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FOR SPACE SCIENCE

How design enables discovery: a Giant Magnetar Flare observed by the Atmosphere-Space Interactions Monitor

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TWEPP, Bergen, 19/09/2022

UNIS
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https://birkeland.uib.no/

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RESEARCH ORGANIZATION PEOPLE EDUCATION PUBLICATION NEWS DATA PROJECTS

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?

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

L. Norenius, 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

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

ANNUAL REPORT 2020

High-energy Radiation from Thunderstorms (and beyond)

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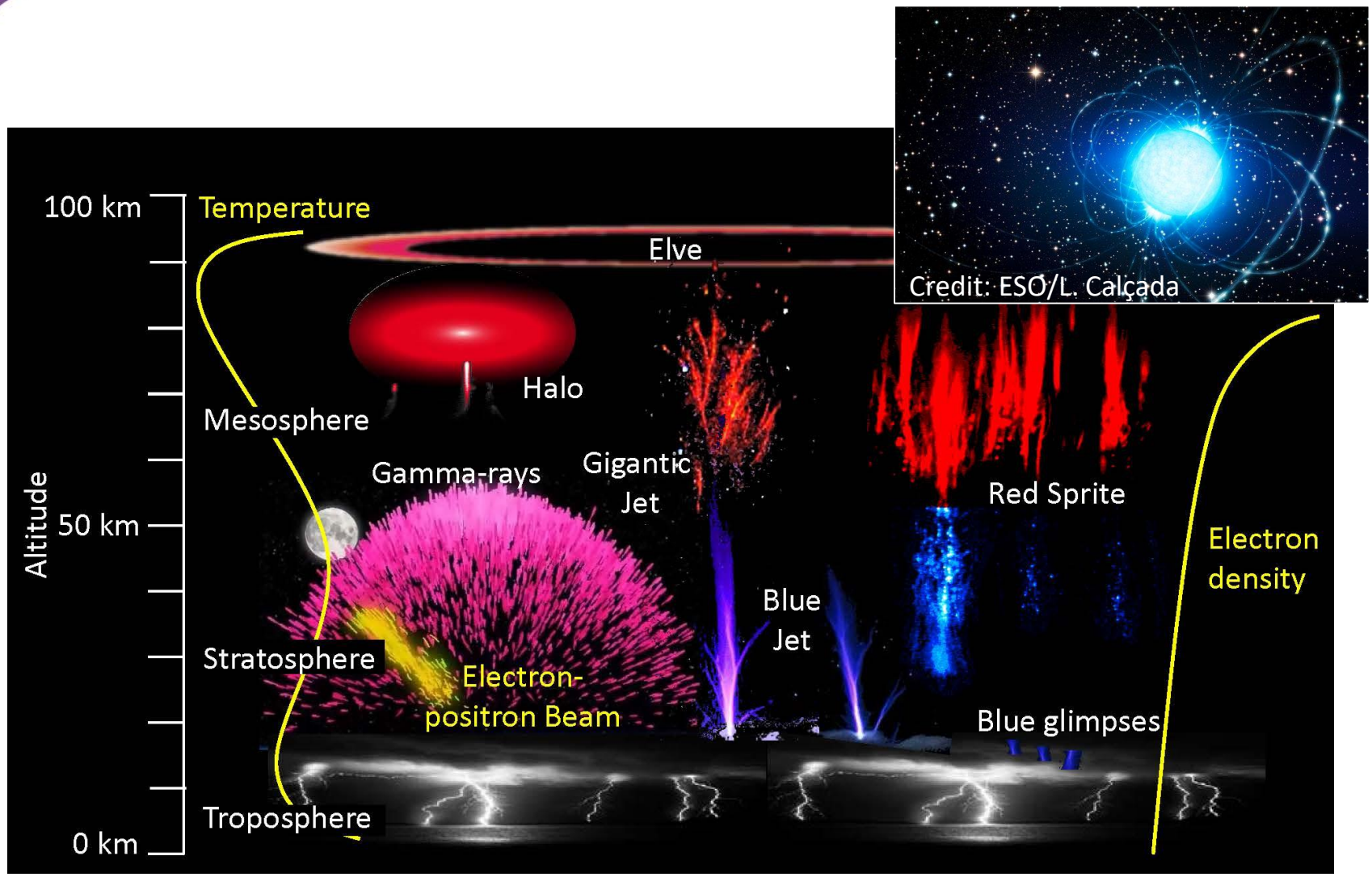

Top question: what is the role of energetic particles from thunderstorms on geospace?

The Milky Way with super-human eyes

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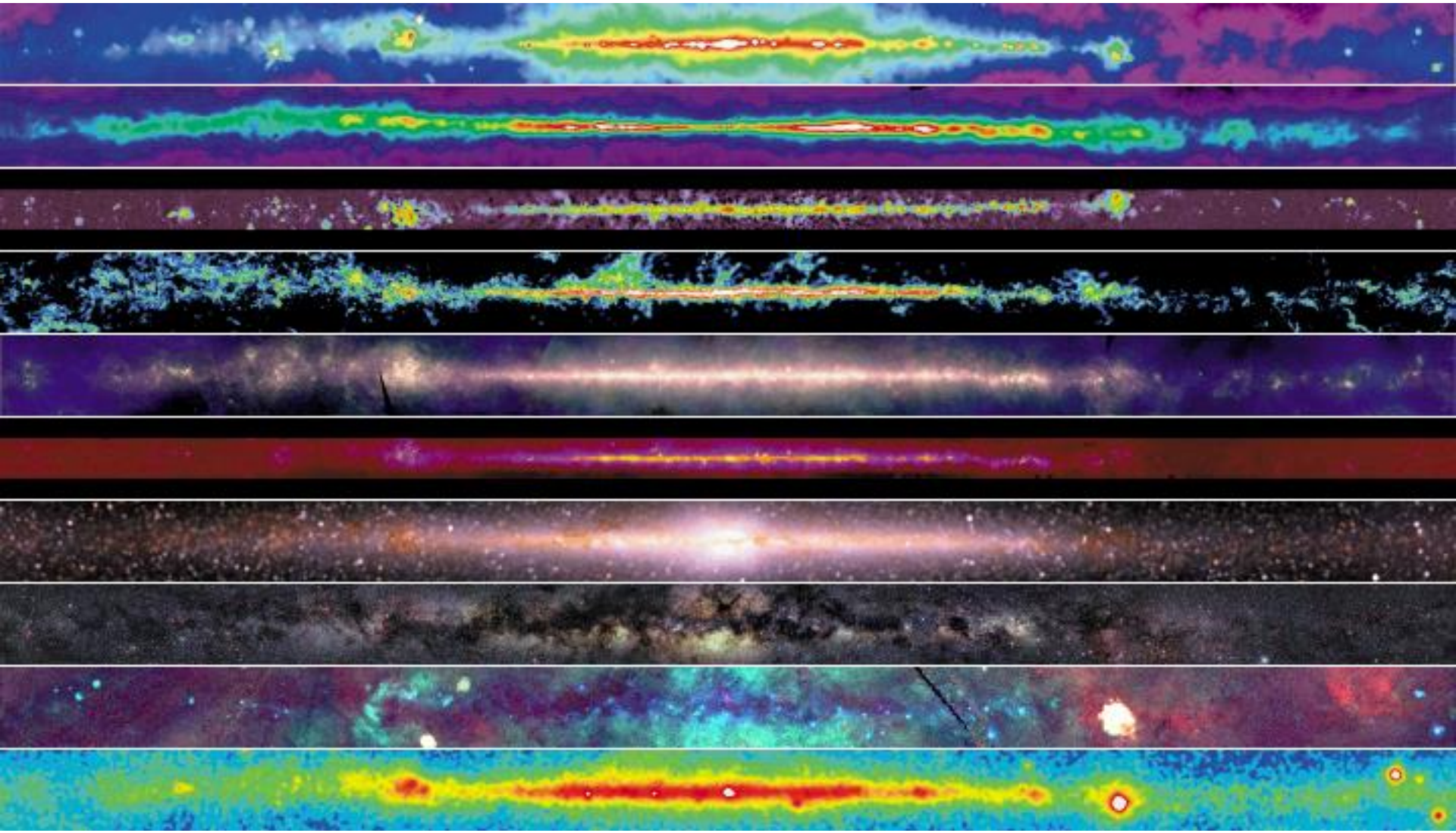
http://www.chromoscope.net/



