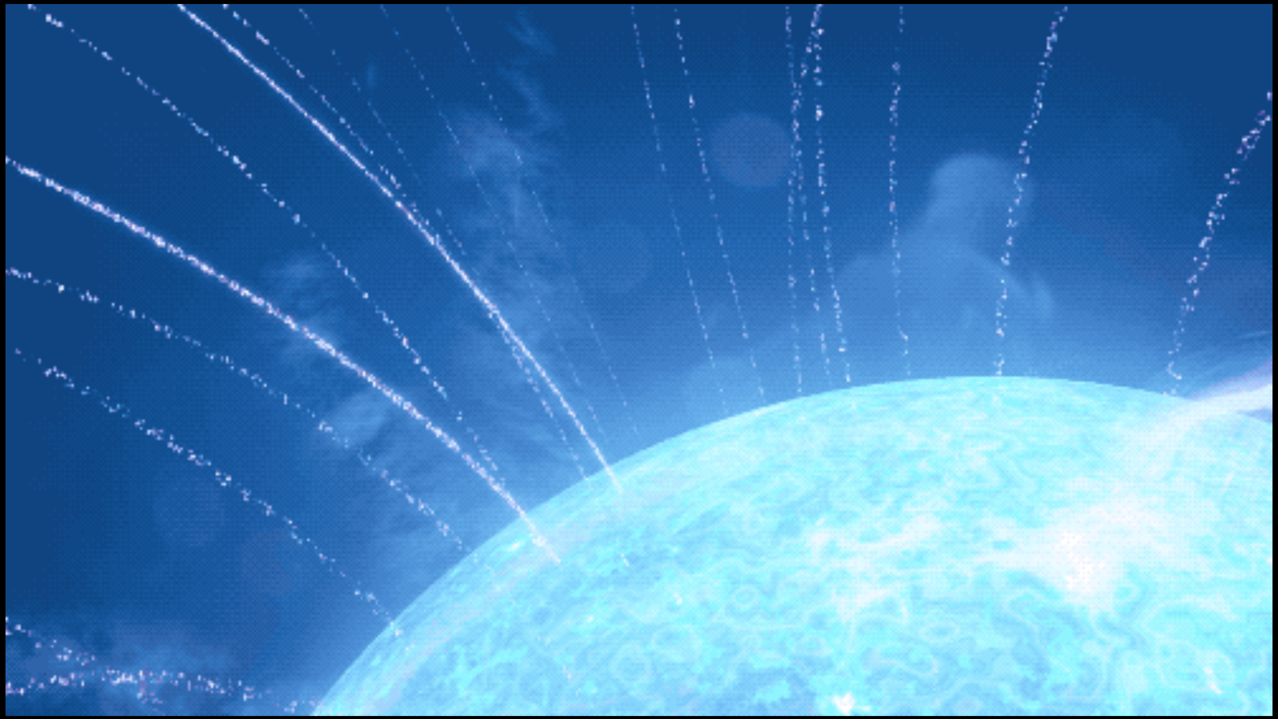
Masquerading Magnetar
GRB 200415A

Oliver J. Roberts (on behalf of a greater team)
oroberts@usra.edu

Universities Space Research Association /
NASA Marshall Space Flight Center
Huntsville, Alabama



Credit: NASA's Goddard Space Flight Center/Chris Smith (USRA/GESTAR)

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Gamma-ray Space Telescope

GRB 200415A

- Triggered ASIM and the Inter-Planetary Network (**IPN**) on the **15th April 2020,** triangulated to a 17 sq. arcmin. region centered on NGC 253 (Sculptor Galaxy), 11Mly away
  (D. Svinkin, K. Hurley et al. Nature, 2021)

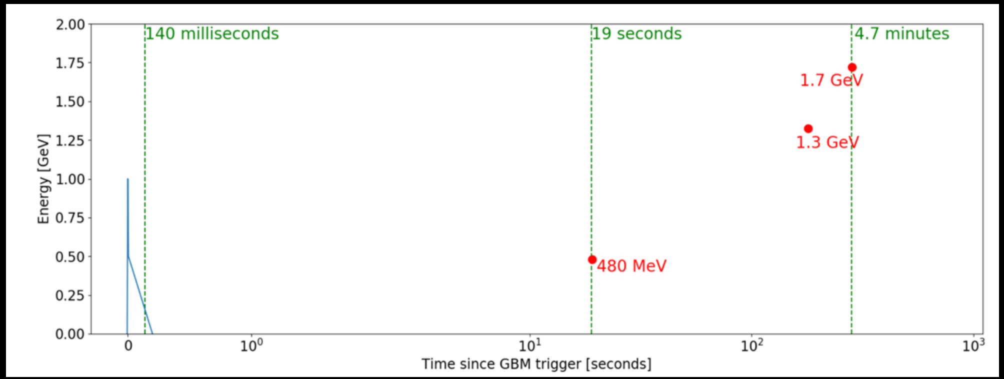
- Chance coincidence with NGC 253: **1 in 230,000**
  (E. Burns et al., ApJL,2021)

- **High Energy Emission (GeV) detection in the LAT**
  (N. Omodei et al., Nature Astronomy, 2021)

- AAS Press briefing of these results: https://www.youtube.com/watch?v=LjroNW7D-E4

