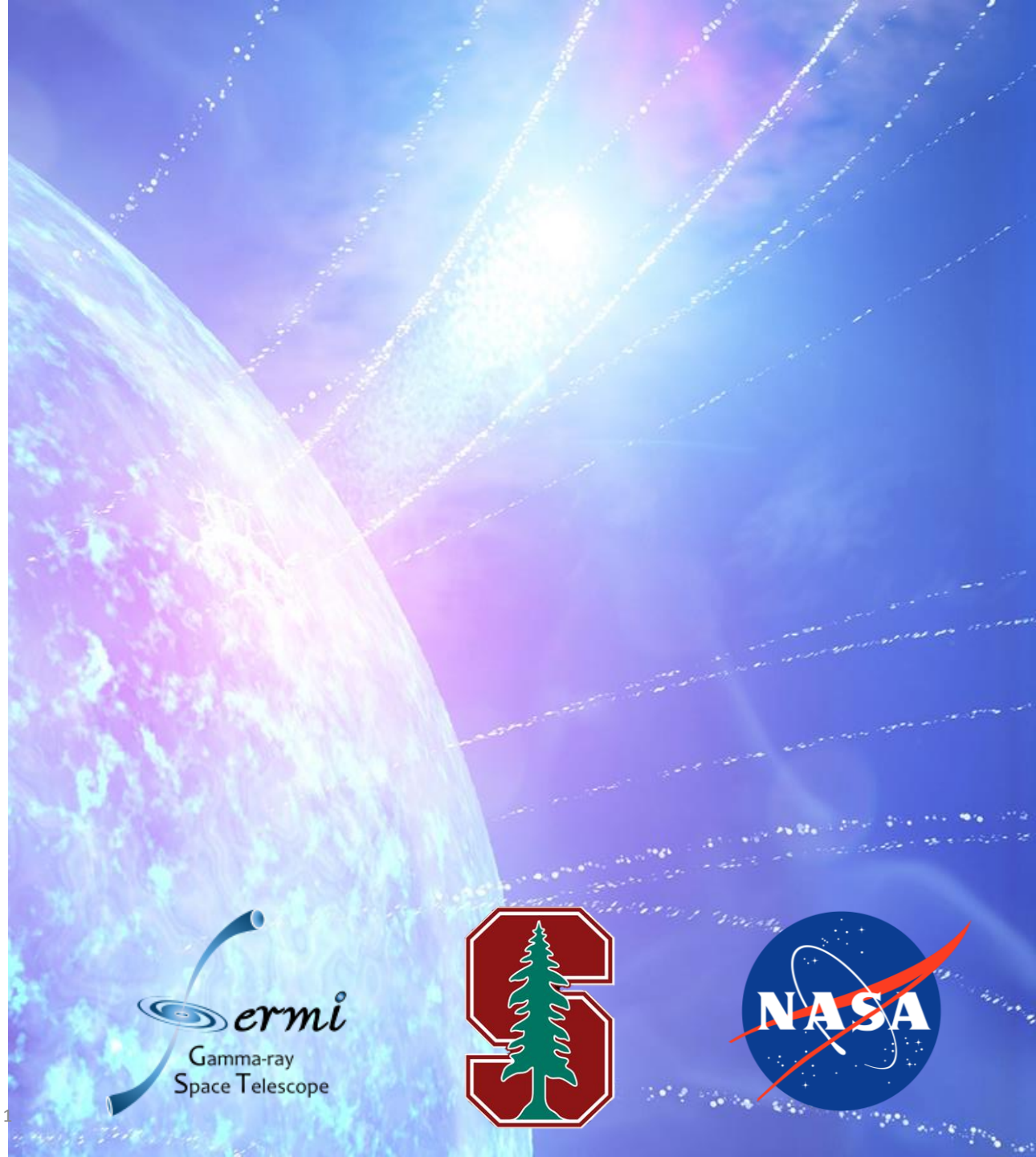
High-energy emission from a magnetar giant flare in the Sculptor galaxy

Niccolò Di Lalla

Stanford University

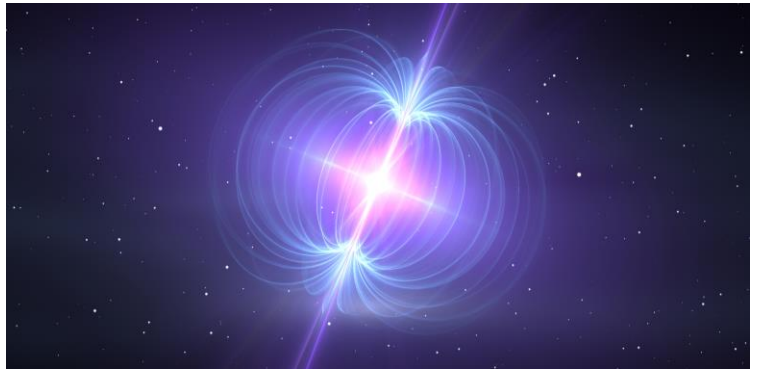
A. Berretta, M. Negro, N. Omodei, F. Piron, S. Razzaque

