

**Short, sharp and shocked:  
the giant flare of a distant magnetar seen by the  
Atmosphere-Space Interactions Monitor.**

**Prof. Martino Marisaldi**

**Birkeland Centre for Space Science, Department of Physics and Technology, UiB**

**Bergen Astronomiske Forening, 08/02/2022**



**RECENT PUBLICATIONS**

M. Heumesser, O. Chanrion, T. Neubert, H. J. Christian, K. Dimitriadou, F. J. Gordillo-Vazquez, A. Luque, F. Javier Pérez-Invernón, R. J. Blakeslee, **N. Østgaard**, et al. (2021), Spectral Observations of Optical Emissions Associated With Terrestrial Gamma-Ray Flashes, *Geophys. Res. Ltr.*, [doi.org/10.1029/2020GL090700](https://doi.org/10.1029/2020GL090700)

L. Norenus, M. Hamrin, O. Goncharov, H. Gunnell, H. Opgenoorth, T. Pitkänen, S. Chong, **N. Partamies**, **L. Baddeley** (2021) Ground-Based Magnetometer Response to Impacting Magnetosheath Jets, *J. Geophys. Res.: Space Phys.*, [doi.org/10.1029/2021JA029115](https://doi.org/10.1029/2021JA029115)

D.K. Whiter, H. Sundberg, B.S. Lanchester, J. Dreyer, **N. Partamies**, et al. (2021), Fine-scale dynamics of fragmented aurora-like emissions, *Ann. Geo.*, [doi.org/10.5194/angeo-39-975-2021](https://doi.org/10.5194/angeo-39-975-2021)

## How is the Earth coupled to space?

The Birkeland Centre for Space Science (BCSS ) is a Norwegian Centre of Excellence ([SFF](#)) whose primary objective is to try to understand the Earth's relationship to space. To this end, BCSS has identified three areas of research:

**Dynamics of the asymmetric geospace:**

- When and why are the auroras in the two hemispheres asymmetric?
- What are the important temporal and spatial scales of geospace dynamics?

**Particle Precipitation:**

- What are the effects of particle precipitation on the atmospheric system?

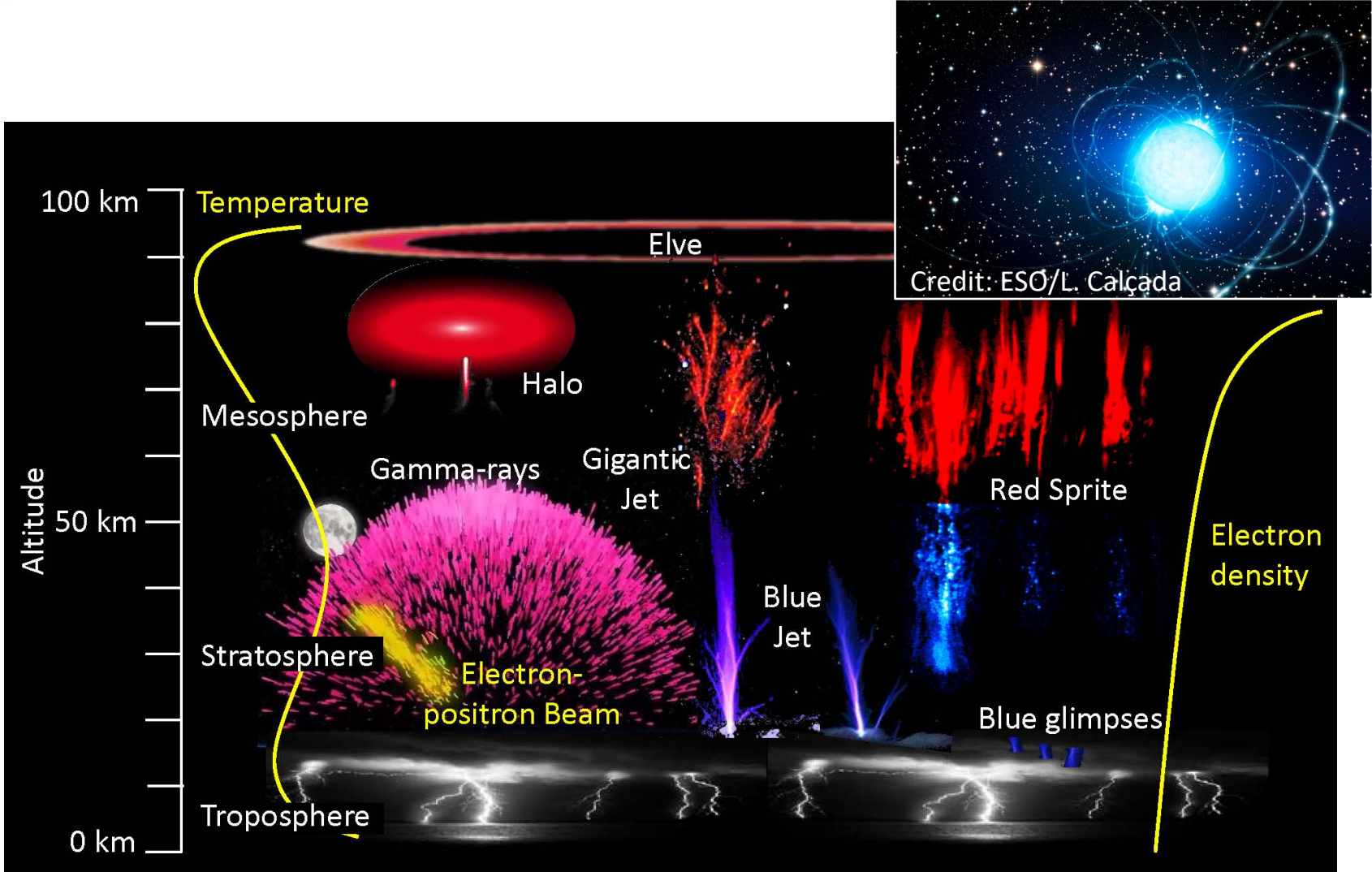
**Hard radiation from thunderstorms:**

- What is the role of energetic particles from thunderstorms on geospace?

**ANNUAL REPORT 2020**



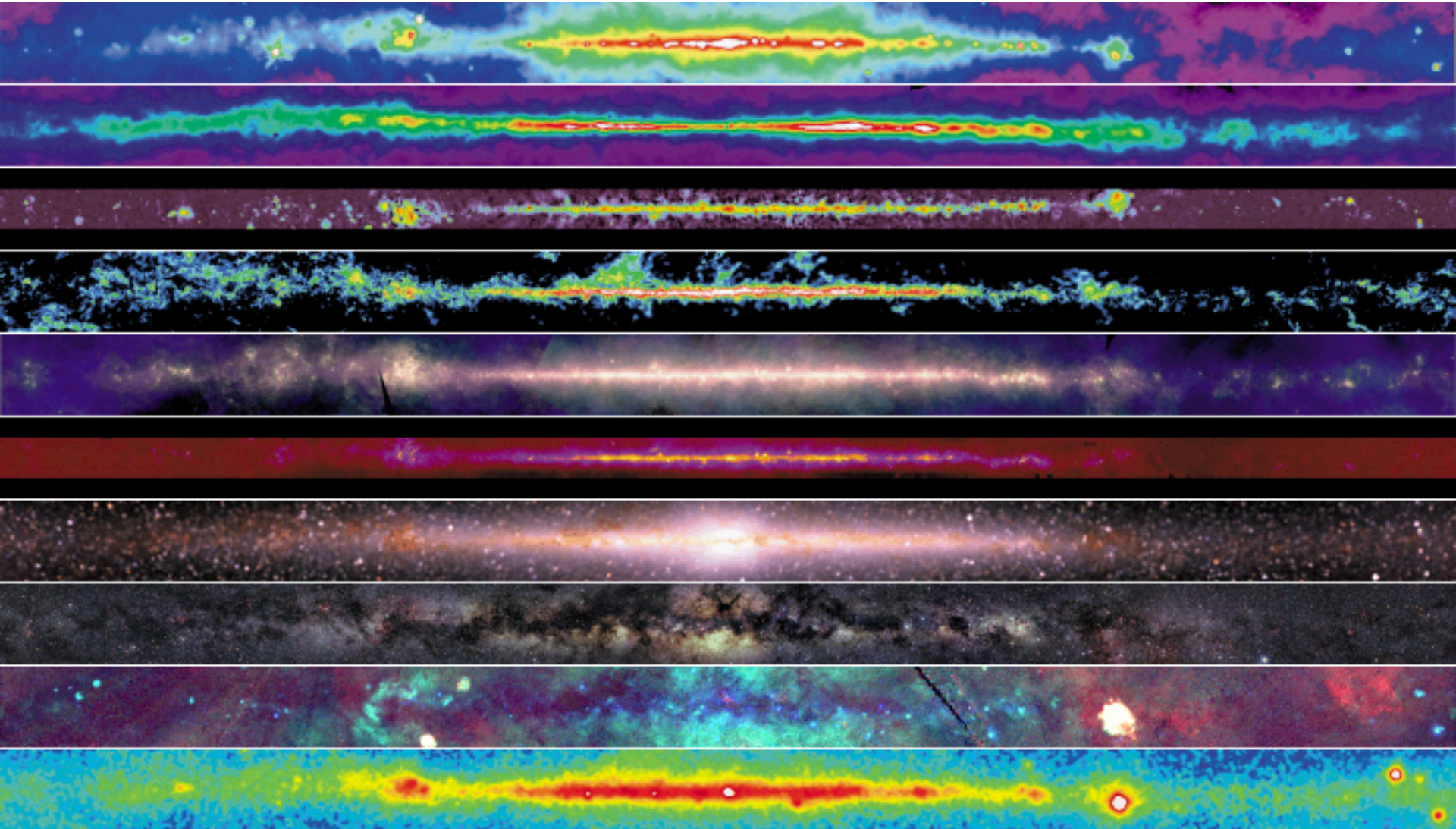
# High-energy Radiation from Thunderstorms (and beyond)



Top question: what is the role of energetic particles from thunderstorms on geospace?

