Fermi LAT and GBM collaborations results on GRB 200415A

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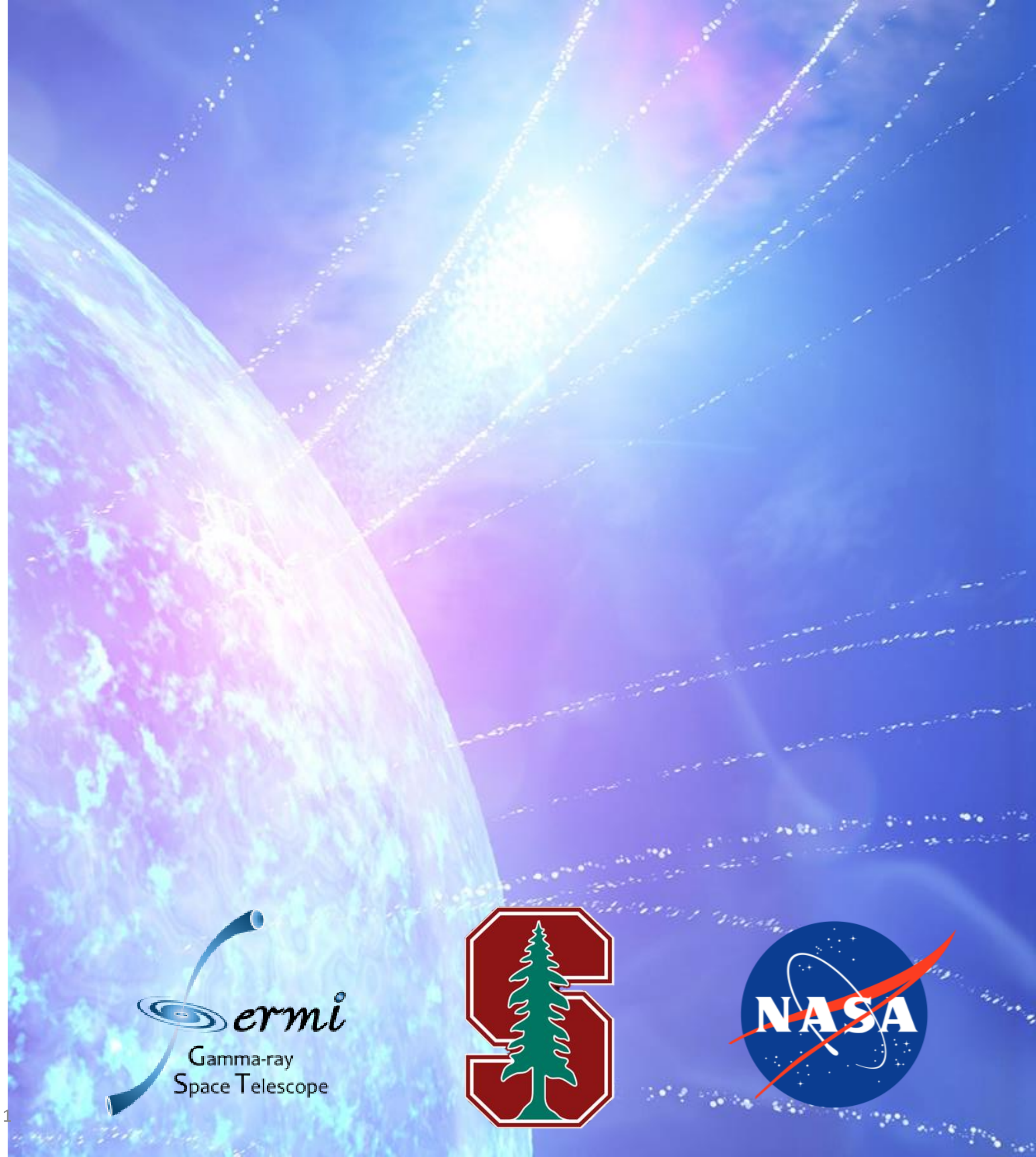

Papers

- Fermi-LAT Collaboration *"High-energy emission from a magnetar giant flare in the Sculptor galaxy"*, Nature Astronomy volume 5, pages 385–391 (2021)
- Roberts O. J. et al. *"Rapid spectral variability of a giant flare from a magnetar in NGC 253"*, Nature volume 589, pages 207–210 (2021)


nature astronomy

LETTERS

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

The Fermi-LAT Collaboration*

Magnetars are the most highly magnetized neutron stars in the cosmos (with magnetic field 10^{13}–10^{15} G). Giant flares from magnetars are rare, short-duration (about 0.1 s) bursts of hard X-rays and soft γ rays[1,2]. Owing to the limited sensitivity and energy coverage of previous telescopes, no magnetar giant flare has been detected at gigaelectronvolt (GeV) energies. Here, we report the discovery of GeV emission from a magnetar giant flare on 15 April 2020 (refs. [3,4] and A. J. Castro-Tirado et al., manuscript in preparation). The Large Area Telescope (LAT) on board the Fermi Gamma-ray Space Telescope detected GeV γ rays from 19 s until 284 s after the initial detection of a signal in the megaelectronvolt (MeV) band. Our analysis shows that these γ rays are spatially associated with the nearby (3.5 megaparsecs) Sculptor galaxy and are unlikely to originate from a cosmological γ-ray burst. Thus, we infer that the γ rays originated with the magnetar giant flare in Sculptor. We suggest that the GeV signal is generated by an ultra-relativistic outflow that first radiates the prompt MeV-band photons, and then deposits its energy far from the stellar magnetosphere. After a propagation delay, the outflow interacts with environmental gas and produces shock waves that accelerate electrons to very high energies; these electrons then emit GeV γ rays as optically thin synchrotron radiation. This observation implies that a relativistic outflow is associated with the magnetar giant flare, and suggests the possibility that magnetars can power some short γ-ray bursts.

*A list of authors and their affiliations appears at the end of the paper.

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Article

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

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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

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[3–6], 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[7–11] 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.

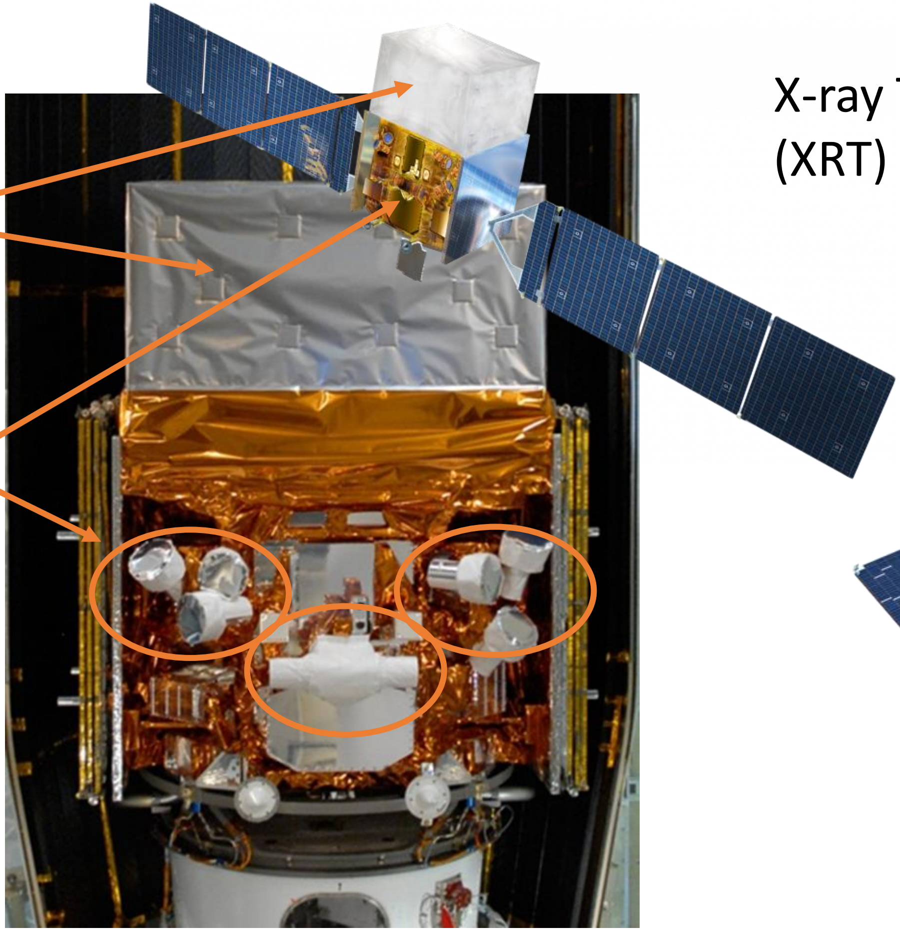
Nature | Vol 589 | 14 January 2021 | 207