Credit: NASA GSFC - https://asd.gsfc.nasa.gov/archive/mwmw/mmw_images.html

The variable gamma-ray sky: Gamma-Ray Bursts

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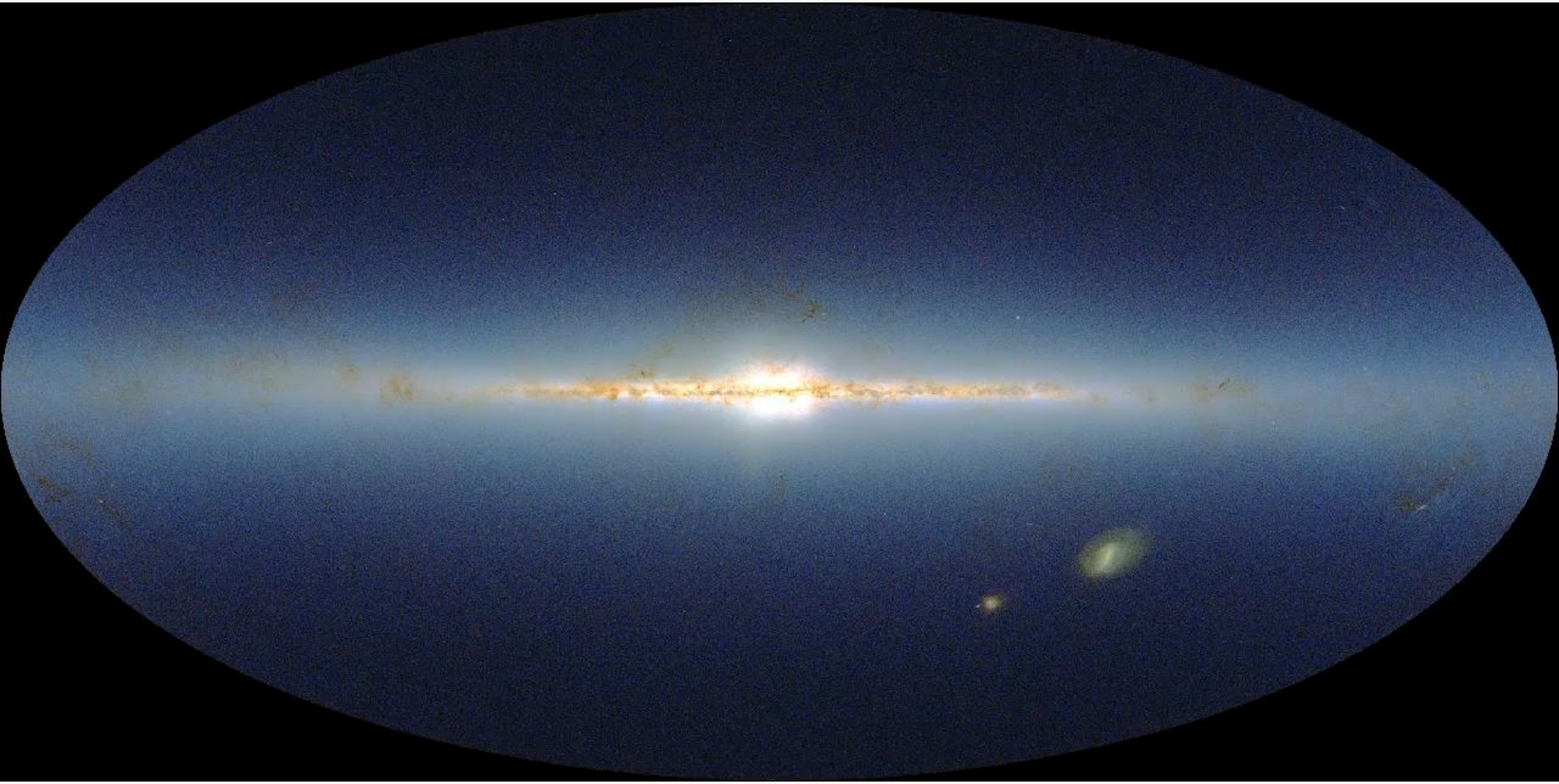

Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio
https://svs.gsfc.nasa.gov/3702

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

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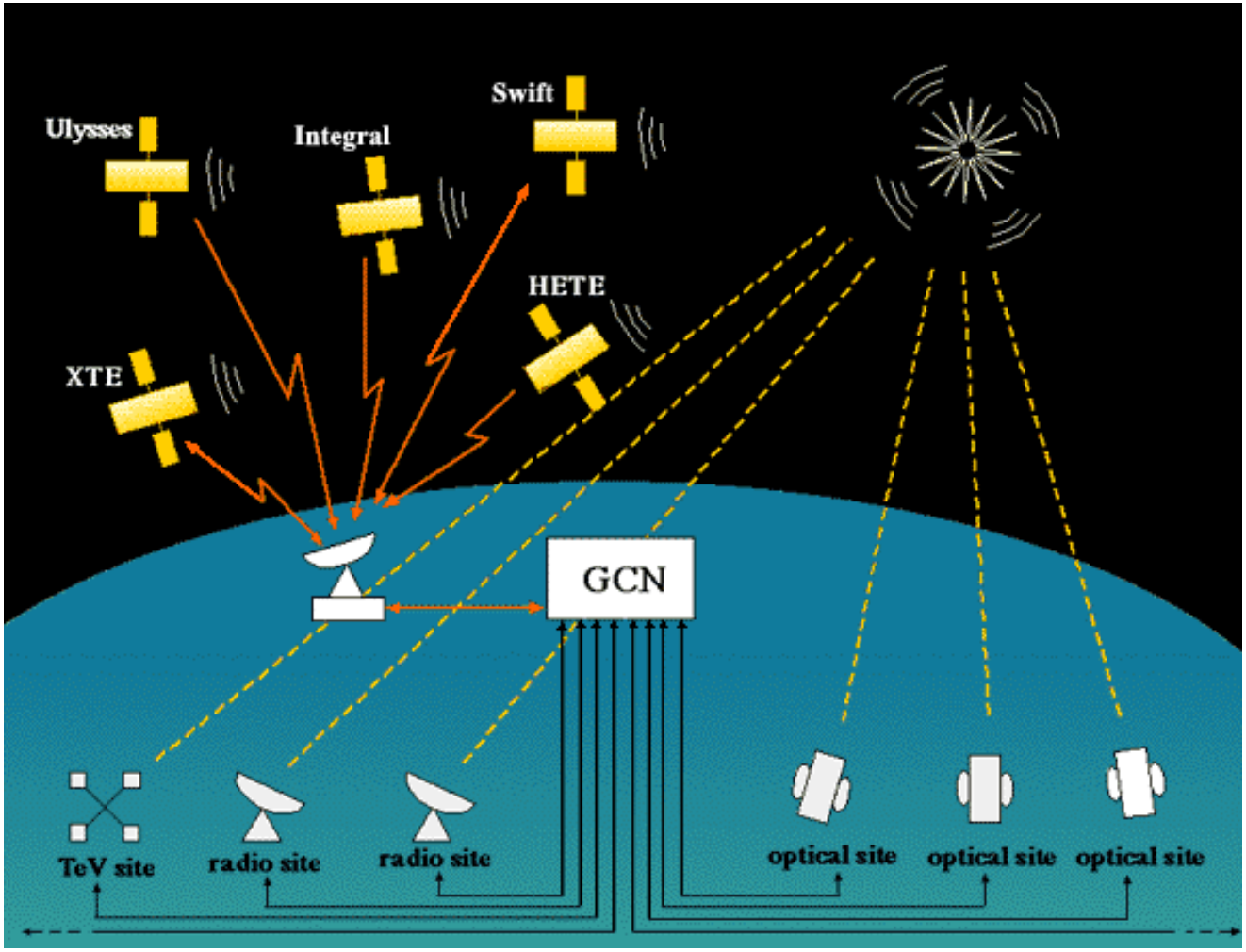

