Magnetar giant flare in NGC 253 seen by Fermi-GBM

Elisabetta Bissaldi (on behalf of a greater team)

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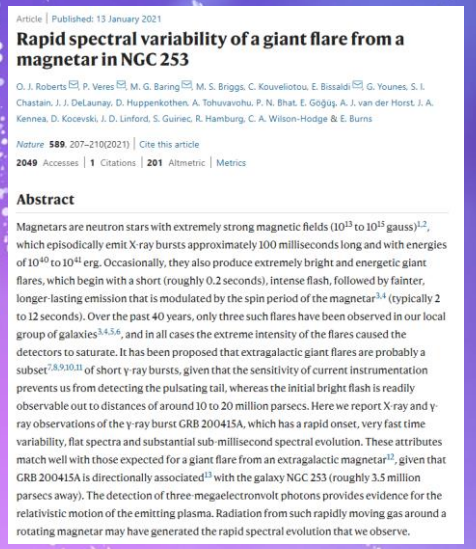

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Rapid spectral variability of a giant flare from a magnetar in NGC 253

O. J. Roberts, P. Veres, M. G. Baring, M. S. Briggs, C. Kouveliotou, E. Bissaldi, G. Younes, S. I. Chastain, J. J. DeLaunay, D. Huppenkothen, A. Tohuvavohu, P. N. Bhat, E. Göğüş, A. J. van der Horst, J. A. Kennea, D. Kocevski, J. D. Linford, S. Guiriec, R. Hamburg, C. A. Wilson-Hodge & E. Burns

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Abstract

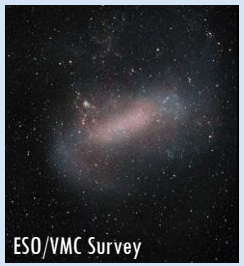
Magnetars are neutron stars with extremely strong magnetic fields (10^{13} to 10^{15} gauss)[1,2], which episodically emit X-ray bursts approximately 100 milliseconds long and with energies of 10^{40} to 10^{41} erg. Occasionally, they also produce extremely bright and energetic giant flares, which begin with a short (roughly 0.2 seconds), intense flash, followed by fainter, longer-lasting emission that is modulated by the spin period of the magnetar[3,4] (typically 2 to 12 seconds). Over the past 40 years, only three such flares have been observed in our local group of galaxies[3,4,5,6], and in all cases the extreme intensity of the flares caused the detectors to saturate. It has been proposed that extragalactic giant flares are probably a subset[7,8,9,10,11] of short γ-ray bursts, given that the sensitivity of current instrumentation prevents us from detecting the pulsating tail, whereas the initial bright flash is readily observable out to distances of around 10 to 20 million parsecs. Here we report X-ray and γ-ray observations of the γ-ray burst GRB 200415A, which has a rapid onset, very fast time variability, flat spectra and substantial sub-millisecond spectral evolution. These attributes match well with those expected for a giant flare from an extragalactic magnetar[12], given that GRB 200415A is directionally associated[13] with the galaxy NGC 253 (roughly 3.5 million parsecs away). The detection of three-megaelectronvolt photons provides evidence for the relativistic motion of the emitting plasma. Radiation from such rapidly moving gas around a rotating magnetar may have generated the rapid spectral evolution that we observe.

Nature Vol.589 (2021)

Magnetar Giant Flares

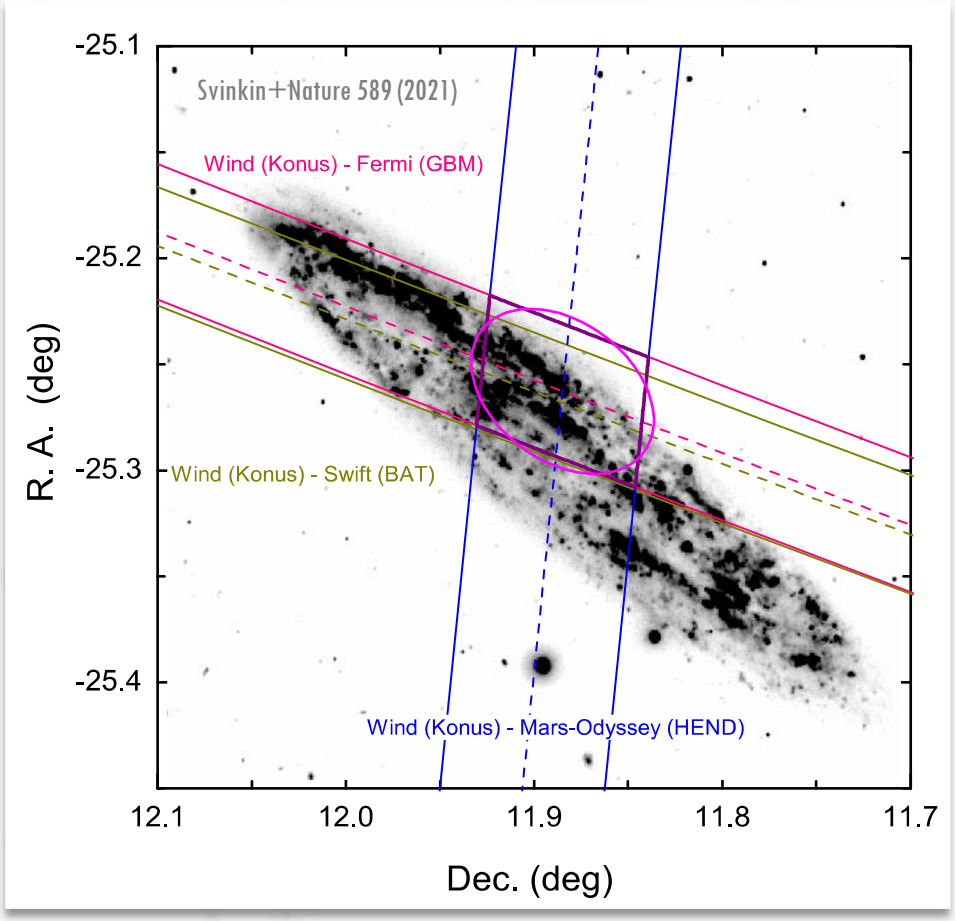
- **Magnetars**
  - Strongly magnetized (~10^{15} G) **neutron stars**, period ~0.1-10 s, luminosity $L_X \sim 10^{31\text{-}36}$ erg/s
    - Never observed at E>100 MeV (before April 15th, 2020!)
  - **Recurrent, short duration bursts** ($10^{36\text{-}41}$ erg/s), with period ~0.1 s
  - **Long lasting bursts** (> 10^{36} erg/s) lasting years (total energy E ~ $10^{41\text{-}43}$ erg)
  - **Giant Flares** $L \sim 10^{44\text{-}47}$ erg/s, lasting ~0.1 s, followed by soft X-ray emission lasting hundreds of seconds

Burns+ApJL (2021)