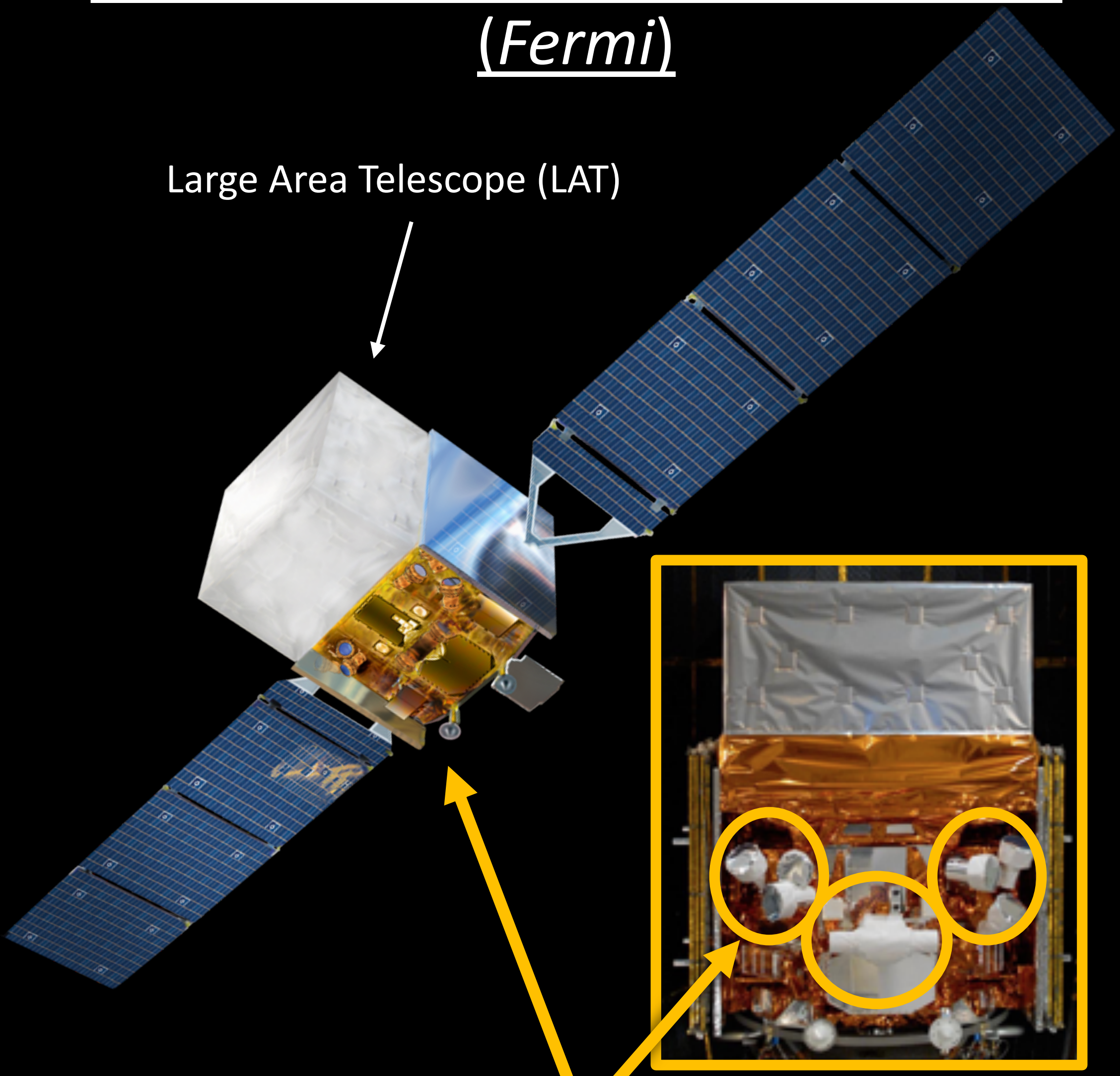
D. Svinkin, et al. Nature 2021 https://www.nature.com/articles/s41586-020-03076-9.

Credit: NASA's Goddard Space Flight Center/Chris Smith (USRA/GESTAR)



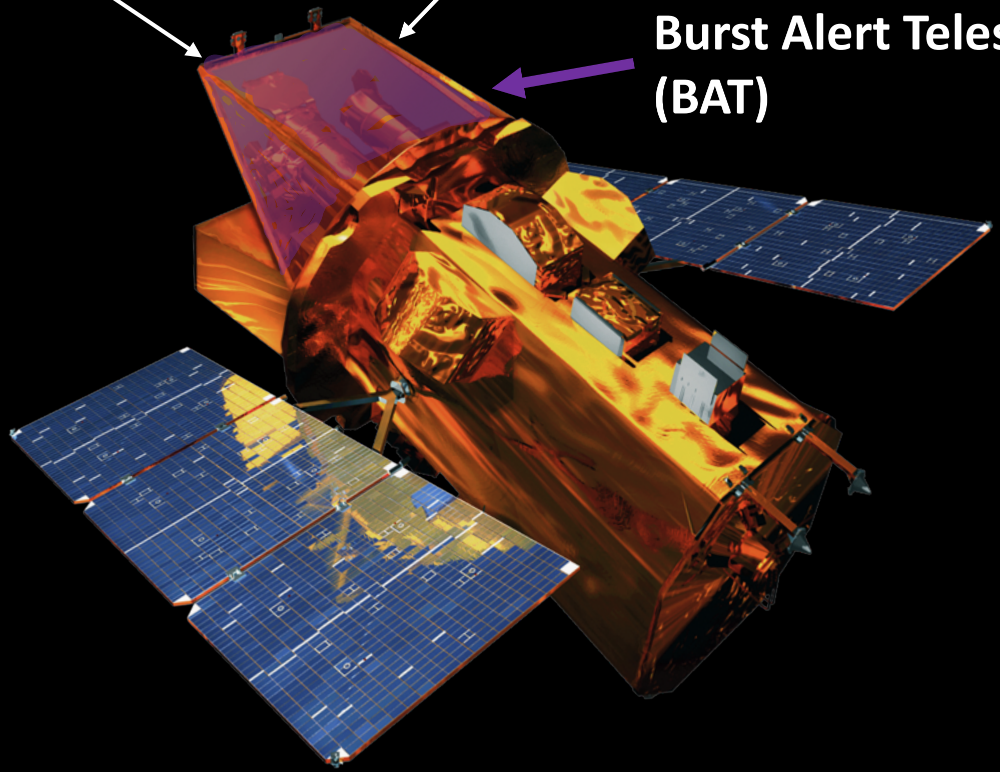
Nicola Omodei on behalf of the Fermi-Lat Collab. (2021): https://www.nature.com/articles/s41550-020-01287-8