Gredits: NASA GSFC https://gcn.gsfc.nasa.gov/

GRB200415A

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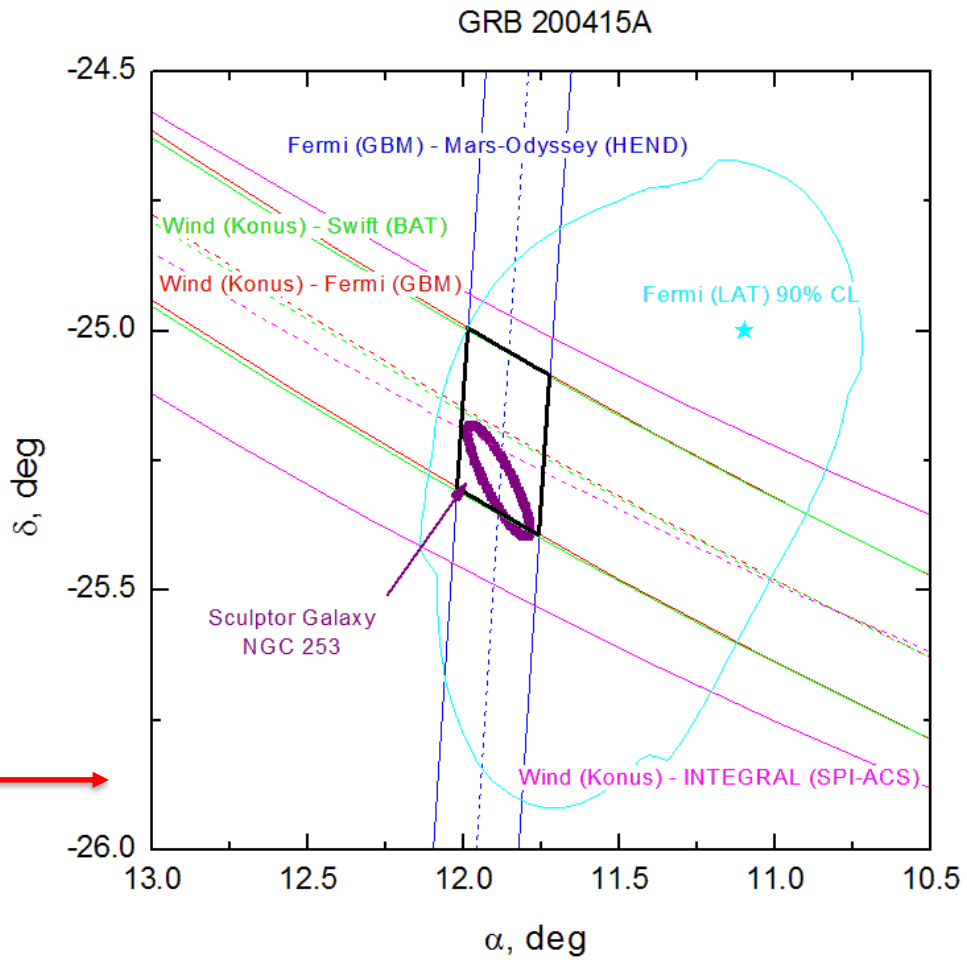
27629 GRB 200415A correction to GCN 27627 (possible magnetar Giant Flare in Sculp
27628 GRB 200422A: MASTER optical observations
27627 GRB 200415A (possible magnetar Giant Flare in Sculptor Galaxy): INTEGRAL
27626 IPN triangulation of GRB 200422A (long/very bright)
27625 IPN Triangulation of a bright 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
27622 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 imspection 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

counts / 0.002 s



← https://gcn.gsfc.nasa.gov/gcn3_arch_old145.html

What is a magnetar?

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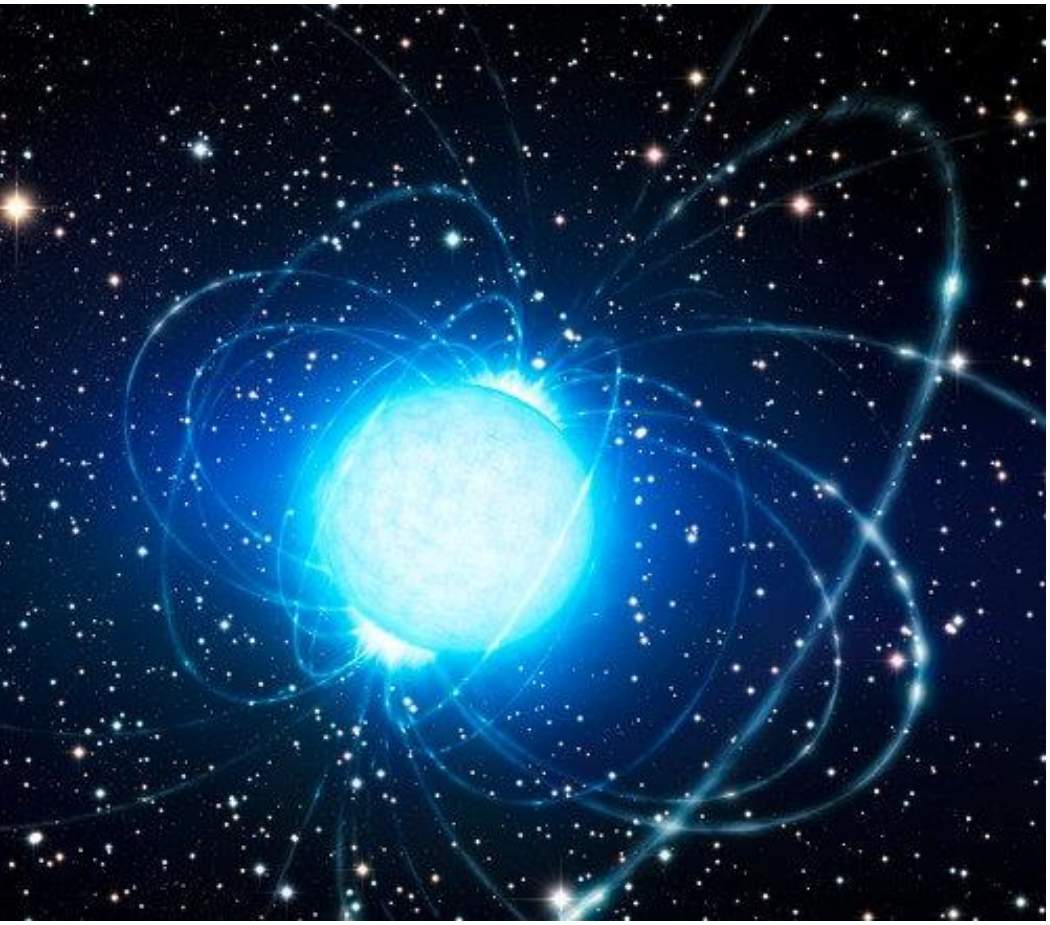

- A young neutron star ($<10^5$ y) with typically long spin periods >2 s
- Powered by a very strong magnetic field $>10^{14}$ G
- ~23 magnetars in our galaxy and the Large Magellanic Cloud
- Magnetic energy powers recurrent burst activity in X-rays – γ-rays
- Occasionally: emission of giant flares in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