March 5, 1979	November 3, 2005	February 1, 2007	February 22, 2007	April 15, 2020
Large Magellanic Cloud	M82 (Cigar Galaxy)	M31 (Andromeda)	M83 (Pinwheel)	NGC 253 (Sculptor)
				
163 kly	11.4 Mly	2.5 Mly	14.7 Mly	11.4 Mly
0.7 x 10^{44} erg	5.3 x 10^{46} erg	1.6 x 10^{45} erg	6.2 x 10^{45} erg	1.3x10^{46} erg*

GRB 200415A

- **Bright transient** triggered the Inter-Planetary Network (**IPN**) and ASIM on **April 15th, 2020**
  - **Fermi Gamma-ray Burst Monitor (GBM) Trigger** at 08:48:05.56 UTC
    The Fermi GBM team, GCN 27579 (2020)
    E. Bissaldi, et al., GCN 27587 (2020)
    O. Roberts et al., Nature Vol.589, 207 (2021)
  - Triangulated by IPN to a 17 sq. arcmin region centered at RA. 11.88°, Dec. -25.26° (J2000), overlapping with **NGC 253 (Sculptor Galaxy)**, active star-burst spiral galaxy at a distance of 3.5 Mpc (11.4 Mly)
    D. Svinkin, et al., GCN 27585 (2021)
    D. Svinkin, et al., Nature Vol.589, 211 (2021)



- Chance coincidence with NGC 253: **1 in 230,000**
  [Talk by M. Negro, ID.792, PoS(ICRC2021)630]
  E. Burns et al., ApJL 907 L28 (2021)

- **High Energy (GeV)** emission [Highlight Talk by N.Di Lalla, ID.1480, PoS(ICRC2021)019]
  - **Fermi Large Area Telescope (LAT) detection**
    N. Omodei, et al. GCN 27586, GCN 27597 (2020)
    M. Ajello, et al., Nature Astronomy, Vol.5, 385 (2021)

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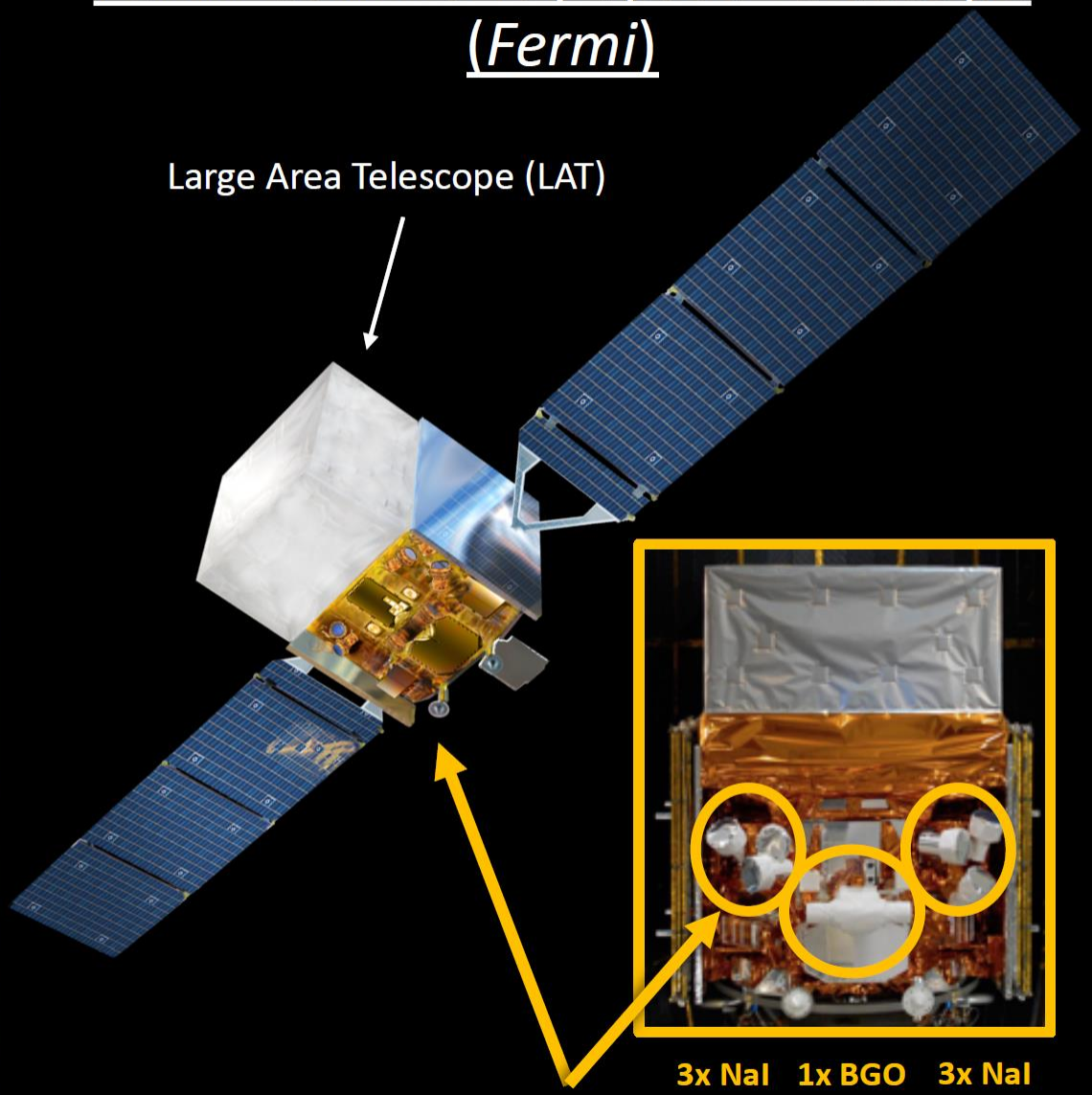
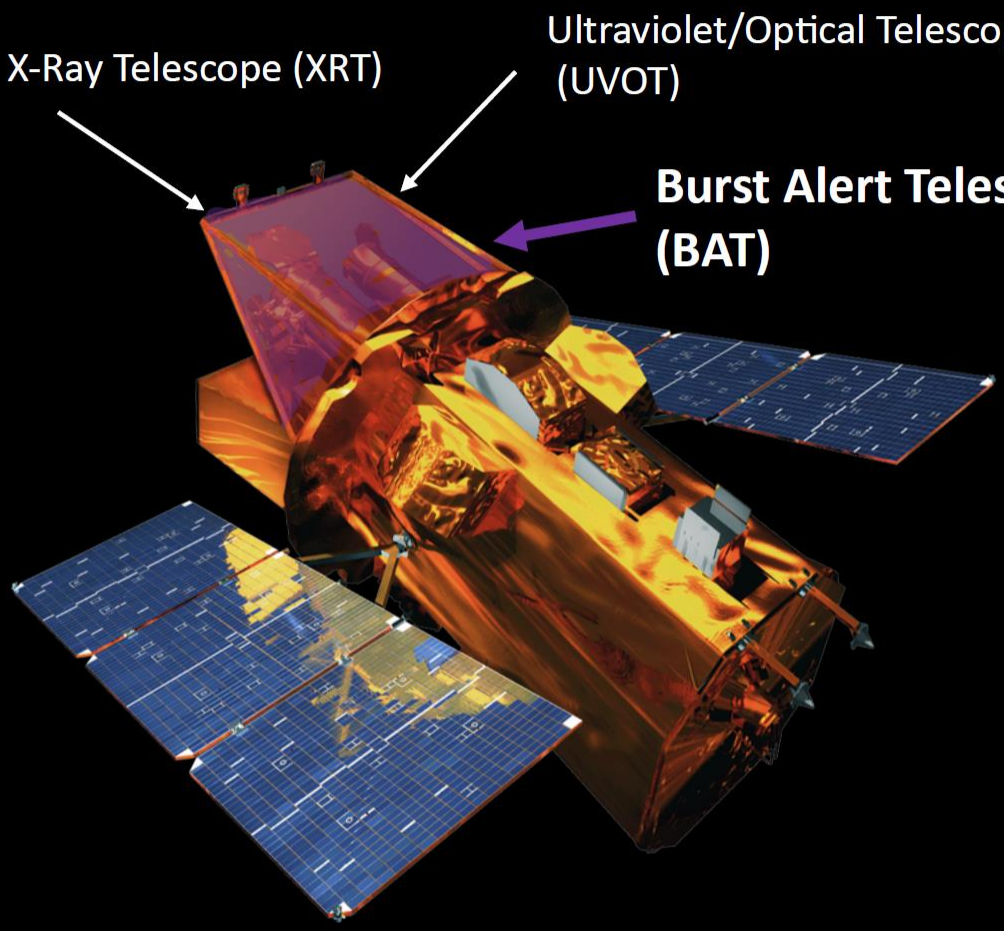
AAS Press Briefing:
https://www.youtube.com/watch?v=LjroNW7D-E4

