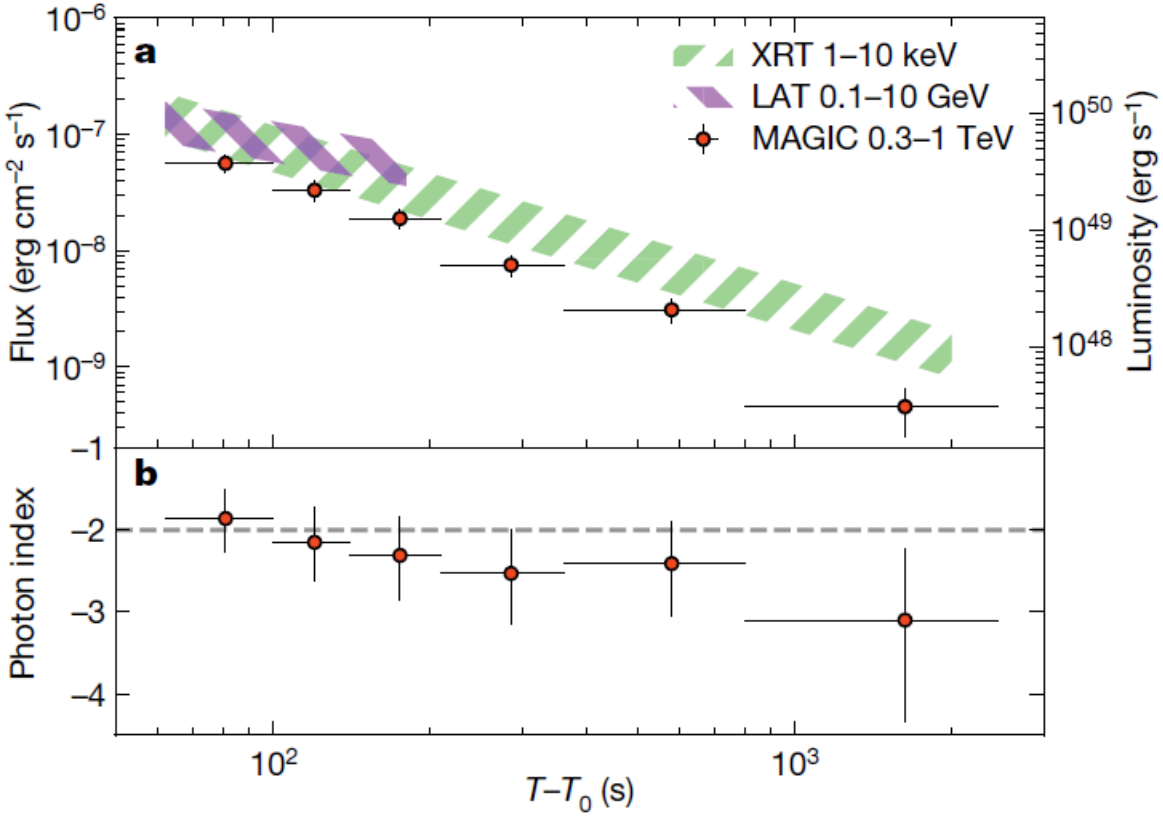
1. **Synchrotron emission** of an electron population in the local magnetic field
   - **Favours** the **similar temporal decay** in all bands
   - **Difficulty** in explaining VHE emission (would require Γ>1000)

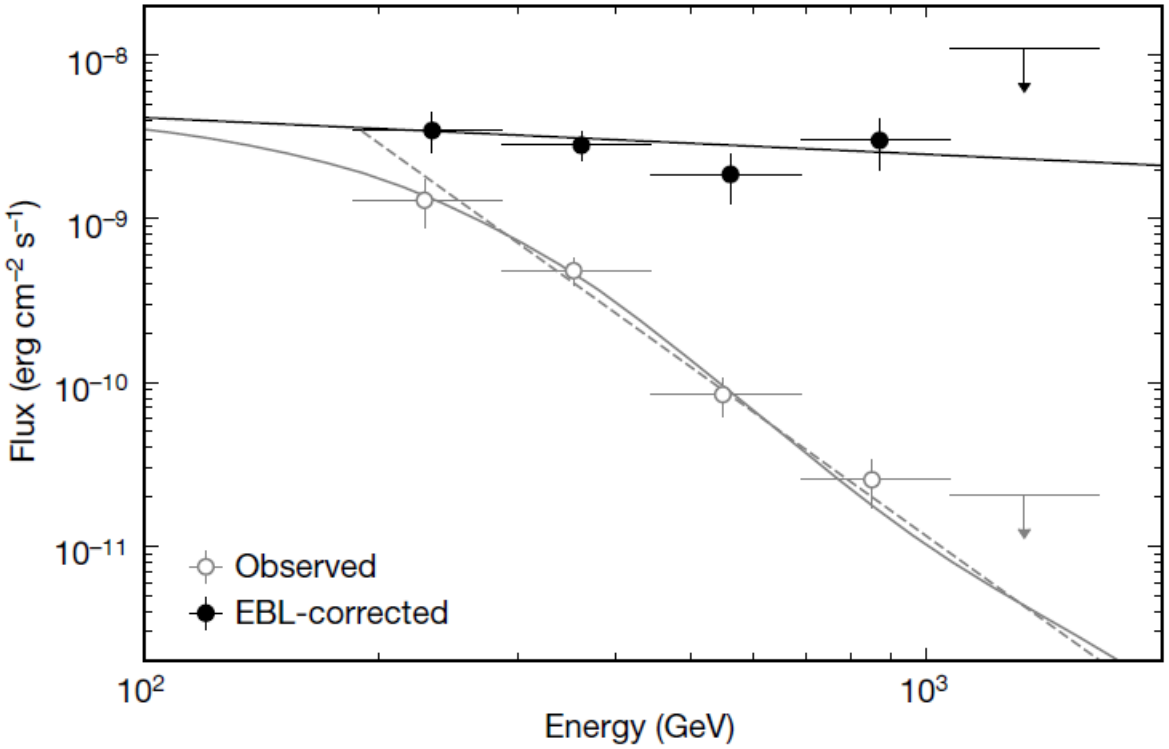
2. **Synchrotron self-Compton (SSC)** scattering
   - VHE at late times is energetically much more easily achievable