Magnetar's giant flares

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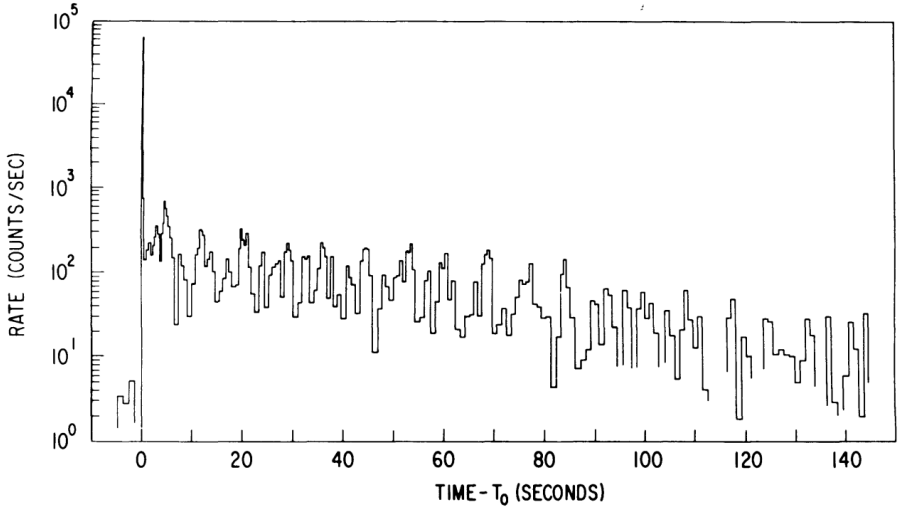
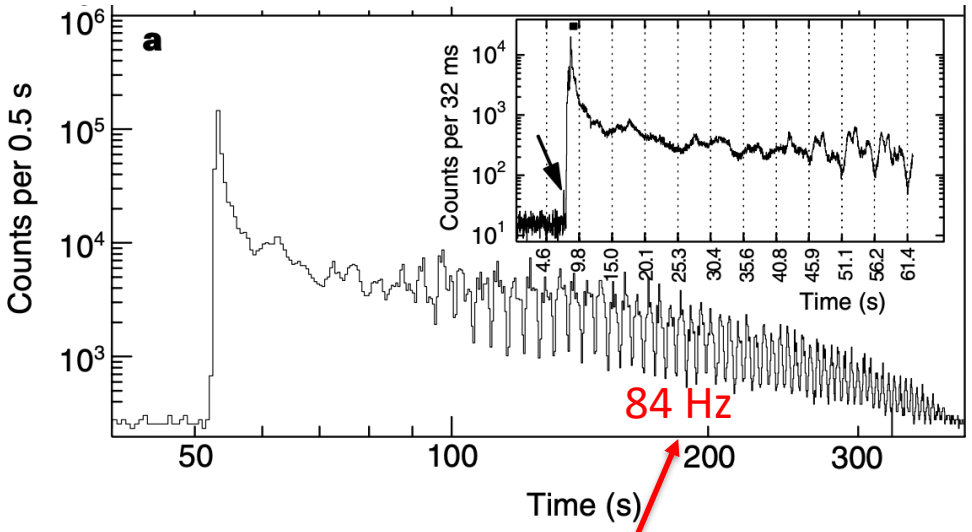
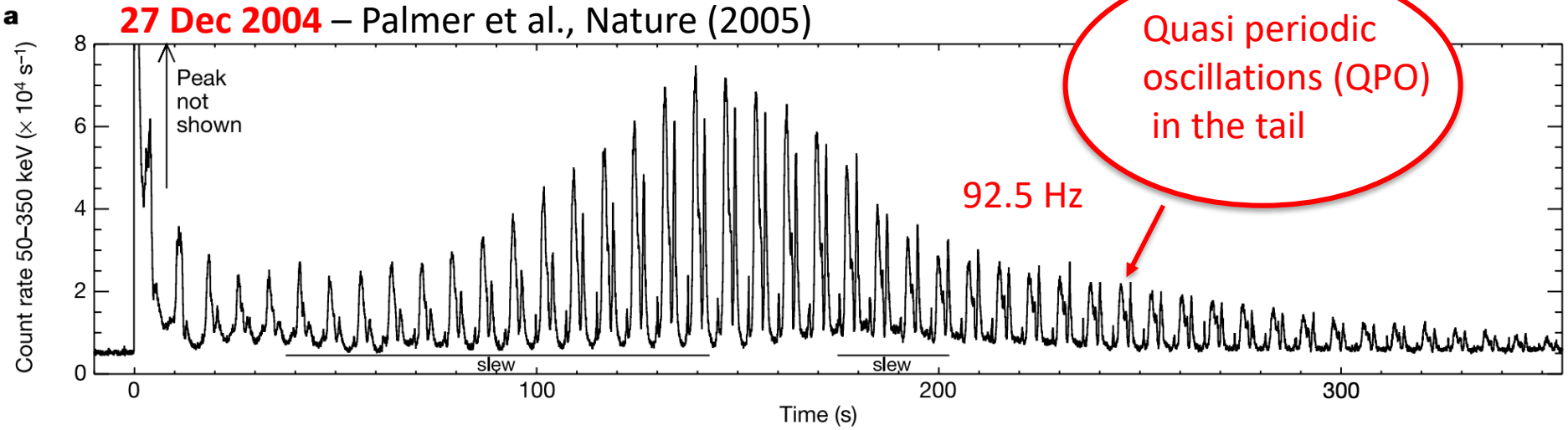
05 Mar 1979 – Cline et al., ApJ (1980)



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



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



Quasi periodic oscillations (QPO) in the tail

92.5 Hz

Magnetar's giant flares: the main peak

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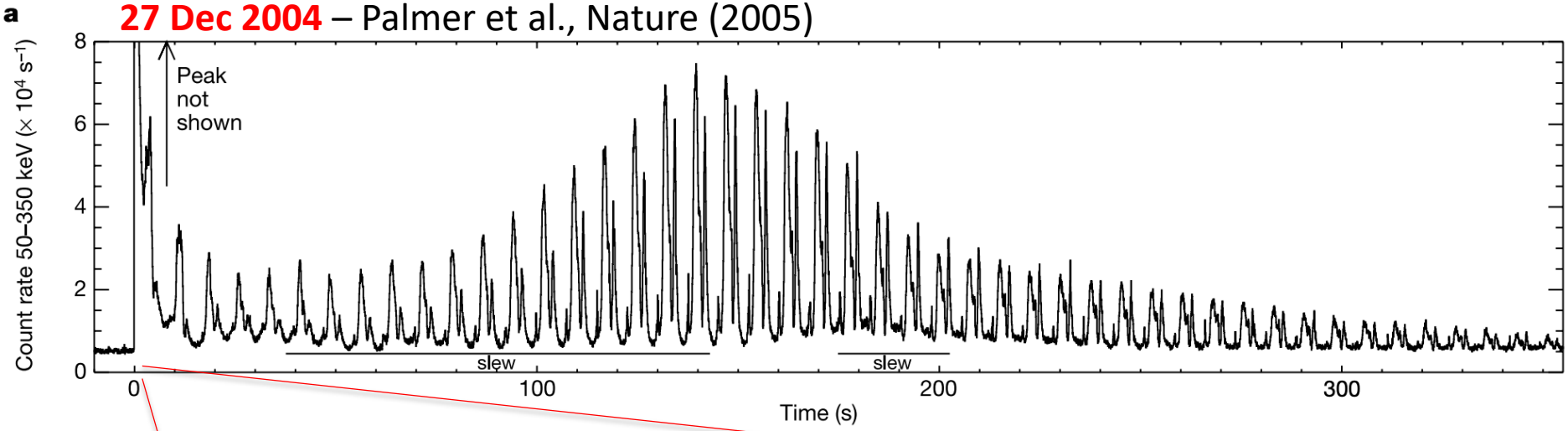
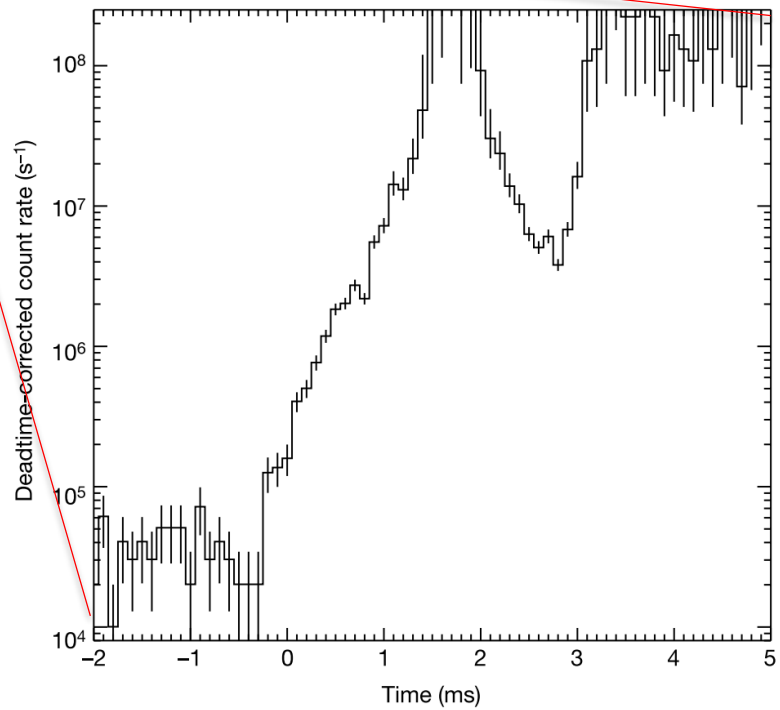
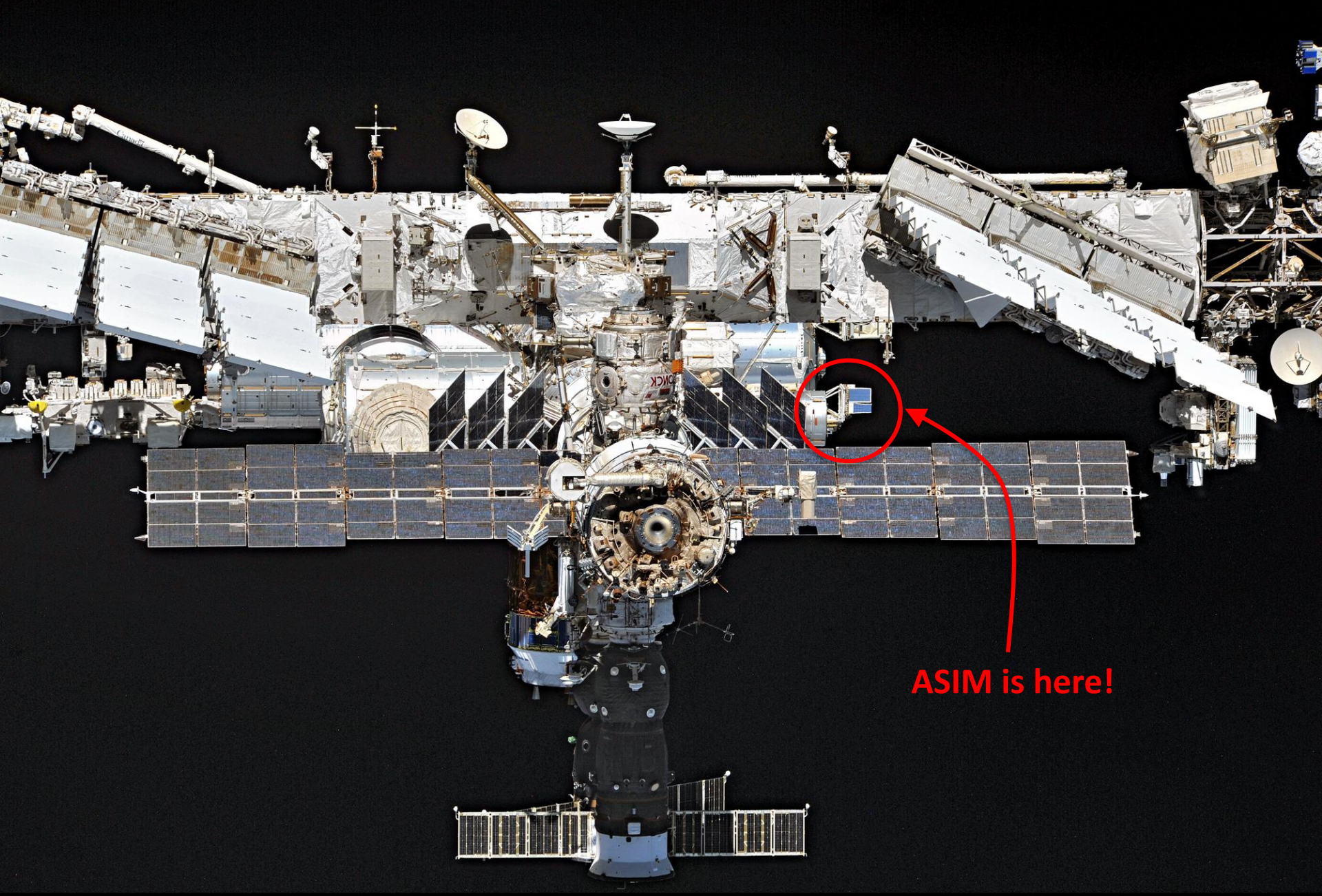
27 Dec 2004 – Palmer et al., Nature (2005)