# The Milky Way with super-human eyes

<http://www.chromoscope.net/>



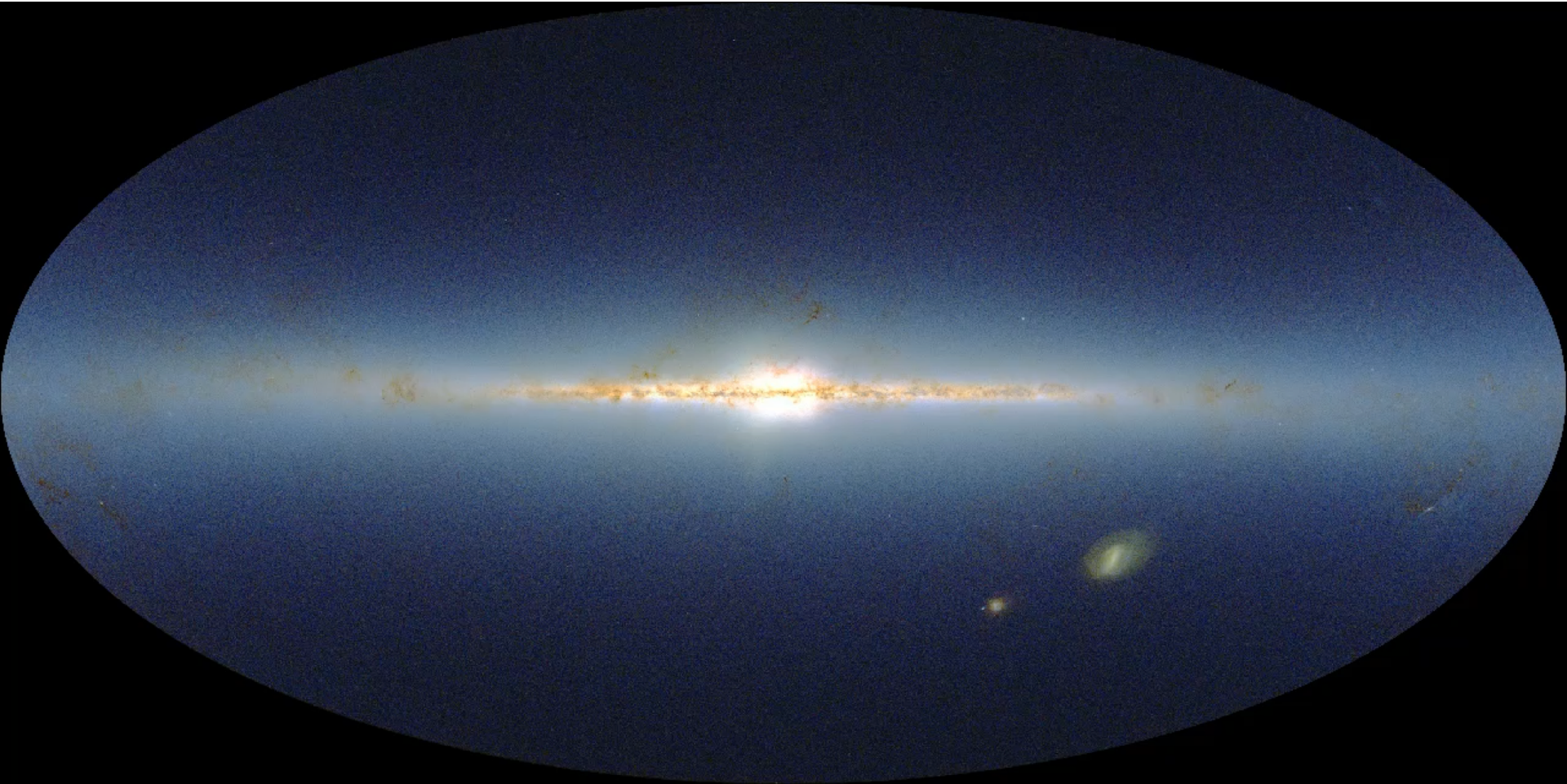
Credit: NASA GSFC - [https://asd.gsfc.nasa.gov/archive/mwmw/mmw\\_images.html](https://asd.gsfc.nasa.gov/archive/mwmw/mmw_images.html)

<https://www.youtube.com/watch?v=mpIp1oFokNA>

Credit: NASA/DOE/International LAT Team

<https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=12019>

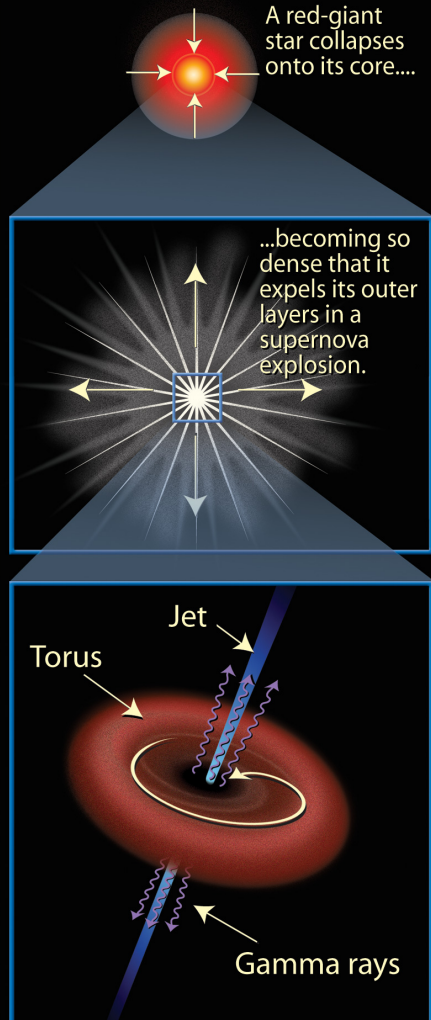
# The variable gamma-ray sky: Gamma-Ray Bursts



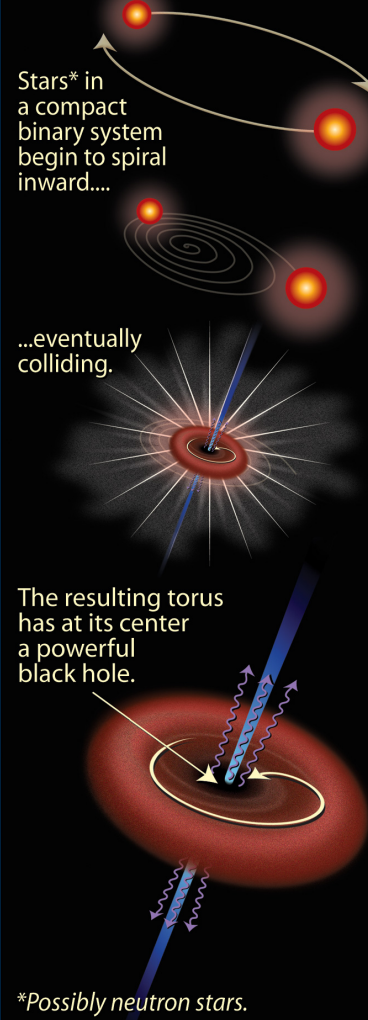
Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio  
<https://svs.gsfc.nasa.gov/3702>

## Gamma-Ray Bursts (GRBs): The Long and Short of It

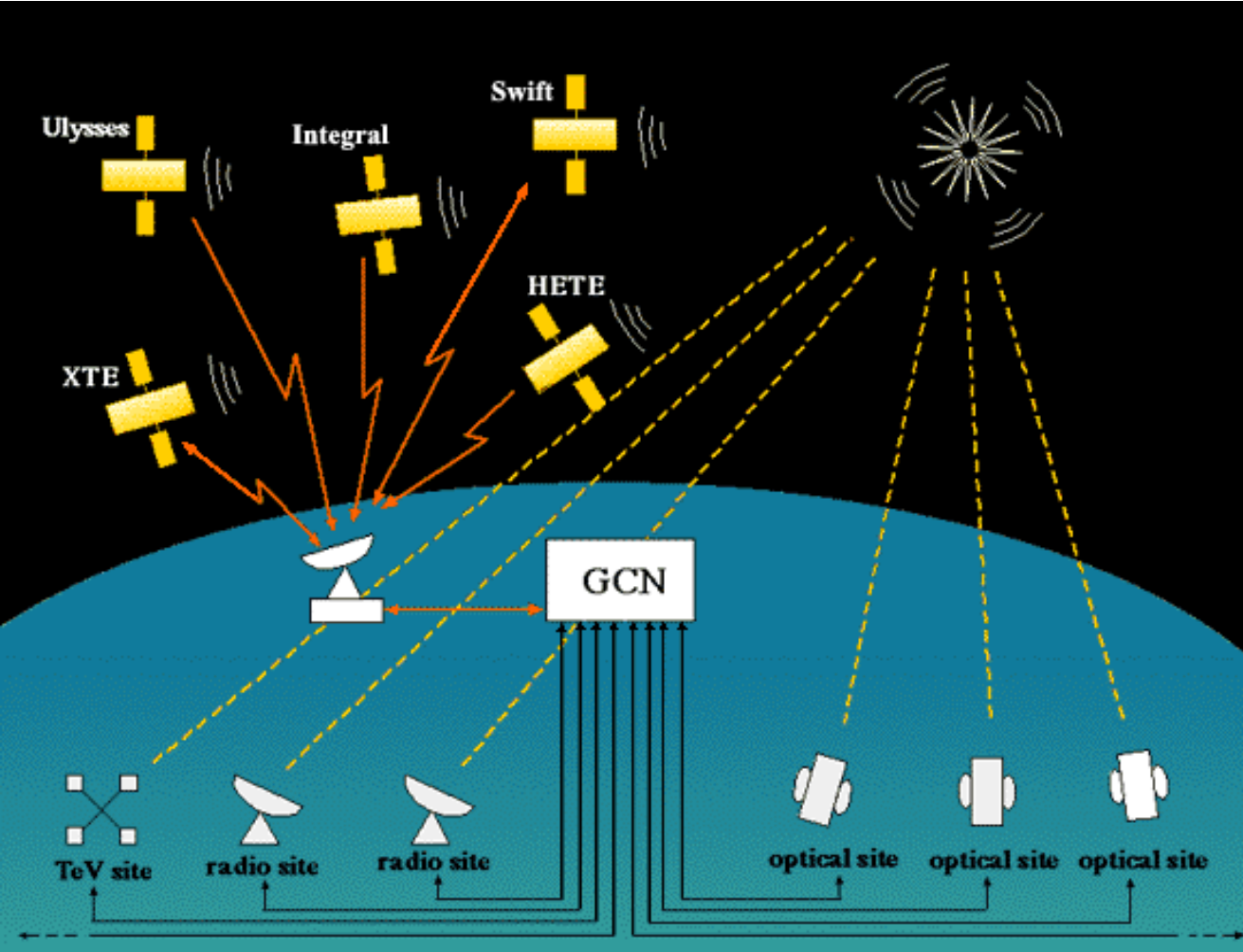
### Long gamma-ray burst ( $>2$ seconds' duration)