Fermi Gamma-ray Space Telescope (*Fermi*)



Gamma-ray Burst Monitor (GBM)

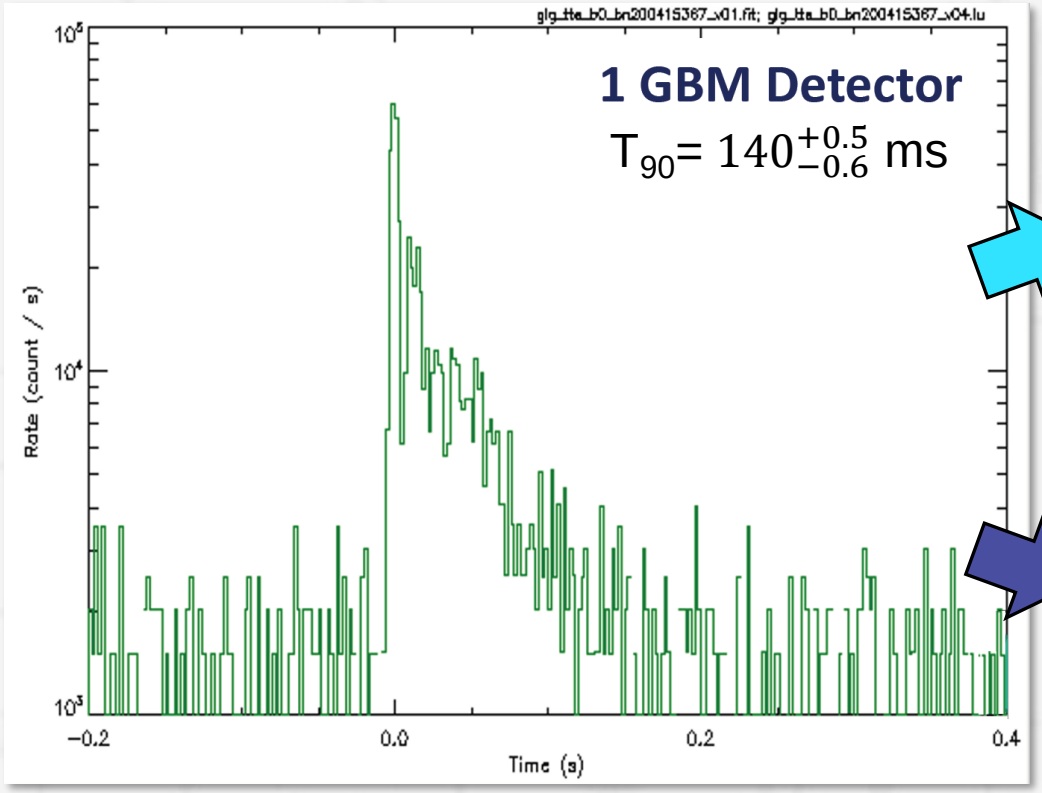
Neil Gehrels Swift Observatory (*Swift*)



GRB 200415A detected offline using the Gamma-ray Urgent Archiver for Novel Opportunities (**GUANO**), a BAT pipeline to search for transients coincident with Gravitational waves.