Energy flux lightcurves at different wavelengths

GRB 190114C

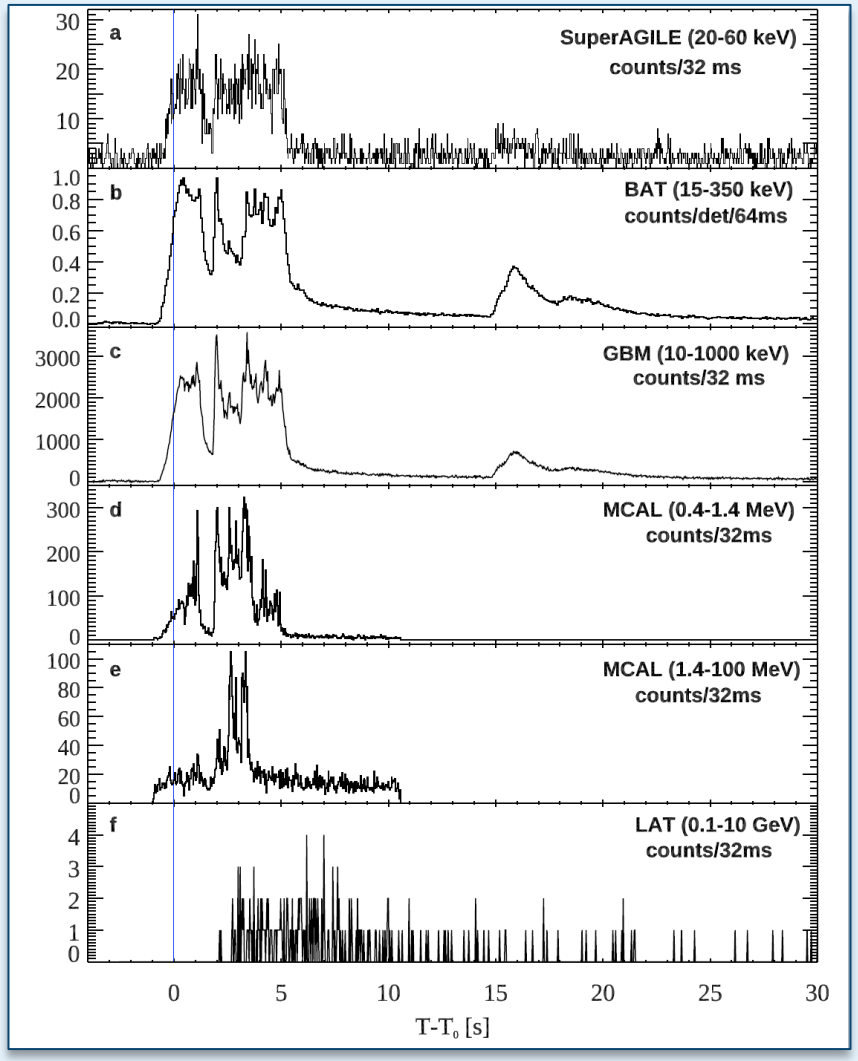




z = 0.4245

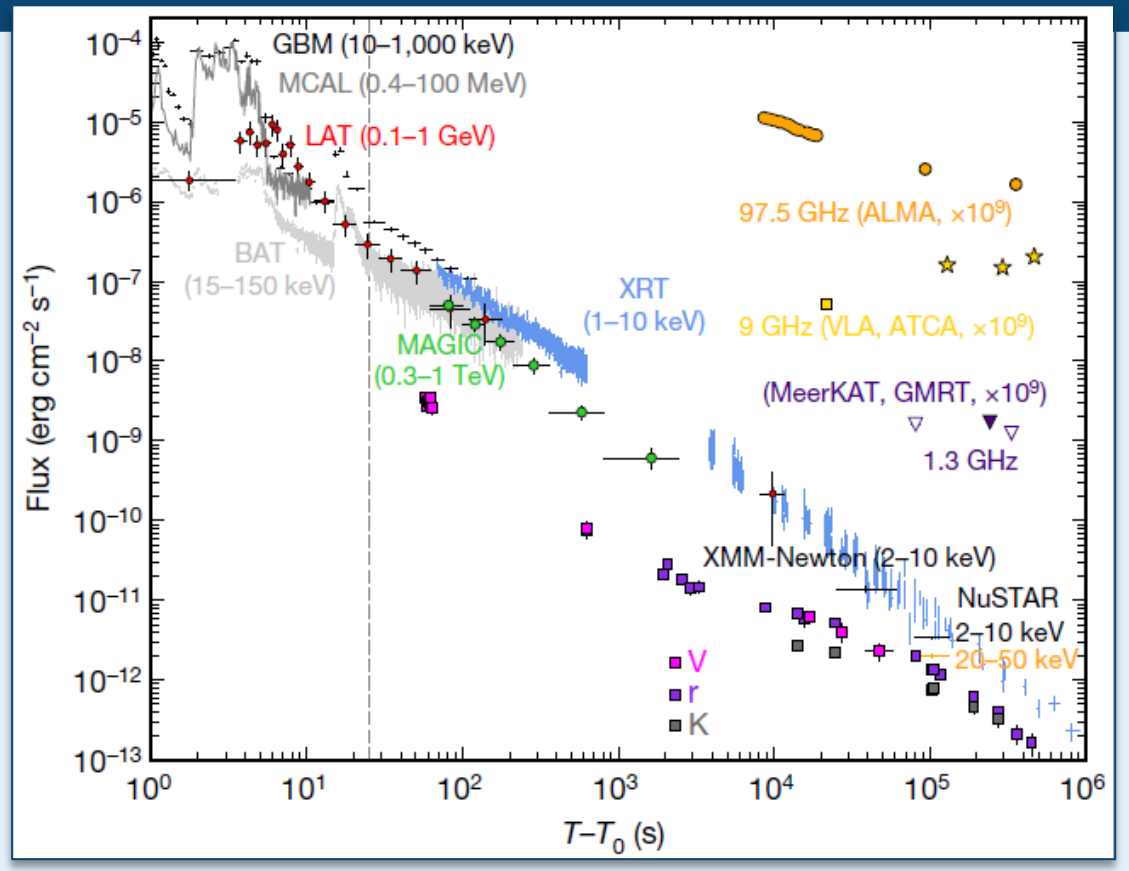
Teraelectronvolt emission from the γ-ray burst GRB 190114C – MAGIC Collaboration+2019