Fermi and Swift

Large Area Telescope

Gamma-ray Burst Monitor

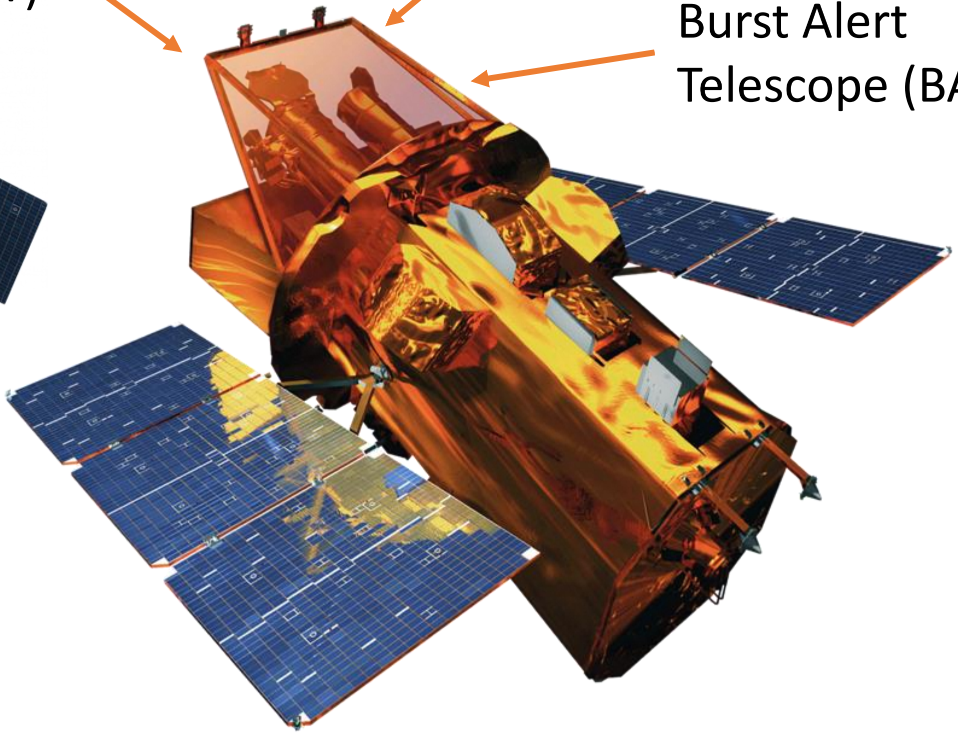
12 x NaI detectors
2 x BGO detectors



X-ray Telescope (XRT)

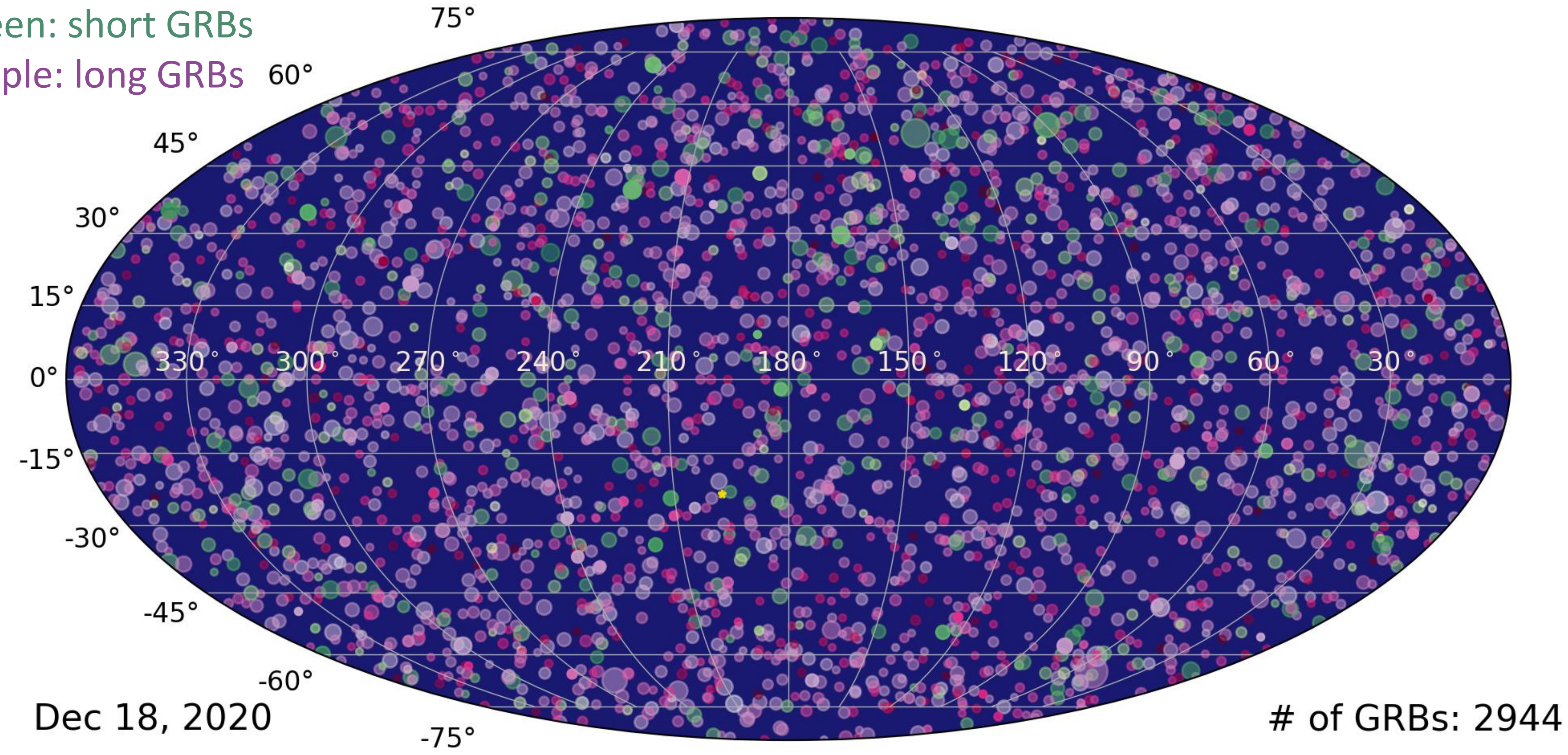
Ultraviolet/Optical Telescope (UVOT)

Burst Alert Telescope (BAT)