- 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)

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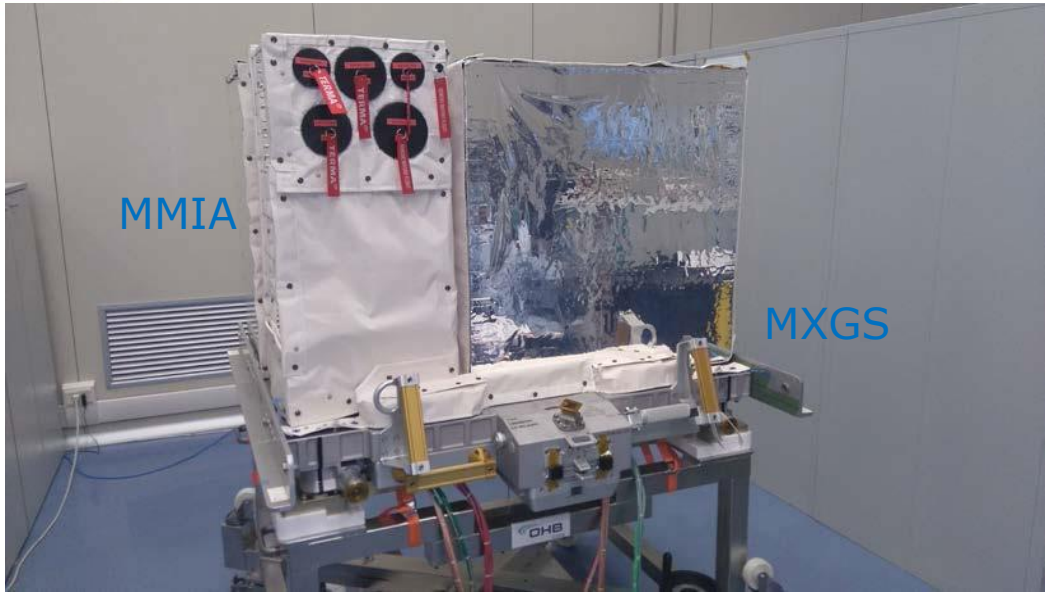

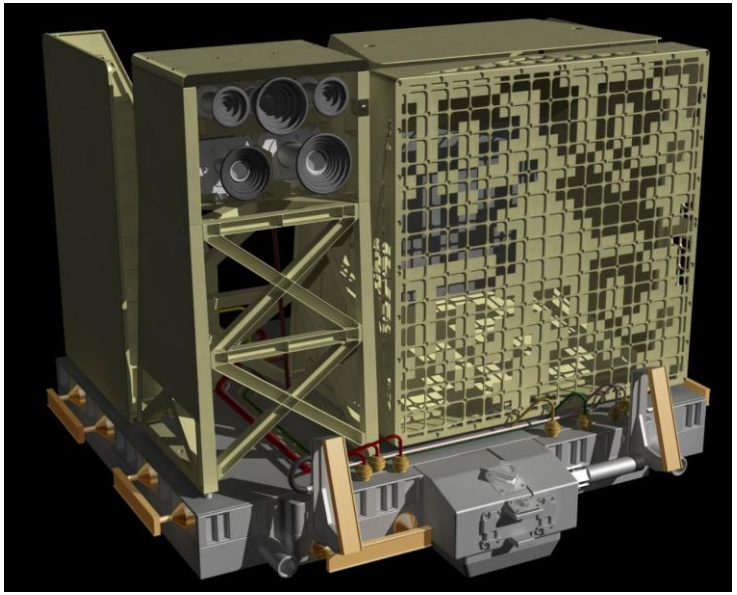

- **MXGS** (The Modular X- and Gamma-ray Sensor)
  - low-energy detector (LED)
  - high-energy detector (HED)
- **MMIA** (The Modular Multispectral Imaging Array)
  - three photometers
  - two cameras
- The instruments view towards the nadir

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

Key points:

- **very high degree of spatial segmentation**
- **Careful accounting for dead-time and pile-up**