Multiwavelength observations of GRB 190114C



Prompt-emission lightcurves from different detectors

MAGIC Collaboration+2019



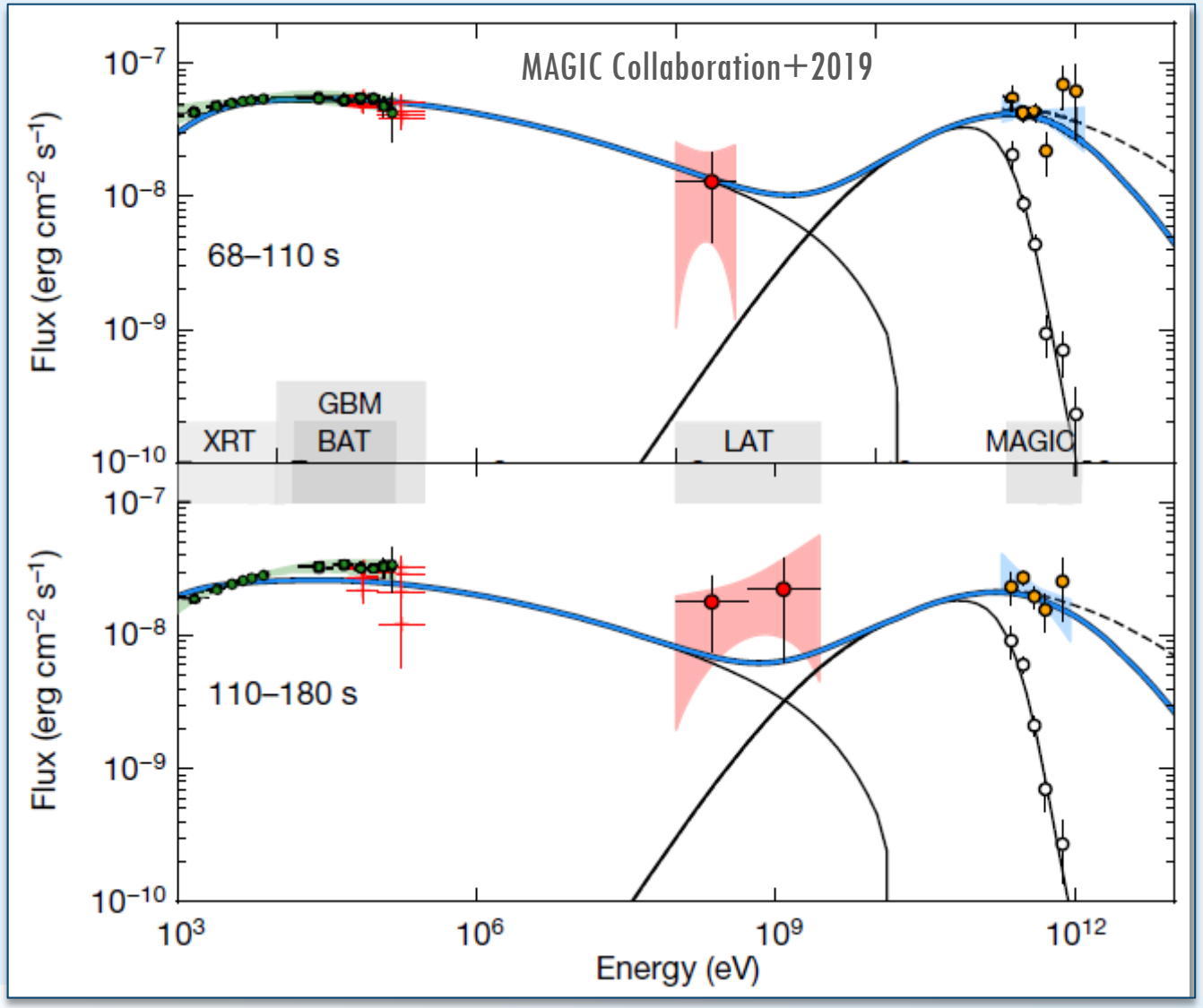
Energy flux lightcurves at different wavelengths from radio to gamma-rays

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

Multiwavelength observations of GRB 190114C

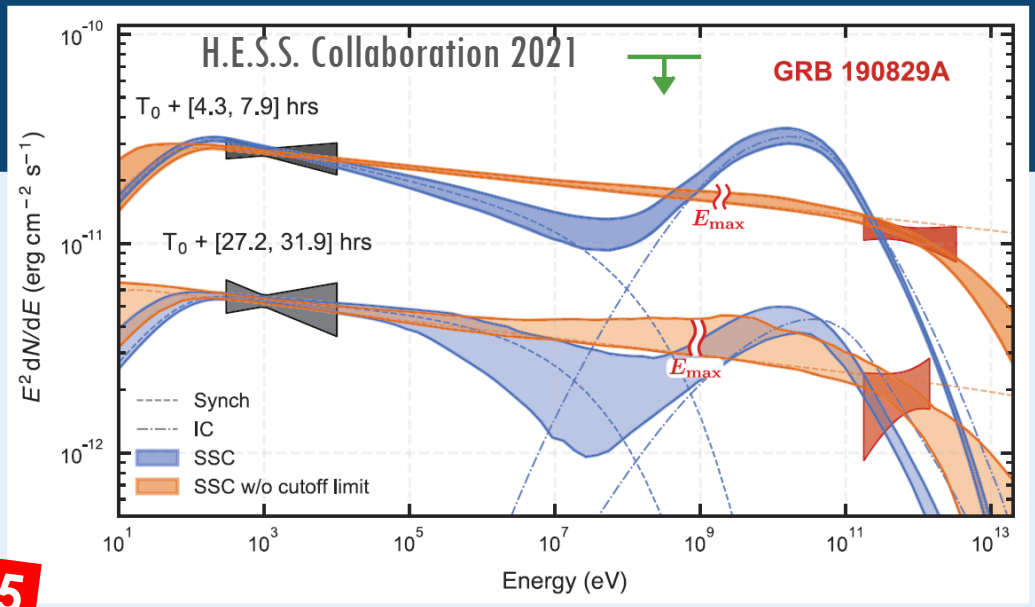
- The spectra from **X-ray to TeV** show the need for an **extra spectral component** to explain the flux increase at the **highest energies**
  - ➔ Same forward shock, but **different emission processes**