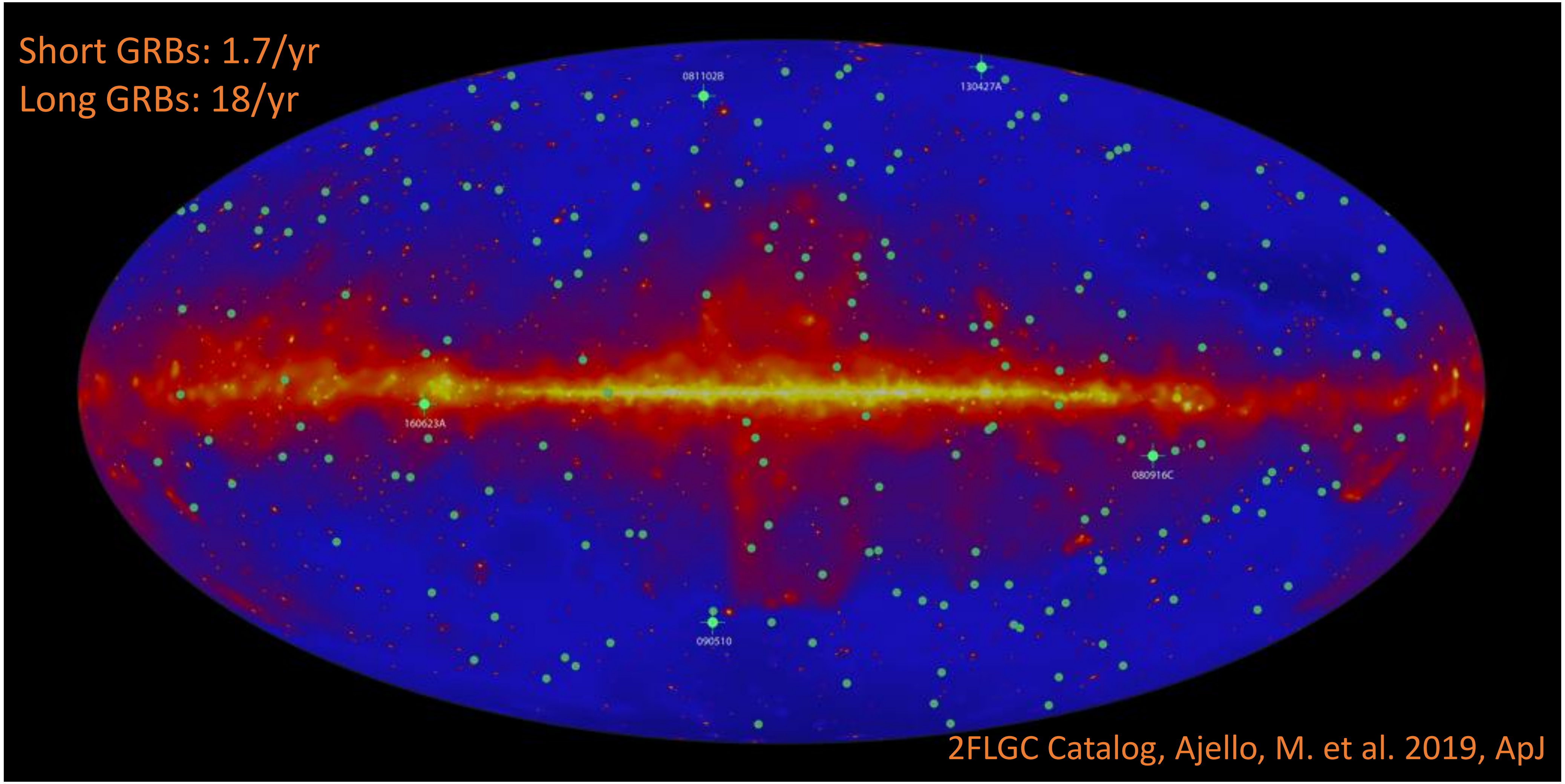


GBM Gamma-ray Bursts

Green: short GRBs
Purple: long GRBs

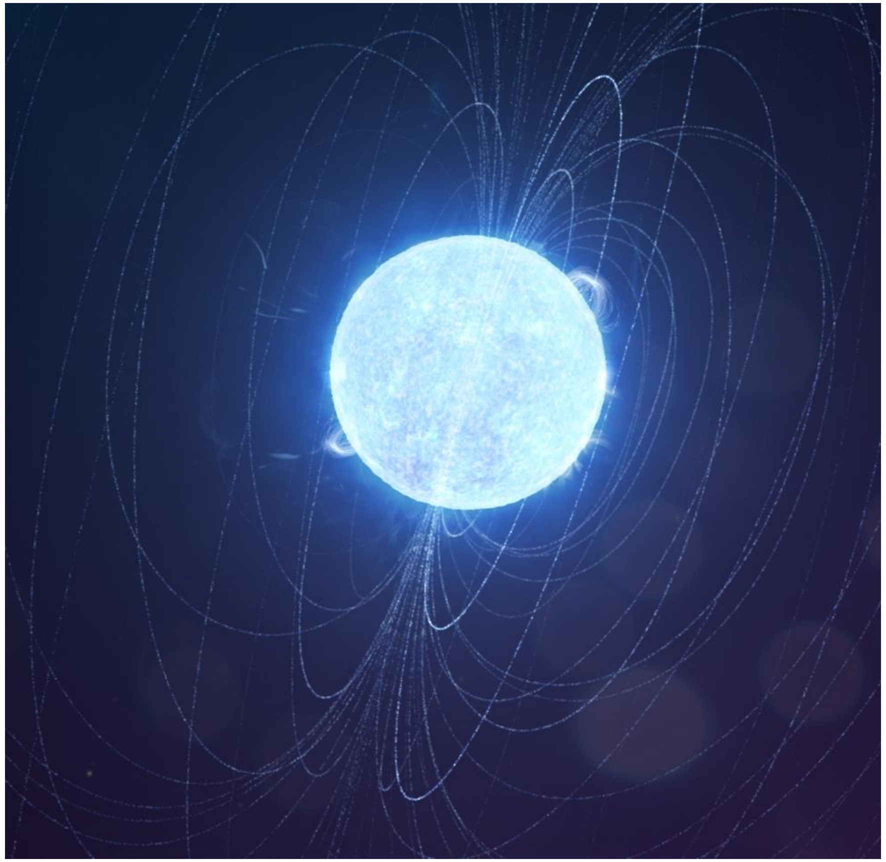


LAT Gamma-ray sky and GRBs



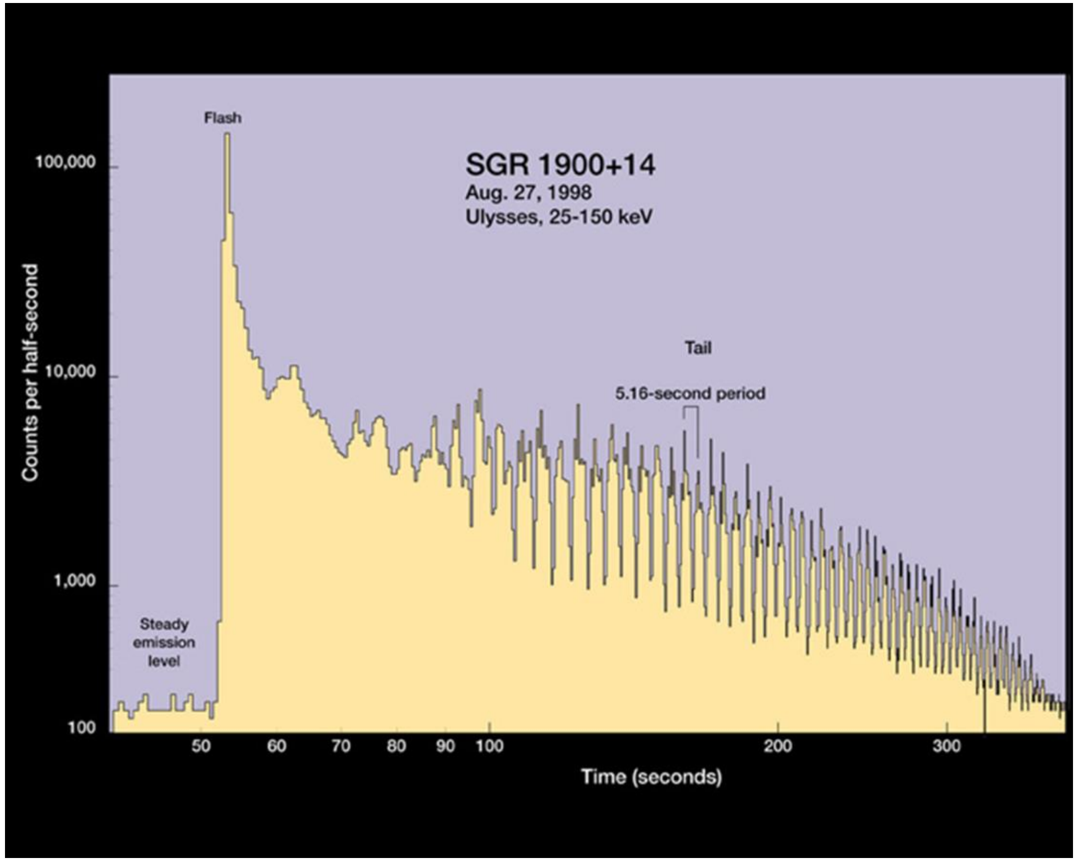
Magnetars

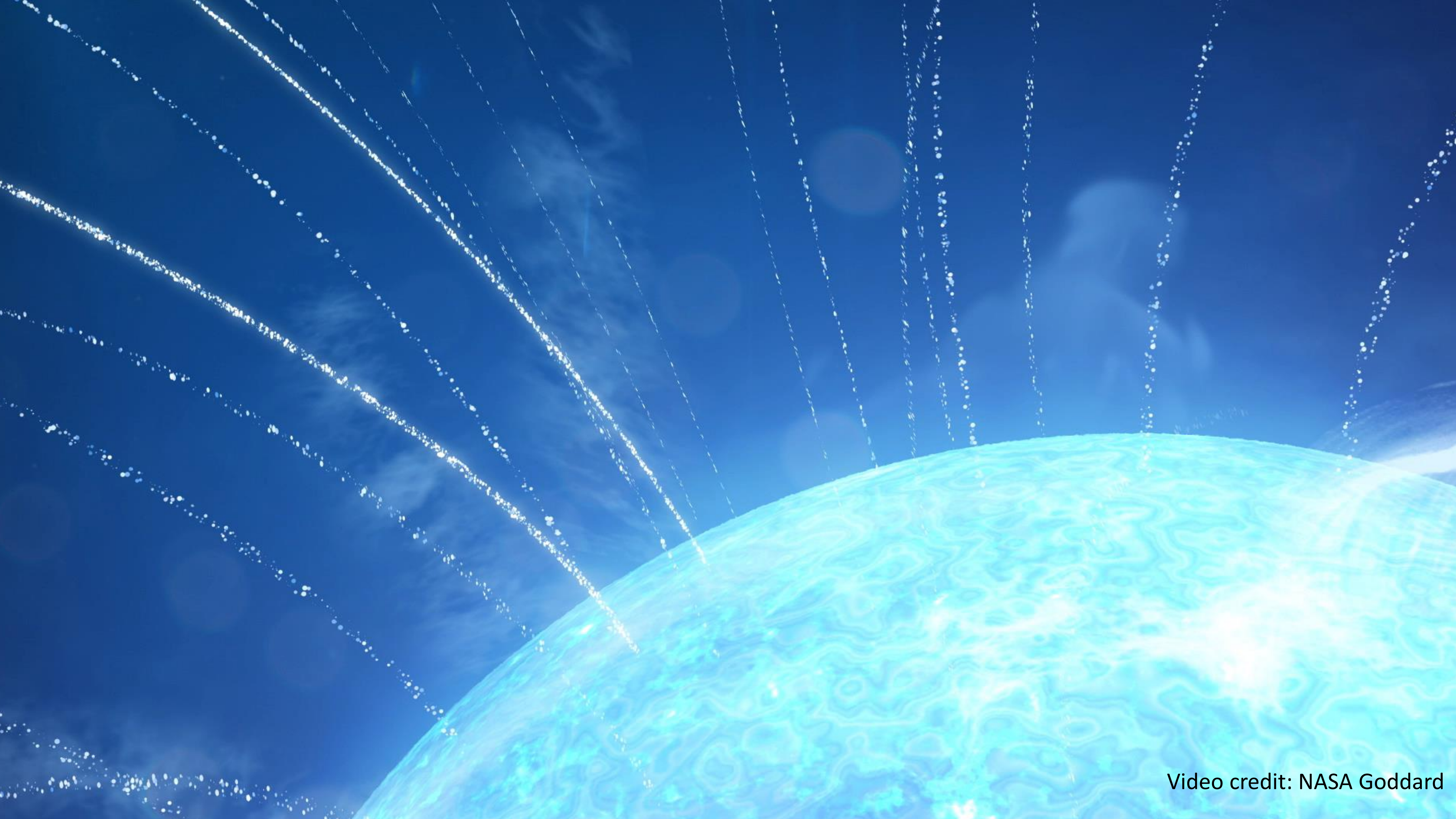
- Strongly magnetized neutron star:
  - Magnetic field ~ 10^{13-15} G
  - Rotation period of 0.1-10 s
  - Steady X-ray luminosity L_X ~ 10^{31-36} erg/s
- Magnetars can manifest:
  - Recurrent short duration bursts L ~ 10^{36-41} erg/s and period ~ 0.1 s
  - Long lasting active phases L > 10^{36} erg/s lasting years
  - Rare Magnetar Giant Flares