Fermi Gamma-ray Space Telescope (*Fermi*)



Gamma-ray Burst Monitor (GBM)

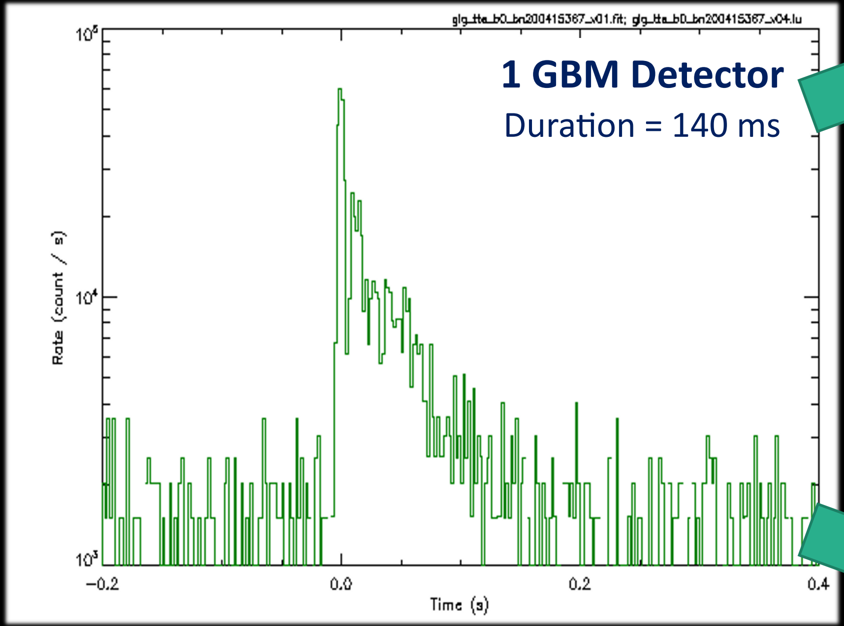
Neil Gehrels Swift Observatory (*Swift*)



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

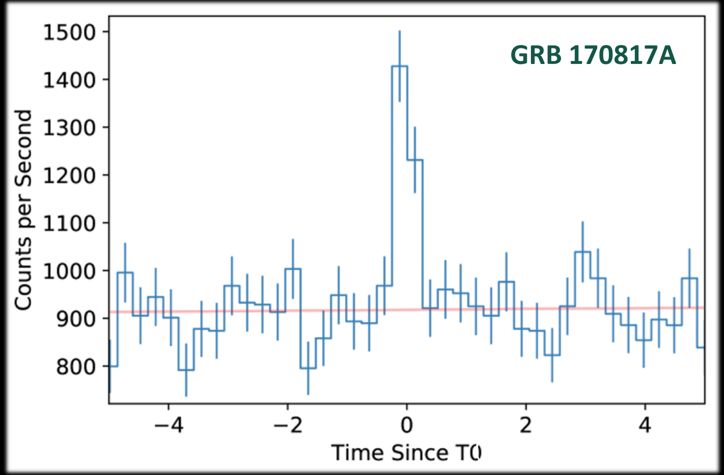
GRB 200415A



O.J. Roberts+ Nature 2021

British Broadcasting Company

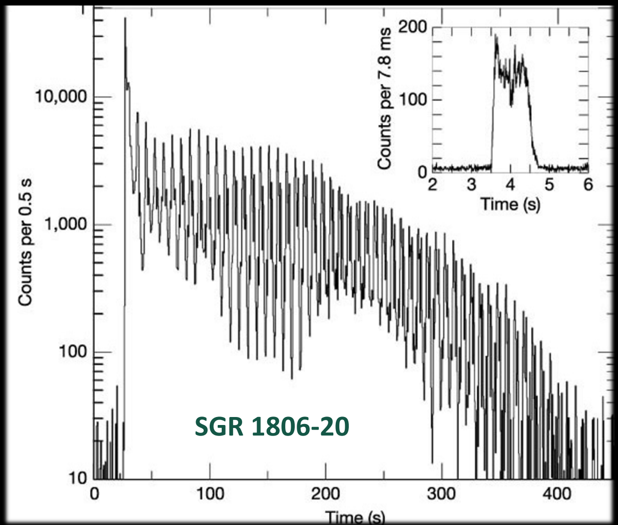
Short Gamma-ray Burst (sGRB)



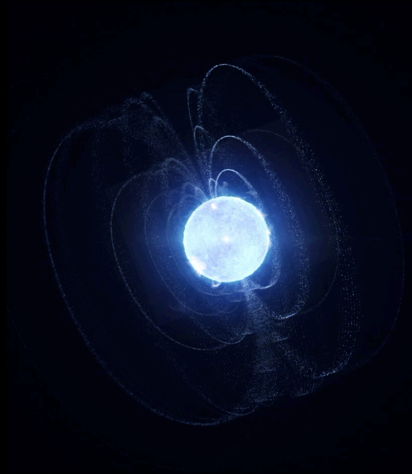
*Goldstein, A., et al., ApJL **848** (2), L14 2017.*