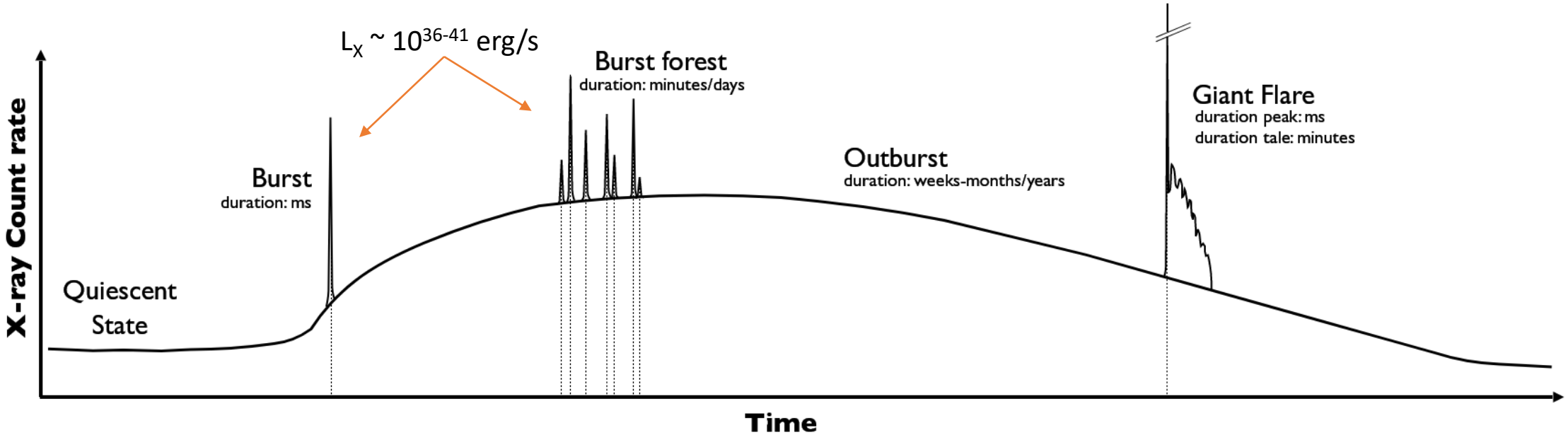
On behalf Fermi-LAT Collaboration



Magnetars

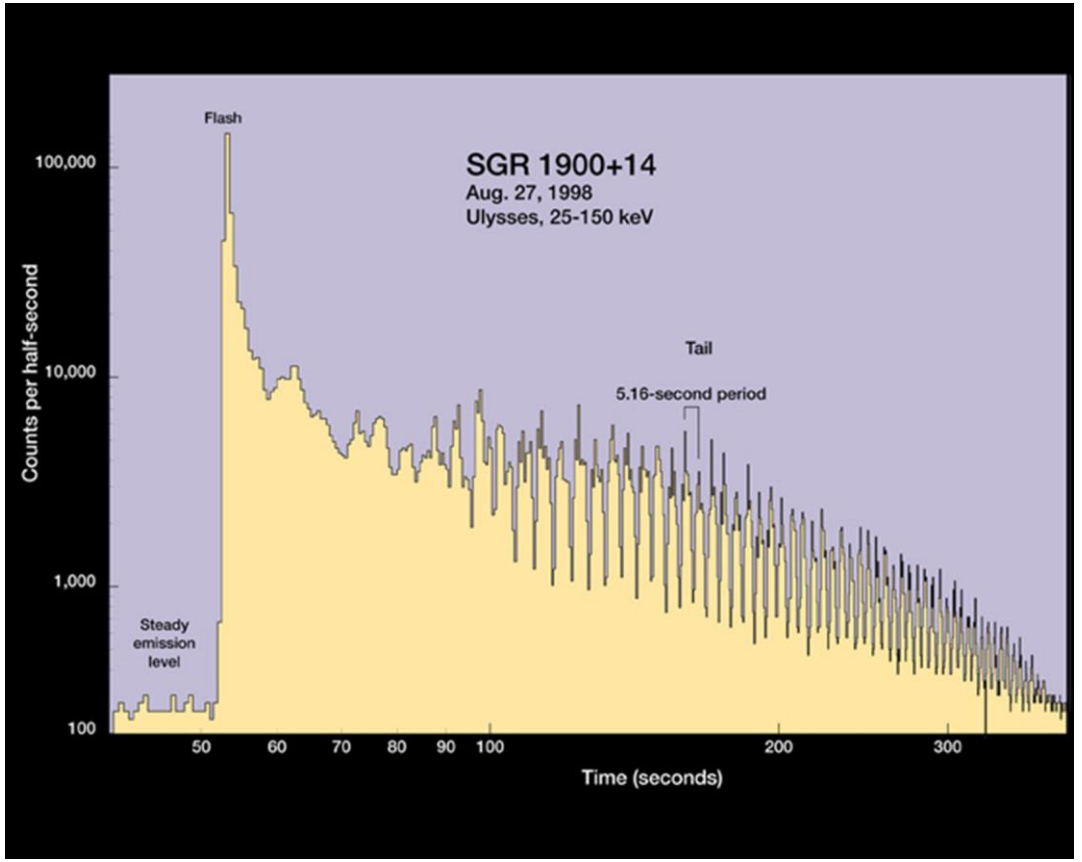
- Strongly magnetized neutron stars:
  - Magnetic field ~ $10^{13\text{-}15}$ G
  - Rotation period of 0.1-10 s
  - Steady X-ray luminosity L_X ~ $10^{31\text{-}36}$ erg/s

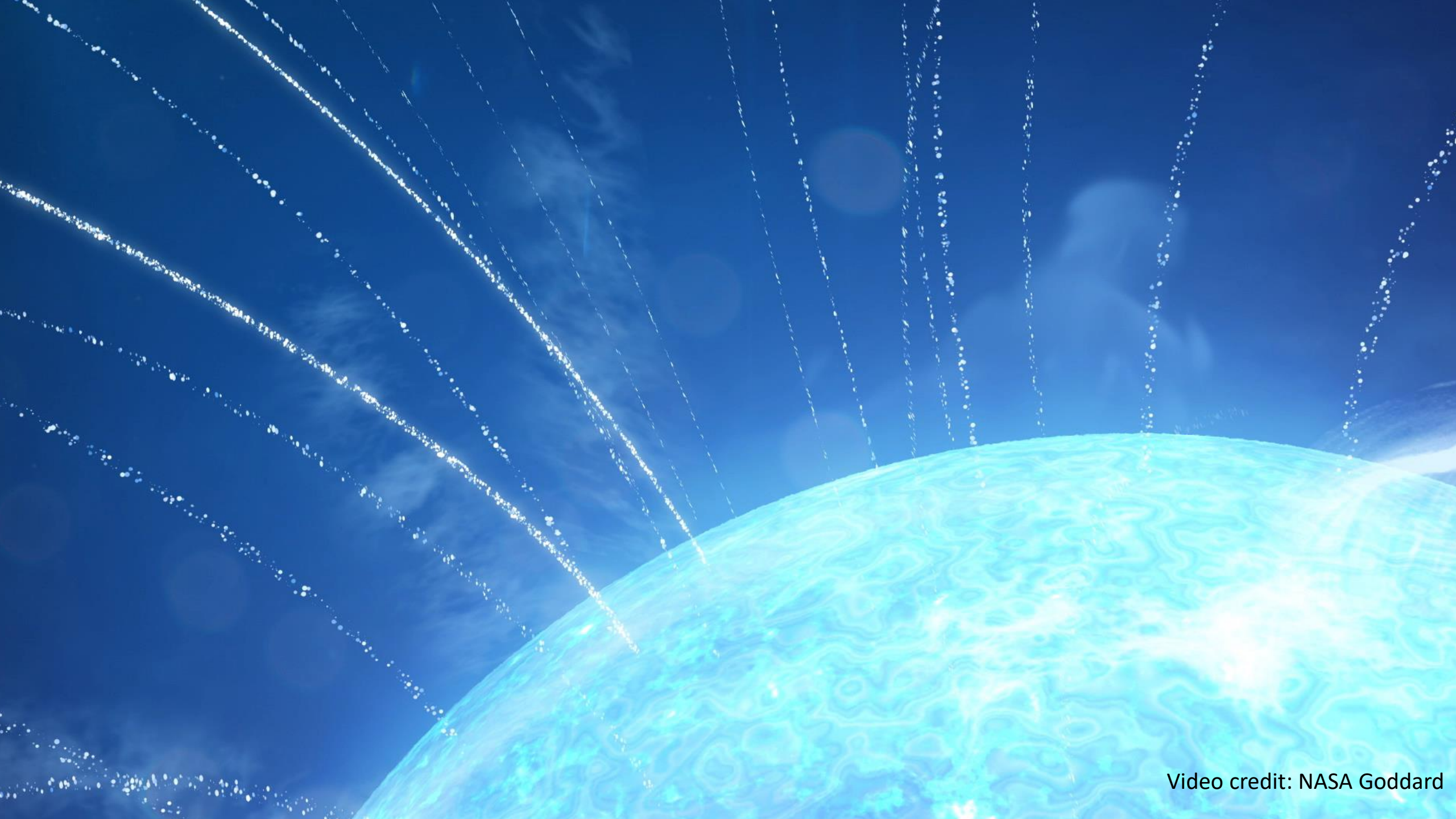




Magnetar Giant Flares

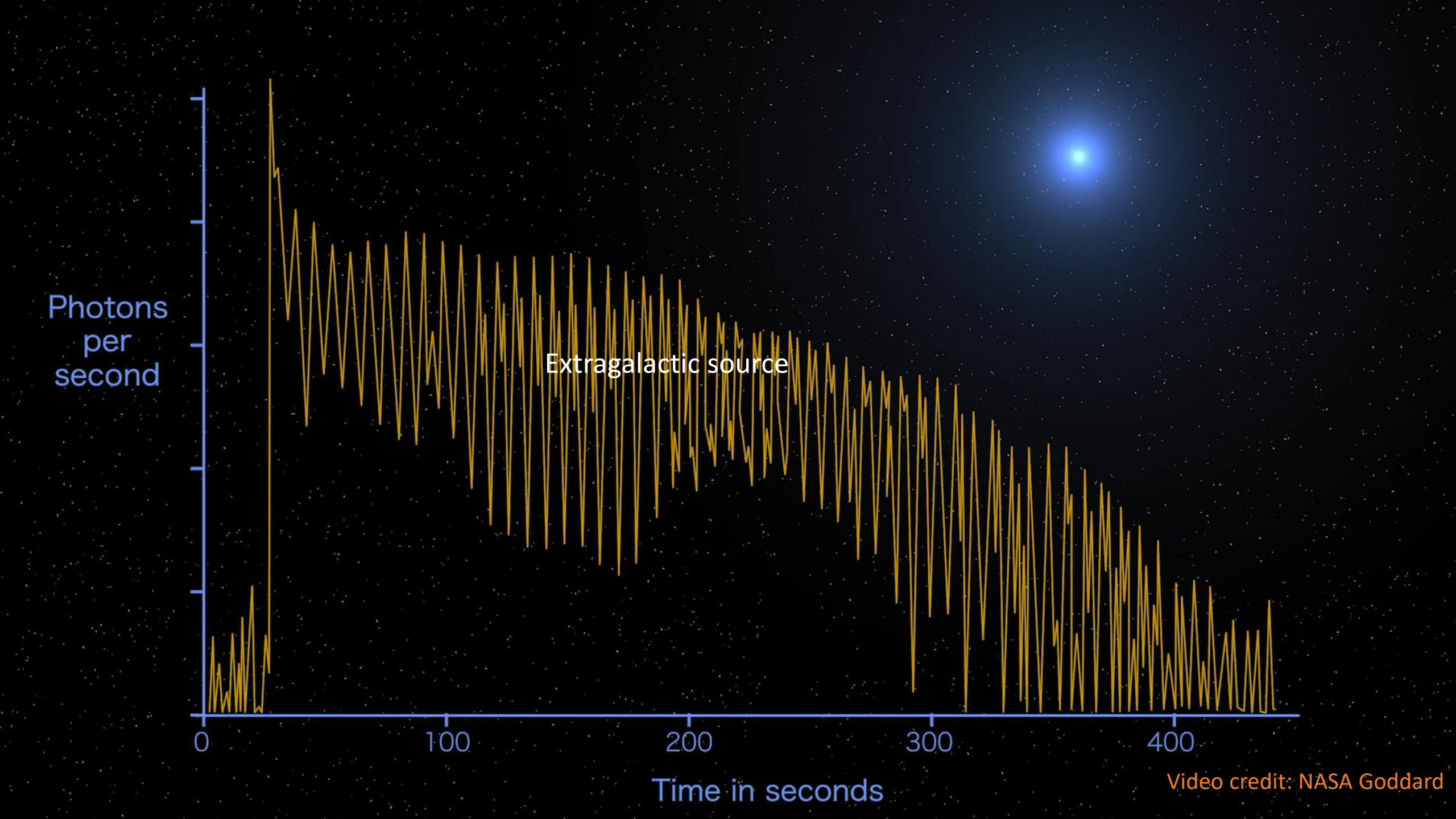
- Rare, short duration bursts of hard X-rays and soft gamma-rays with luminosity ~ $10^{44\text{-}47}$ erg/s:
  - Bright and variable initial spike lasting a few tenths of a second
  - Dimmer pulsating tail lasting a few hundred of seconds
- Triggered by extreme starquakes:
  - Induced by the extreme magnetic field which causes crustal fractures and the release of hot plasma