### Short gamma-ray burst ( $<2$ seconds' duration)



# GRB follow-up: The GRB Coordinates Network (GCN)

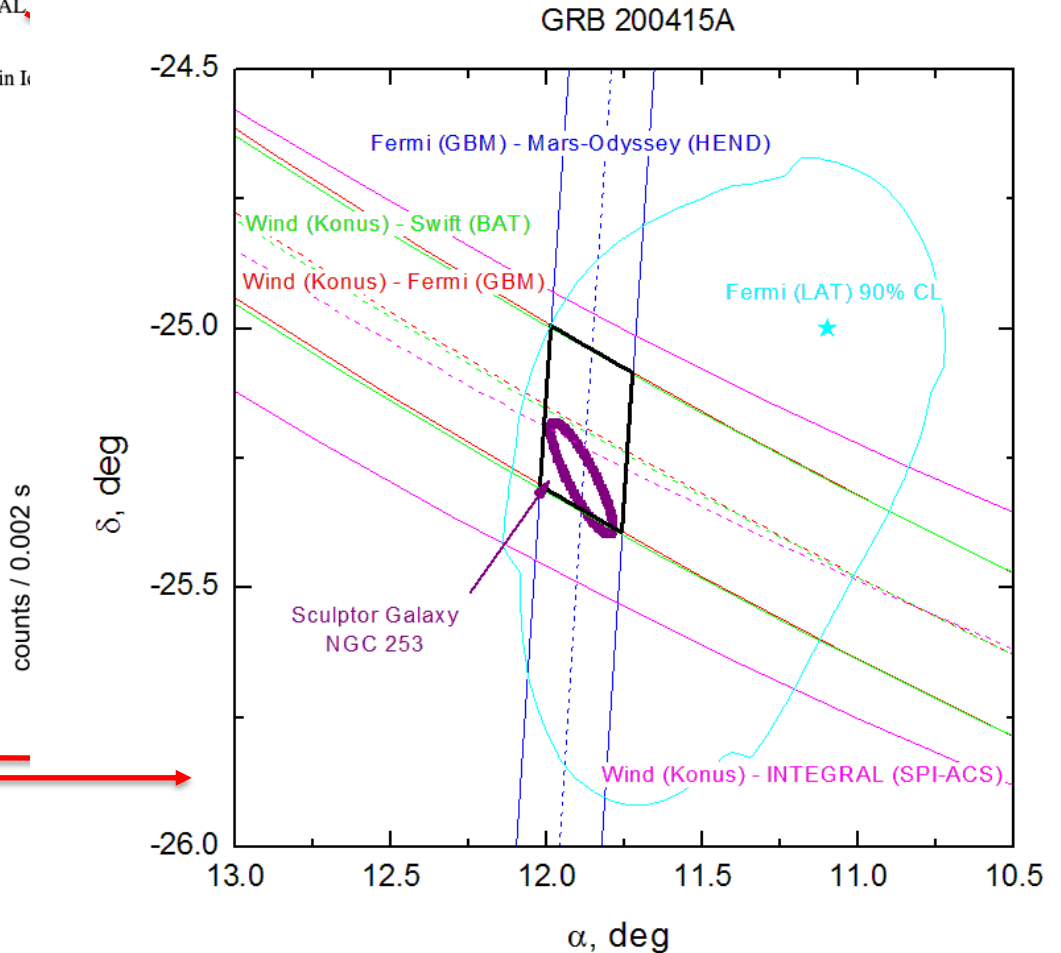


Credits: NASA GSFC <https://gcn.gsfc.nasa.gov/>

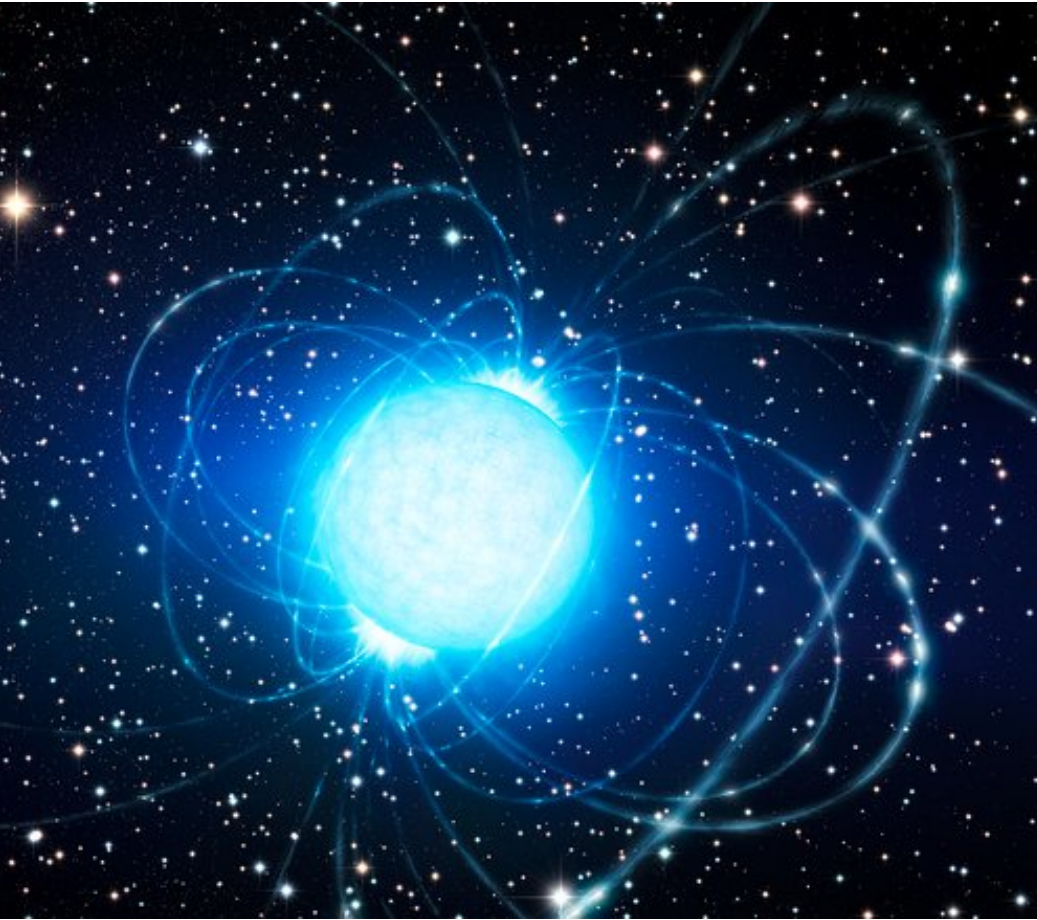


# GRB200415A

- 27629 GRB 200415A: correction to GCN 27627 (possible magnetar Giant Flare in Sculp
- 27628 GRB 200422A: MASTER optical observations
- 27627 GRB 200415A (possible magnetar Giant Flare in Sculptor Galaxy): INTEGRAL,
- 27626 IPN triangulation of GRB 200422A (long/very bright)
- 27625 IPN Triangulation of a bright burst from SGR 1935+2154
- 27624 IceCube-200421A: Upper limits from a search for additional neutrino events in I
- 27623 bright SGR burst detected by CALET Gamma-Ray Burst Monitor
- 27619 GRB 200415A: ASIM observation
- 27621 GRB 200410A: Liverpool Telescope First Hour Observations
- 27620 Fermi-LAT Gamma-ray Observations of IceCube-200421A
- 27619 IceCube-200421A: No Neutrino Counterpart in ANTARES data
- 27618 Fermi GRB 200421A: Global MASTER-Net observations report
- 27617 IceCube-200421A: No significant detection in HAWC
- 27616 GRB 200421A: Fermi GBM Final Real-time Localization
- 27615 IceCube-200421A: not observable by Fermi-GBM
- 27614 IceCube Alert 200421.02: Global MASTER-Net observations report
- 27613 IceCube-200421A: No counterpart candidates in INTEGRAL SPI-ACS
- 27612 IceCube-200421A - IceCube observation of a high-energy neutrino cand
- 27611 IceCube Alert 200420.97: Global MASTER-Net observations report
- 27610 GRB 200412B: continued Mondy and Terskol optical observations
- 27609 GRB 200420: Fermi GBM Final Localization Correction
- 27608 Fermi GRB 200420A: Global MASTER-Net observations report
- 27607 GRB 200420A: Fermi GBM Final Real-time Localization
- 27606 Fermi trigger No 608935505: Global MASTER-Net observations report
- 27605 GRB 200412B: continued Terskol optical observations
- 27604 GRB 200412B: continued AbAO, Mondy, TSHAO, Terskol optical obs
- 27603 GRB 200410A: Optical upper limit
- 27602 GRB 200416A: Swift/UVOT Detection
- 27601 GRB 200416A: Swift-BAT refined analysis
- 27600 GRB 200412B: Swift XRT confirmation of afterglow and UVOT upper
- 27599 GRB 200415A: MASTER inspection and possible localisation
- 27598 GRB200412B: GROWTH India detection of afterglow
- 27597 GRB 200415A: Fermi-LAT localization update
- 27596 Konus-Wind observation of GRB 200415A (a magnetar Giant Flare in S
- 27595 Improved IPN error box for GRB 200415A (consistent with the Sculpto
- 27594 GRB 200416A: Swift-XRT refined Analysis
- 27593 GRB 200412B: continued Tautenburg observations
- 27592 GRB 200416A: Fermi GBM observation
- 27591 GRB 200416A: Swift detection of a burst with an optical afterglow
- 27590 Fermi GRB 200415A: Global MASTER-Net observations report
- 27589 GRB 200411A: Chandra observations indicative of temporal steepening
- 27588 GRB 200412A: AstroSat CZTI detection
- 27587 GRB 200415A: Fermi GBM observation
- 27586 GRB 200415A: Fermi-LAT detection
- 27585 IPN triangulation of GRB 200415A (possible Magnetar Giant Flare in Sculptor Galaxy?)
- 27584 GRB 200410A: CALET Gamma-Ray Burst Monitor detection
- 27583 GRB 200412B: Mondy optical observations
- 27582 GRB 200412B: continued Tautenburg observations
- 27581 Konus-Wind observation of GRB 200412B
- 27580 GRB 200415A: BALROG localization (Fermi Trigger 608633290 / GRB 200415367)
- 27579 GRB 200415A: Fermi GBM Final Real-time Localization



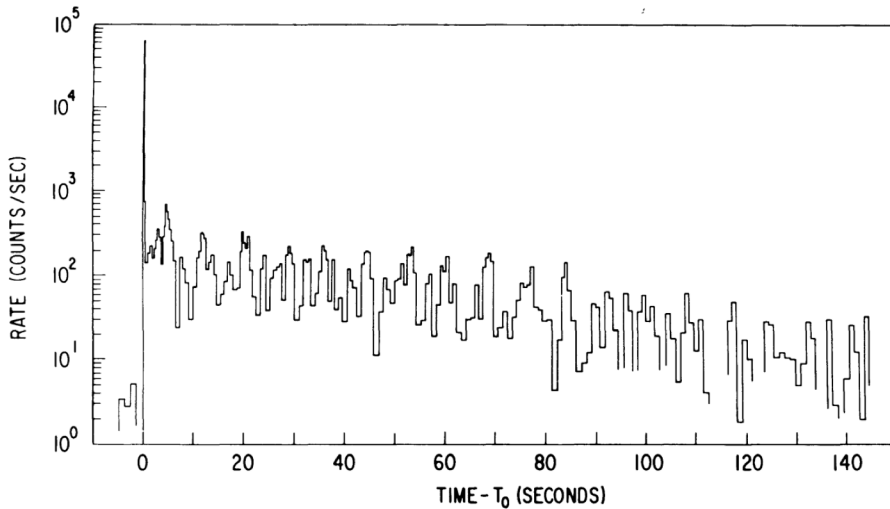
# What is a magnetar?



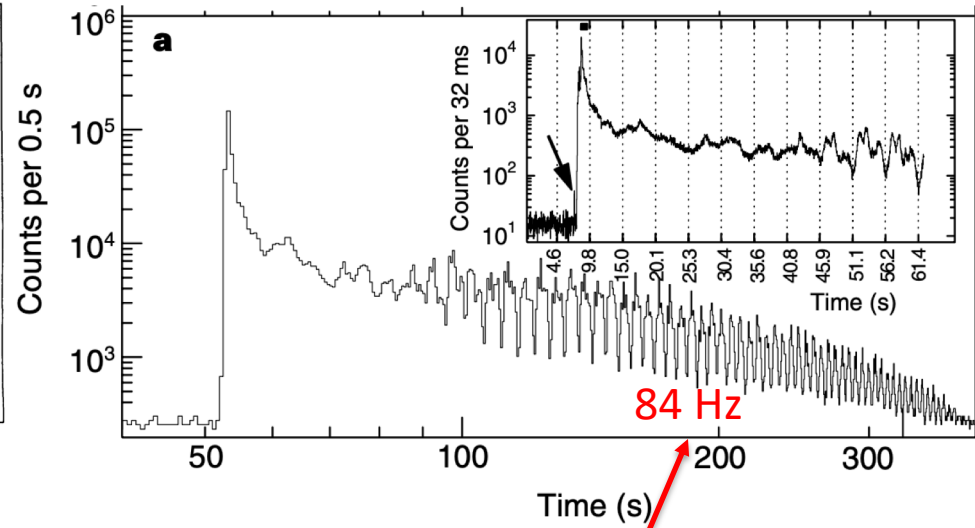
- A young neutron star ( $<10^5$  y) with typically long spin periods  $>2$  s
- Powered by a very strong magnetic field  $>10^{14}$  G
- $\sim 23$  magnetars in our galaxy and the Large Magellanic Cloud
- Magnetic energy powers recurrent burst activity in X-rays –  $\gamma$ -rays
- Occasionally: emission of giant flares in X-rays –  $\gamma$ -rays (3 detected so far)