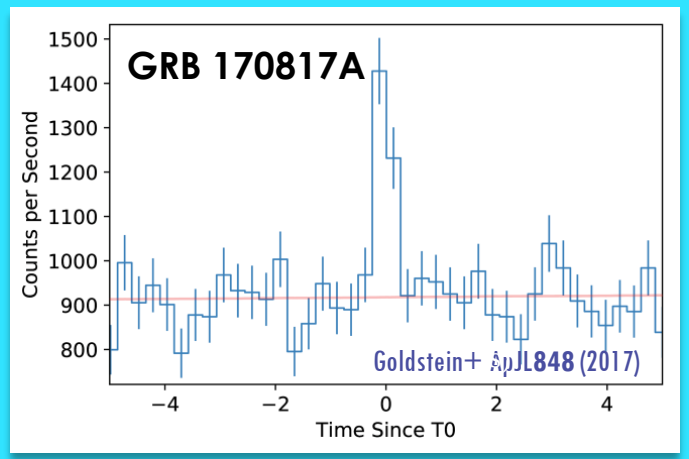
All images courtesy of NASA

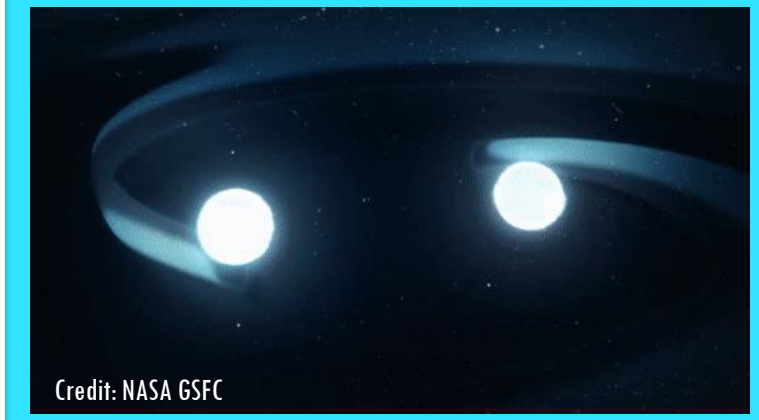
GRB 200415A



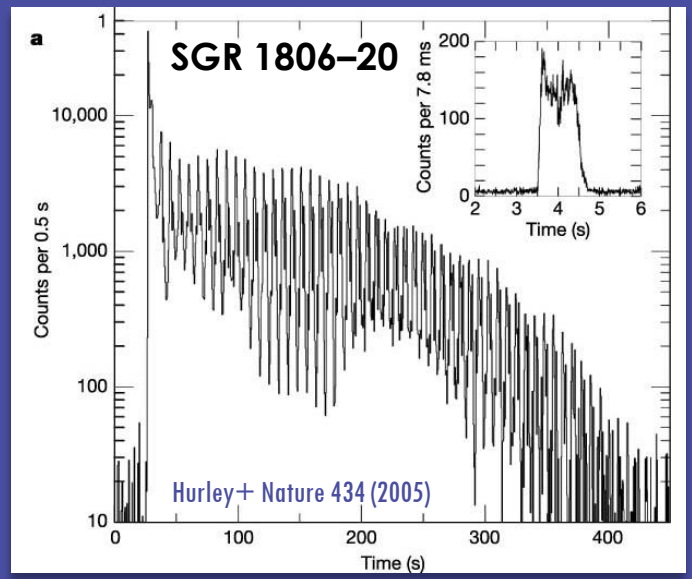
Roberts+ Nature 589 (2021)

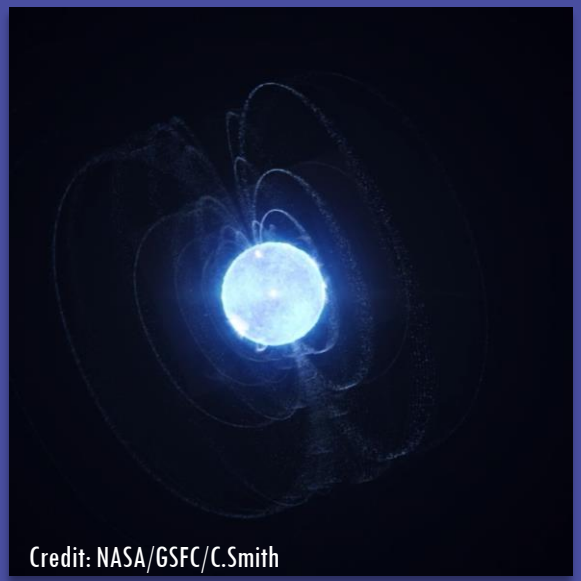
Short Gamma-ray Burst (sGRB)