Video credit: NASA Goddard


Galactic source
Video credit: NASA Goddard



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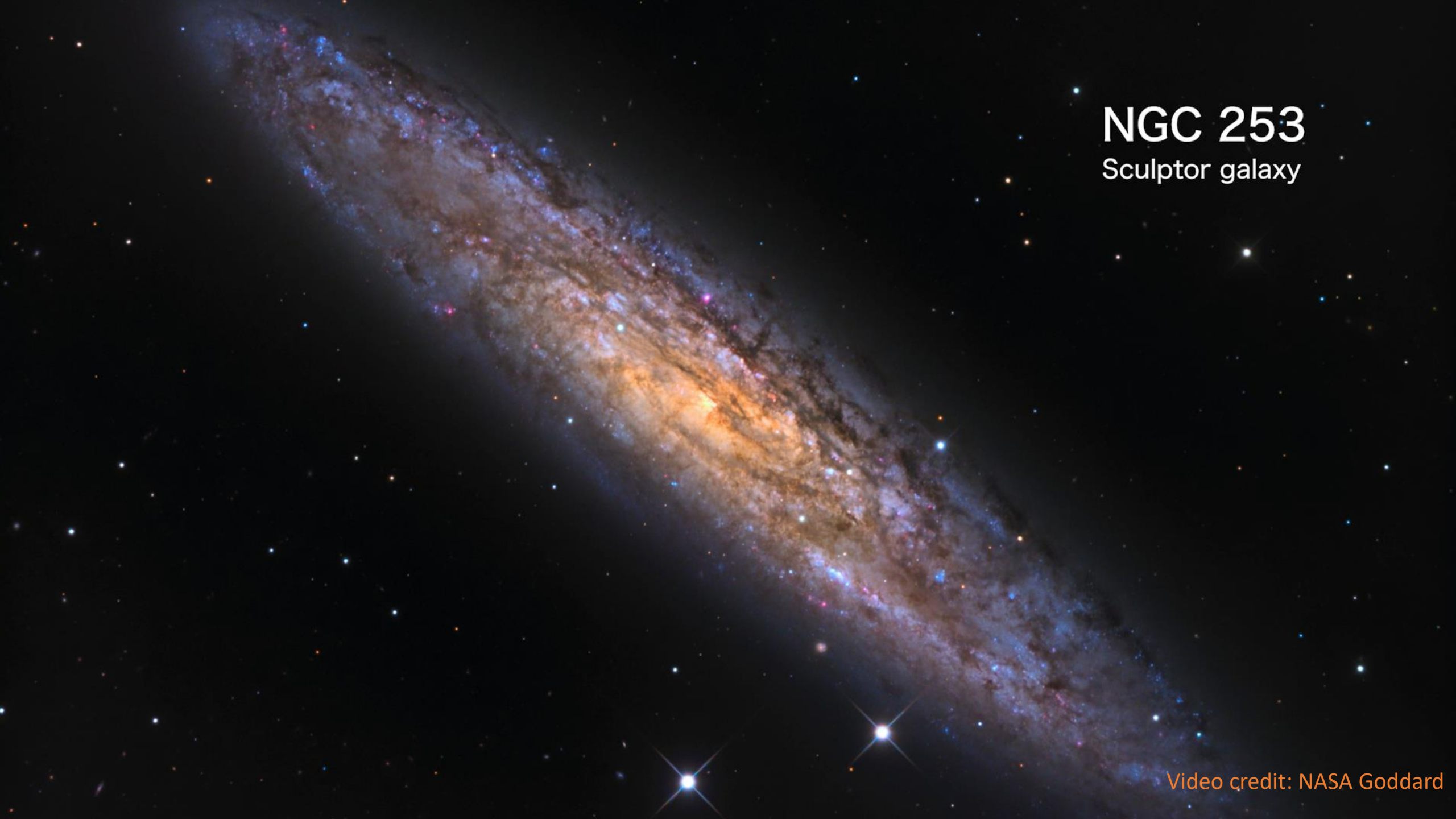
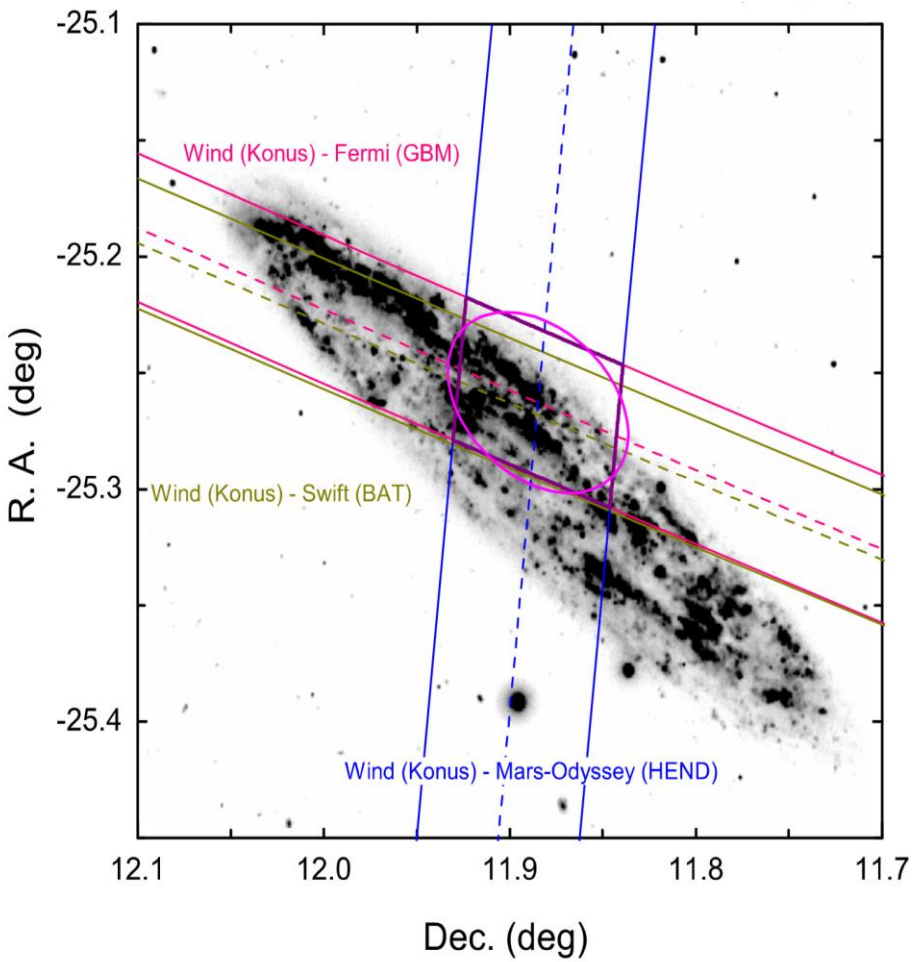