# Magnetar's giant flares

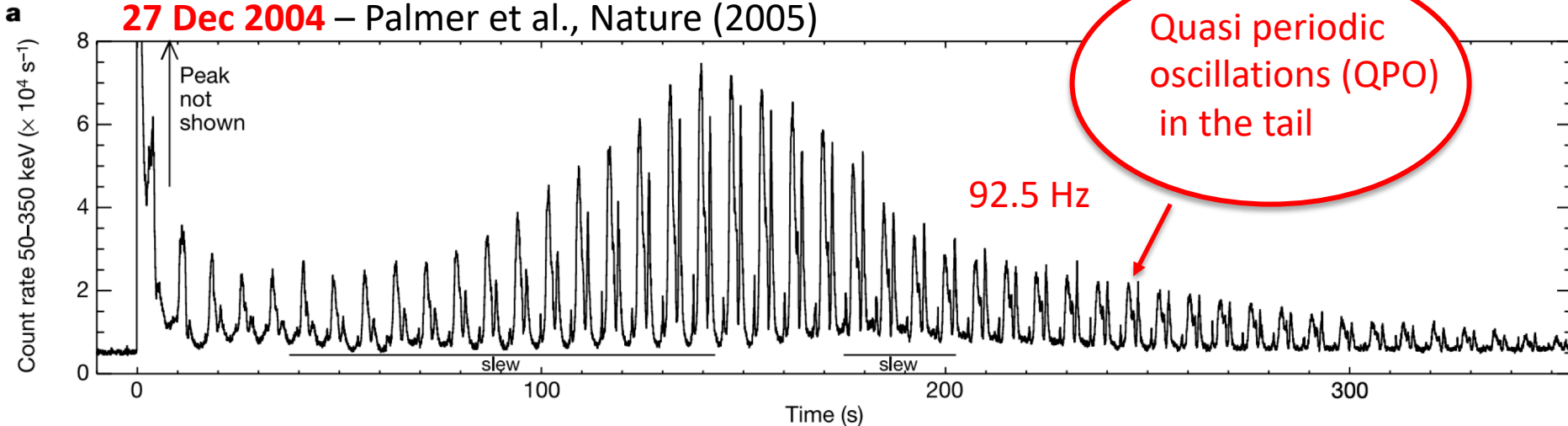
**05 Mar 1979** – Cline et al., ApJ (1980)



**27 Aug 1998** – Hurley et al., Nature (1999)

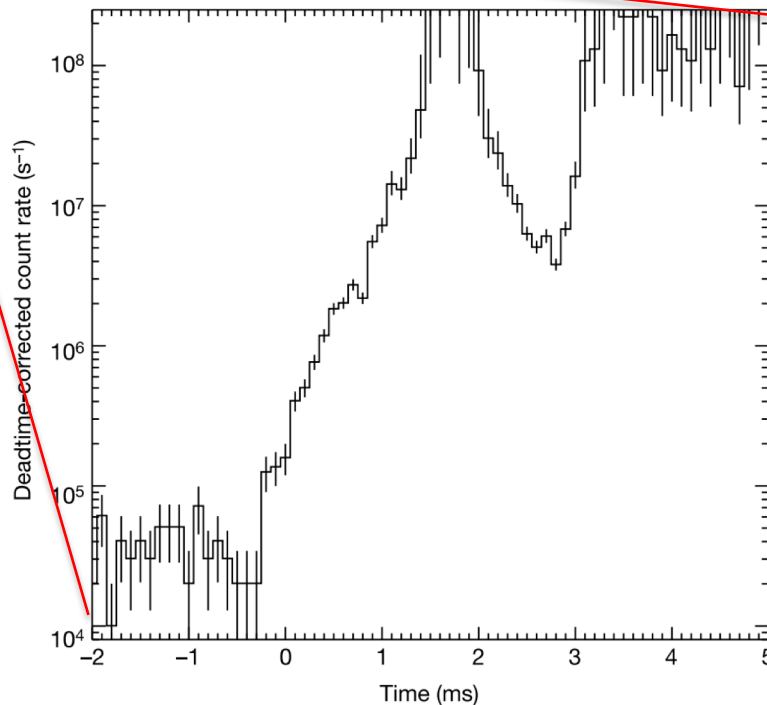
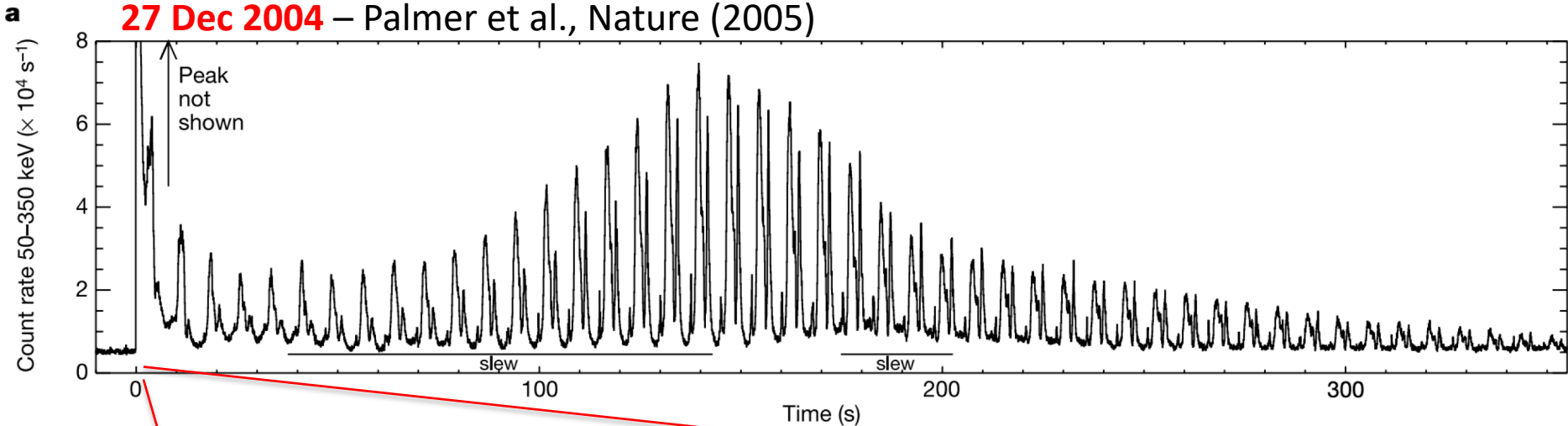