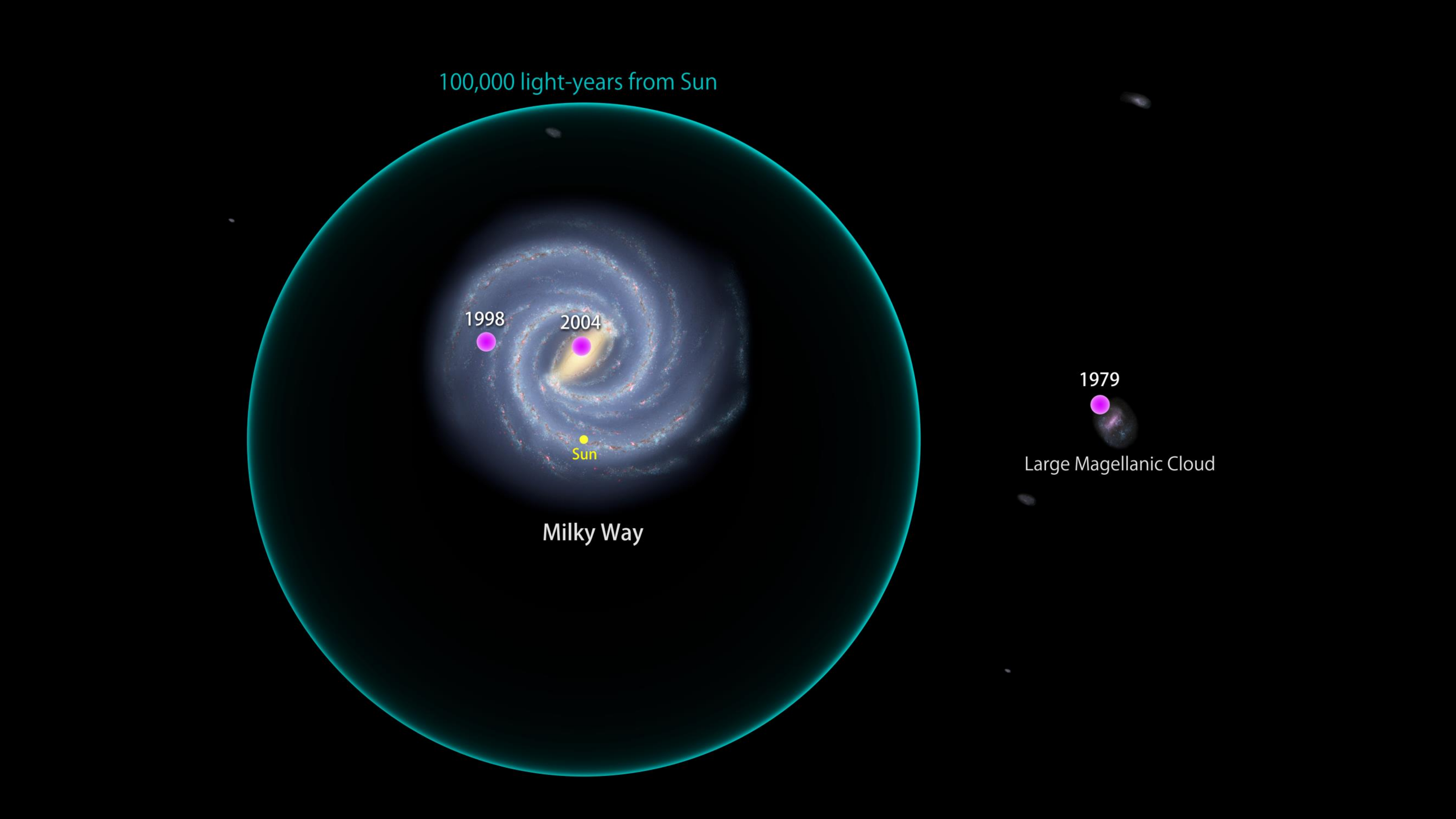
Magnetar Giant Flares

- 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

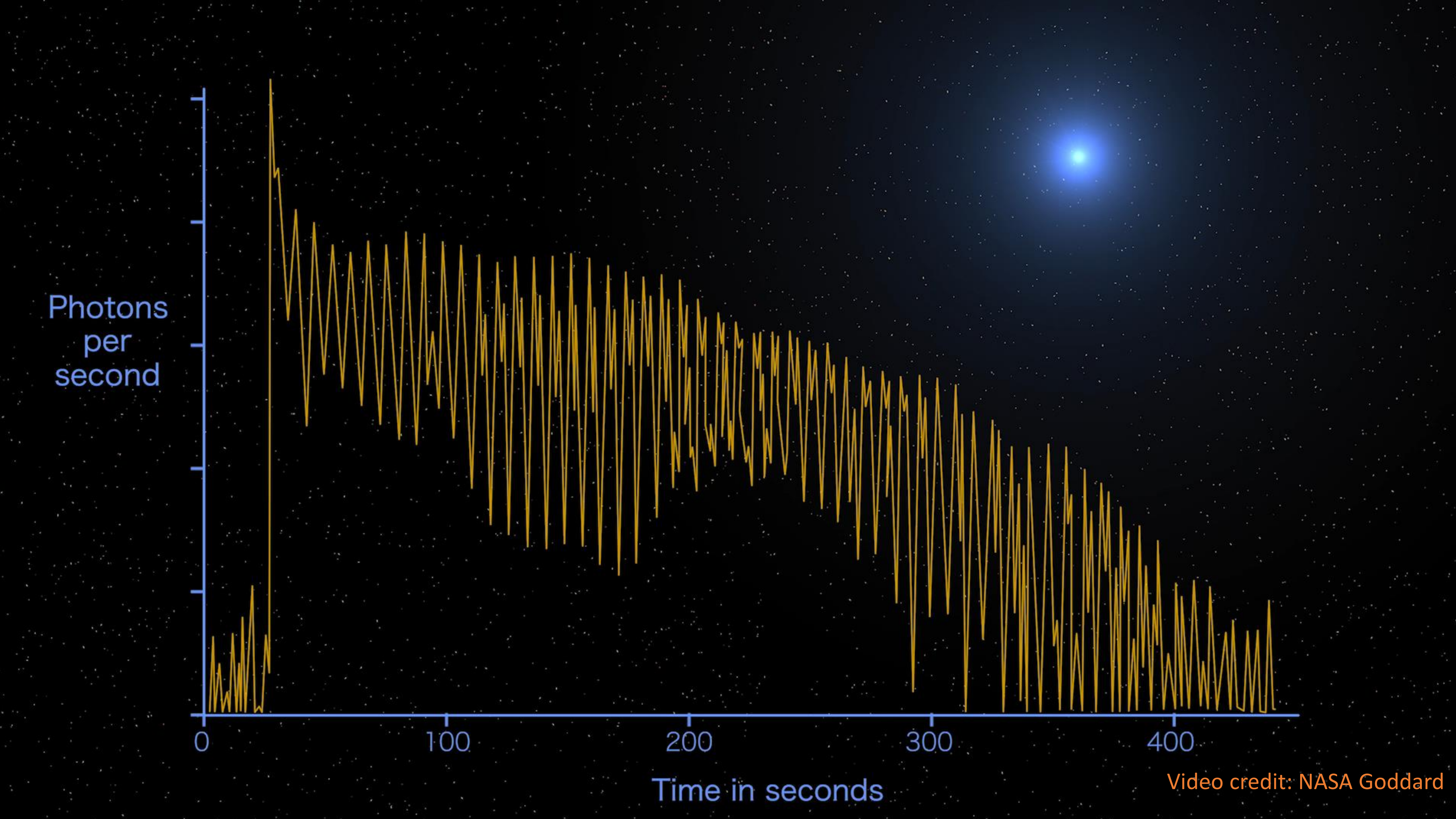




Video credit: NASA Goddard


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

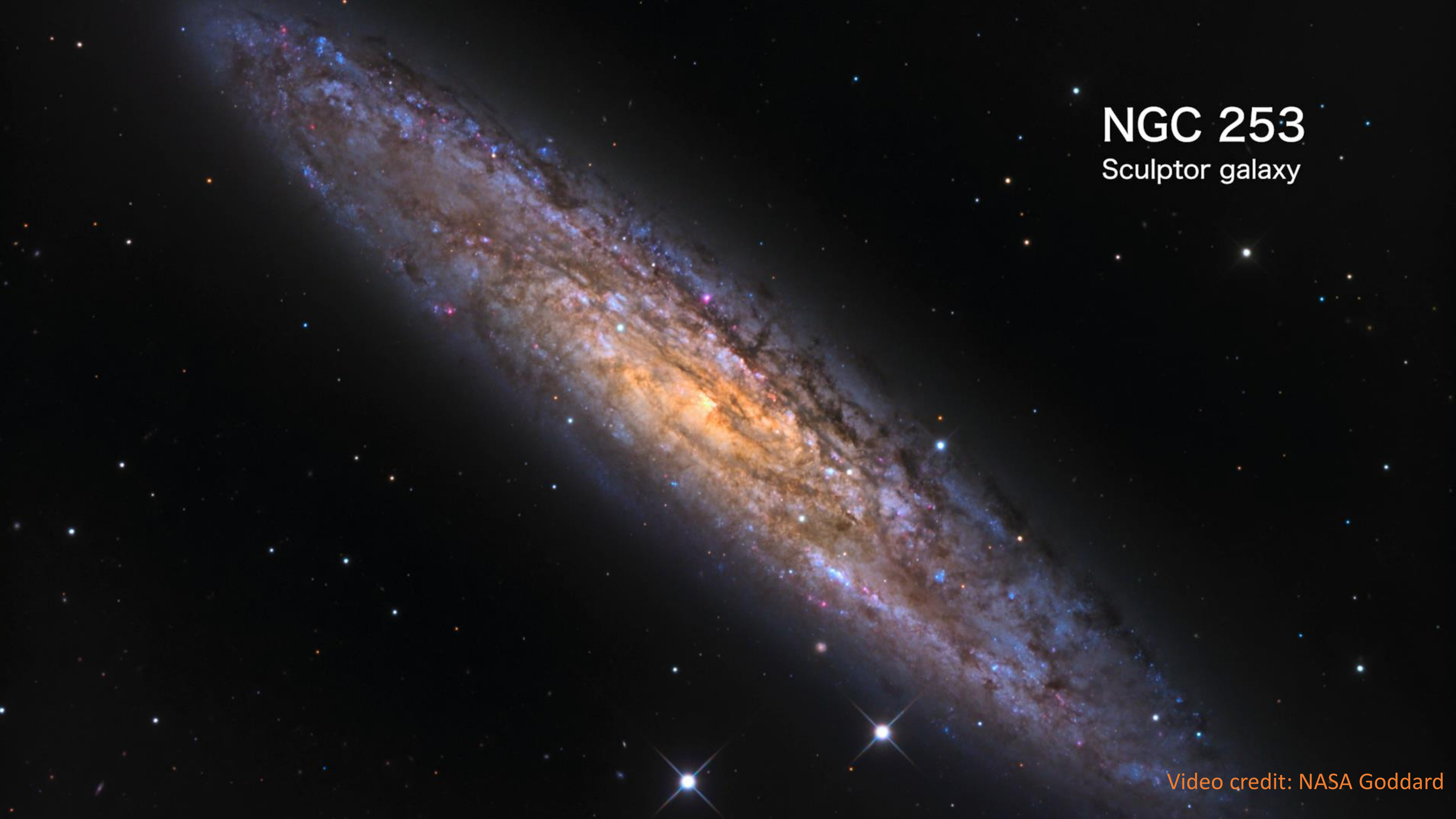
Video credit: NASA Goddard


Photons per second
0
100
200
300