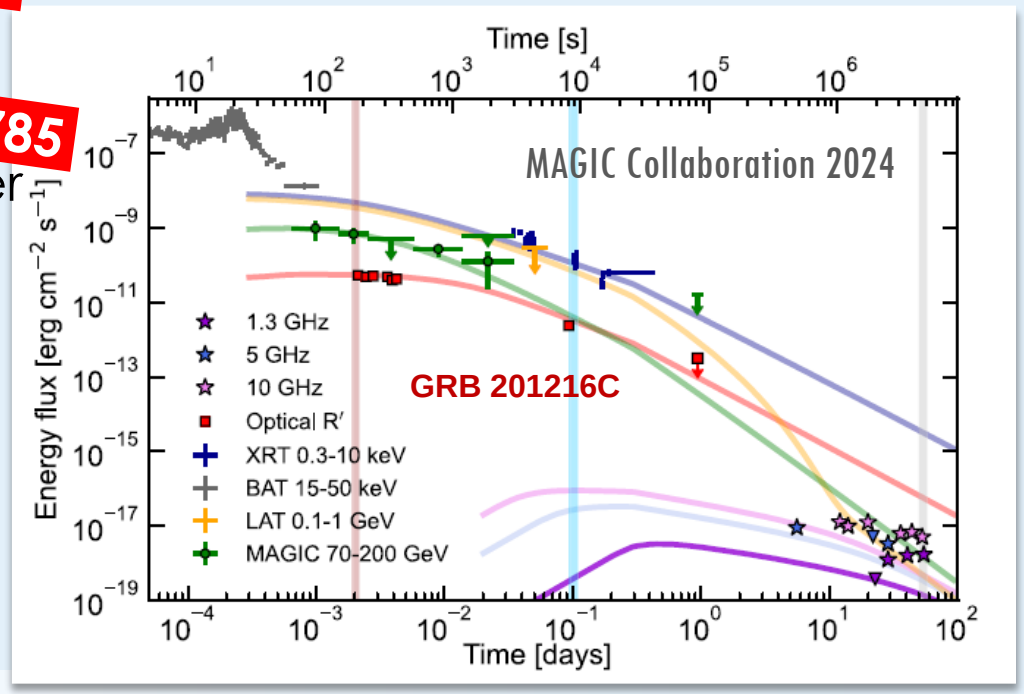
- Extra component generated by **Synchrotron Self-Compton**
  - Synchrotron photons are Compton up-scattered by the same electrons accelerated in the shocks