MXGS – Modular X- Gamma-ray Sensor

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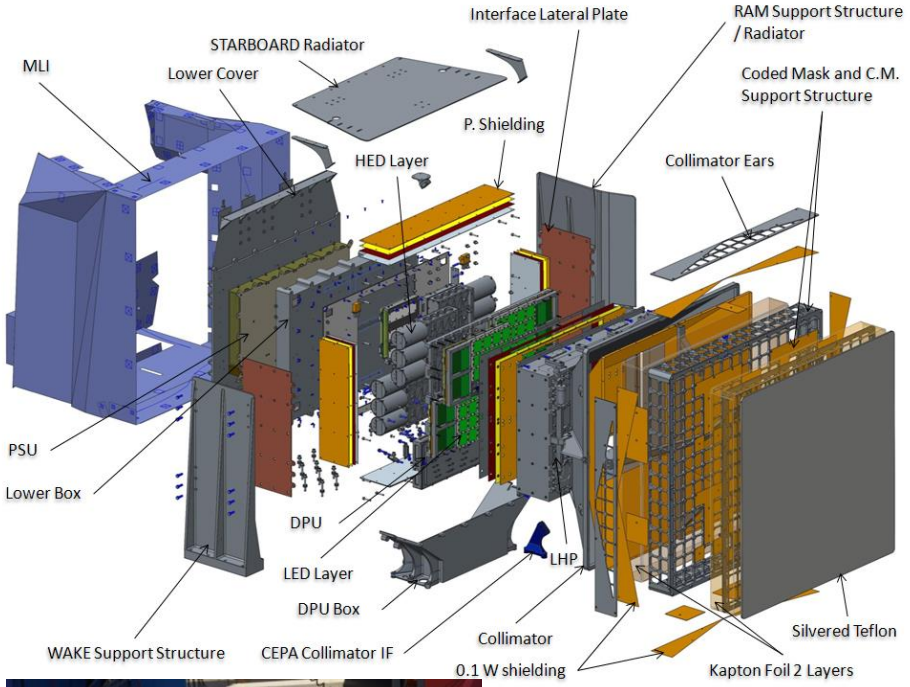
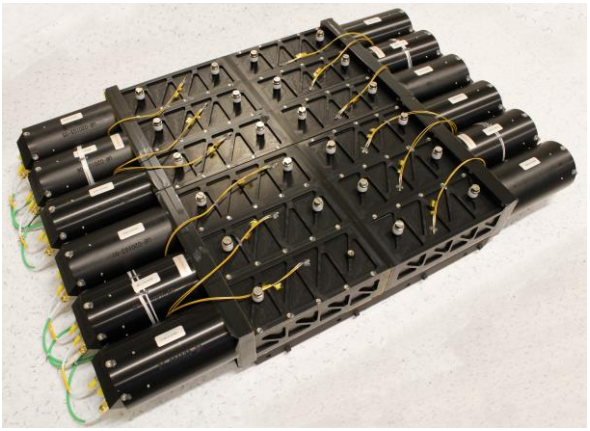
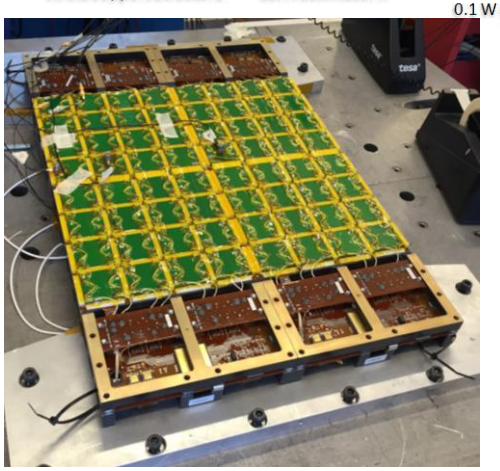




300keV- above 30MeV, <1 us

HED (High-Energy Detector)

- 12 independent BGO scintillating crystals
- 4 independent readout chains (DAU)
- 28 ns time-tagging accuracy
- 550 ns dead time / detector



50-400 keV, 1.4 us

LED (Low-Energy Detector)

- 16k CZT pixels with XA ASIC readout (128 ASICs)
- 4 independent readout chains (DAU)
- 1 μs time-tagging accuracy
- 1.4 μs dead time / ASIC
- Multi-hit collection for simultaneous hits in same chain (8 ASICs)

ASIM main target: Terrestrial Gamma-ray Flashes (TGF)

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1. TGFs are short

Average duration ~0.1 ms

2. TGFs are energetic

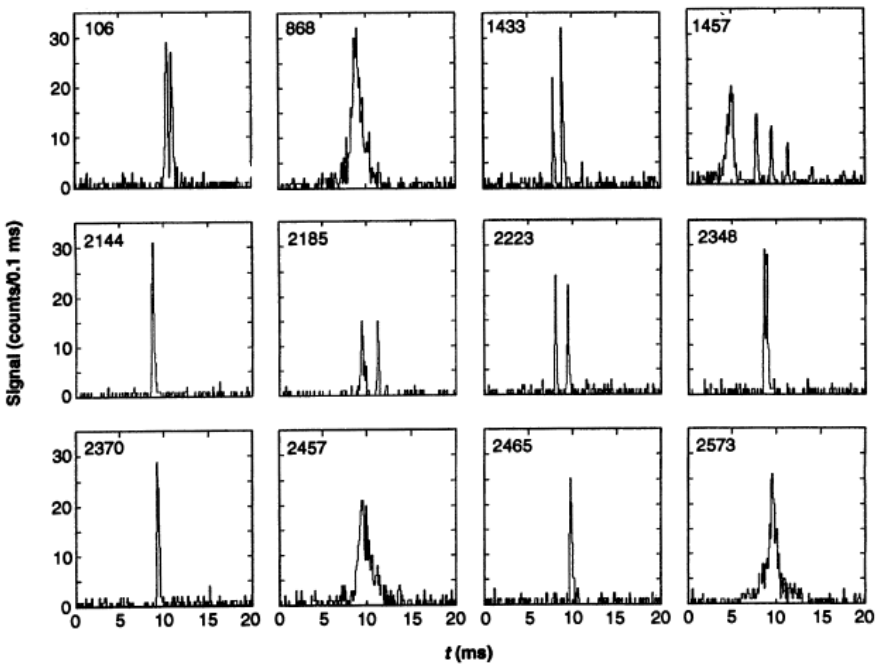
Average energy ~MeV, single photon energy up to tens of MeV

3. TGFs are associated with lightning

4. TGFs are produced near thundercloud tops

5. TGFs are bright – have very high fluxes

At least ~10^{17} energetic electrons in <0.1ms



Fishman et al., 1994

How do a TGF look like?

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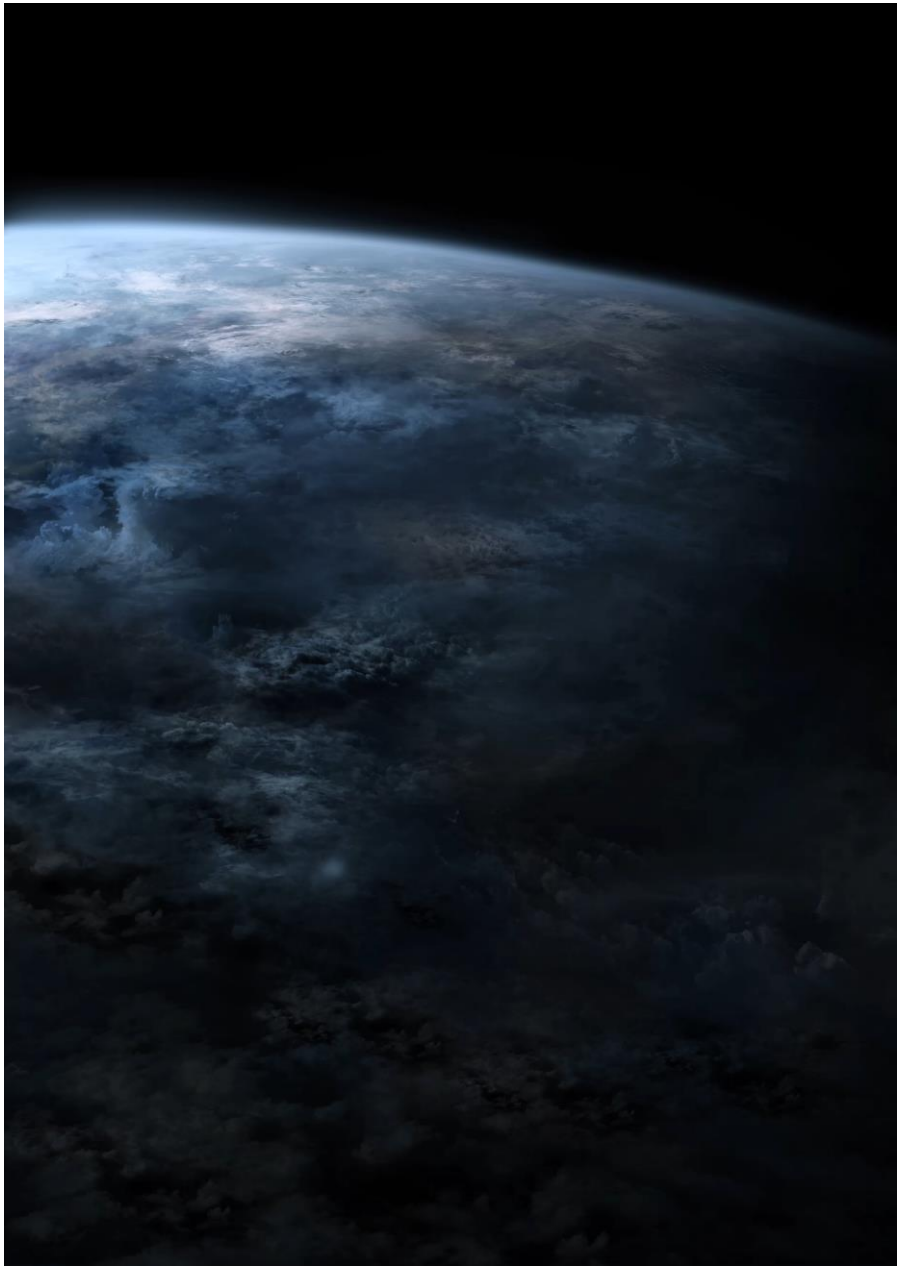