NGC 253
Sculptor galaxy
Video credit: NASA Goddard

GRB 200415A

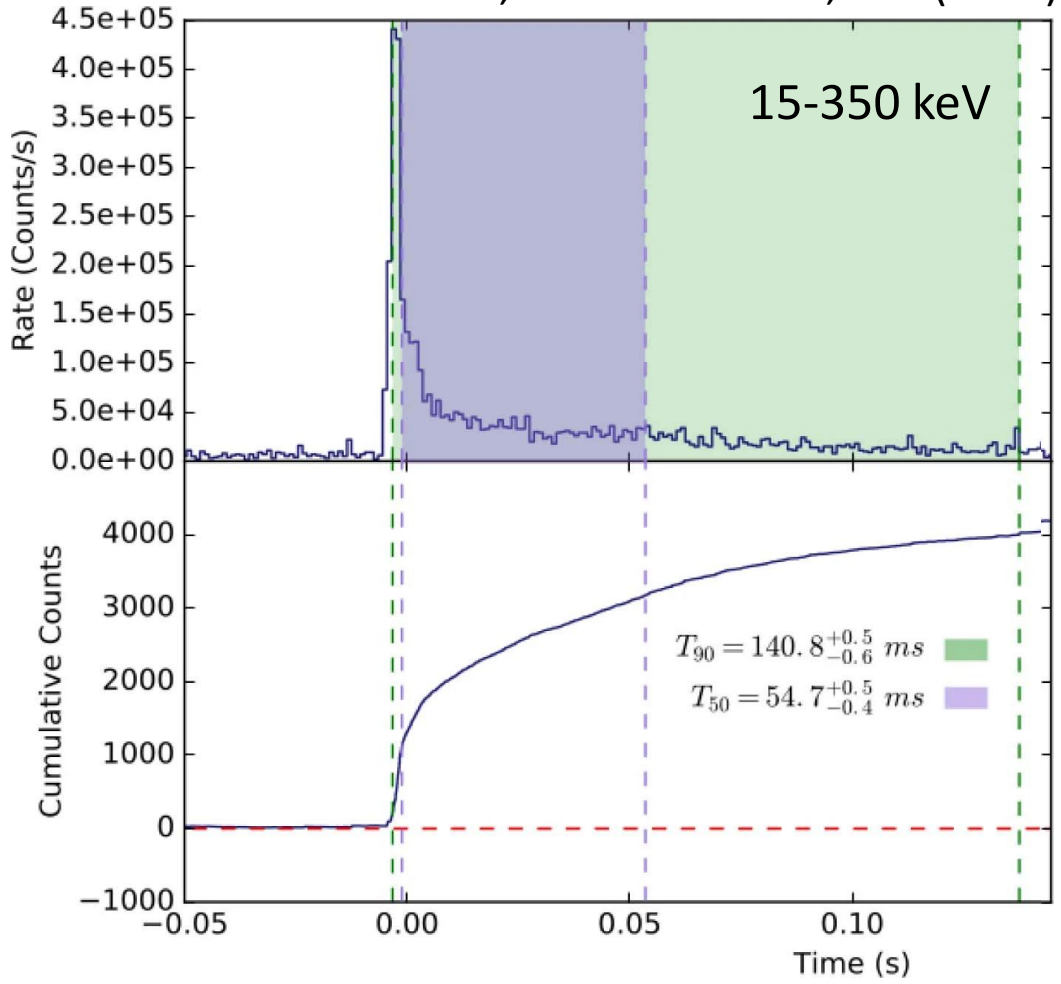
- Bright transient on April 15th 2020:
  - GBM triggered at 08:48:05.56 UTC
    - O. Roberts et al., Nature Vol. 589, 207 (2021)
  - Localized by the Inter-Planetary Network in a 17 arcmin^2 region overlapping with NGC 253,
    - D. Svinkin, et al., Nature Vol.589, 211 (2021)
  - Active star-bursting spiral galaxy at a distance of 3.5 Mpc
- Chance coincidence with NGC 253: 1 in 230,000
    - E. Burns et al., ApJL 907 L28 (2021)



D. Svinkin, et al., Nature Vol. 589, 211 (2021)

Swift BAT light curve

O. Roberts et al., Nature Vol. 589, 207 (2021)



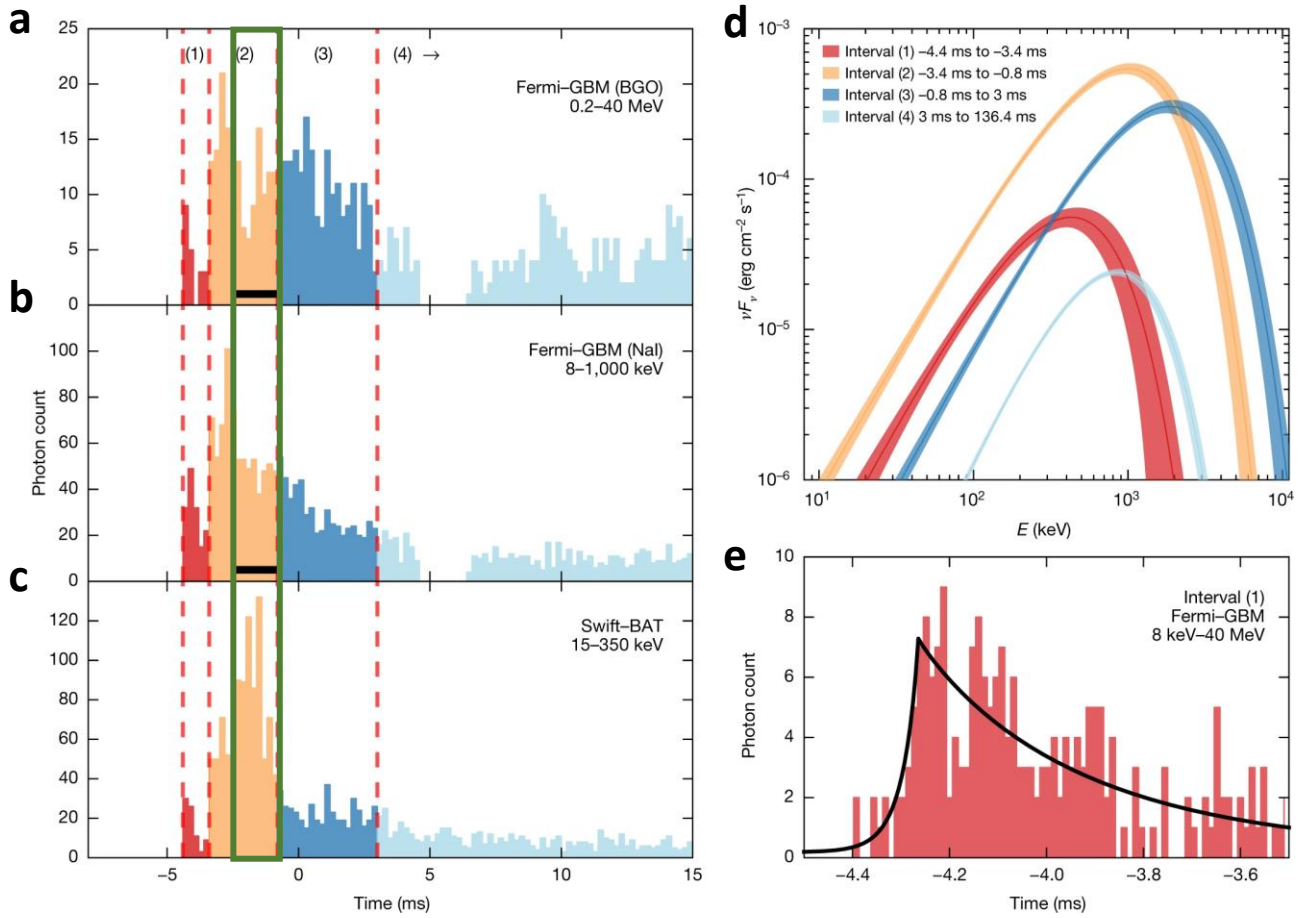
Short GRB

?