University of Warwick/Mark Garlick

Magnetar Giant Flare

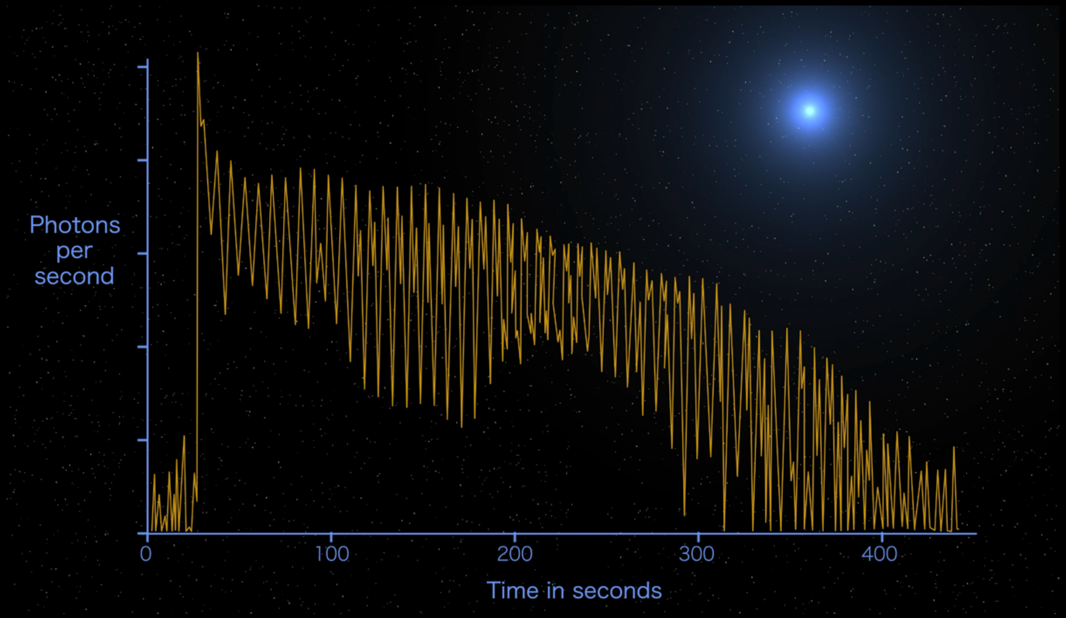


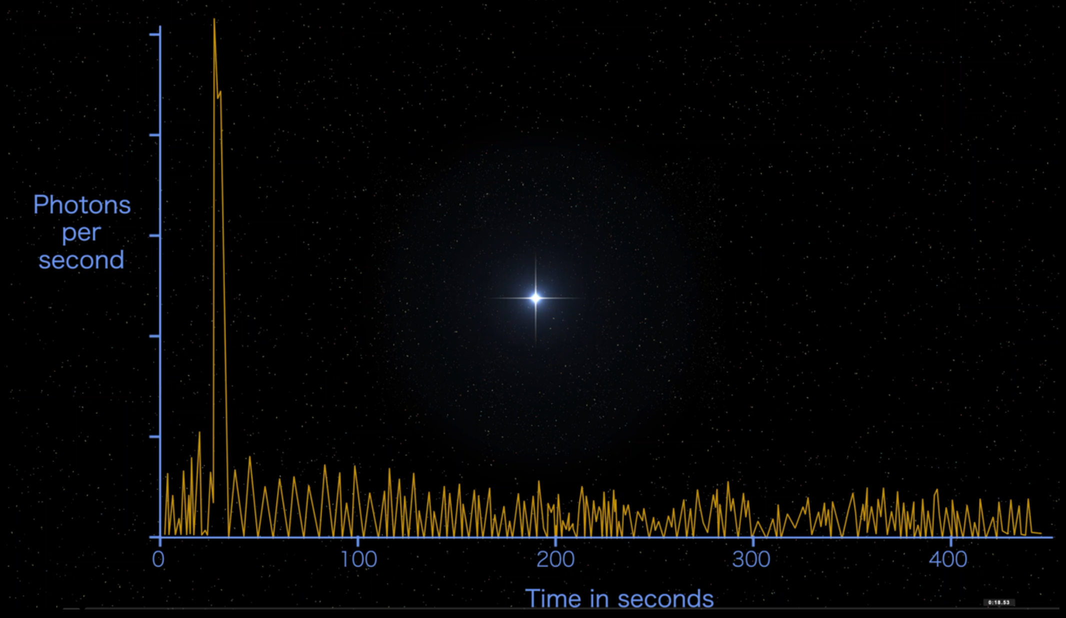
Hurley, K., Boggs, S., Smith, D. *et al. Nature* **434,** 1098–1103 (2005)



Credit: NASA's GSFC / Chris Smith (USRA/GESTAR)

Credit: NASA’s Goddard Space Flight Center/Chris Smith (USRA/GESTAR)





Sculptor Galaxy (NGC 253)

About 11 Million Light Years

GRB 200415A Trivia (Observations)

Total energy emitted: 10^{46} erg

- ***All*** nuclear tests: 10^{25} erg
- **10 quadrillion times** more energy than Chicxulub impact (10^{30} erg)

Total luminosity emitted: 10^{47} erg/s

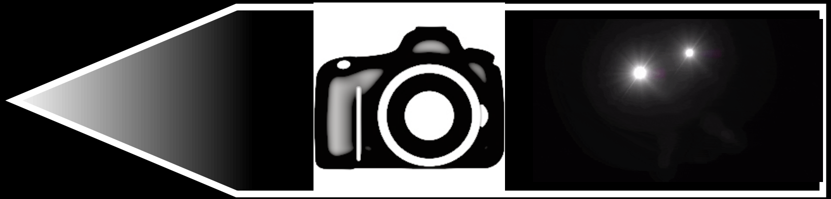
No modulated tail after the initial, 140 ms bright burst

Highest energy photon: 3 MeV in GBM

- A million times more energy than blue light (~3 eV).
- 50x more energy than a typical medical X-ray.