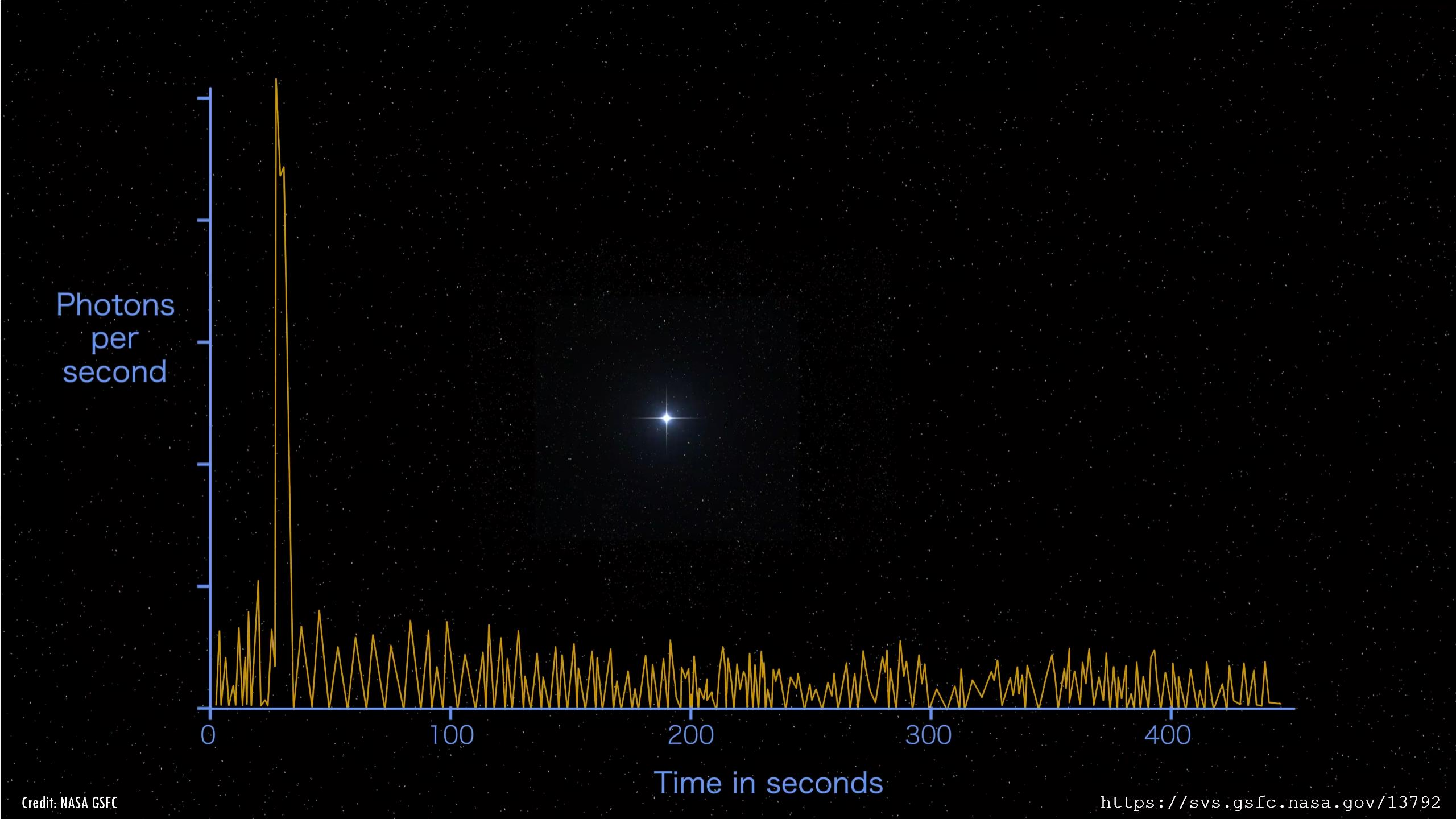




Magnetar Giant Flare





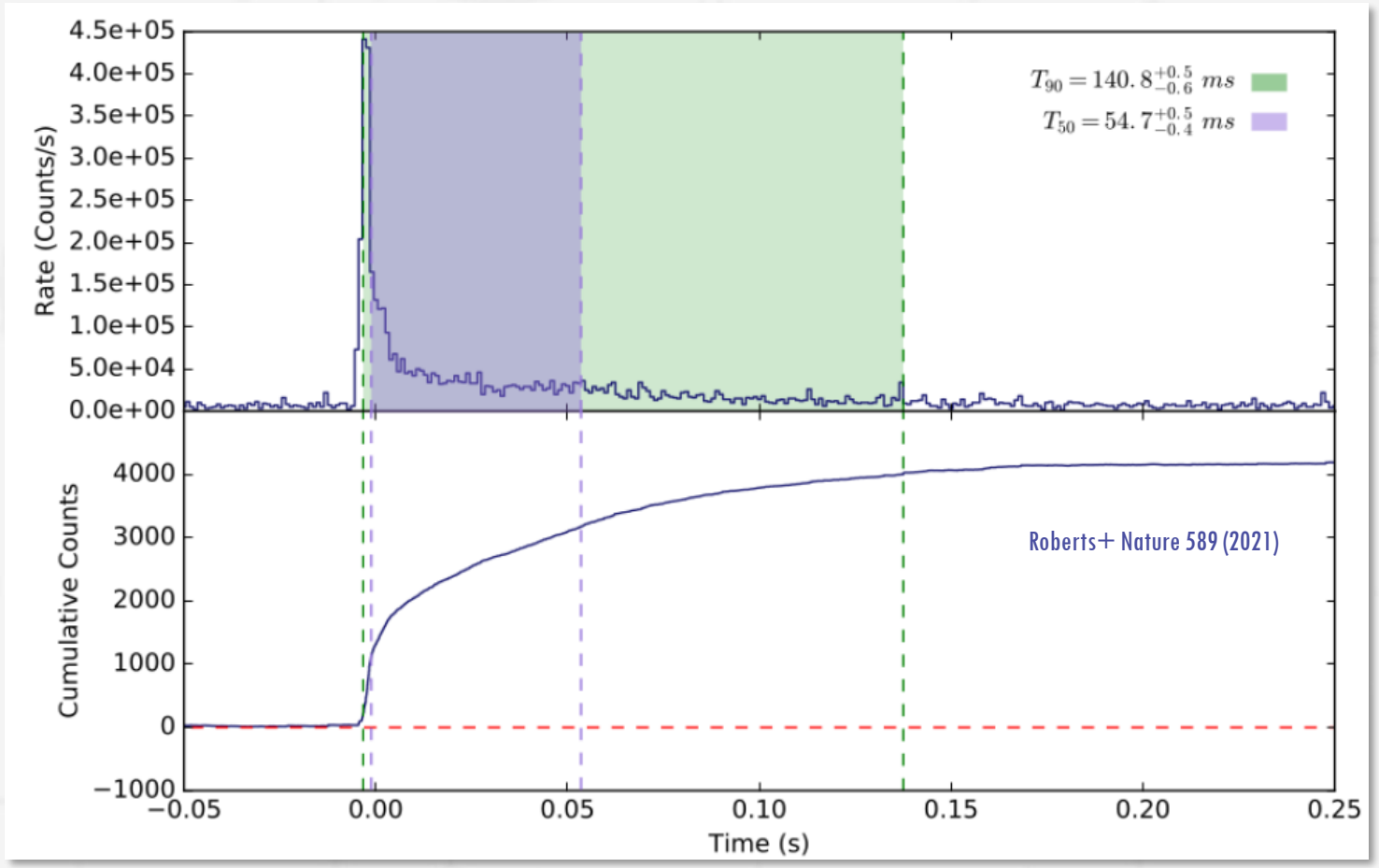


Credit: NASA GSFC

https://svs.gsfc.nasa.gov/13792

GRB 200415A Fermi-GBM Observations

- The T_{90} (green) and T_{50} (purple) durations were calculated using the Swift–BAT data (15 – 350 keV) in count space. The errors are at the 1σ confidence level.