**27 Dec 2004** – Palmer et al., Nature (2005)

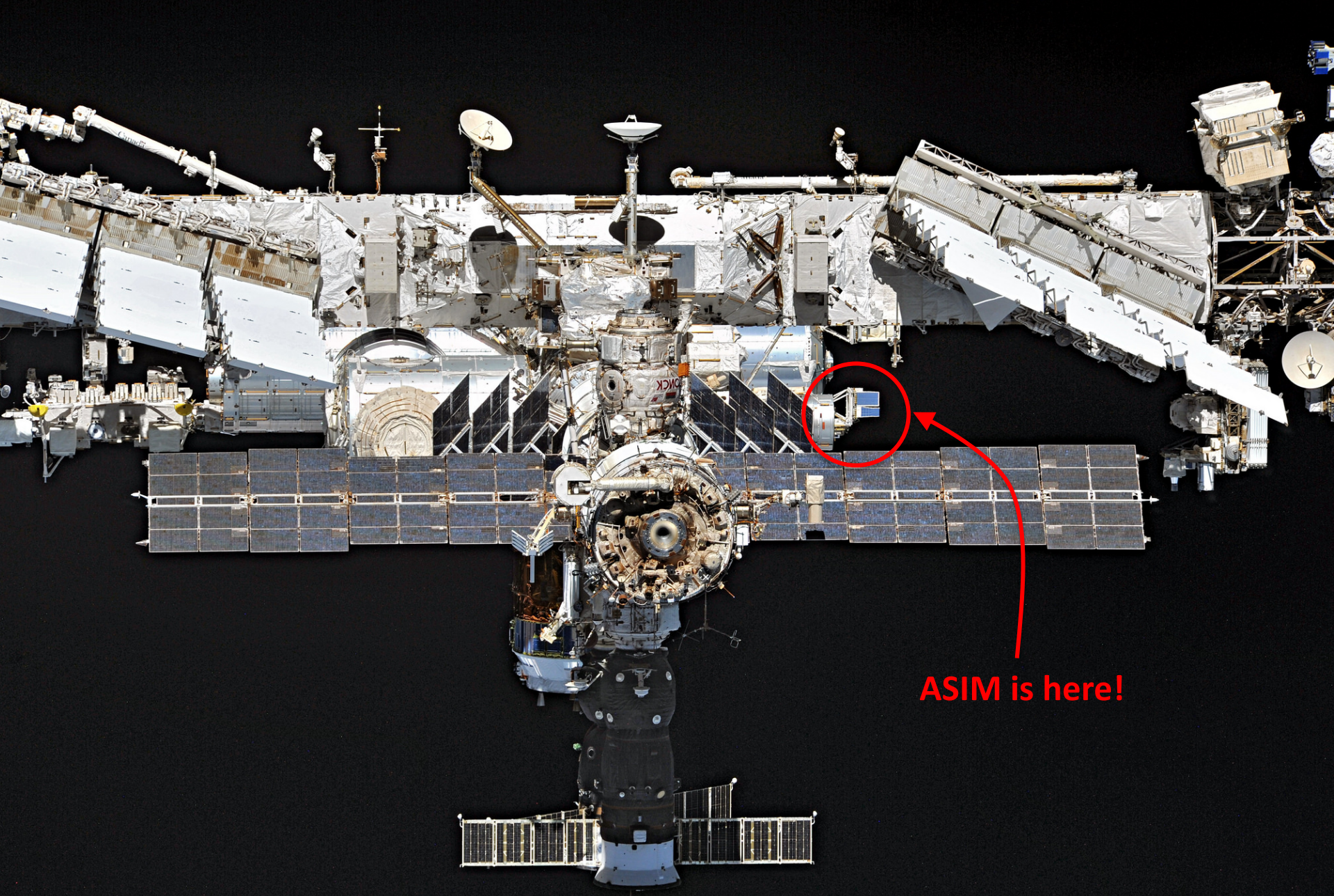


# Magnetar's giant flares: the main peak

**27 Dec 2004** – Palmer et al., Nature (2005)

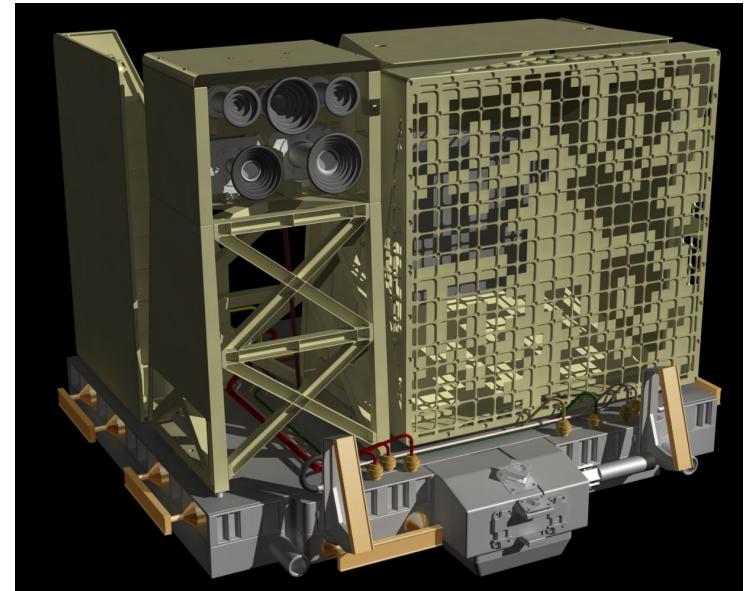
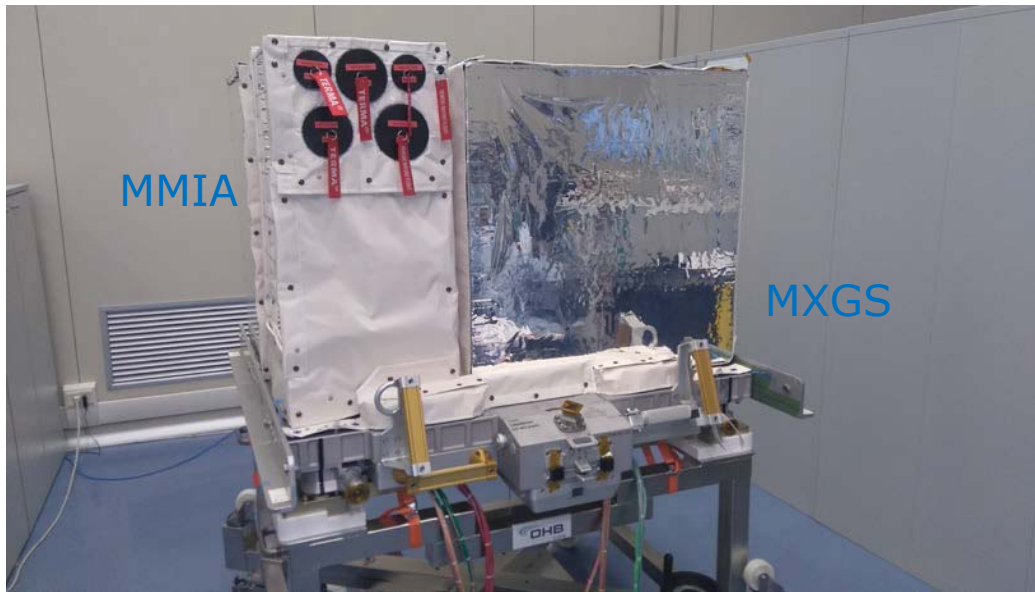


- Note the scale in time and count rate!
- The main peak is saturated because of instrumental effects: the flux is so high that the instrument cannot detect all photons



**ASIM is here!**

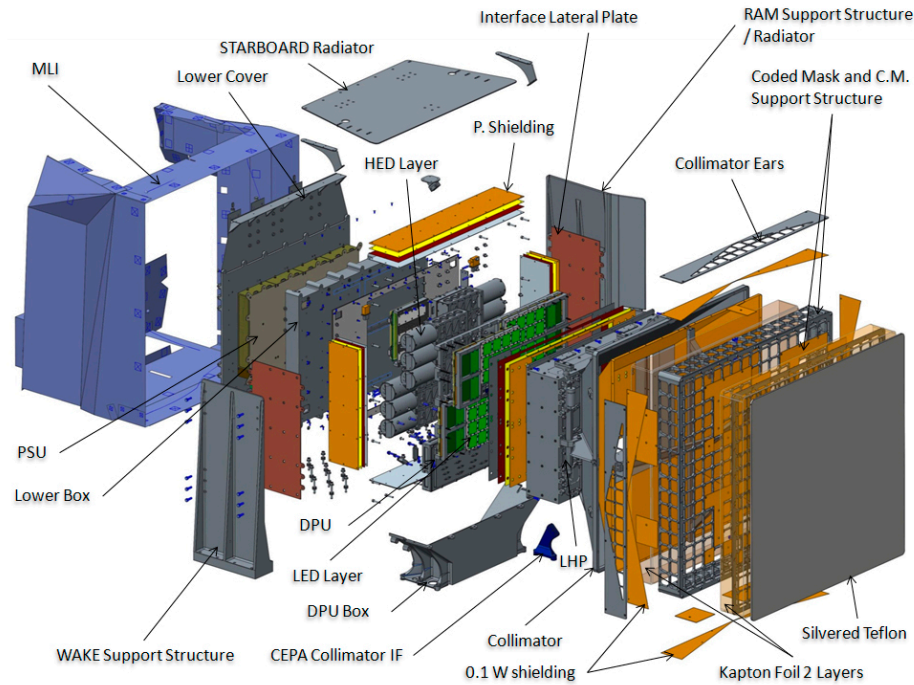
# The Atmosphere Space Interactions Monitor (ASIM)



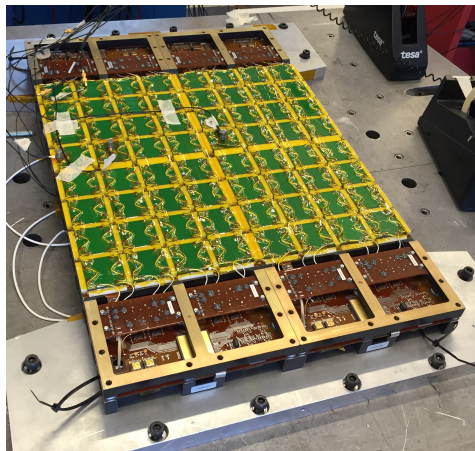
- **MXGS** (The Modular X- and Gamma-ray Sensor)
  - low-energy detector (LED)
  - high-energy detector (HED)
- **MMIA** (The Modular Multispectral Imaging Array)
  - three photometers
  - two cameras
- The instruments view towards the nadir

Neubert et al., Sp. Sci. Rev. (2019): the mission  
Østgaard et al., Sp. Sci. Rev. (2019): MXGS  
Chanrion et al., Sp. Sci. Rev. (2019): MMIA

# MXGS – Modular X- Gamma-ray Sensor

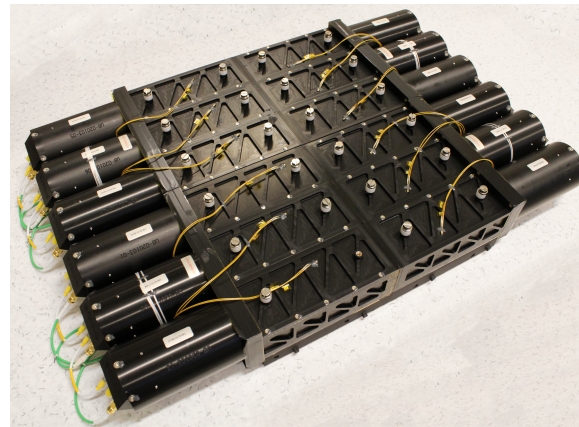


**LED**  
**CZT**  
solid state  
detector



50-400 keV, 1.4 us, 16000 pixels

**HED**  
**BGO**  
scintillating  
crystal



300keV- above 30MeV, <1 us

## 1. TGFs are short

Average duration  $\sim 0.1$  ms

## 2. TGFs are energetic

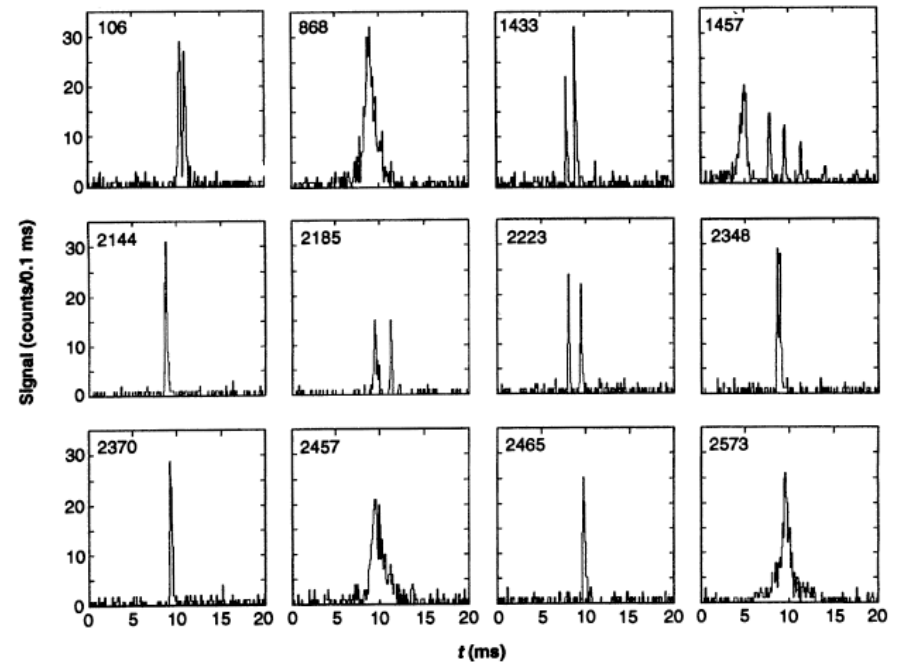
Average energy  $\sim$  MeV, single photon energy up to tens of MeV

## 3. TGFs are associated with lightning

## 4. TGFs are produced near thundercloud tops

## 5. TGFs are bright

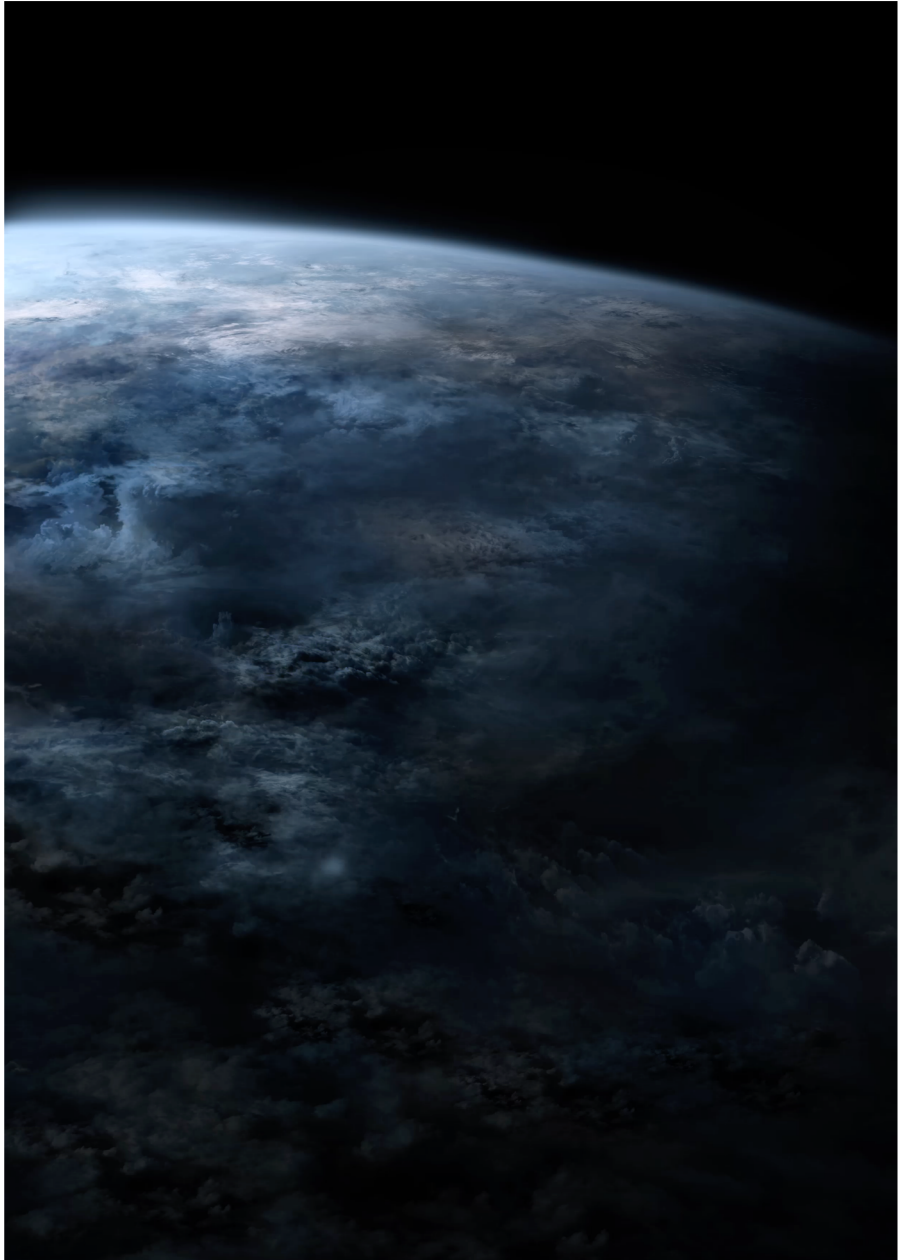
At least  $\sim 10^{17}$  energetic electrons ( $\sim 10$  kJ) in 0.1ms