MGF

Fermi GBM observation

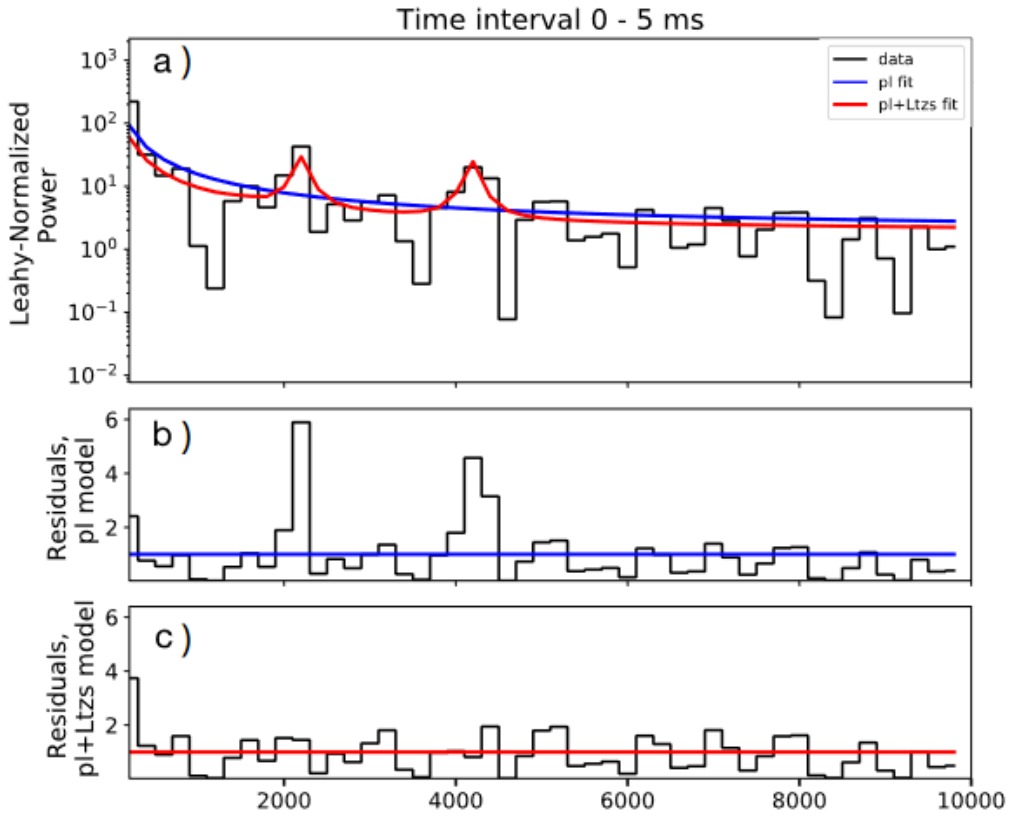
- Flux and spectral shape unusual for a short GRB:
  - 77 μs rise time
  - Sub-ms spectral evolution
  - Flat spectrum (α ~ 0), Ep ~ MeV
  - 180 Hz QPO at 2.5σ in the burst decay
- Very bright:
  - Liso = 1.1 x 10^{47} erg/s
  - Eiso = 1.5 x 10^{46} erg
  - Highest energy photon: 3 MeV
- No radio counterpart (VLA) or GW emission (KAGRA)



O. Roberts et al., Nature Vol. 589, 207 (2021)

ASIM observation

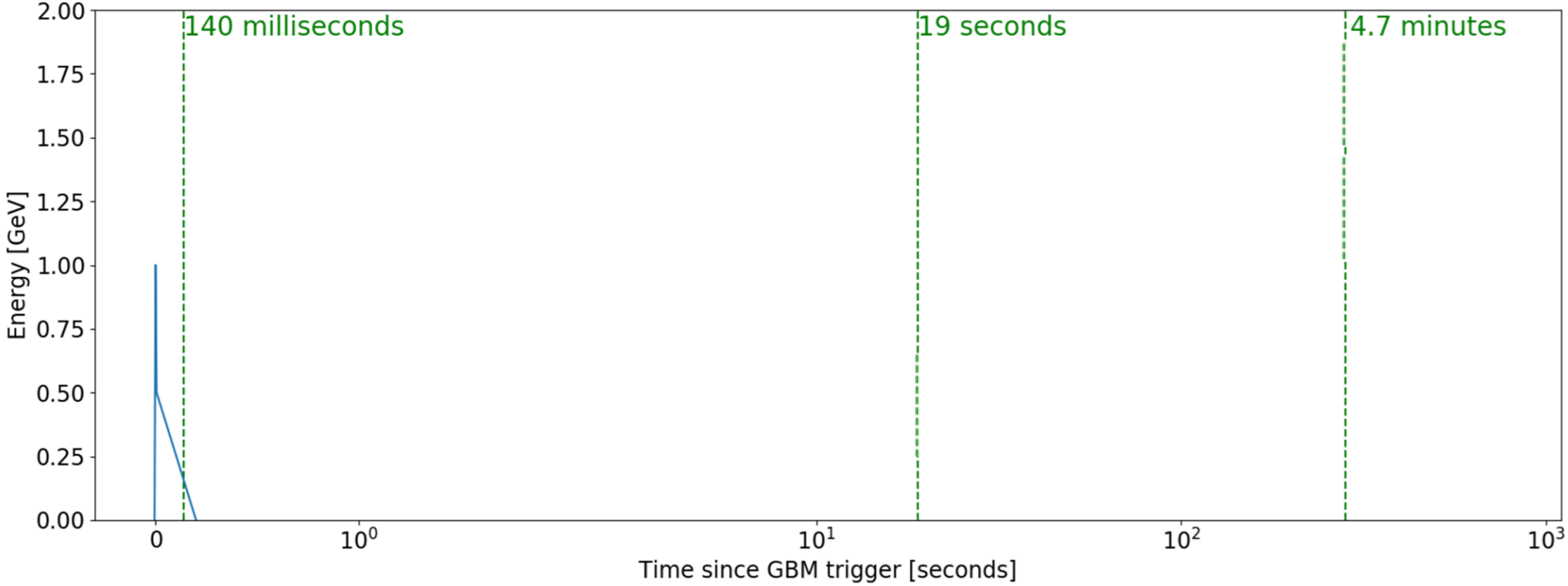
- ASIM Modular X- and Gamma-ray Sensor:
  - LED (50-400 keV) and HED (400 keV-40 MeV)
- Not suffering from saturation effects:
  - Recorded fine structure of the first burst (0.8-3.2 ms) with μs time resolution
- Two significant QPOs during the first peak:
  - 2156 ± 150 Hz (chance probability ~ 10^{-9})
  - 4256 ± 323 Hz (likely first harmonic)
  - Confirmed using SWIFT BAT data
- Alfven waves in the magnetosphere during the magnetic reconnection



A. J. Castro-Tirado et al., Nature Vol. 600 (2021)

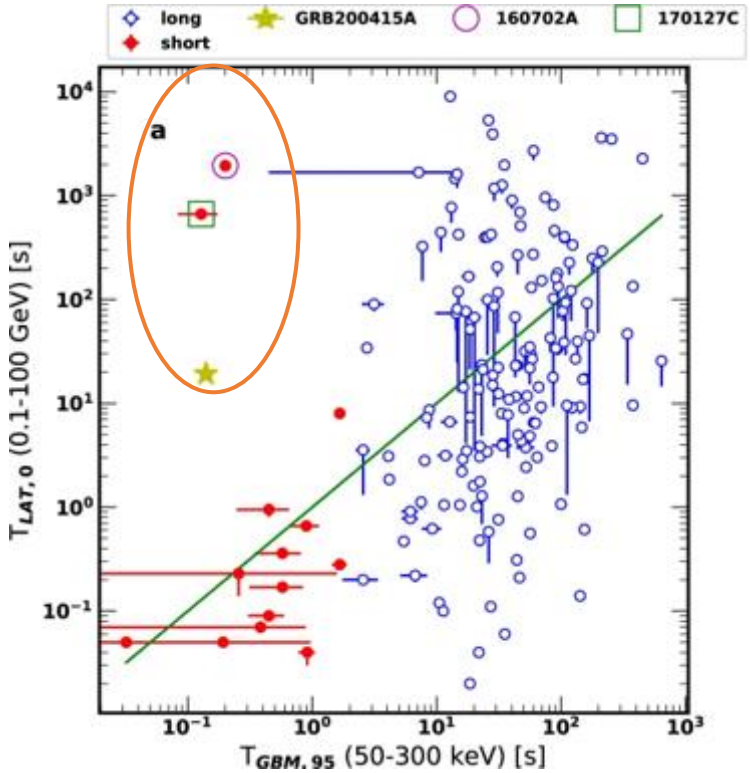
Fermi LAT light curve

GRB200415A was well within the LAT FoV until 500s after the GBM emission



A peculiar LAT GRB?