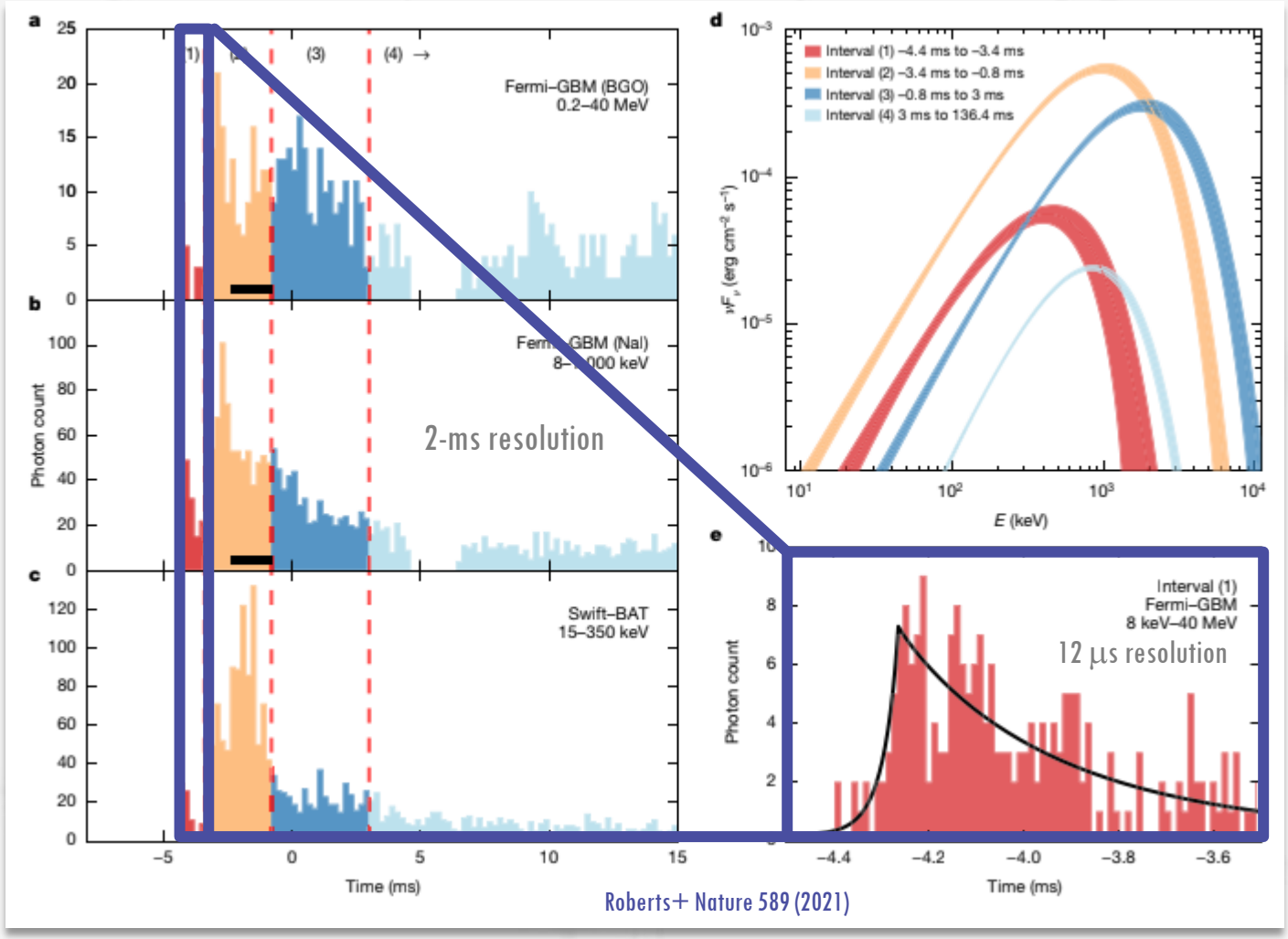
GRB 200415A Fermi-GBM Observations

- Total energy: E_{iso}= **1.5 x 10^{46} erg**
- Total luminosity: L_{iso}= **1.1 x 10^{47} erg s^{-1}**

- **Highest energy** GBM photon: **3 MeV**
- **Sub-ms variability** in photon energy
- Very rapid **flare risetime ~77 μs**

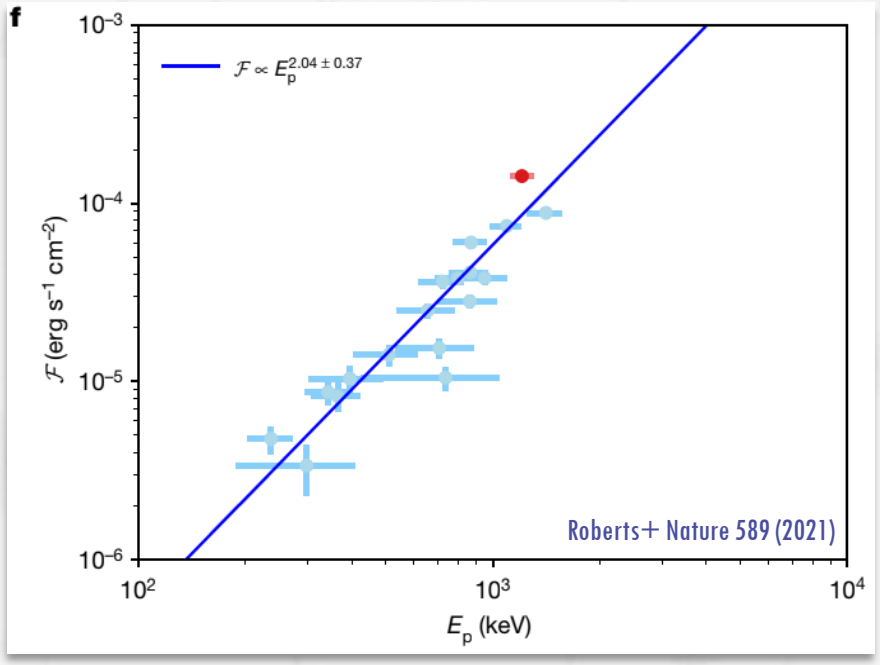
- No instrumental limitations due to the source
  - **No modulated tail** after the initial 140 ms long bright burst
  - Possible signature of seismic vibrations → Candidate **QPO** (2.5σ) at 180 Hz

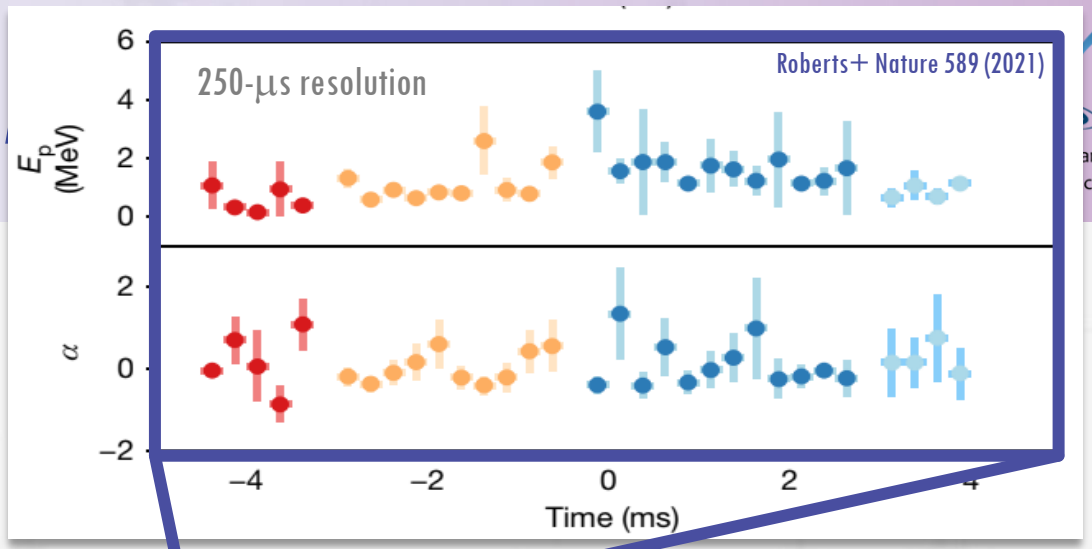
- **No radio** counterparts (VLA)