Fishman et al., 1994



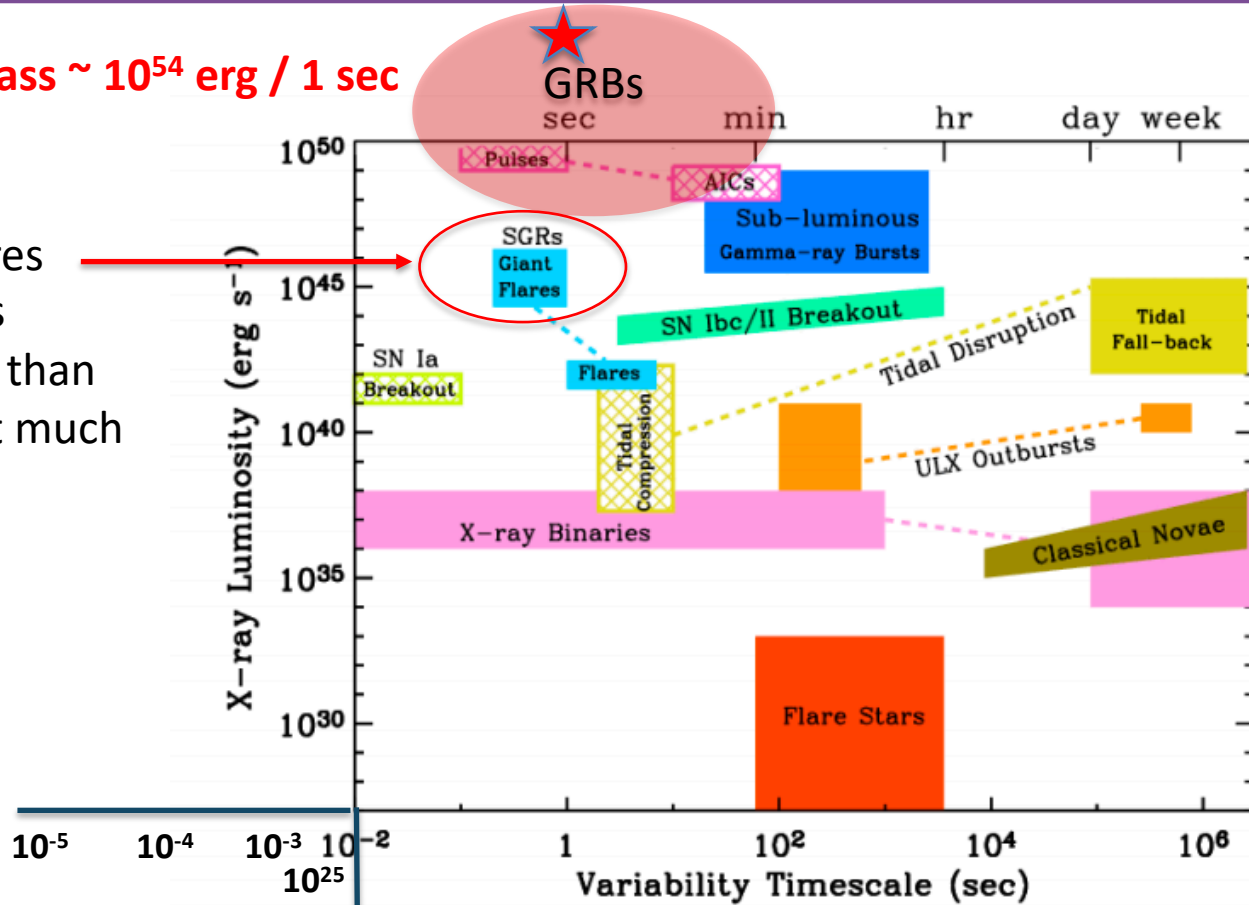
# How do a TGF look like?



Neubert et al., 2019, Science

1 solar mass  $\sim 10^{54}$  erg / 1 sec

Giant Flares  
much less  
energetic than  
GRBs, but much  
closer



TGFs

1 MJ = 1



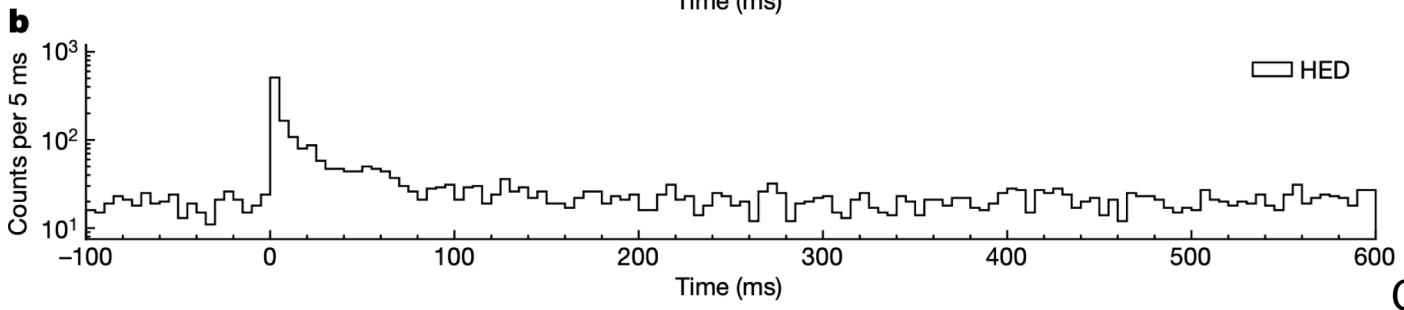
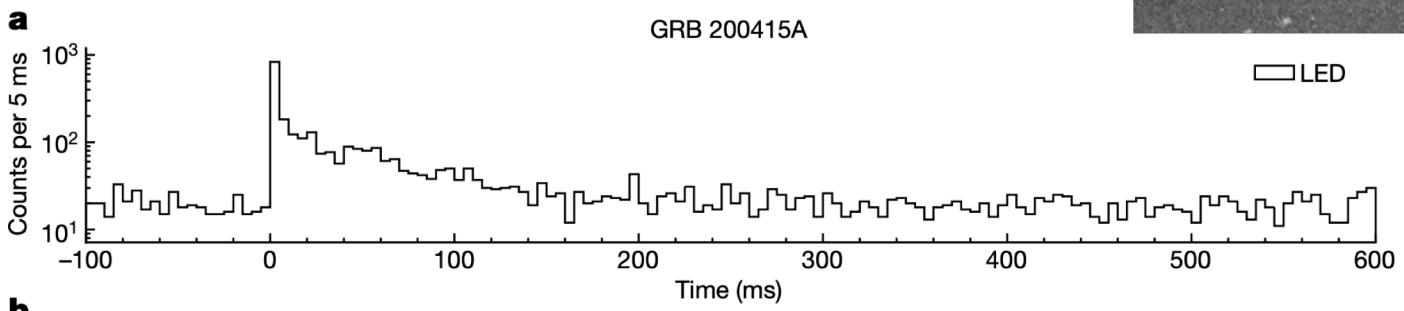
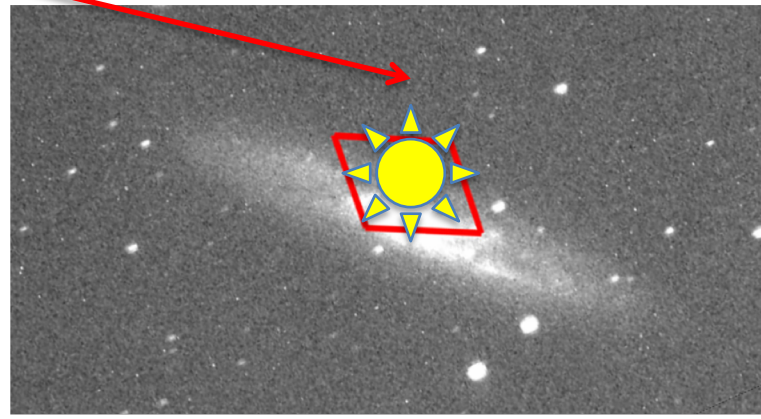
Soderberg+2009

1 MJ /  $10^{-4}$  s = 10 GW =  $10^{17}$  erg / s

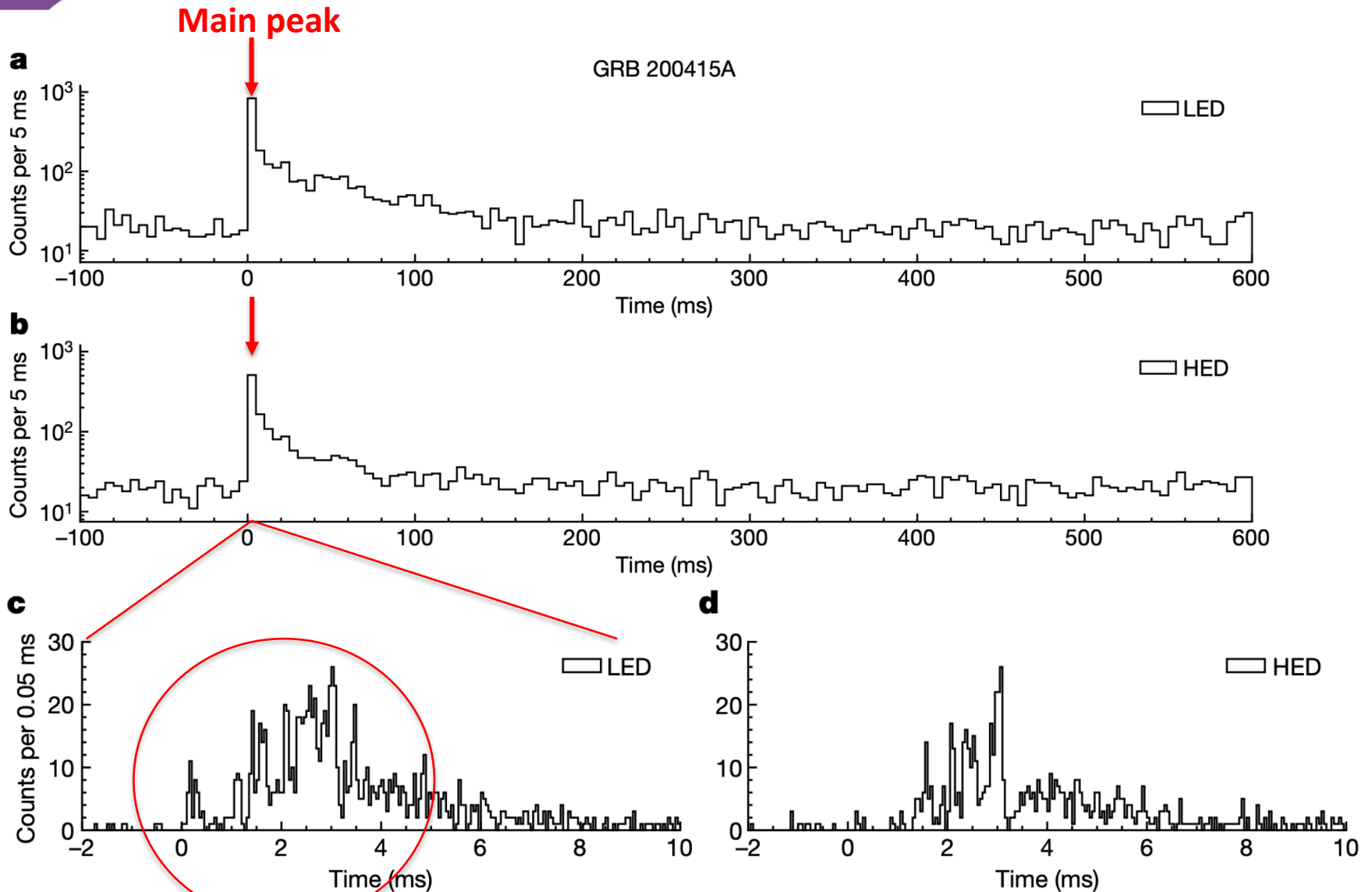
# ASIM view of the giant flare from the Suptor galaxy