Variable, submillisecond changes in photon energy

Flare onset is 77 microseconds (>10x quicker than camera flash)

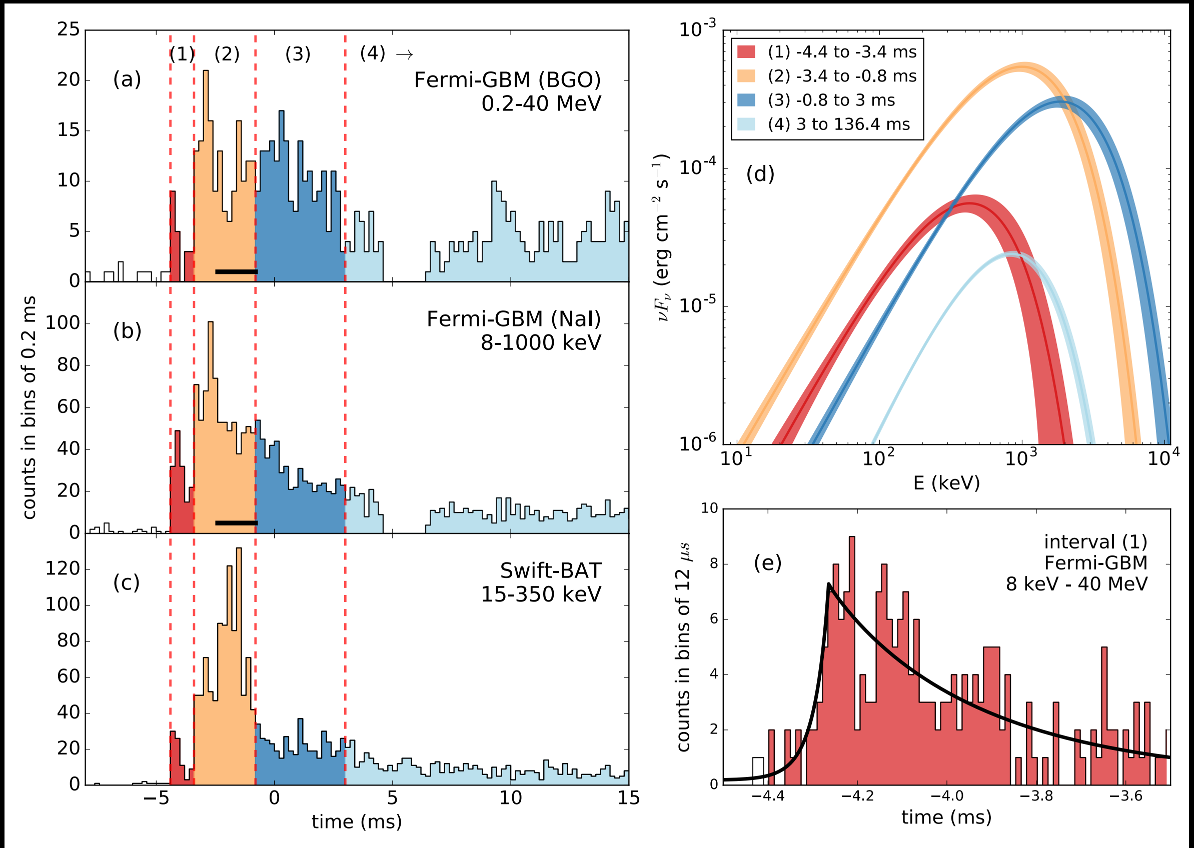


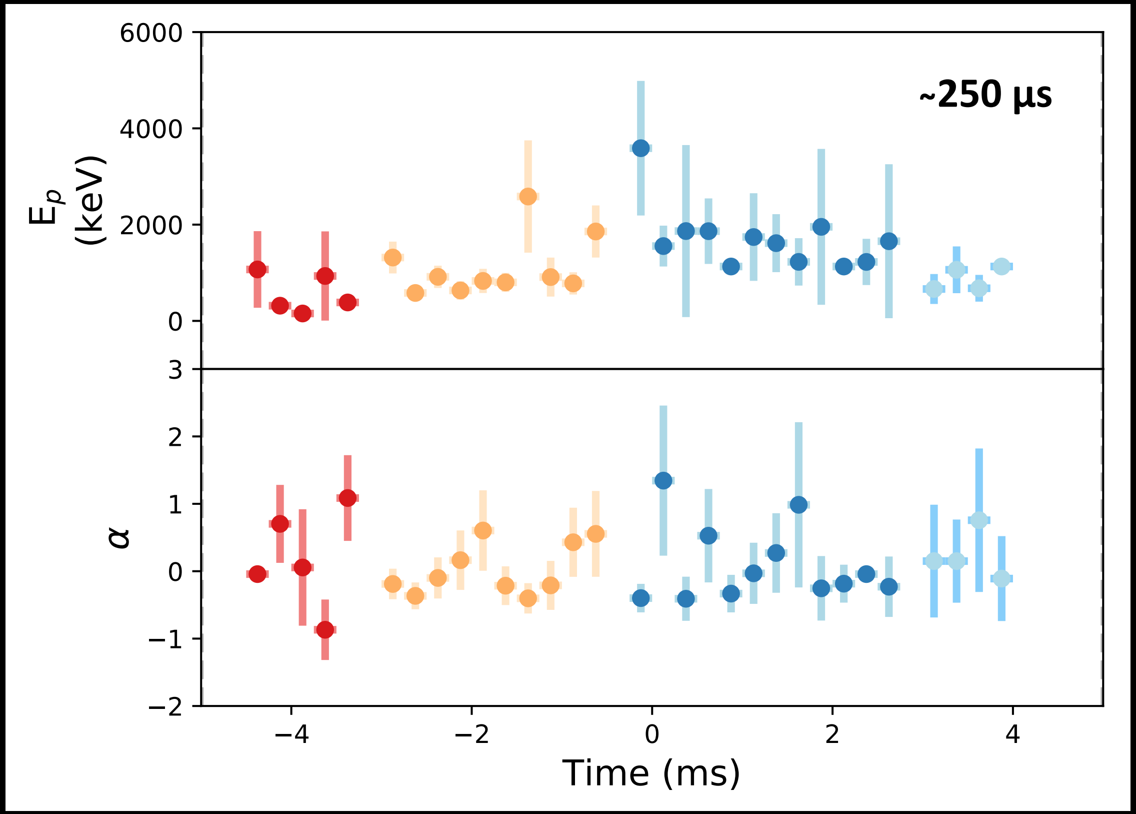
Evidence of “starquakes” in neutron star crust