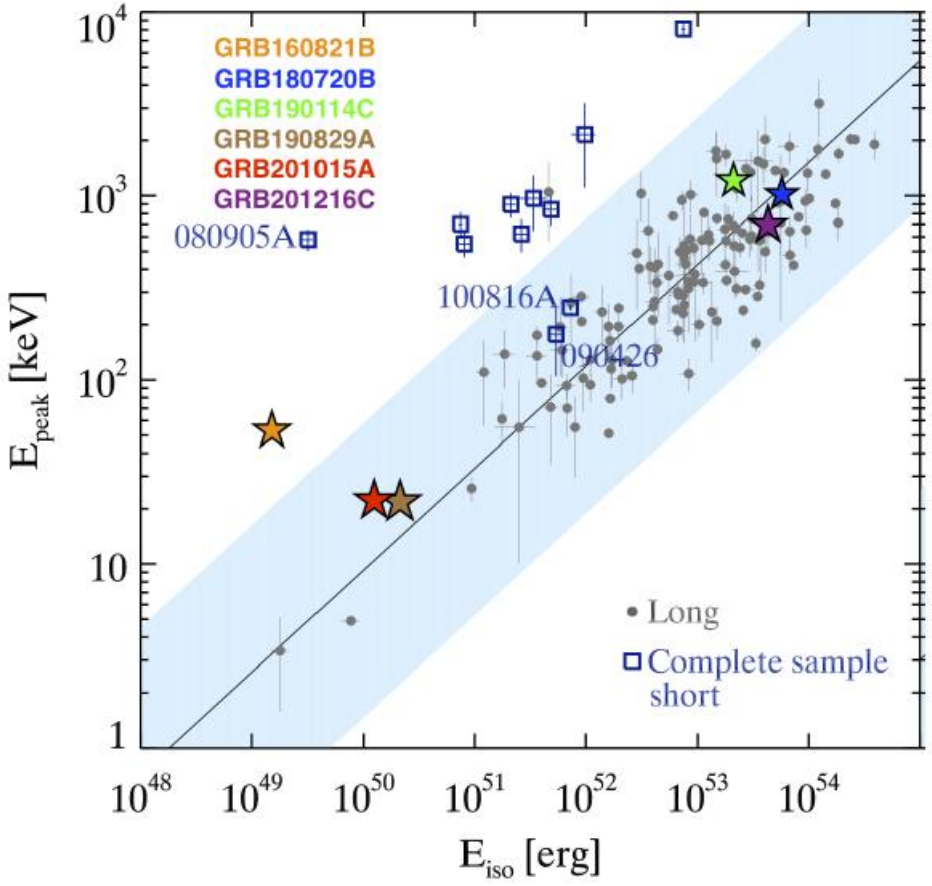


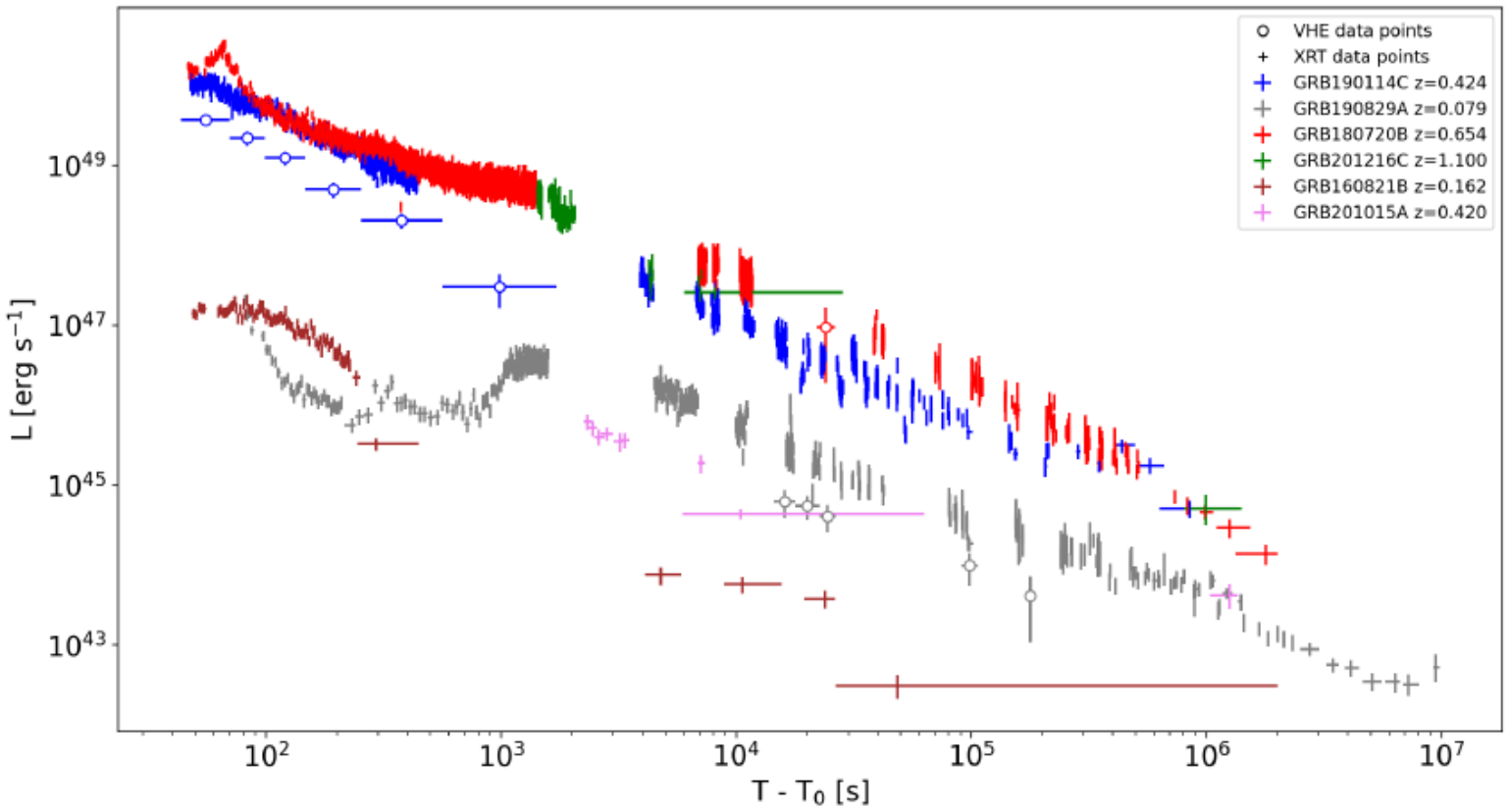
More GRBs @ TeV energies

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







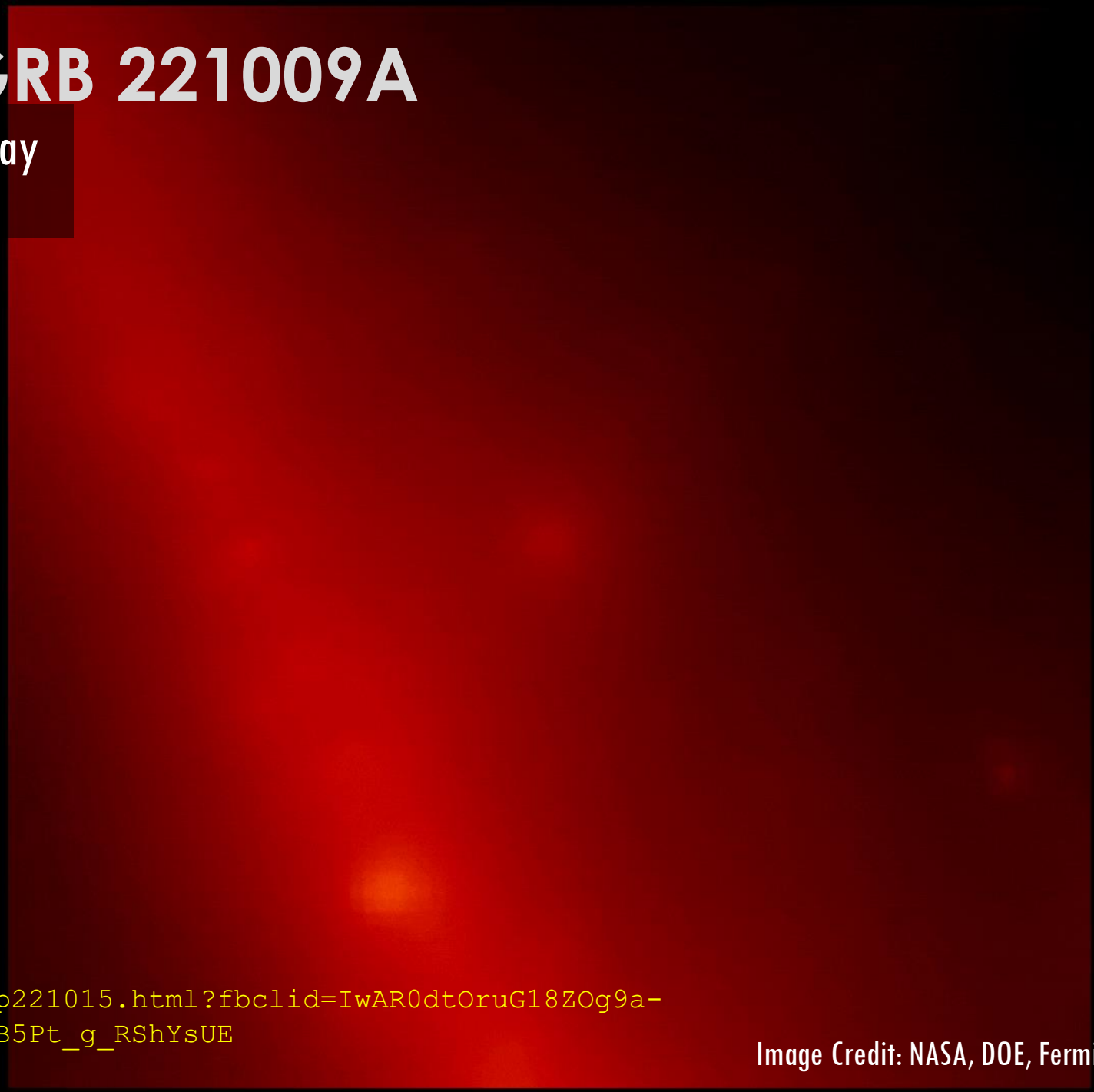


Gamma-Ray Bursts Afterglow Physics and the VHE Domain – Miceli &Nava 2022

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

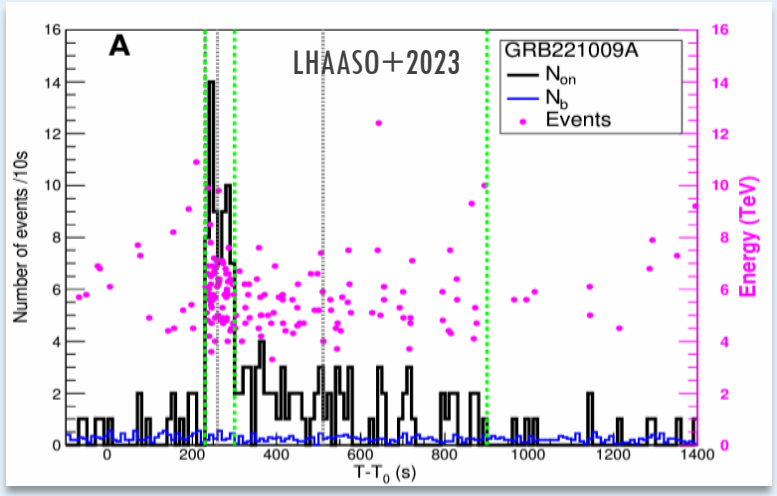
Image Credit: NASA, DOE, Fermi LAT Collaboration, R.Pillera

GRB 221009A – Timeline of events