Fermi LAT Collaboration, Nature Astronomy Vol. 5 (2021)

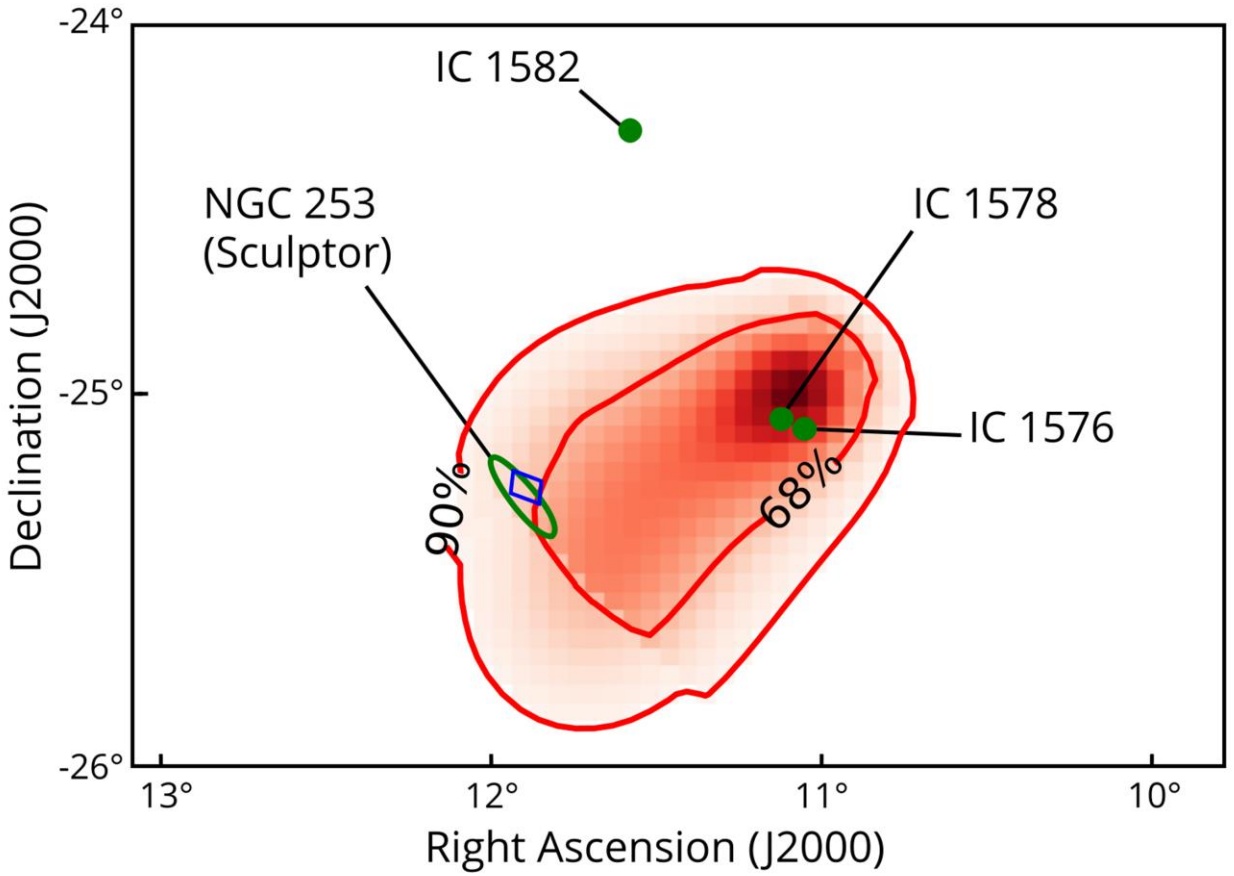


GRB 200415A is the only LAT sGRB within the FoV that was detected much later the end of the GBM prompt emission

LAT Localization map

- Likelihood analysis and TS map:
  - Maximum TS = 29 at RA = 11.13°, dec = -24.97°
  - 4 NGC 2000 galaxies in the 3° x 3° ROI
  - NGC 253 at 72% localization CL
- L.R. association results:

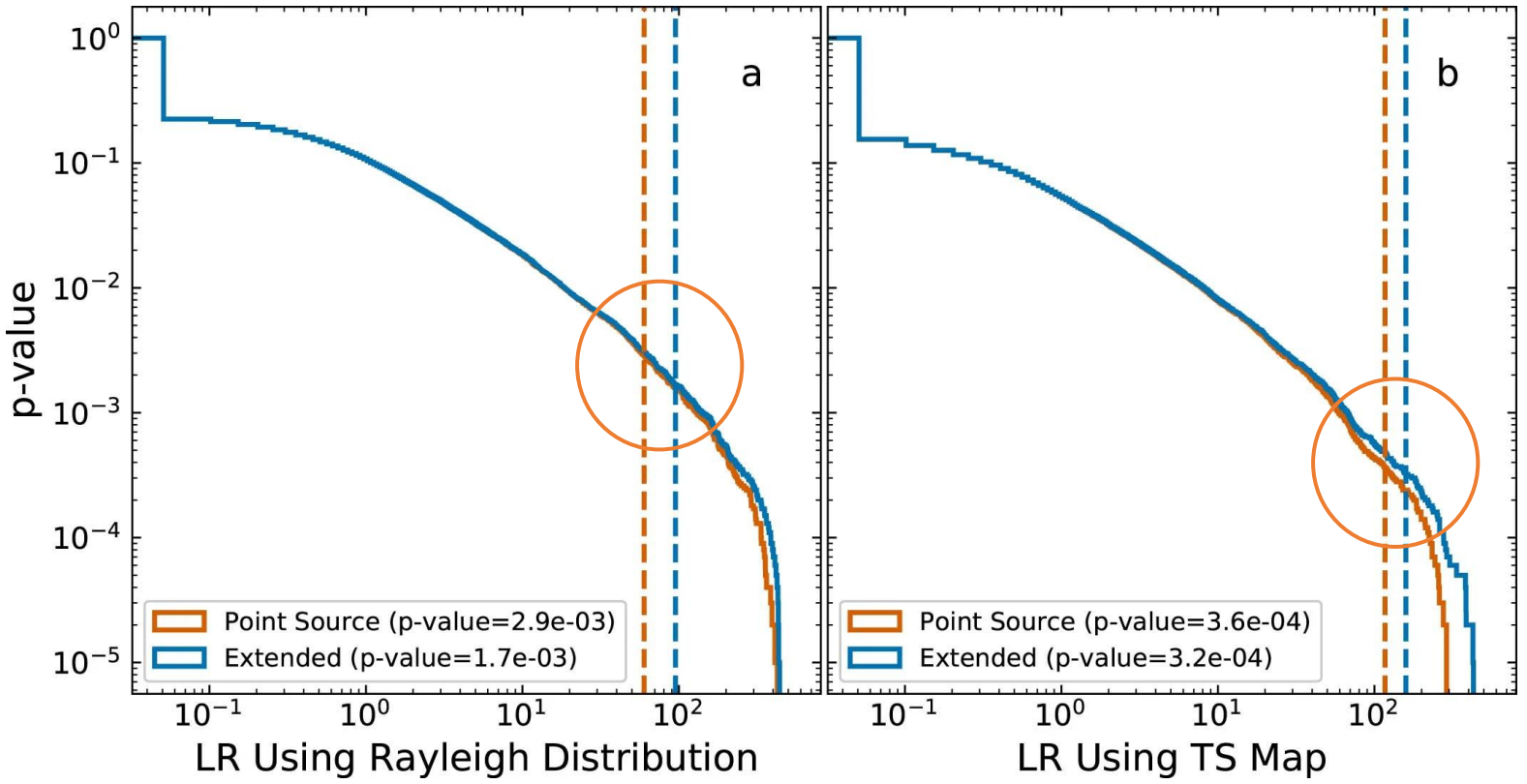
Galaxy	IC 1576	IC 1578	IC 1582	NGC 253
L.R.	2.1	2.9	0.3	60



Fermi LAT Collaboration, Nature Astronomy Vol. 5 (2021)