400
Time in seconds
Video credit: NASA Goddard

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

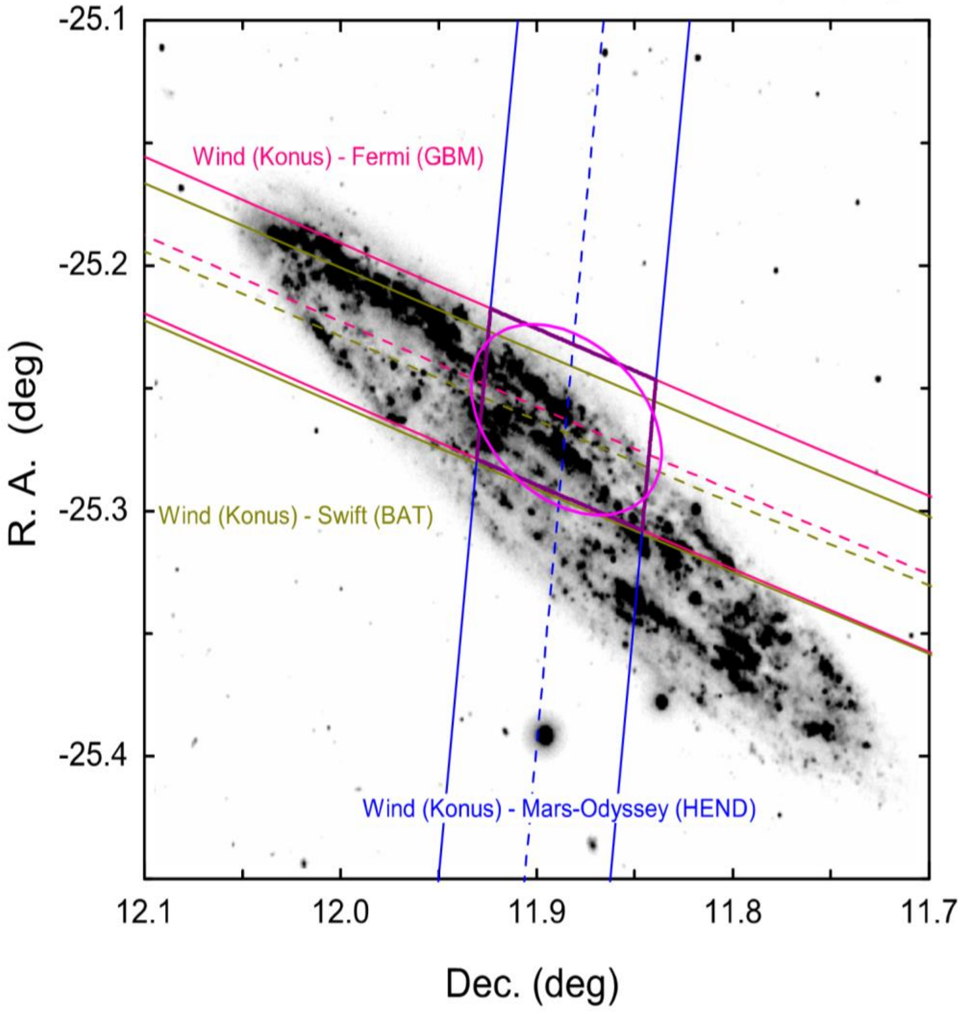
Michela Negro’s talk

July 14th at 6 PM Berlin Time [link]

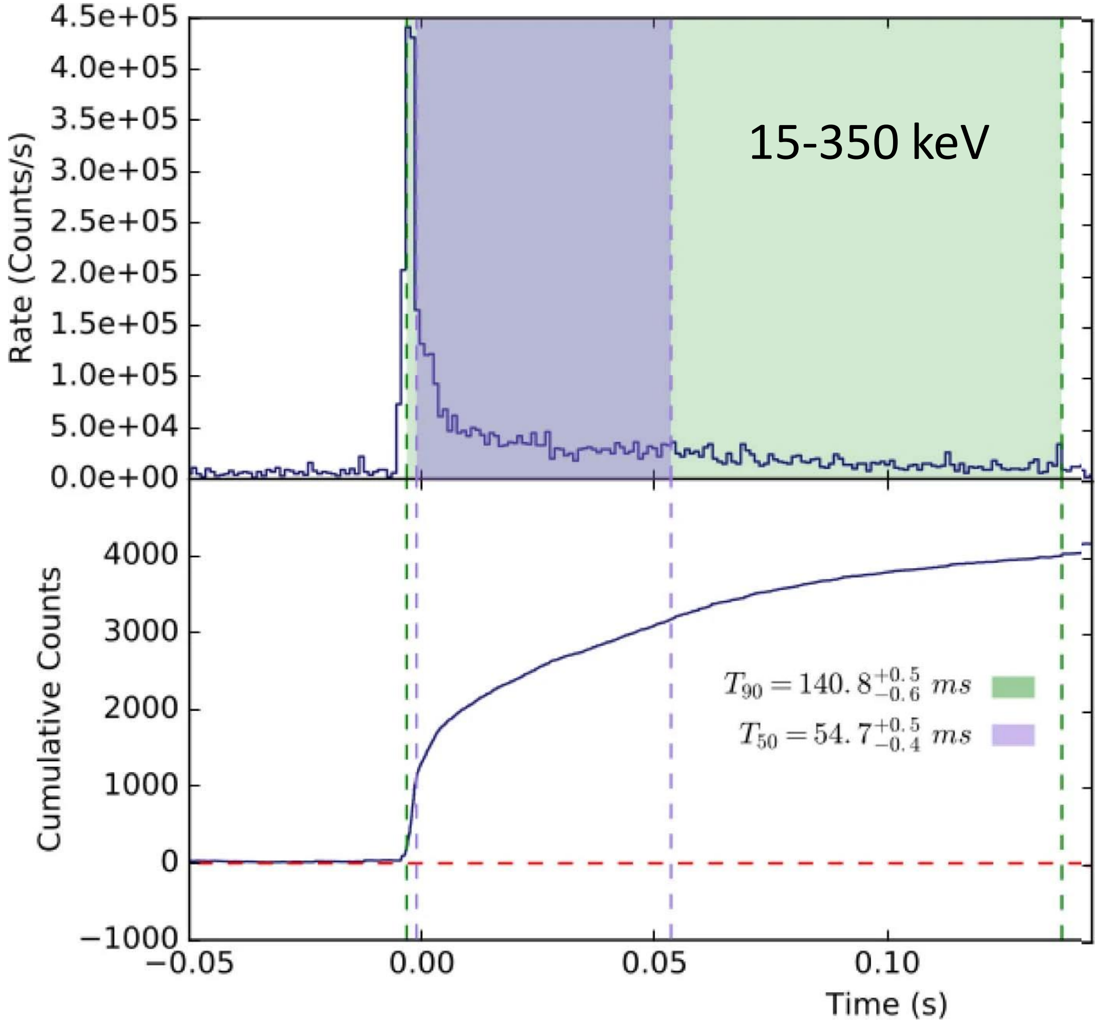

NGC 253
Sculptor galaxy
Video credit: NASA Goddard

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)