11 million light years

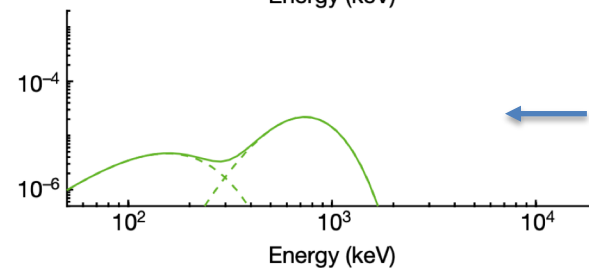
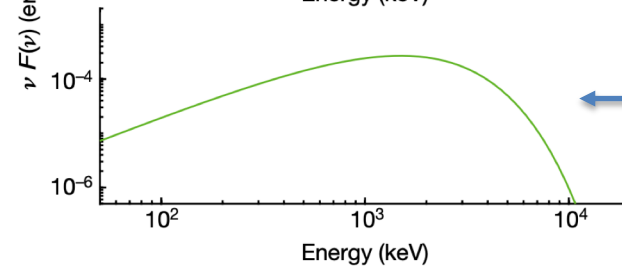
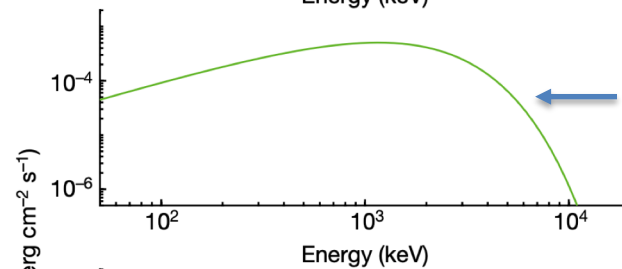
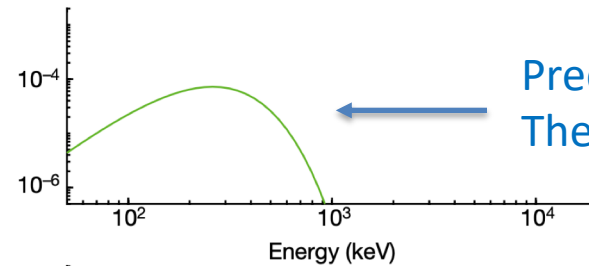
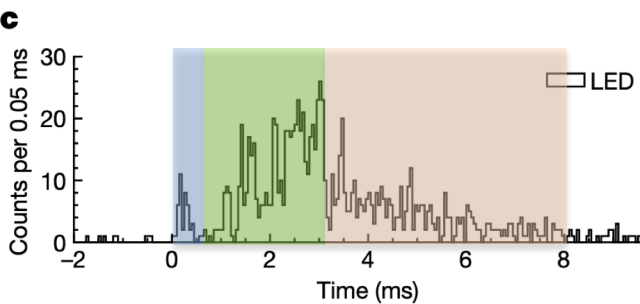
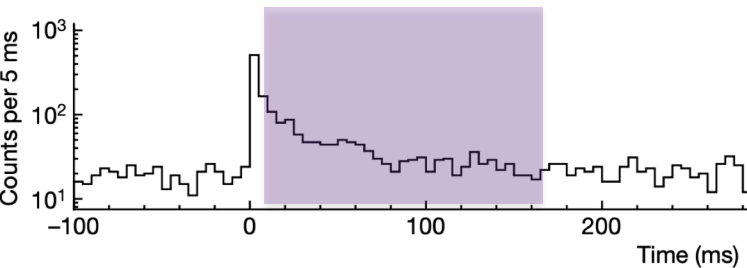


# A closer look...



**Time structure? Spectral evolution?**

# Spectral evolution: anatomy of the emission

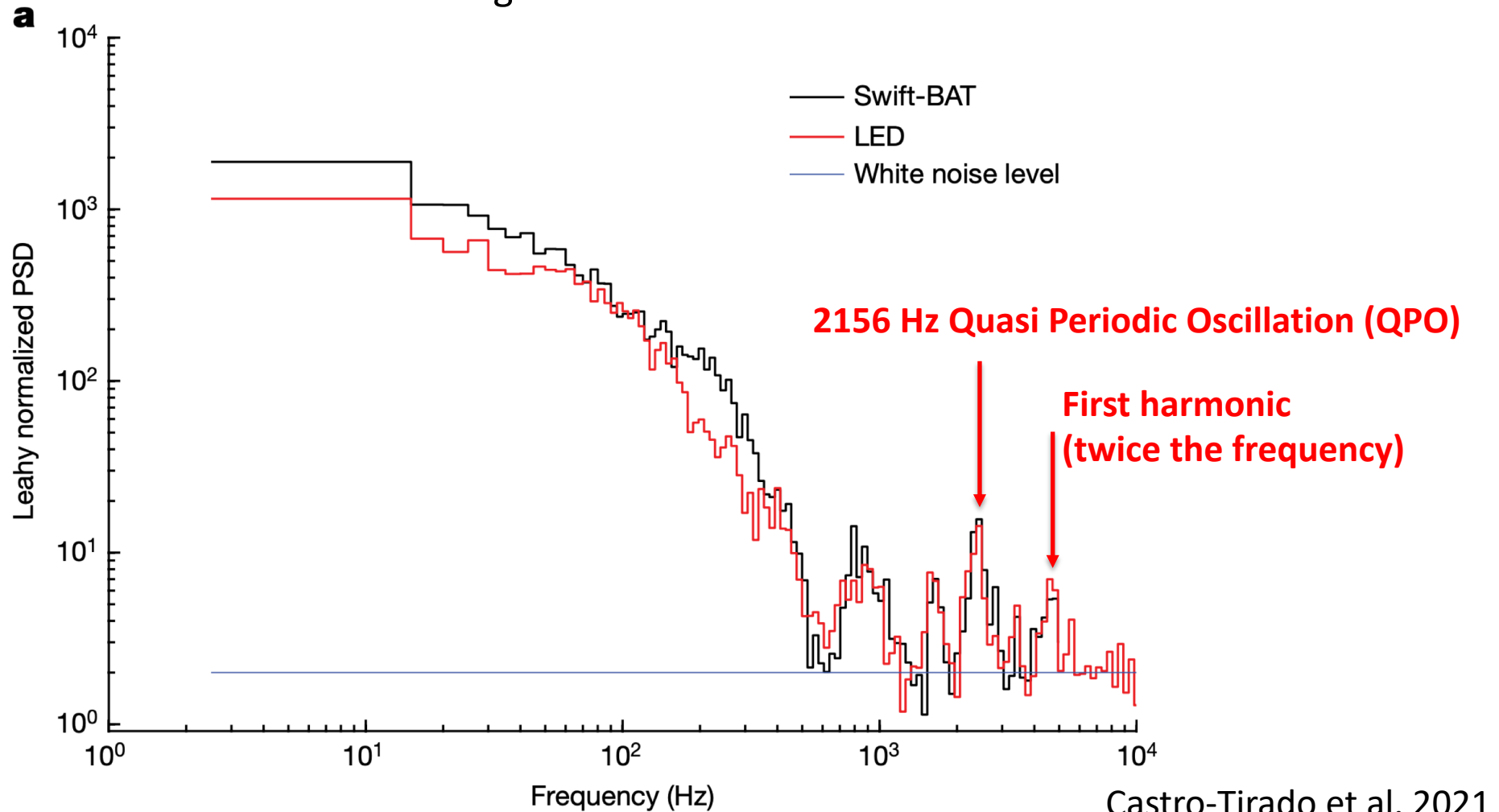


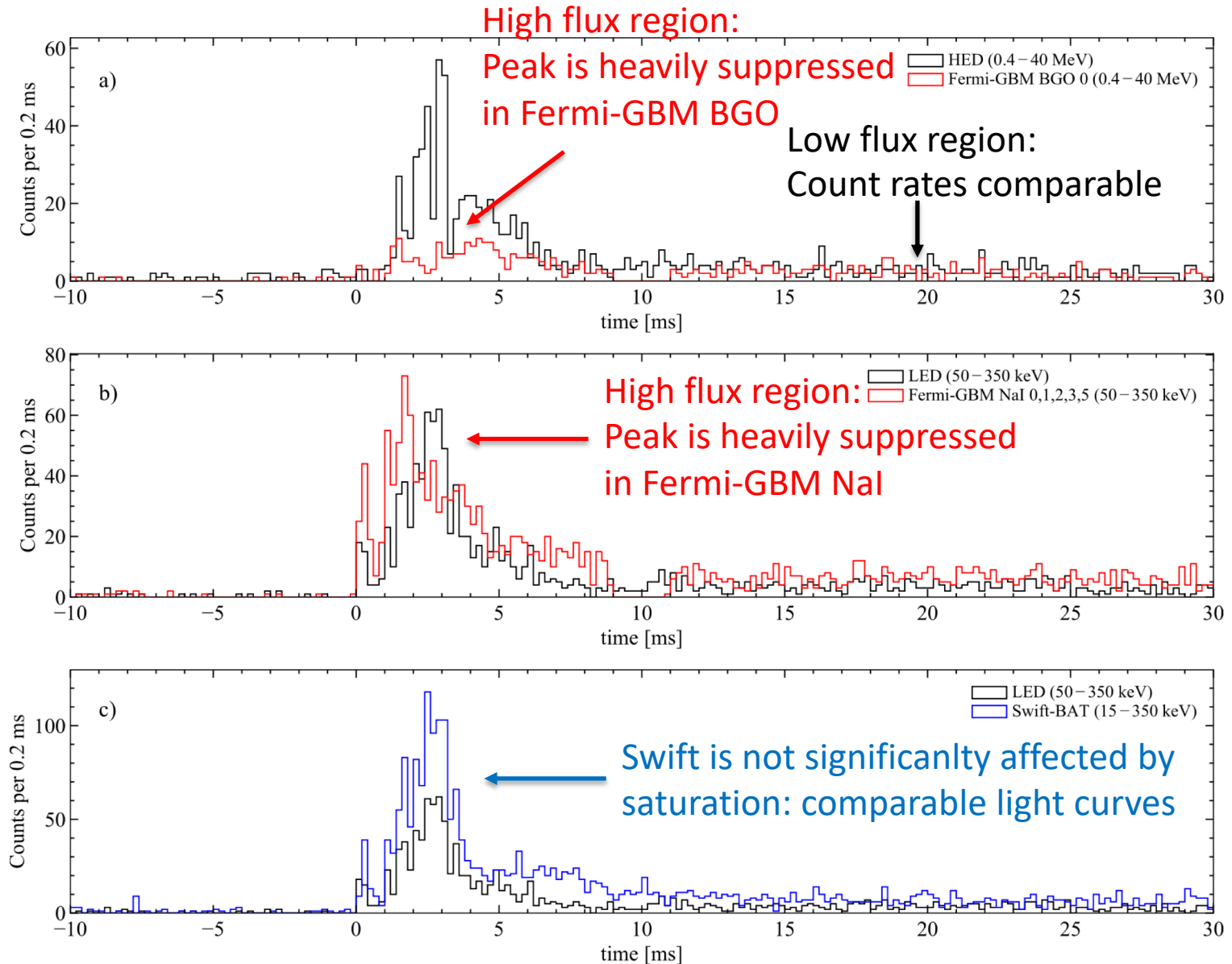
## Scenario:

- Magnetic reconnection event
- Boost at higher energies by plasma interaction with the ultra-strong magnetic field

## Two physical scenarios:

- Magnetospheric instabilities close to the surface
- Magneto-elastic oscillations in the crust





## Article

# Very-high-frequency oscillations in the main peak of a magnetar giant flare

<https://doi.org/10.1038/s41586-021-04101-1>

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 Check for updates

A. J. Castro-Tirado<sup>1,2</sup>, N. Østgaard<sup>3</sup>✉, E. Göğüş<sup>4</sup>✉, C. Sánchez-Gil<sup>5</sup>, J. Pascual-Granado<sup>1</sup>, V. Reglero<sup>6,7</sup>, A. Mezentsev<sup>3</sup>✉, M. Gabler<sup>6</sup>✉, M. Marisaldi<sup>3,8</sup>✉, T. Neubert<sup>9</sup>, C. Budtz-Jørgensen<sup>9</sup>, A. Lindanger<sup>3</sup>, D. Sarria<sup>3</sup>, I. Kuvvetli<sup>9</sup>, P. Cerdá-Durán<sup>6</sup>, J. Navarro-González<sup>7</sup>, J. A. Font<sup>6,10</sup>, B.-B. Zhang<sup>11,12,13</sup>, N. Lund<sup>9</sup>, C. A. Oxborrow<sup>9</sup>, S. Brandt<sup>9</sup>, M. D. Caballero-García<sup>1</sup>, I. M. Carrasco-García<sup>14</sup>, A. Castellón<sup>2,15</sup>, M. A. Castro Tirado<sup>11,16</sup>, F. Christiansen<sup>9</sup>, C. J. Eyles<sup>7</sup>, E. Fernández-García<sup>1</sup>, G. Genov<sup>3</sup>, S. Guziy<sup>17,18</sup>, Y.-D. Hu<sup>19</sup>, A. Nicuesa Guelbenzu<sup>20</sup>, S. B. Pandey<sup>21</sup>, Z.-K. Peng<sup>11,12</sup>, C. Pérez del Pulgar<sup>2</sup>, A. J. Reina Terol<sup>2</sup>, E. Rodríguez<sup>1</sup>, R. Sánchez-Ramírez<sup>22</sup>, T. Sun<sup>1,23,24</sup>, K. Ullaland<sup>3</sup> & S. Yang<sup>3</sup>

- First evidence of quasi periodic oscillations in the peak phase of a Giant Magnetar Flare
- Results published in the prestigious journal Nature, Dec 2021
- Results made possible by the peculiar architecture of the instrument, very tolerant to high count rate
- More than one year of work by several members of BCSS HRT group
- Build up of a large international collaboration with lead scientists in GRB science
- Establish ASIM as a key player outside its design scope

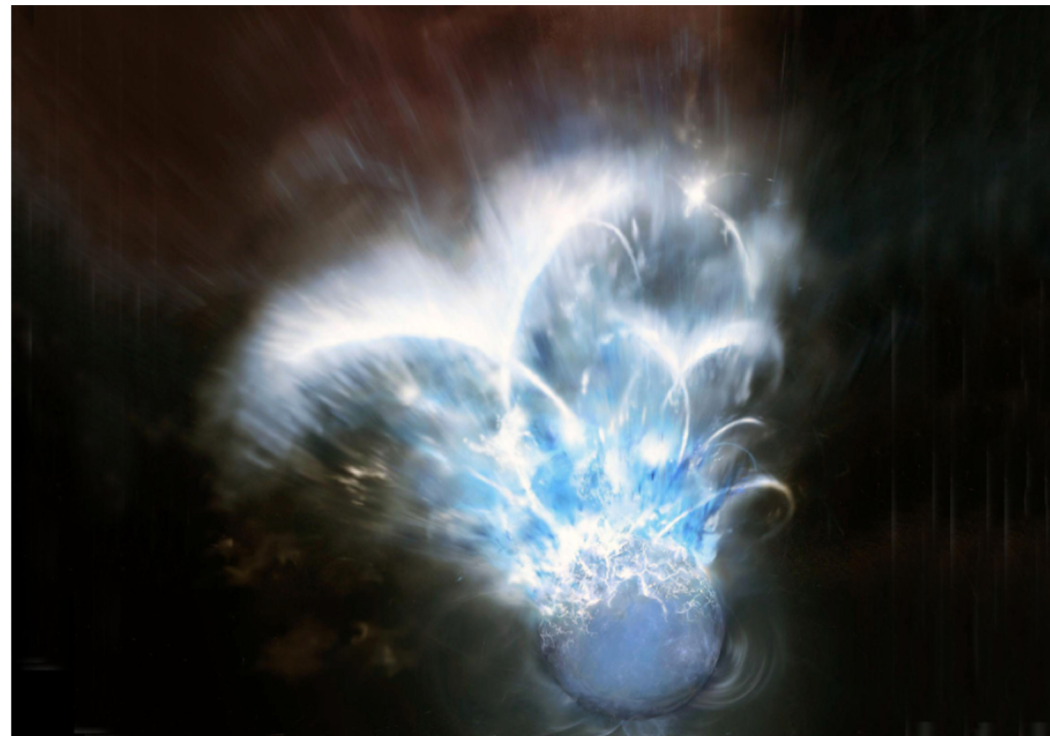


... and a successful public outreach story!



<https://birkeland.uib.no/media-news-about-the-new-asim-observations/>

> 600 media outlet in international media



[https://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/transients/grb200415\\_asim.html](https://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/transients/grb200415_asim.html)

Credits for the title of this talk!

*Short, Sharp, Shocked*

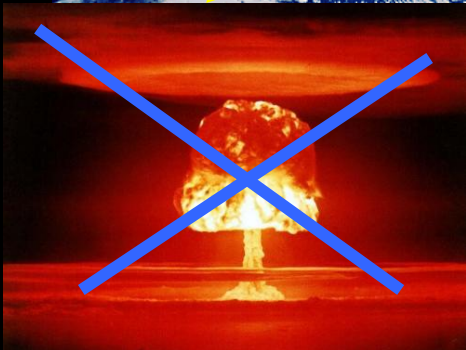
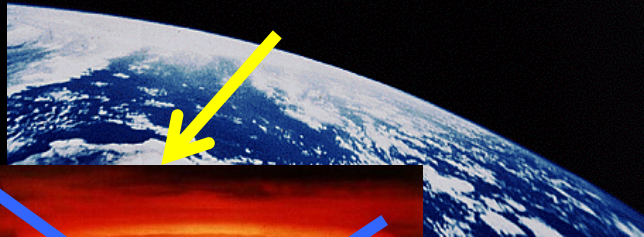
Vela satellites '70-'80  
looking down to Earth...



**GRB**

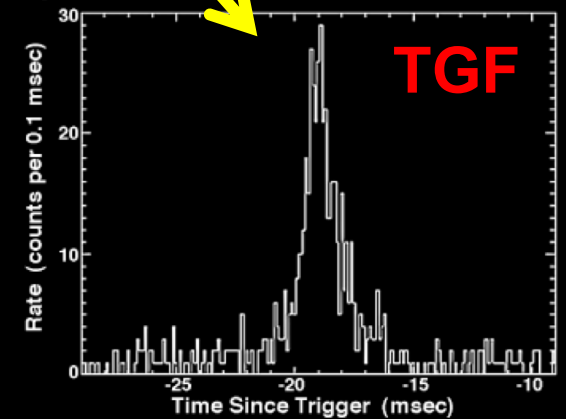


BATSE onboard CGRO 1991 – 2000  
looking up to space...

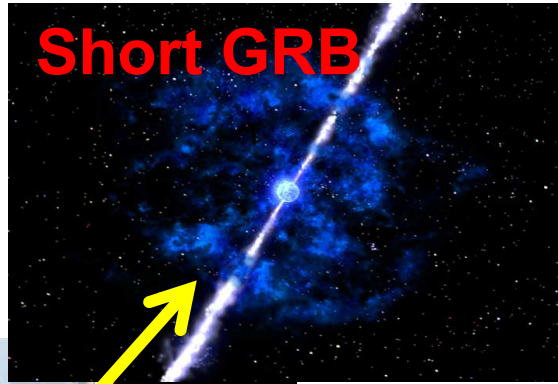


?

Light Curve for a Terrestrial Gamma Flash



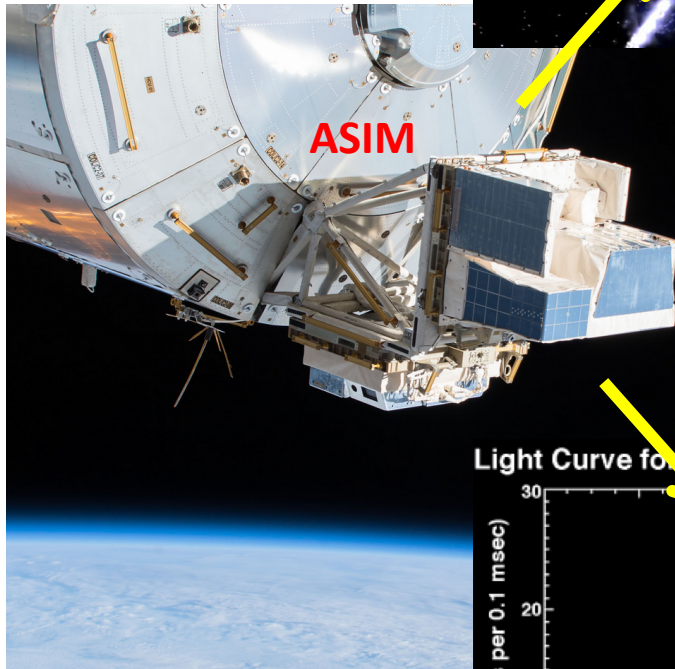
'Kind of' expected



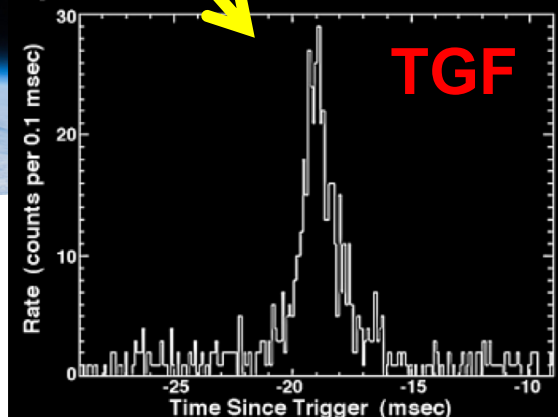
Giant magnetar flare



Unexpected: discovery!



Light Curve for a Terrestrial Gamma Flash



Expected by design

Up for more discoveries...