Neubert et al., 2019, Science

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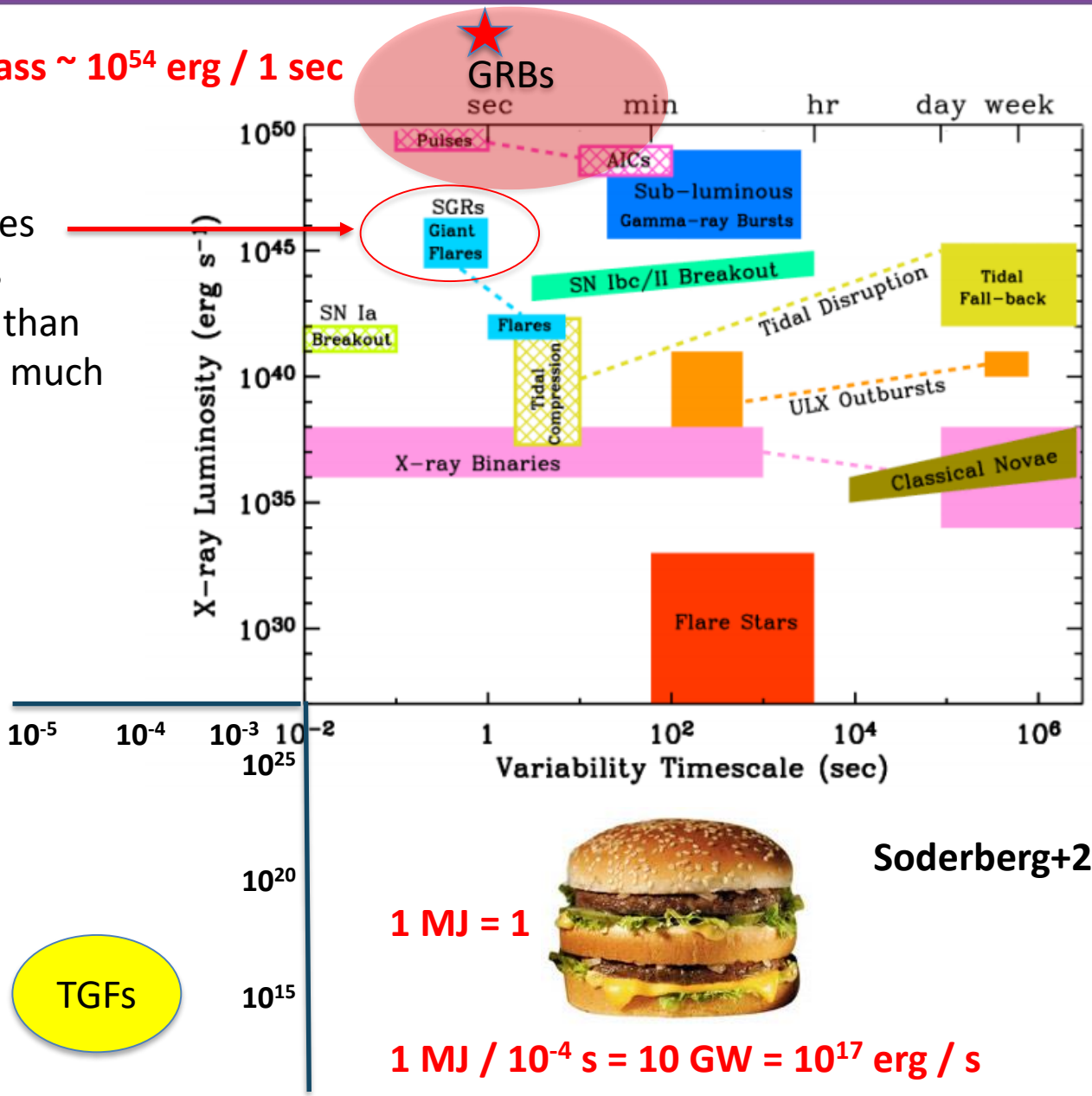
1 solar mass ~ 10^{54} erg / 1 sec

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 Scuptor galaxy

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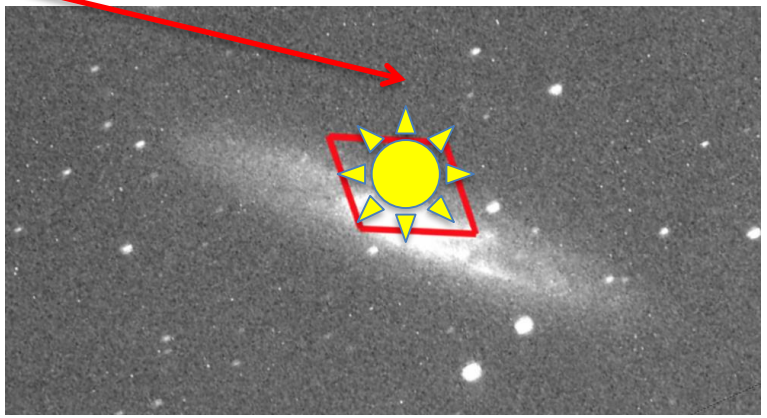
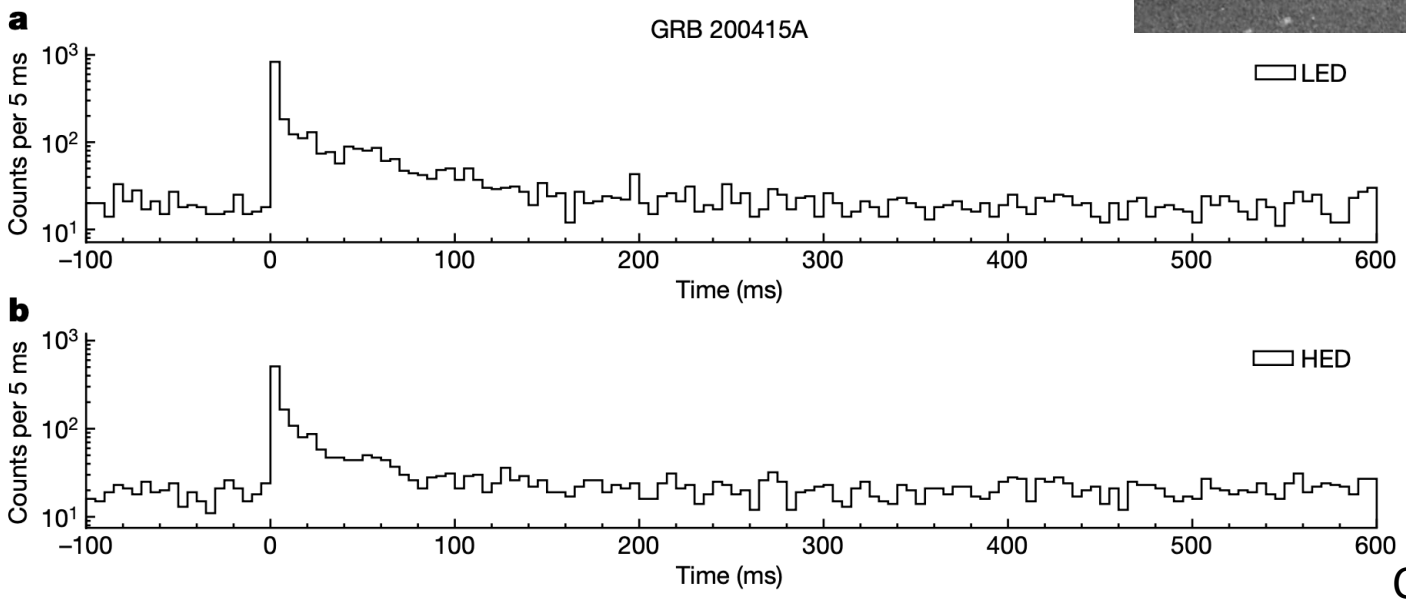
11 million light years





Castro-Tirado et al. 2021

A closer look...