Swift BAT light curve



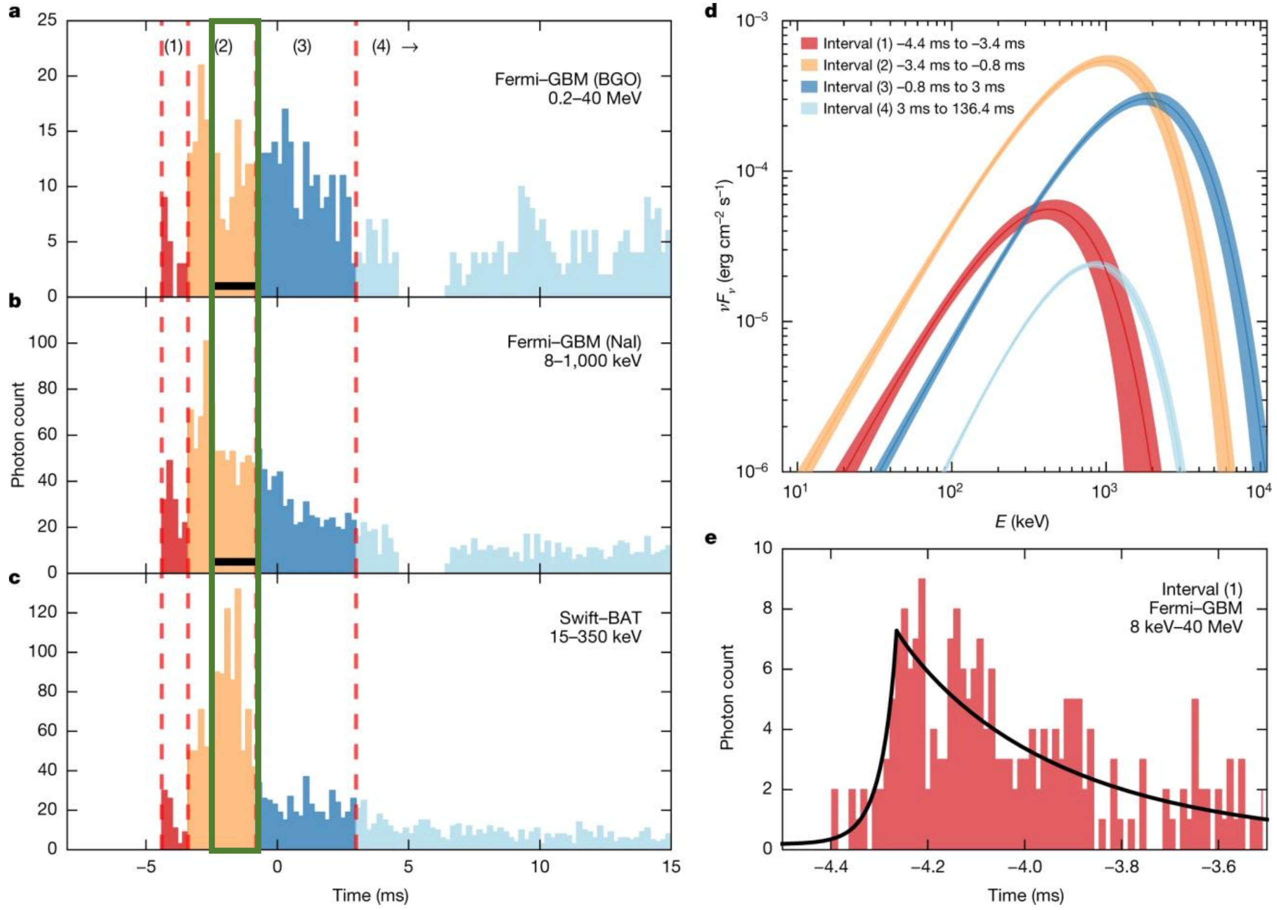
Short GRB

?

MGF

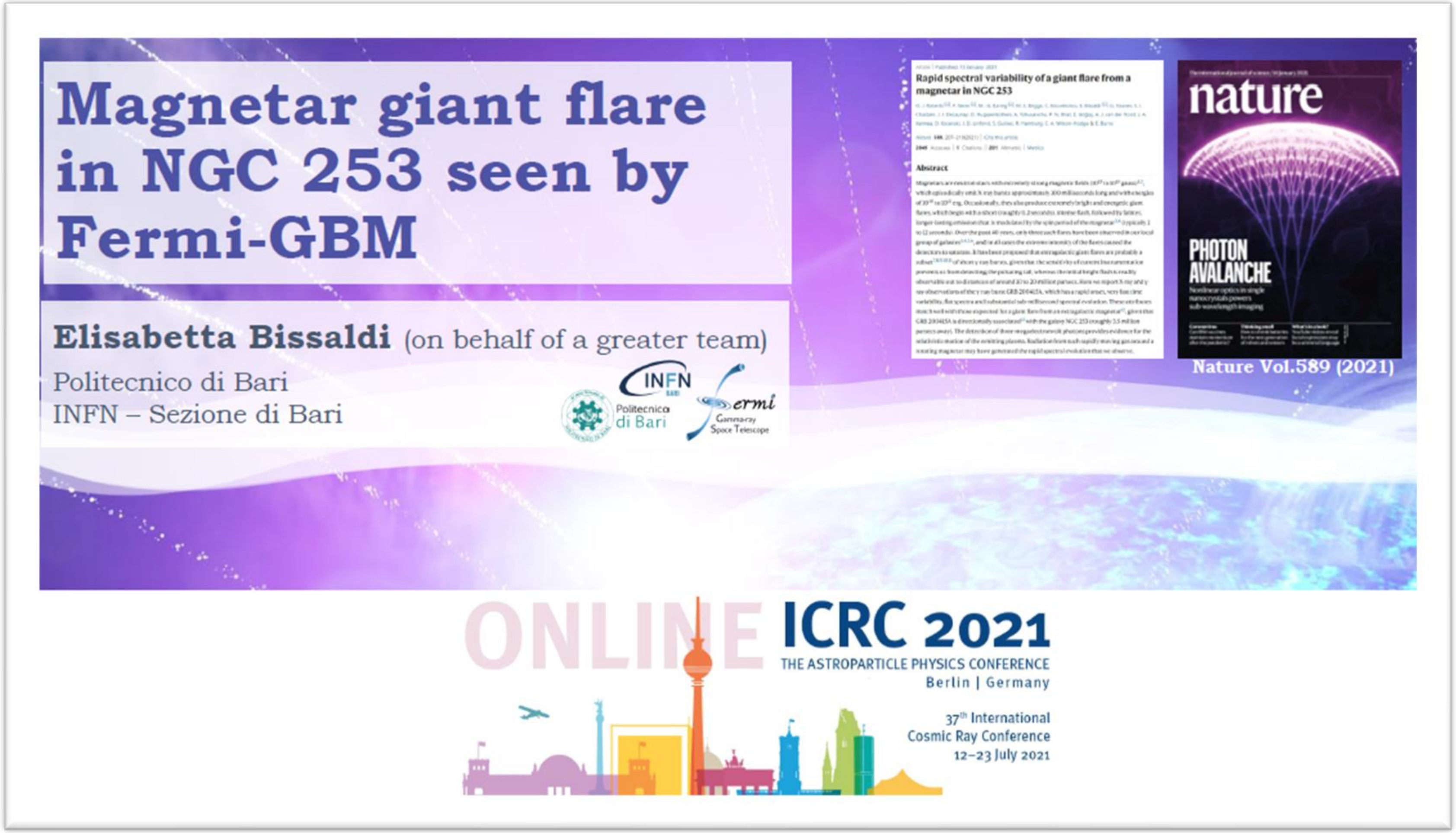
Fermi GBM observation

- 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 and very energetic:
  - Eiso = 1.5 x 10^{46} erg
  - Liso = 1.1 x 10^{47} erg/s
  - Highest energy photon: 3 MeV
- No radio counterpart (VLA) or GW emission (KAGRA)