Spatial association

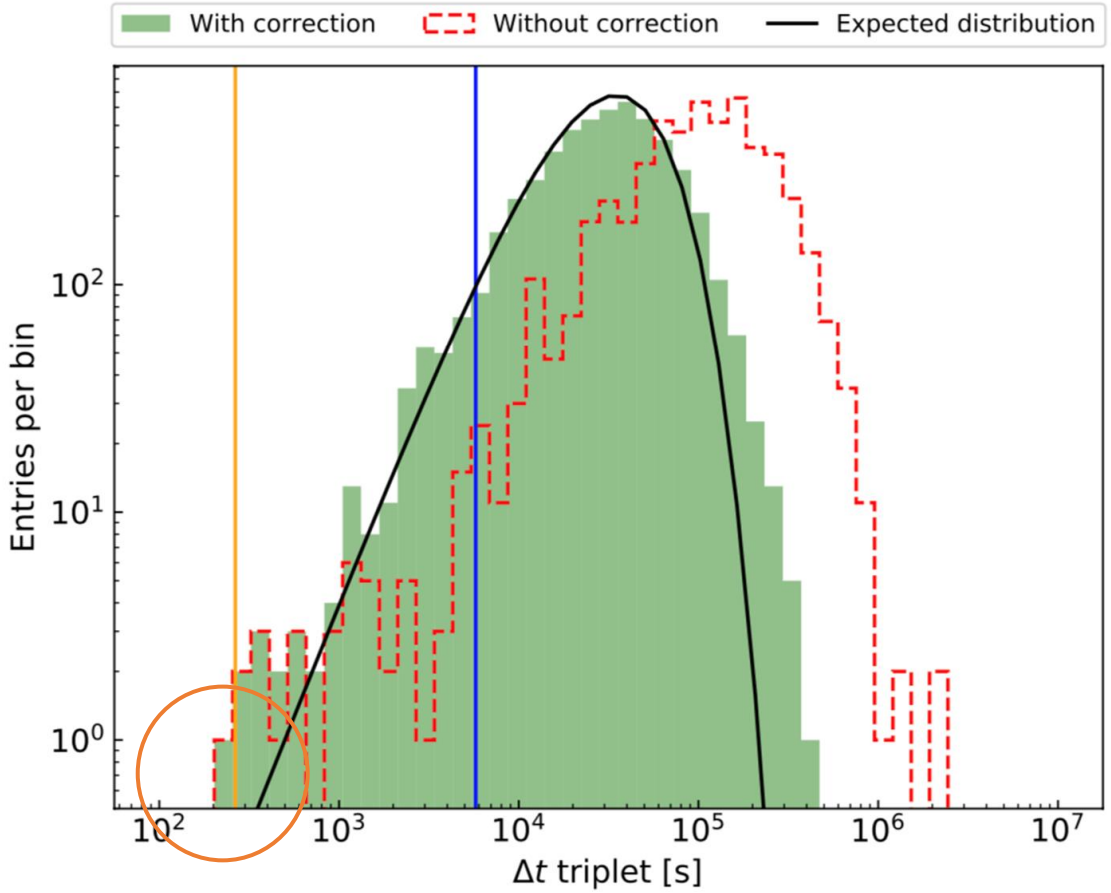
Fermi LAT Collaboration, Nature Astronomy Vol. 5 (2021)



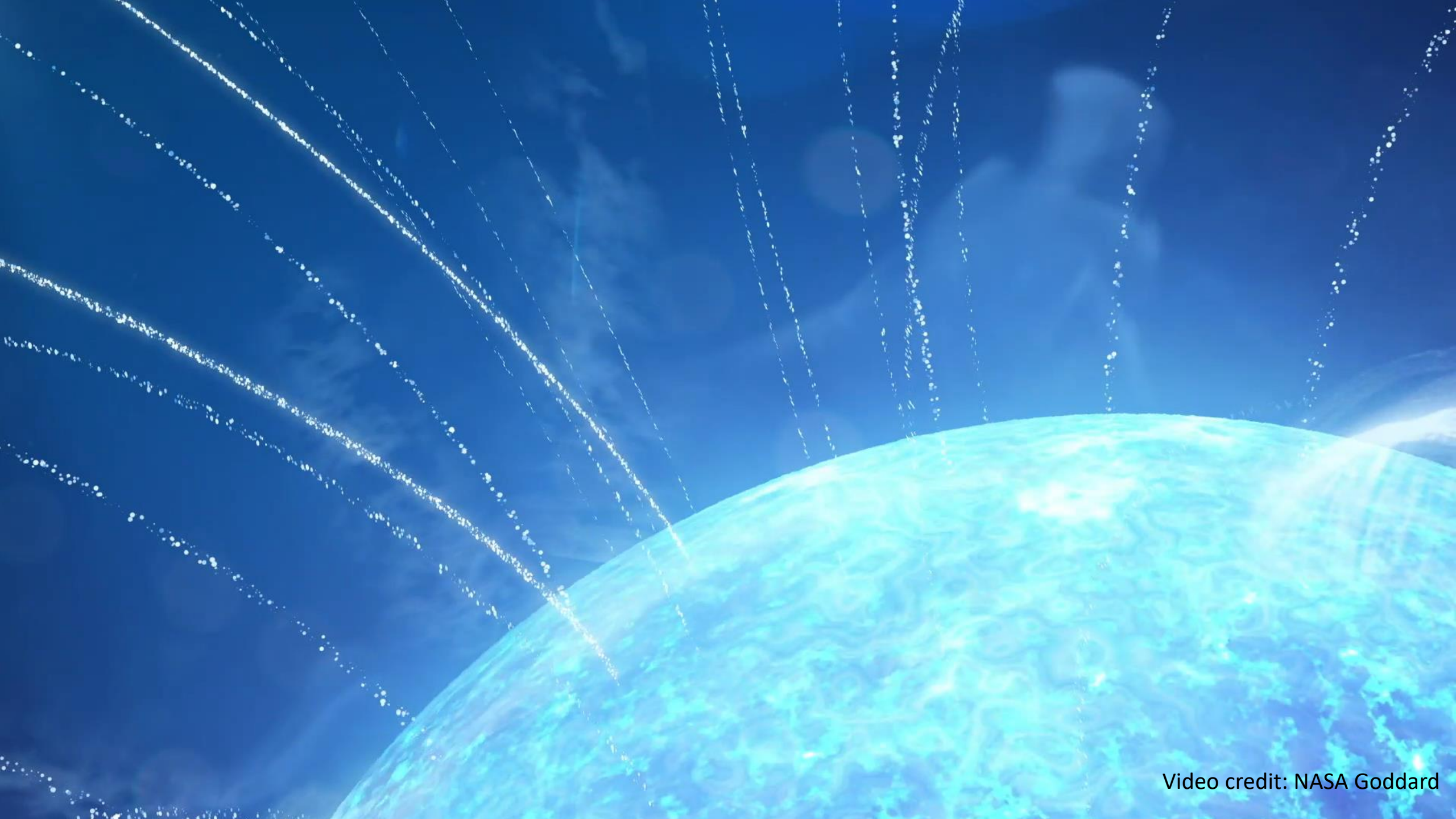
False Alarm Rate ~ 1 chance coincidence in 200-1800 years

Temporal association

- Significance 5.3 σ:
  - 3 events in ~ 300 seconds in the Sculptor region [Li&Ma, 1983]
- $\Delta t_i = t_{i+2} - t_i$
- Expected distribution:
  - Obtained using the Poisson statistics
- In 12 years of LAT data:
  - 3 years of livetime
  - Only 1 triplet has a smaller Δt (TS=16)
- Probability of chance coincidence with GBM signal: 1 in million years