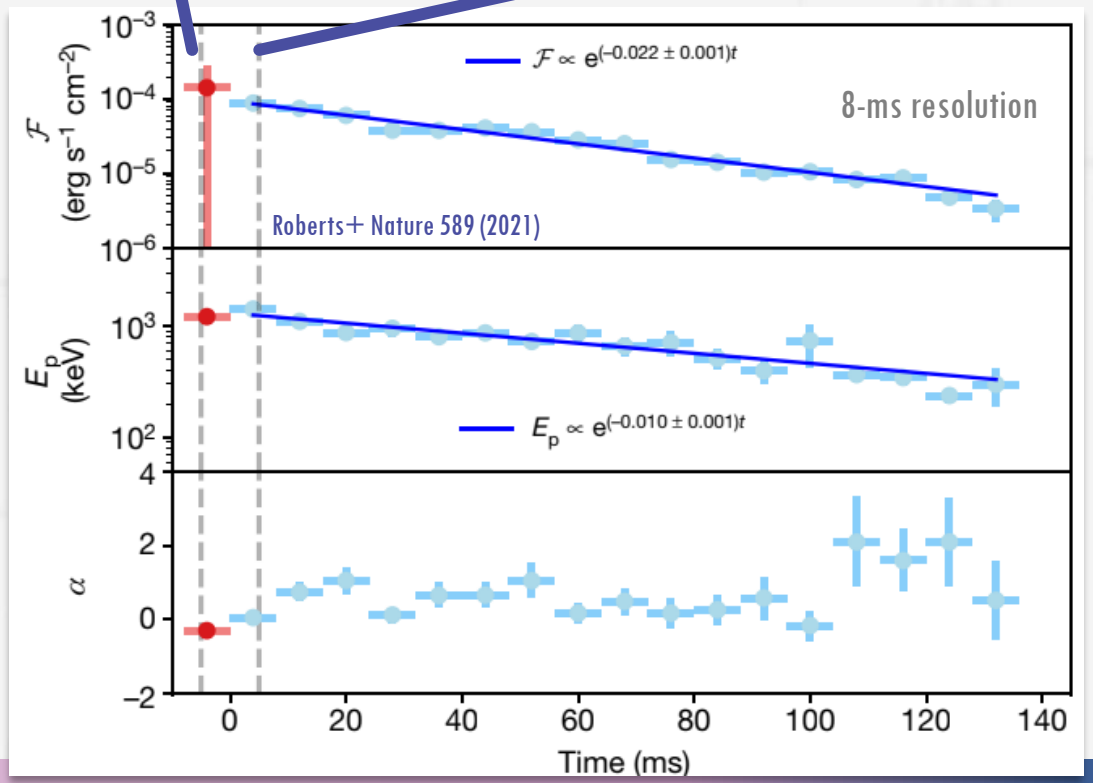


GRB 200415A Fermi-GB

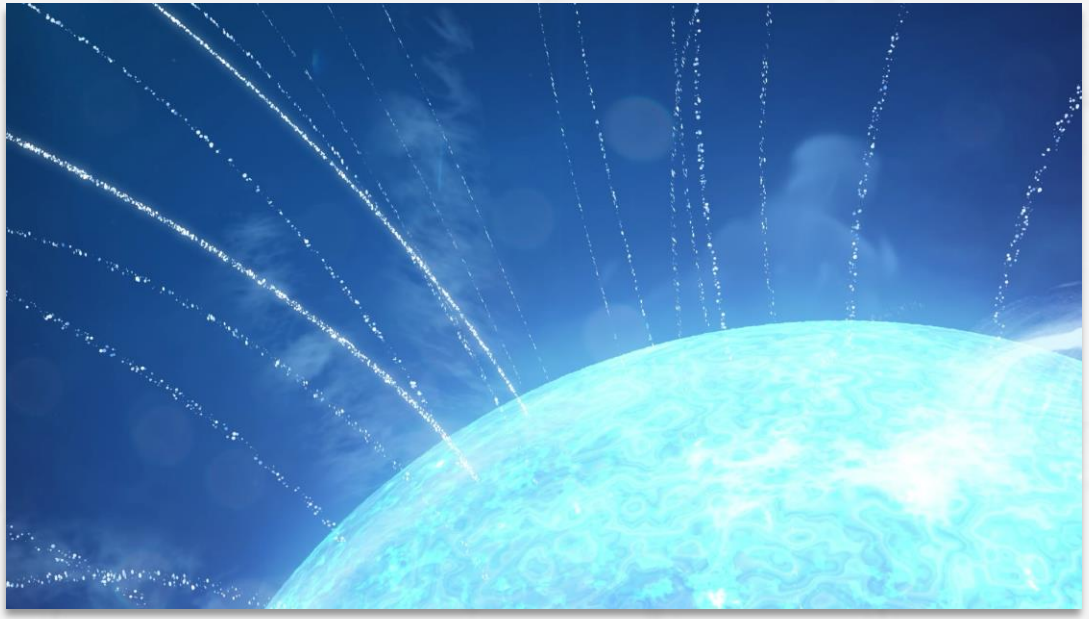
- **Comptonized spectrum throughout,** non-thermal
  - **Flat spectral index (α =0)** over burst duration
  - Energy Flux Decay; $\tau_{\mathcal{F}}$ **= 45±3 ms**
  - Peak Energy Decay; τ_{Ep} **= 100±1 ms**
- Distinctive $\mathcal{F} \propto E_p^2$ correlation







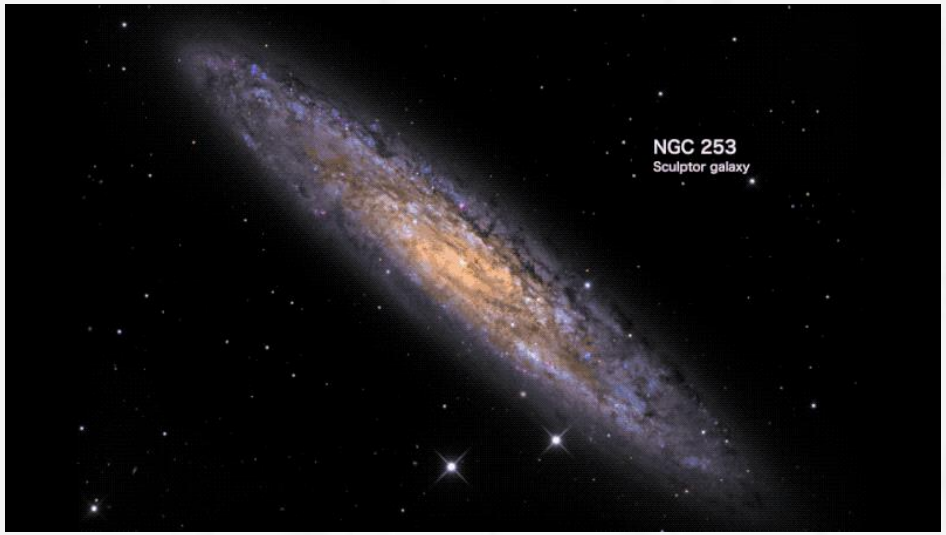
GRB 200415A Fermi-GBM Observations



- The flux, and spectral shape of GRB 200415A are **unusual/unlikely for a short GRB**, when compared to catalogs from previous space missions
- Origin of MGFs: Energy release by **crustal fractures** ejects **hot plasma** into the inner magnetosphere
  - MeV-band emission must come from a **relativistic outflow** (>0.98c) that is initially highly opaque
  - Spectral index ~0: Wind that is **highly opaque** to electron scattering (so-called "Compton cloud")
  - **Inconsistent** with synchrotron GRB emission scenarios
- Sub-ms spectral evolution: **Relativistic lighthouse beaming effect** or relativistic-boosted wind acceleration and subsequent coasting/cooling
- 77 μs risetime: **Extremely unlikely for a GRB**