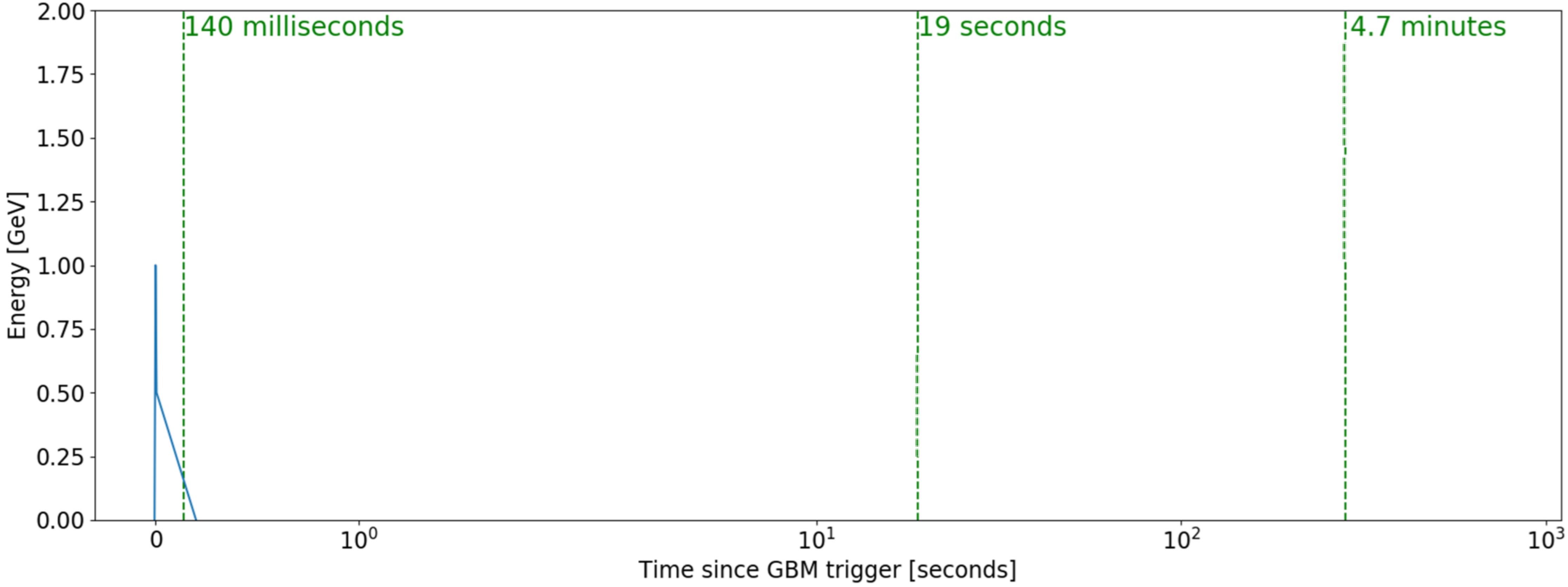
Elisabetta Bissaldi's talk

July 14th at 6 PM Berlin Time [link]

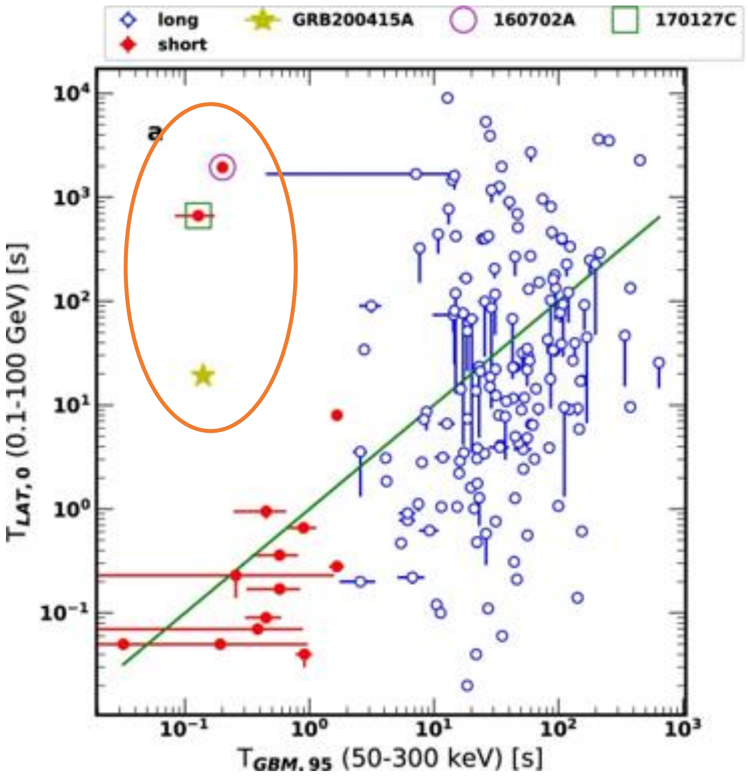


Fermi LAT light curve

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



A peculiar LAT GRB?

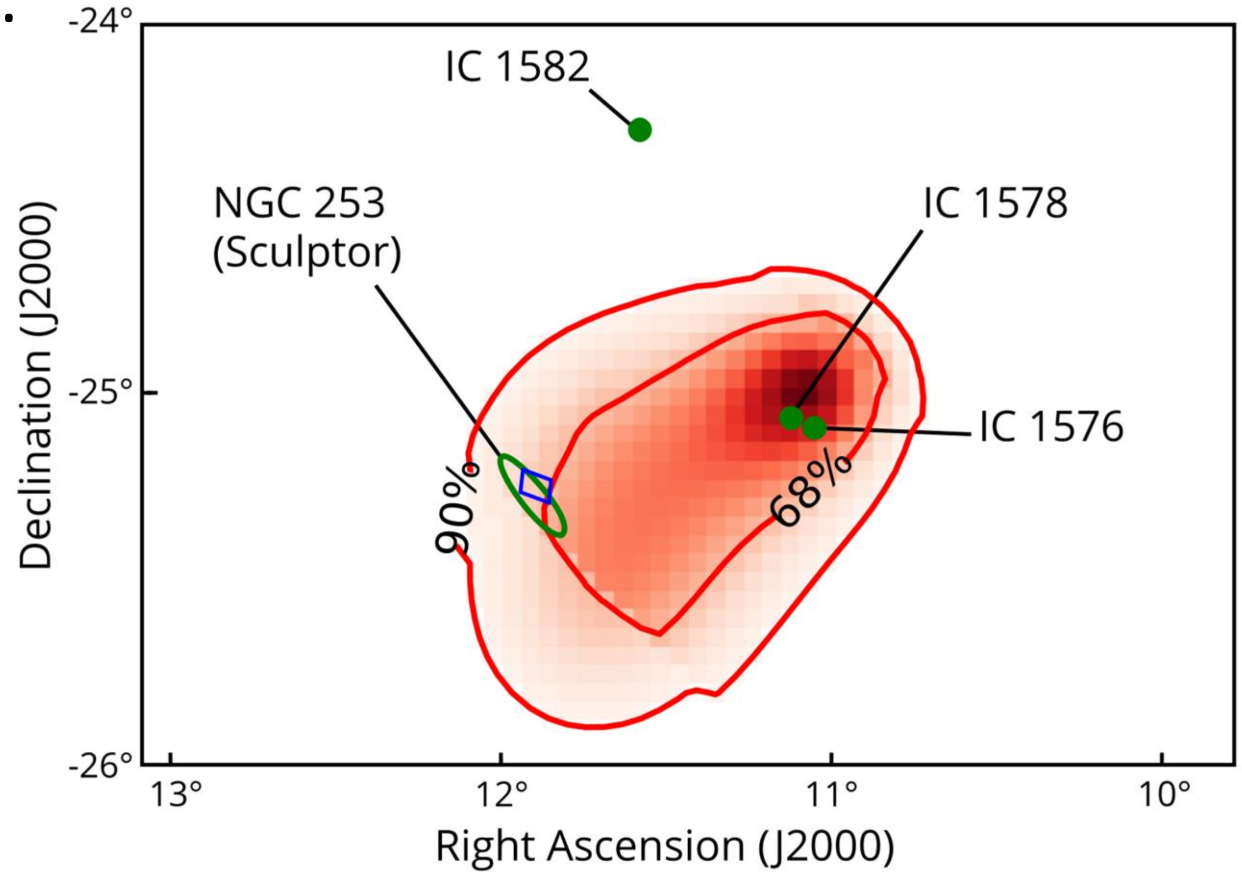


GRB 200415A is the only LAT sGRB within the FoV that was detected much later the end of the GBM prompt emission