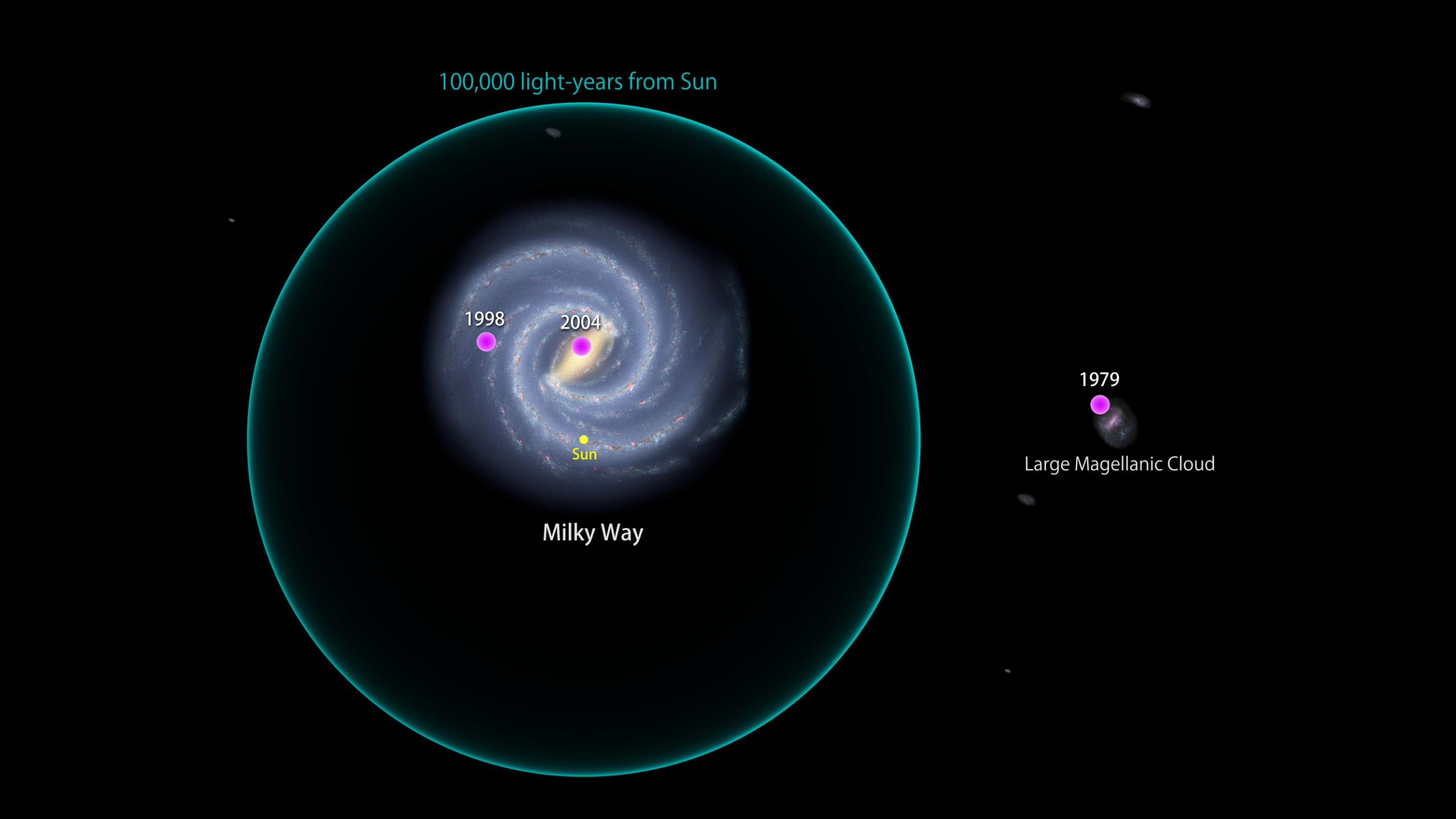
Fermi LAT Collaboration, Nature Astronomy Vol. 5 (2021)



Video credit: NASA Goddard

Case closed?

- Not yet:
  - Clear detection of tale pulsations is needed to absolutely prove magnetar origin
  - Repeating burst would ensure a not cataclysmic event
- But clear fingerprint at the crime scene:
  - Burst morphology (in star-forming galaxy):
    - Initial spike, spectral evolution and properties, QPOs
  - Absence of gravitational waves yet so nearby
- With an unexpected discovery:
  - Delayed high energy gamma rays seen by the LAT
    - Do all MGF produce GeV emission? Is the delay a constant?

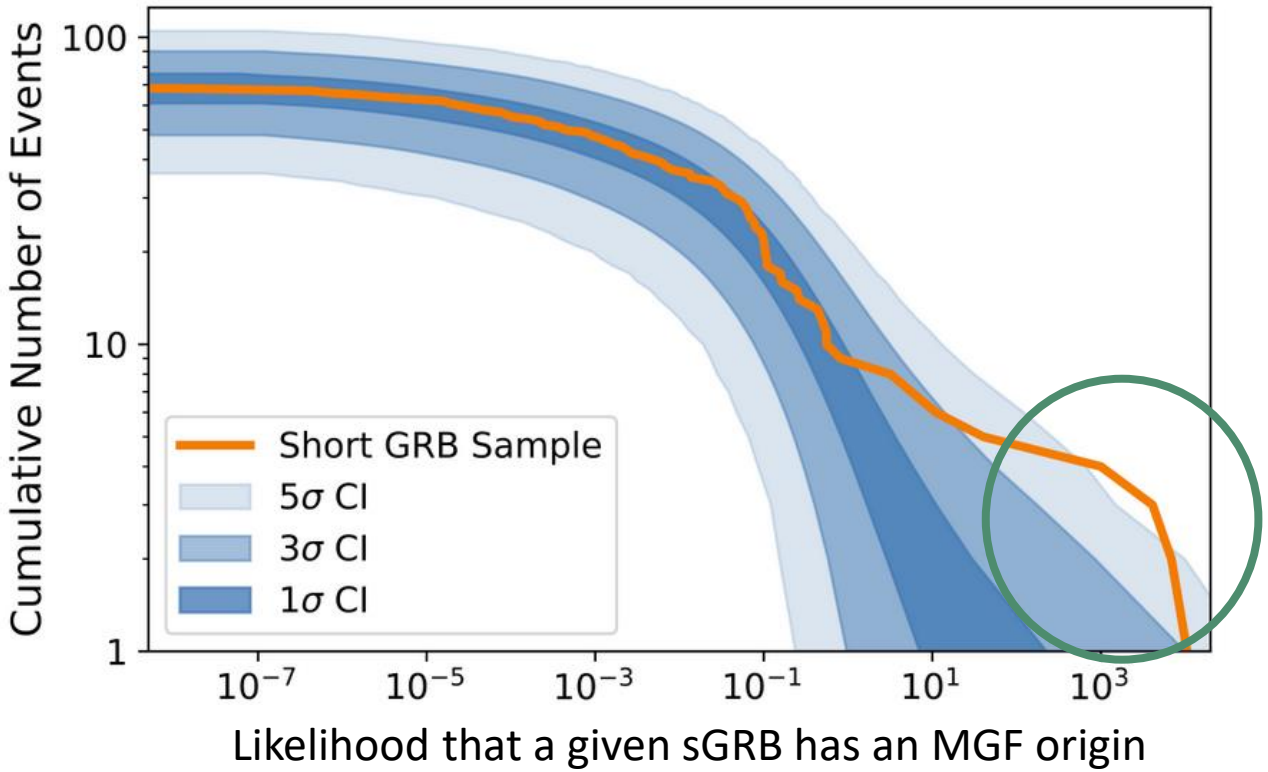

100,000 light-years from Sun
1998
2004
Sun
Milky Way
1979
Large Magellanic Cloud

There should be many more MGFs in the Universe than short GRBs!

Local population of extragalactic GRBs

- New class of local GRBs:
  - 4 events deviate from the background at more than 5σ
- Common characteristics:
  - Very short rise time (a few ms)
  - Intrinsic energetic (10^{46} erg), much fainter than cosmological GRBs (~10^{50} erg)
  - Very hard spectrum (α ~ 0) and high peak energy (> MeV)
  - Alignment to nearby star-forming galaxies

E. Burns et al., ApJL 907 L28 (2021)



MGF intrinsic rate

- MGFs are the dominant gamma-ray transient detected from extragalactic sources:
  - Some magnetars could produce multiple MGFs
  - Repeating GRBs?
- Additional MGF candidates may be identified in the GBM and LAT dataset:
  - Analysis still ongoing!

Event	Local Rates ($Gpc^{-3}\ yr^{-1}$)	Identified events
Magnetar Giant Flares	380,000	7
Neutron Star Mergers (short GRBs)	320[a]	~ 2000
Collapsars (long GRBs)	~100[b]	~10,000
Type Ia Supernovae	30,100[d]	~15,000[e]
Core-Collapse Supernovae	~70,000[d]	~ 8000[e]

E. Burns et al., ApJL 907 L28 (2021)

Integral rates	
< 10 Mpc	< 25 Mpc
Predicted MGF Detections over GBM Lifetime	
$5.6^{+5.8}_{-4.5}$	15^{+16}_{-12}

Selected Fermi GI proposal

Conclusions

- Fermi LAT Collaboration reported the high-energy detection of a magnetar giant flare coming from NGC 253:
  - The first detection at GeV energies!
- Simple physical model can explain the observations
- MGFs may constitute a fraction of current short GRB samples:
  - Search for additional MGF candidates in Fermi data still ongoing
- Further details:
  - LAT observation, Fermi LAT Collaboration, Nature Astronomy [link]
  - IPN localization, Svinkin et al., Nature [link]
  - GBM/Swift results, Roberts et al. Nature [link]
  - ASIM observation, A.J. Castro-Tirado et al., Nature [link]
  - Population of Magnetar Giant Flares, Burns et al., ApJL [link]