Open questions

- Can we confirm Flux and E_p decay trends, Flux $\propto E^2_p$?
- Do we expect photon energies >3 MeV?
- Are sub-ms spectral evolution and sub-ms risetime (light curve variability) expected in short cosmological GRBs too or is this "purely" a MGF phenomenon?
- What about the galaxies (SFR, metallicities, etc) that produce them?
  - Star-forming galaxies only?
- QPOs in the tails of galactic giant flares?
- Rate of giant flares per magnetar: < 0.02 /yr – Repeating MGFs/sGRBs?
- Are 2% of all detected short GRBs in fact due to MGFs (0.3% of total GRBs)?
- Do all giant flares produce GeV emission?
- Is the plasma ultra-relativistic? (1806-20 was 0.7c)
- Many more…



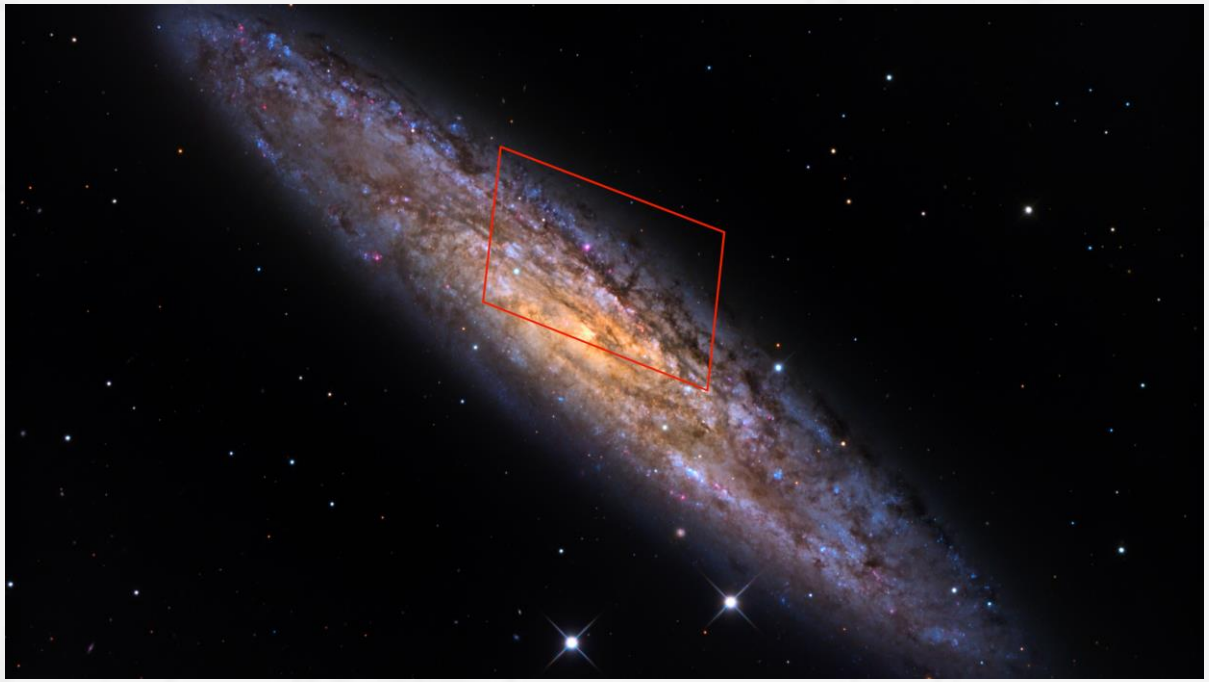
Credit: Copyright Adam Block/Mount Lemmon SkyCenter/University of Arizona

Summary and outlook

- 200415A is the clearest example yet of a **giant flare from an extragalactic magnetar.**
  - We need more event like this to link MGFs as potential source of sGRBs

- Unsaturated instrument spectra allow **new discoveries** to be made, opening a new front on studying the emission mechanism of these cataclysmic events

- These "repeating GRBs" may contribute a sizeable fraction of events to be present in GRB catalogs



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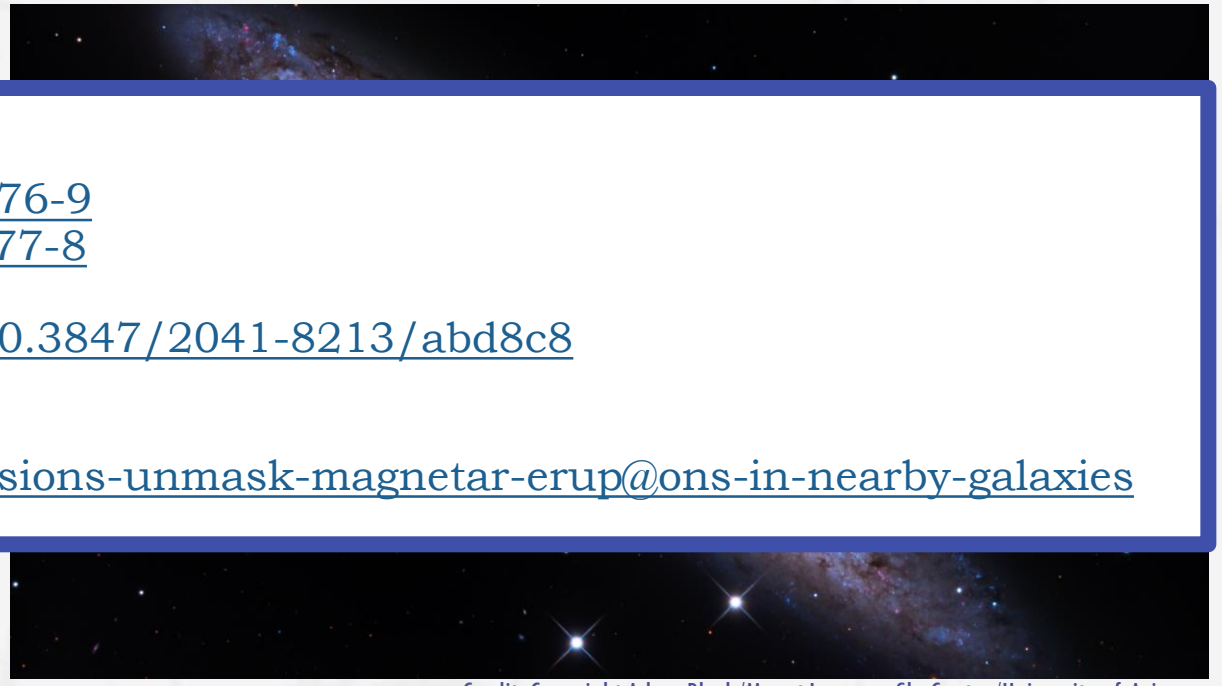

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Paper Links
IPN: https://www.nature.com/ar@cles/s41586-020-03076-9
GBM/GUANO: http://doi.org/10.1038/s41586-020-03077-8
LAT: http://doi.org/10.1038/s41550-020-01287-8
Populations paper: https://iopscience.iop.org/ar@cle/10.3847/2041-8213/abd8c8

NASA press release
https://www.nasa.gov/feature/goddard/2021/nasa-missions-unmask-magnetar-erup@ons-in-nearby-galaxies

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Thank you!


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