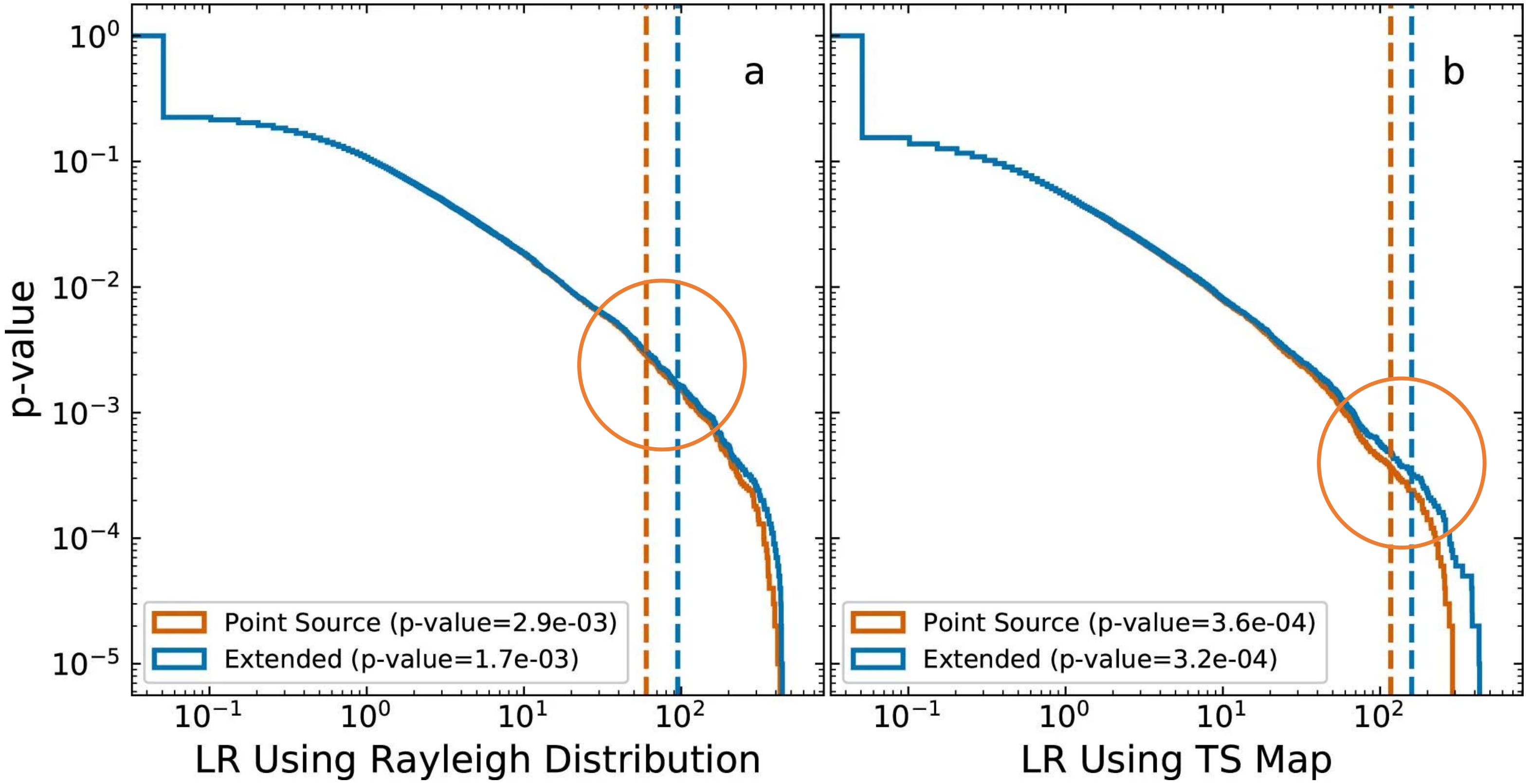
LAT Localization map

- 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



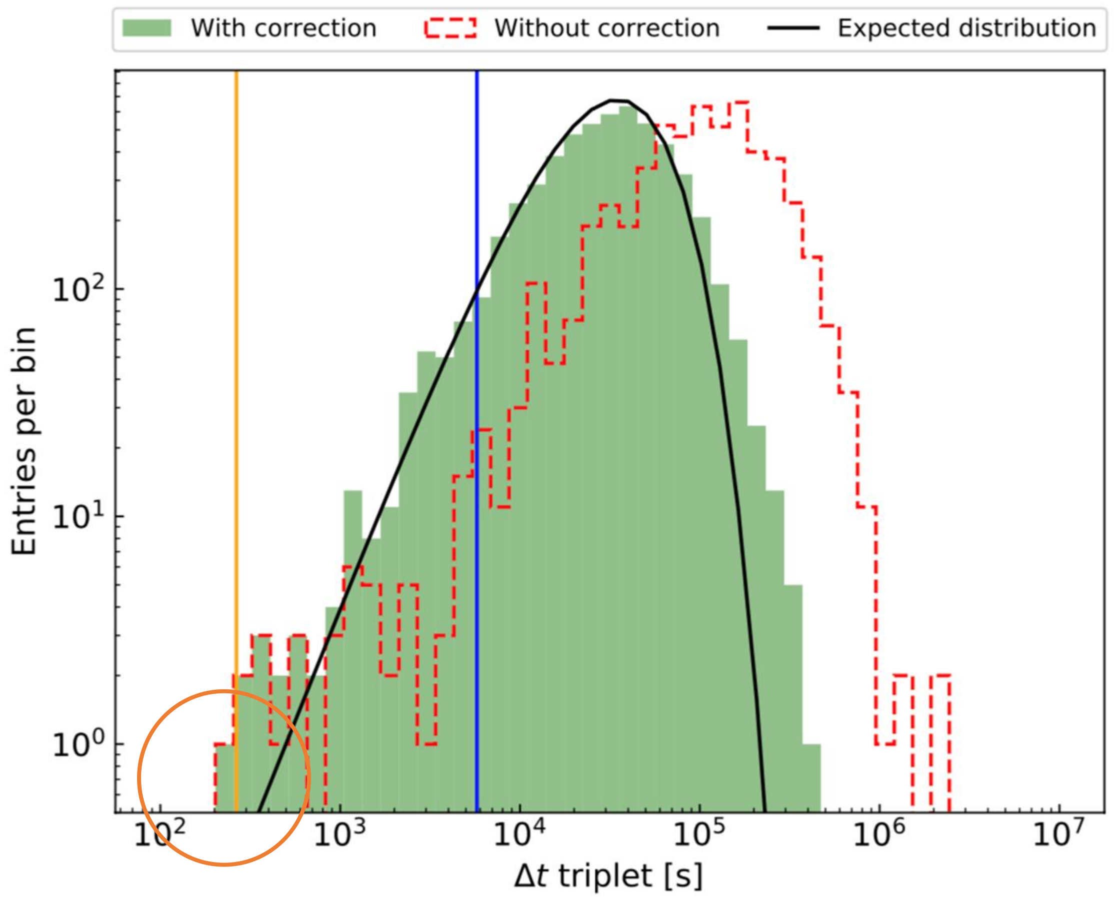
Spatial association

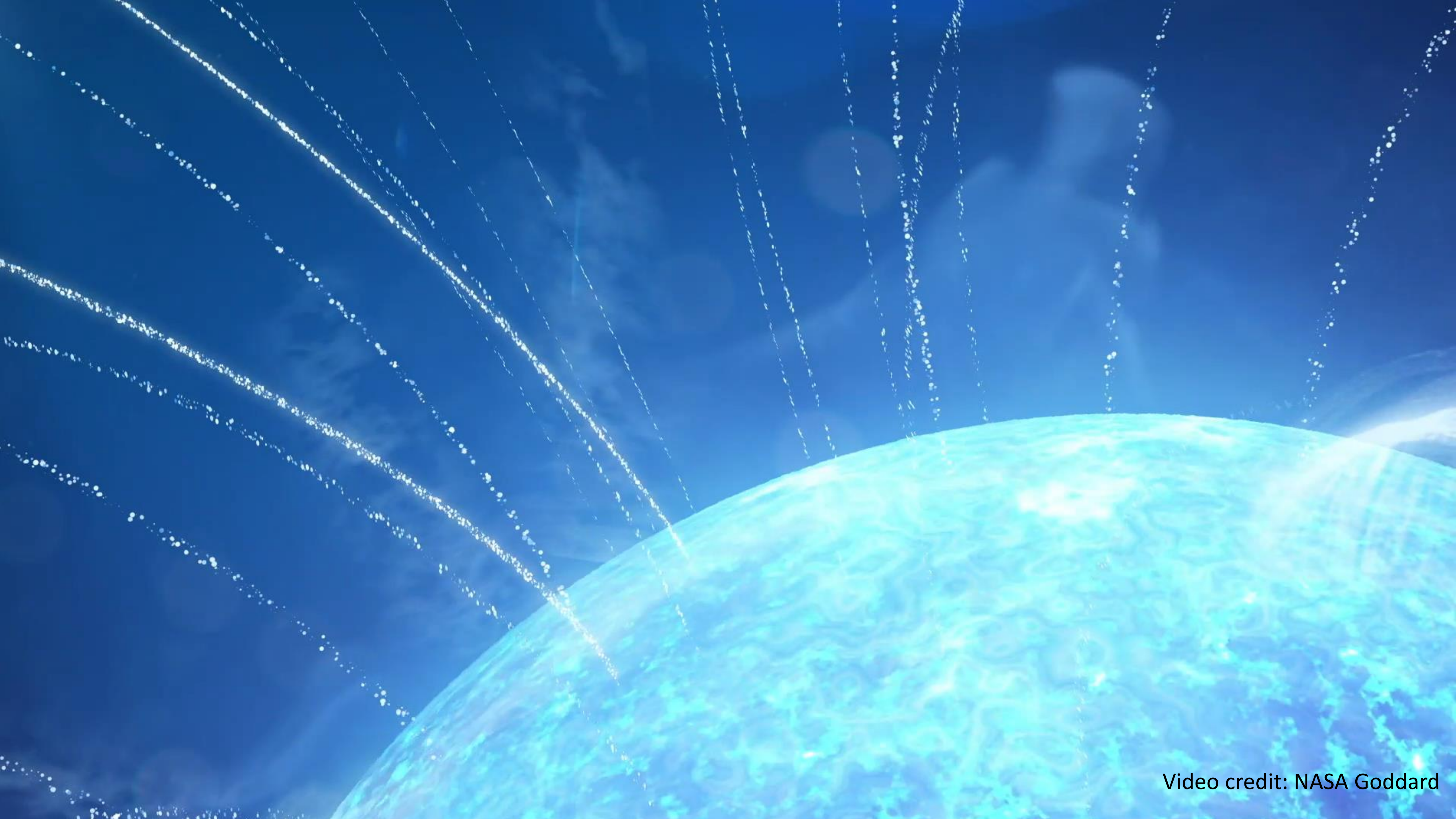


False Alarm Rate ~ 1 chance coincidence in 200-1800 years

Temporal association

- Significance 5.3σ:
  - 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




Video credit: NASA Goddard

Case closed?

- Not yet:
  - Clear detection of pulsations is needed to absolutely prove magnetar origin
  - Repeating burst to ensure a not cataclysmic event
    - But do MGFs repeat?
- But clear fingerprint at the crime scene:
  - Burst morphology (in star-forming galaxy):
    - Initial spike, spectral evolution and properties
  - 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?

Conclusions

- Fermi LAT and GBM Collaborations reported the high-energy detection of a magnetar giant flare coming from NGC 253:
  - The first detection at GeV energies!
- Simple physical model explains the observations
- MGFs may constitute a fraction of current short GRB samples
- Further details:
  - The Fermi LAT Collaboration, Nature Astronomy [link]
  - GBM/Swift results, Roberts et al. Nature [link]
  - IPN localization, Svinkin et al., Nature [link]
  - Population of Magnetar Giant Flares, Burnes et al., ApJL [link]