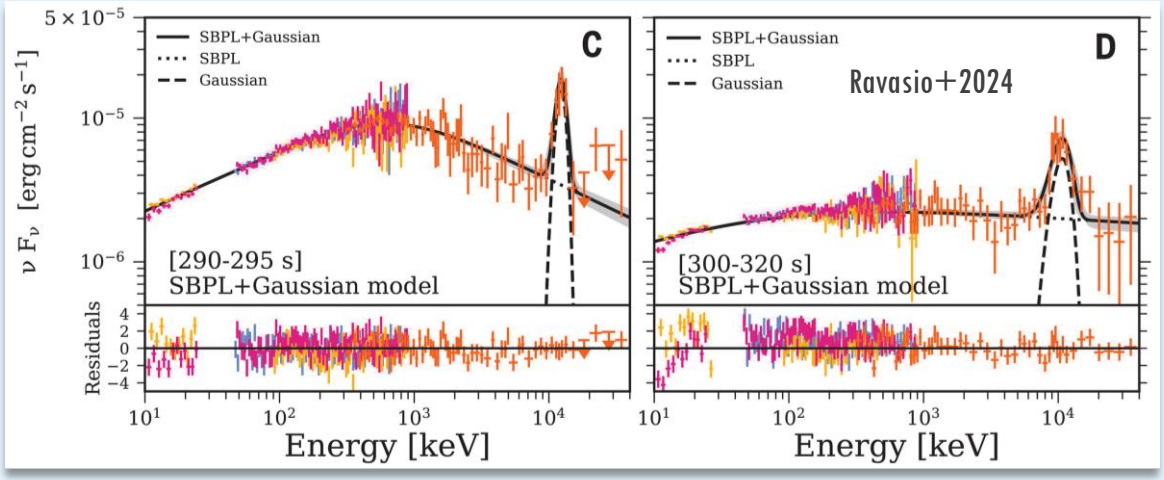
- **Oct.9 2022**
  - 13:16:60 UT **(T_0)** Fermi-GBM trigger 221009553 (no prompt GCN notices)
  - 14:10:17 UT **(T_0+3200s)** Swift trigger (GCN after 20min - Swift J1913.1+1946)
  - 20:54:36 UT Fermi-GBM reports that trigger 221009553 is superbright+long **GRB 221009A** → location consistent with Swift → **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 (>100σ) + **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