No instrumental limitations due to the source

No radio counterparts (VLA)

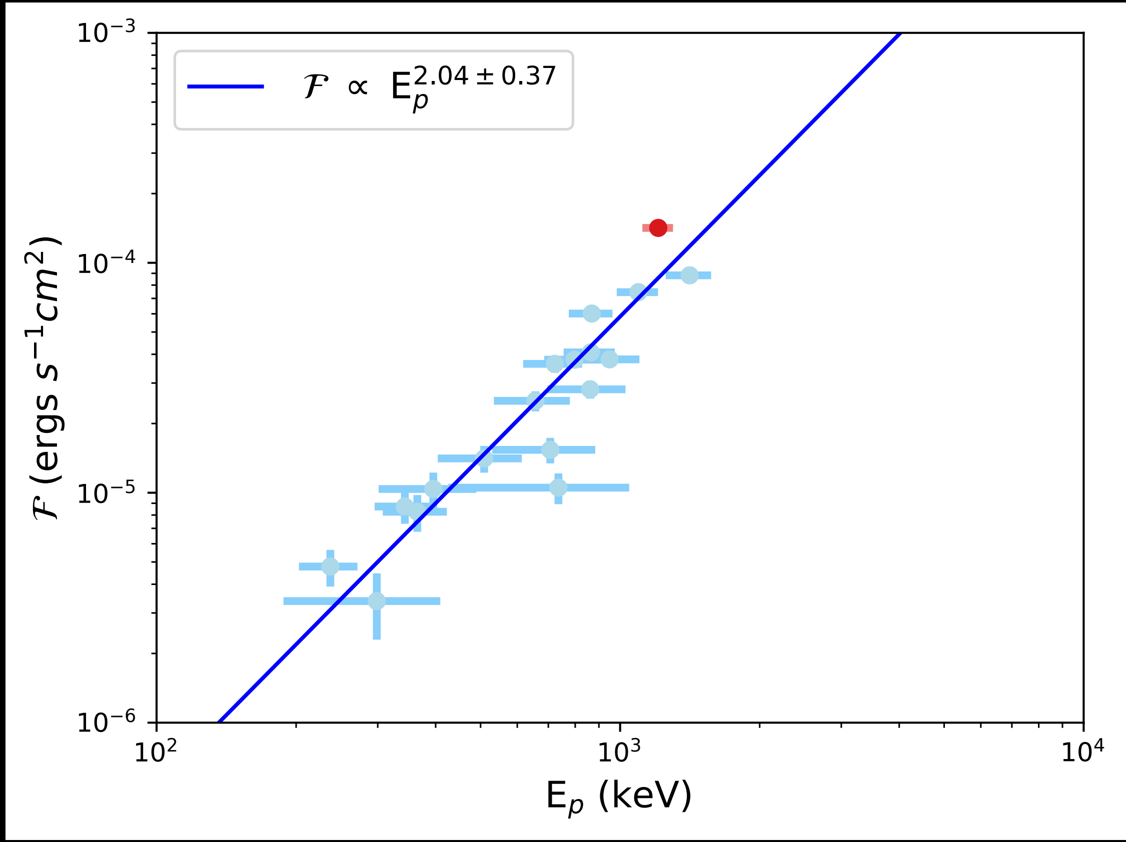
GRB 200415A Trivia (Observations)