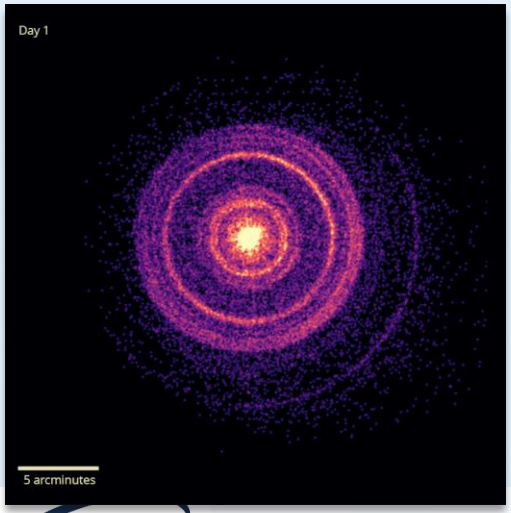
LHAASO detection of the TeV afterglow



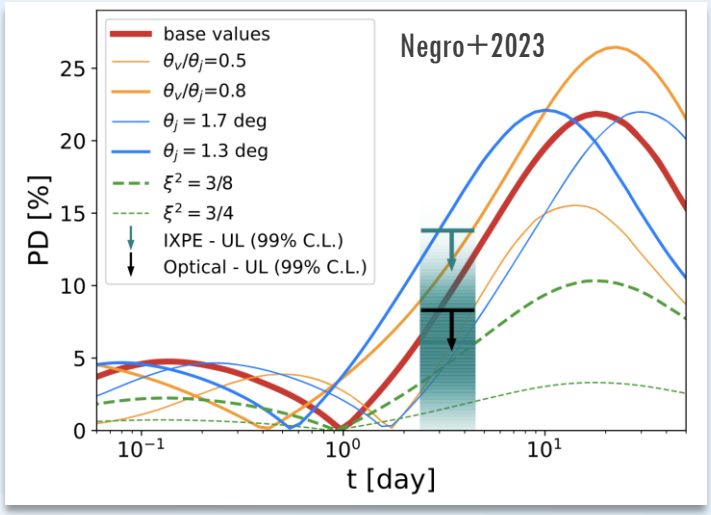
An MeV emission line in its spectrum

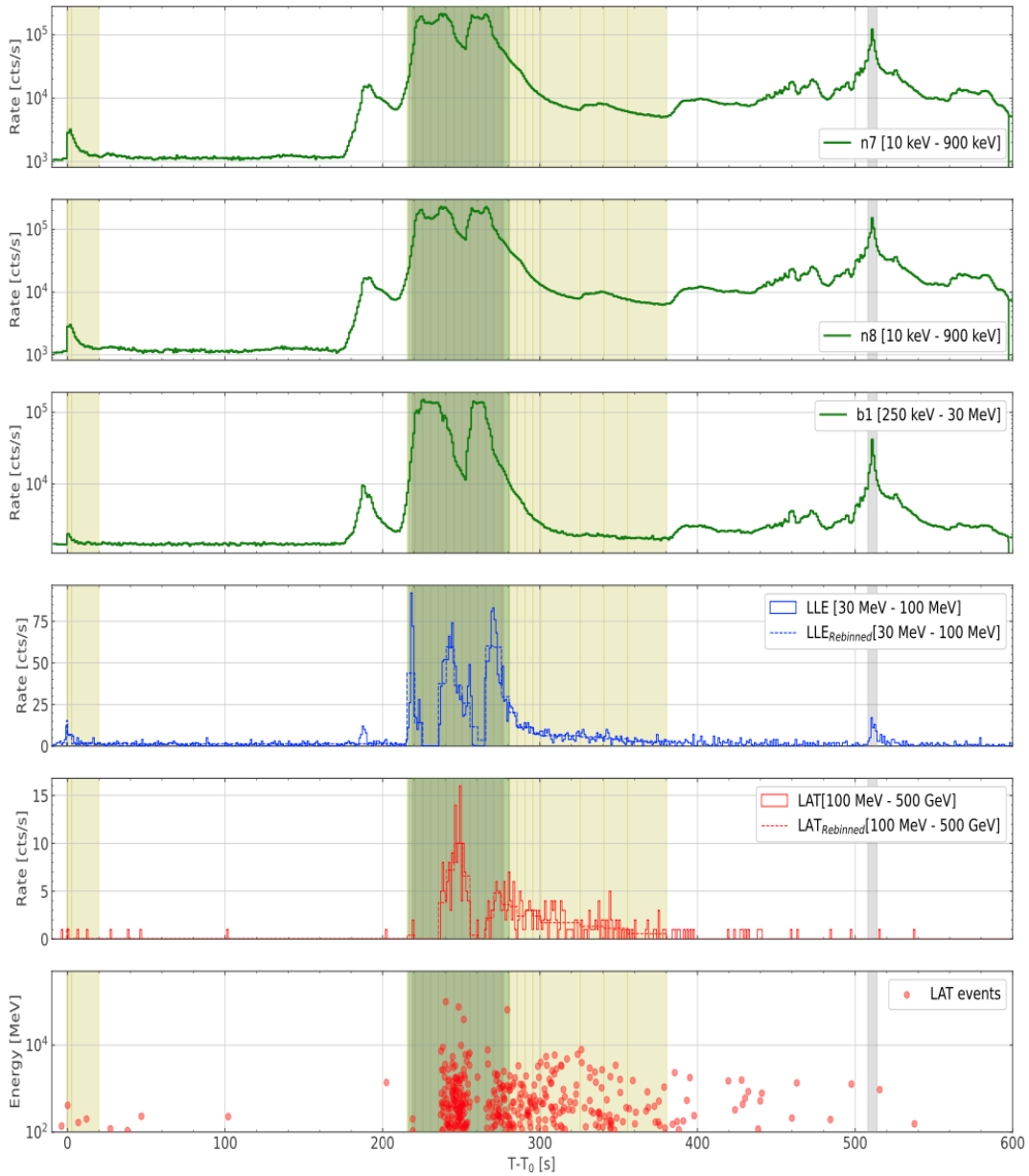


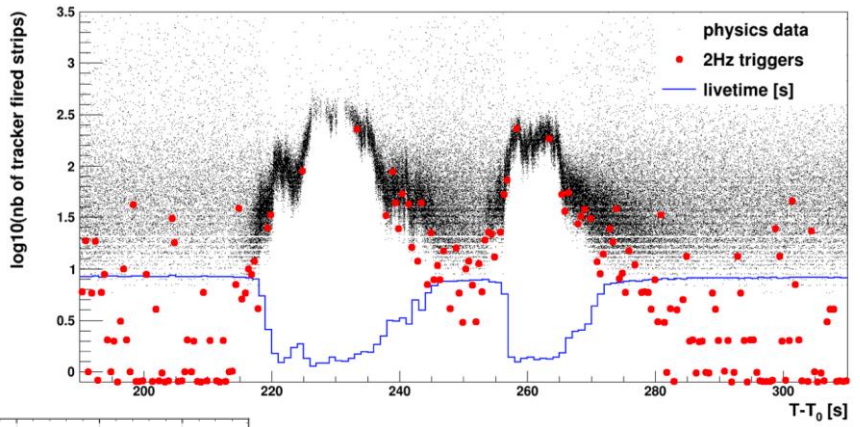
Dust scattering rings visible in Swift and XMM

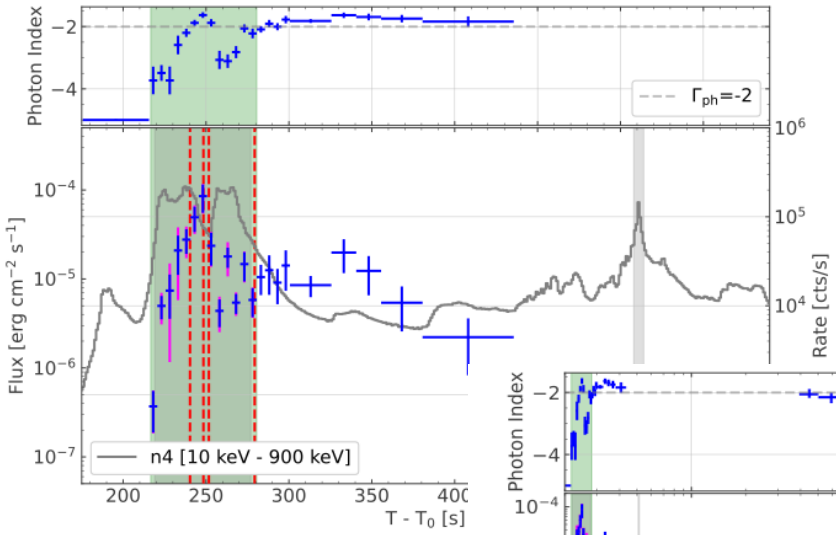


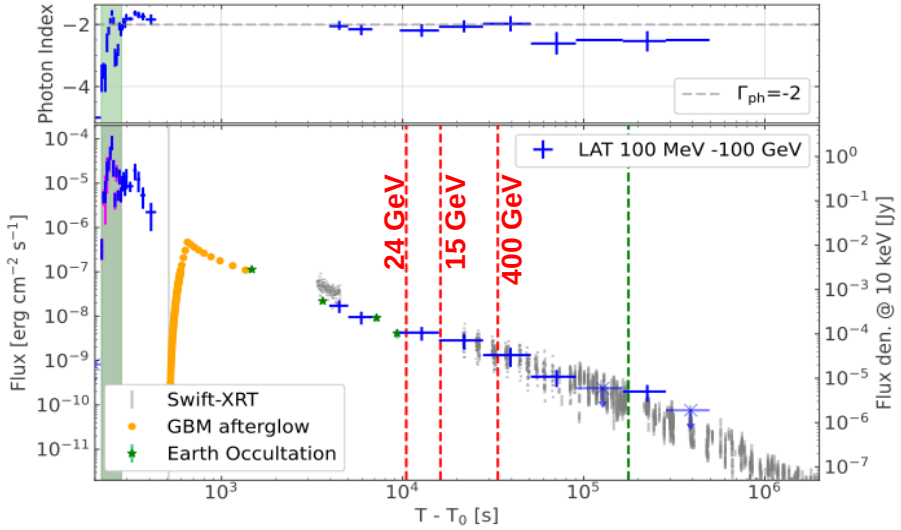
X-ray polarization UL on both prompt and afterglow





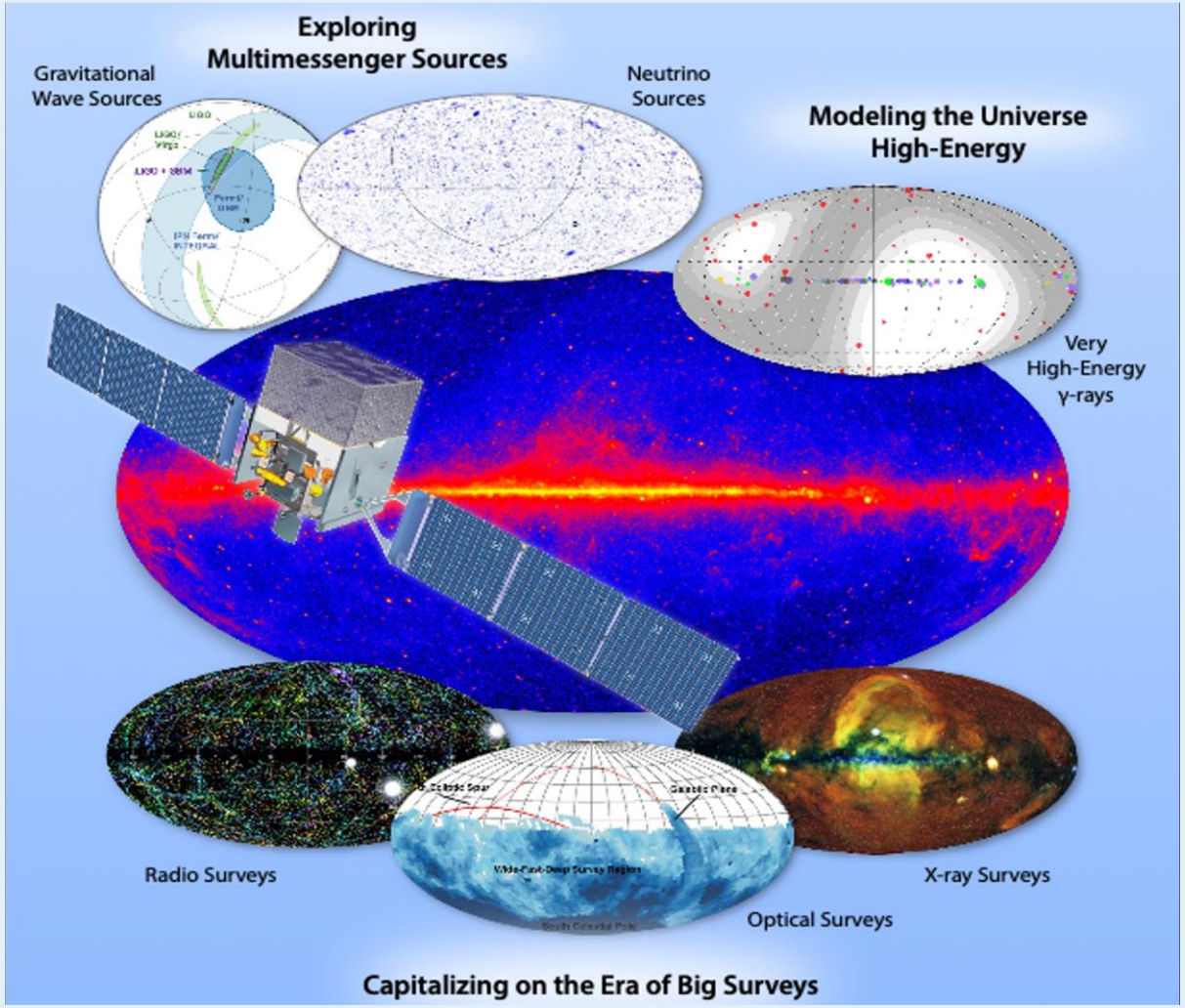






GRB 221009A: the B.O.A.T Burst that Shines in Gamma Rays – Axelsson+2024 [https://arxiv.org/abs/2409.04580]

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 spacecrafts
  - Lifetime of orbit extends into the mid-2030s

Thank you!

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