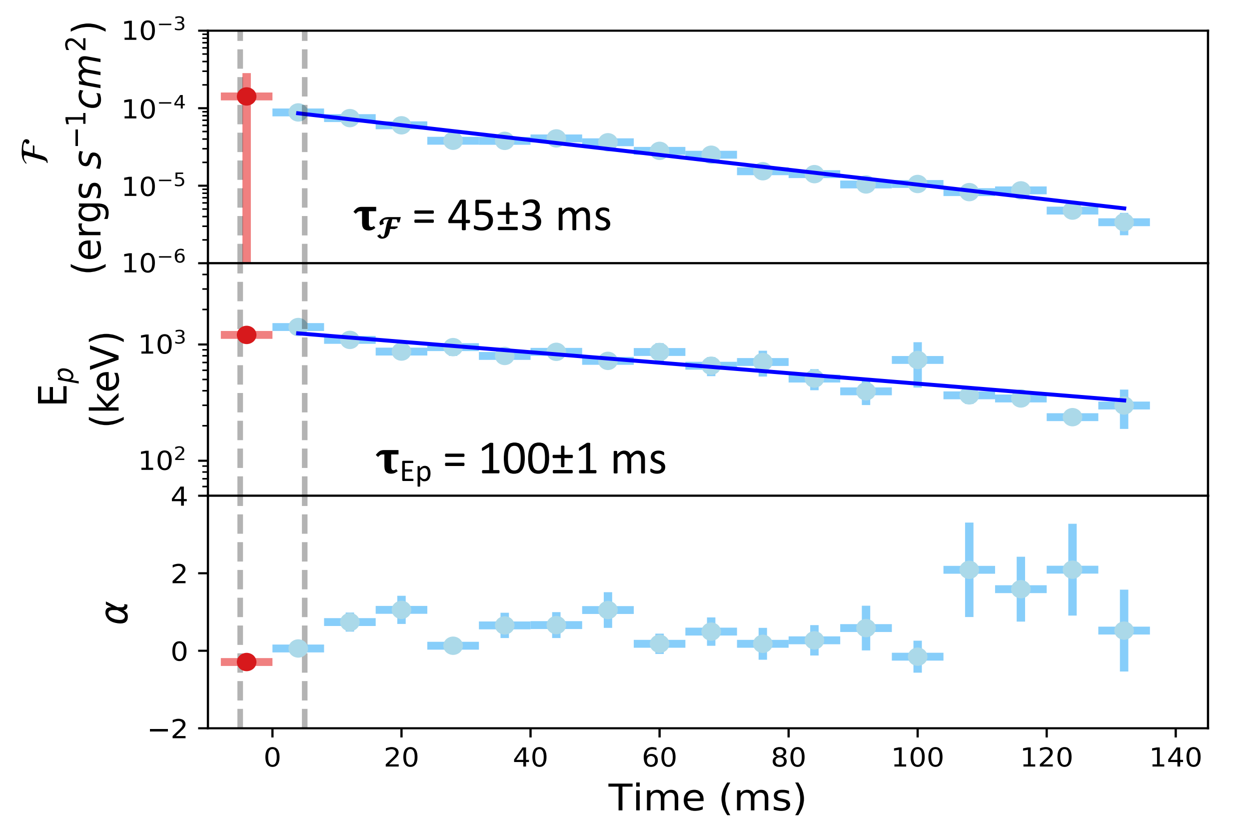




Further Details: O.J. Roberts et al., Nature: http://doi.org/10.1038/s41586-020-03077-8

Further Observations





Temporal binning = 8 ms

Further Details: O.J. Roberts et al., Nature: http://doi.org/10.1038/s41586-020-03077-8

Interpretations

- **Energy released by crustal fractures ejects hot plasma, like a photon torpedo…**
- **MeV-band emission:** Relativistic outflow (>0.98c) that is initially, highly opaque.
  - $L_{iso} >> L_{edd}$ ($10^{47\text{-}48} >> 10^{38}$ erg s^{-1}), relativistic wind ($\Gamma >> 1$)
  - Wind transparency to QED pair-production by 3 MeV photons implies $\Gamma \sim 6$
- **$\mathcal{F} \propto E_p^2$:** Explained by relativistic Doppler boosting
- Spectral index **α~0:** Wind that is highly opaque to electron scattering; 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.*

CBS Television Studios

Universal Pictures

The flux, and spectral shape of GRB 200415A are **unusual/unlikely for a short GRB**, when compared to catalogs from previous space missions

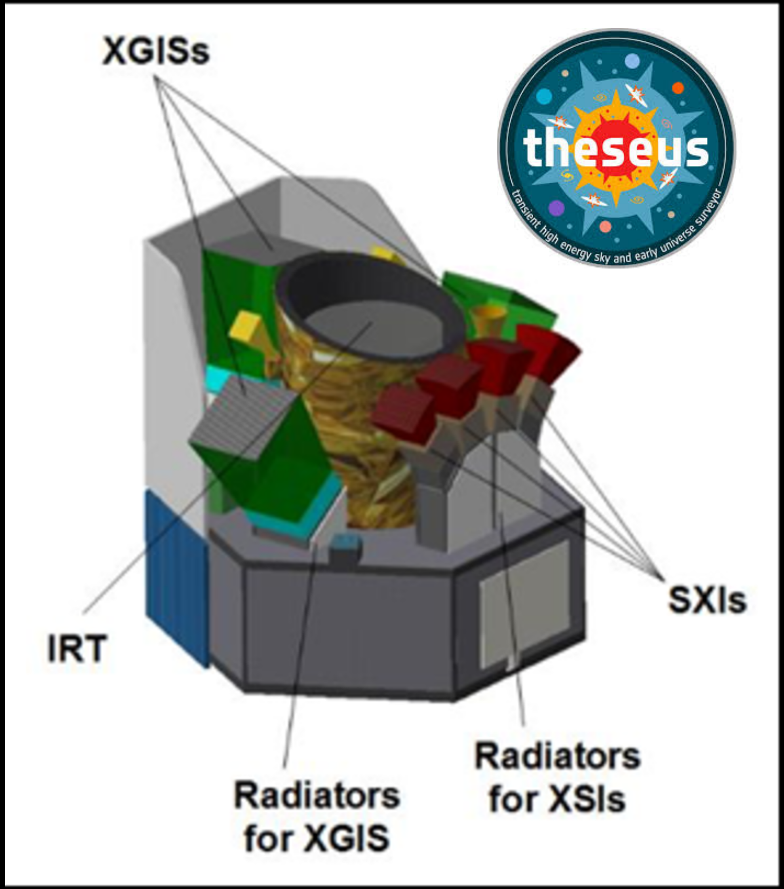
Have we cracked it? No.

- Outstanding questions need more observations:
  - Do all giant flares produce GeV emission?
  - Reducing the uncertainty in the volumetric rate.
    $R_{MGF} = 3.8^{+4.0}_{-3.1} \times 10^5\ Gpc^{-3} yr^{-1}$
  - Is the plasma ultra-relativistic? (1806-20 was 0.7c)
  - Confirm Flux and E_p decay trends, Flux α E_p^2.
  - Do we expect photon energies >3 MeV?
  - Is 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 detected short GRBs MGFs (0.3% of total GRBs)?
  - Many more…

What do we need to answer these? THESEUS.

- **High timing resolution** **(10 μs)**:
  - Confirmation of sub-ms spectral evolution
  - Measurement of decay trends
- High sensitivity **(10^{-9}-10^{-10} erg cm^{-2}s^{-1} 5σ @ 1000s)**:
  - QPOs in galactic GFs, stats for extragalactic GFs.
- Precise localization capability **(~10 arcmin for 6σ)**:
  - Independently localize to galaxies without IPN (SFR, etc).
- Wide FoV **(177 x 77 deg^2)**:
  - Validate rate estimates
  - Increasing sample size
- Broad spectral range **(0.3 keV – 20 MeV)**:
  - Full spectral coverage, higher E photons?
  - Ultra-relativistic plasma?

Expect a couple during mission lifetime (3.5 yrs) - See *Doyle et al.*



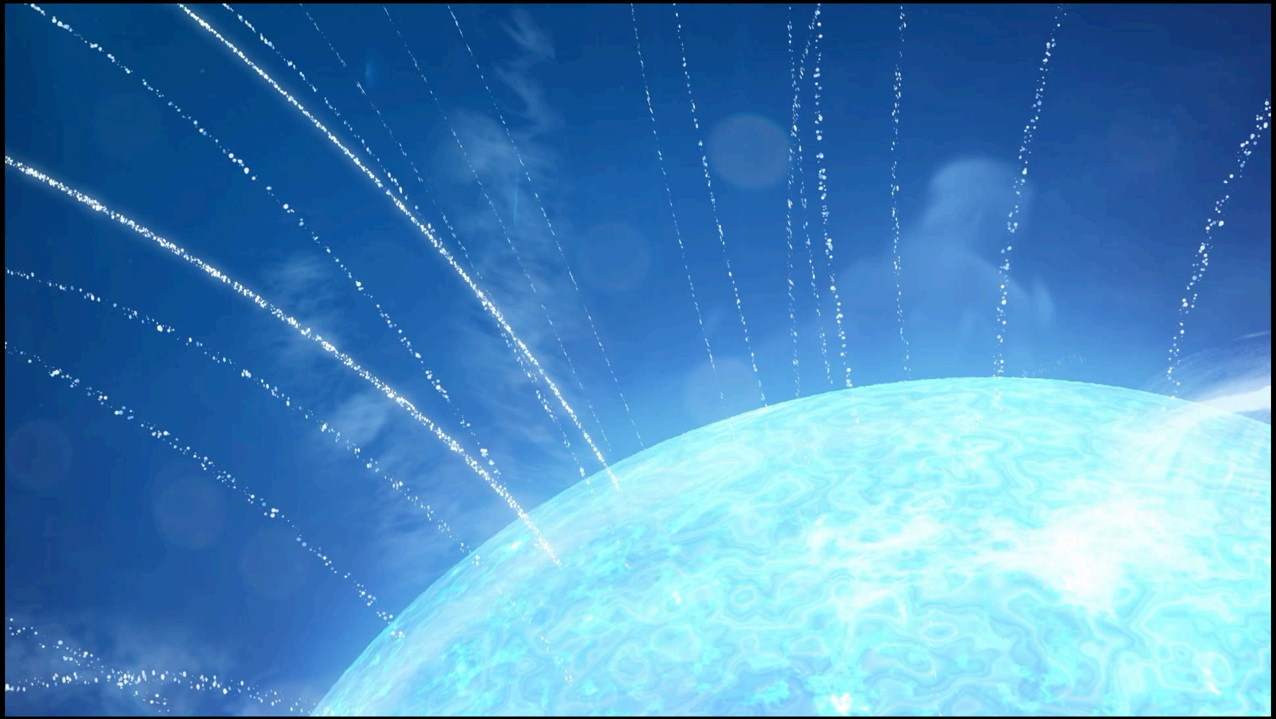
Credit: ESA

Other questions:

- **How fast will the readout be, DPU?**
- **Data bandwidth, rates, telemetry, etc. for high time resolution data, triggering algorithms?**

- 200415A is the clearest example yet of a giant flare from an extragalactic magnetar
- Unsaturated instrument spectra allow new discoveries to be made, opening a new front on studying the emission mechanism of these cataclysmic events.
- The instrumentation on THESEUS looks to be well-suited to future studies of these transients.

Credit: NASA’s Goddard Space Flight Center/Chris Smith (USRA/GESTAR)



USRA Universities Space Research Association

Fermi Gamma-ray Space Telescope

Swift

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Link to the Large Area Telescope paper: http://doi.org/10.1038/s41550-020-01287-8
Link to Populations paper: https://iopscience.iop.org/article/10.3847/2041-8213/abd8c8
Link to the NASA press release (with video): https://www.nasa.gov/feature/goddard/2021/nasa-missions-unmask-magnetar-eruptions-in-nearby-galaxies