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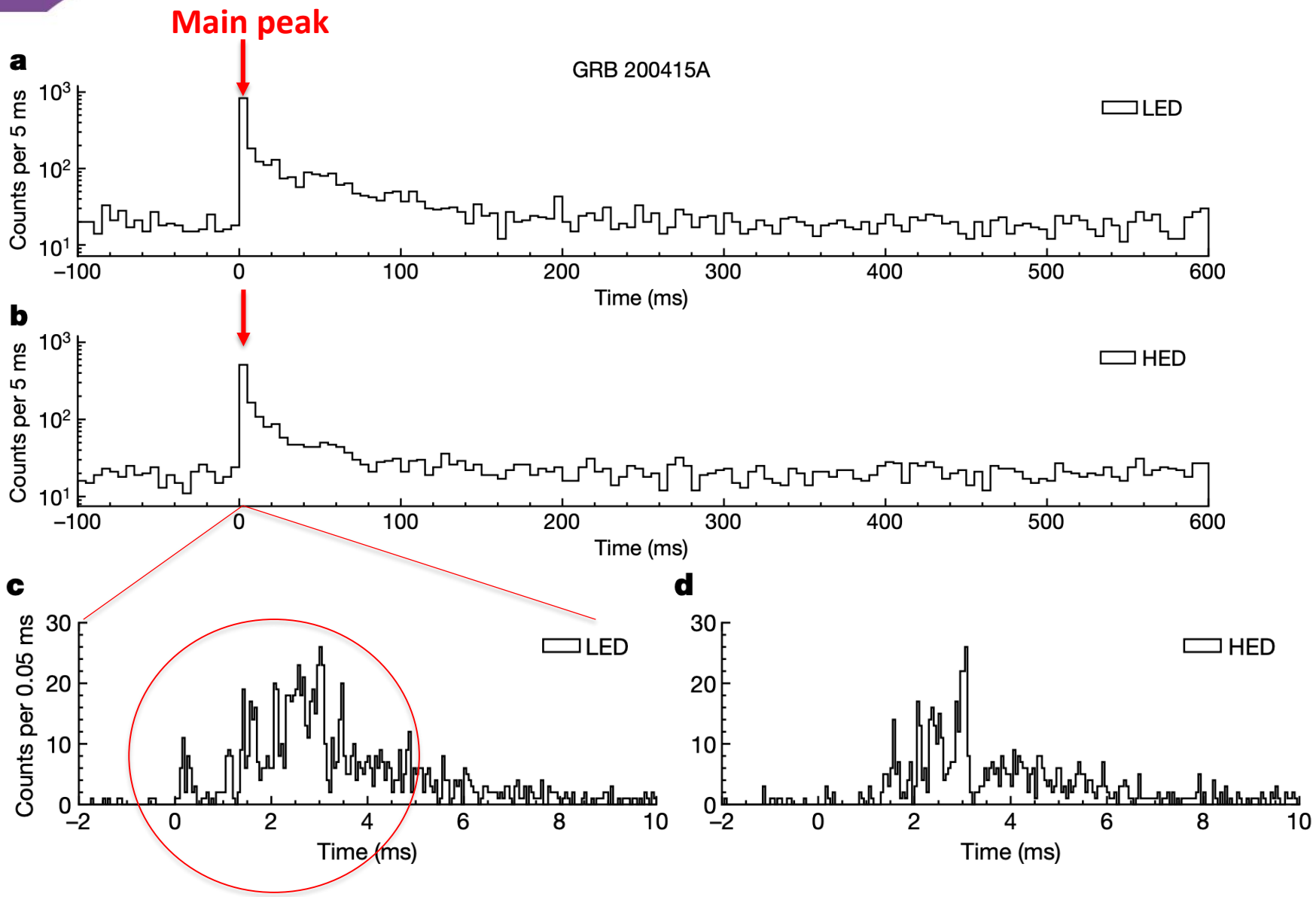

Time structure? Spectral evolution?

Castro-Tirado et al. 2021

Spectral evolution: anathomy of the emission

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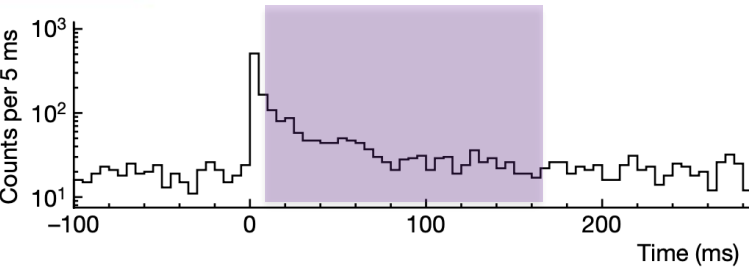
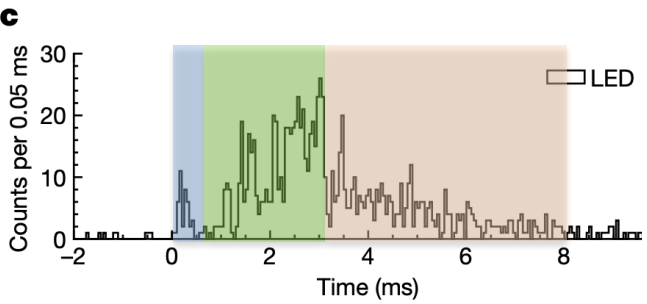
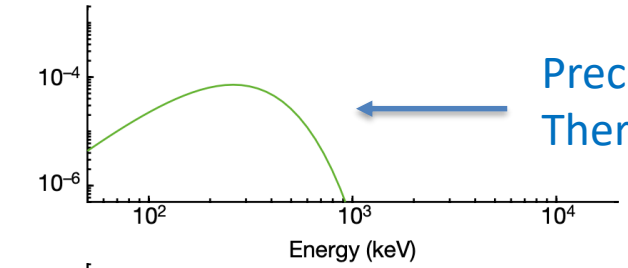
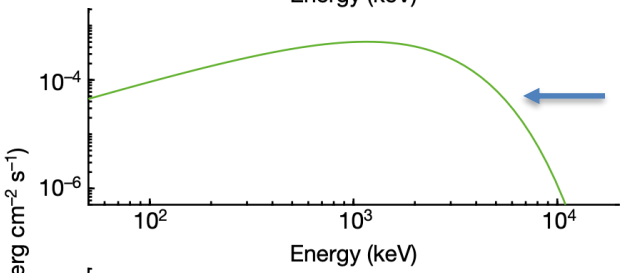


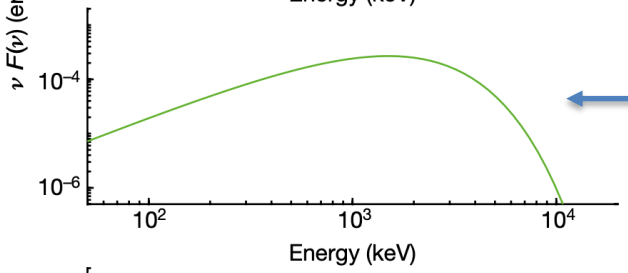




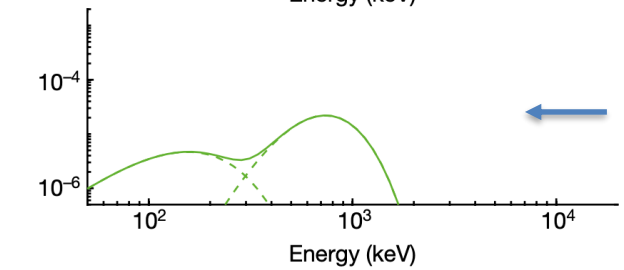
Precursor 0 – 0.8 ms
Thermal fireball



Peak 0.8 – 3.2 ms
Acceleration to higher energies



Decay 3.2 – 8 ms
Further higher energies, but flux decreasing



Tail 8 – 160 ms
Decreasing in energies and flux, the thermal fireball emerges again

Scenario:

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

Castro-Tirado et al. 2021

Time variability: insights into the source

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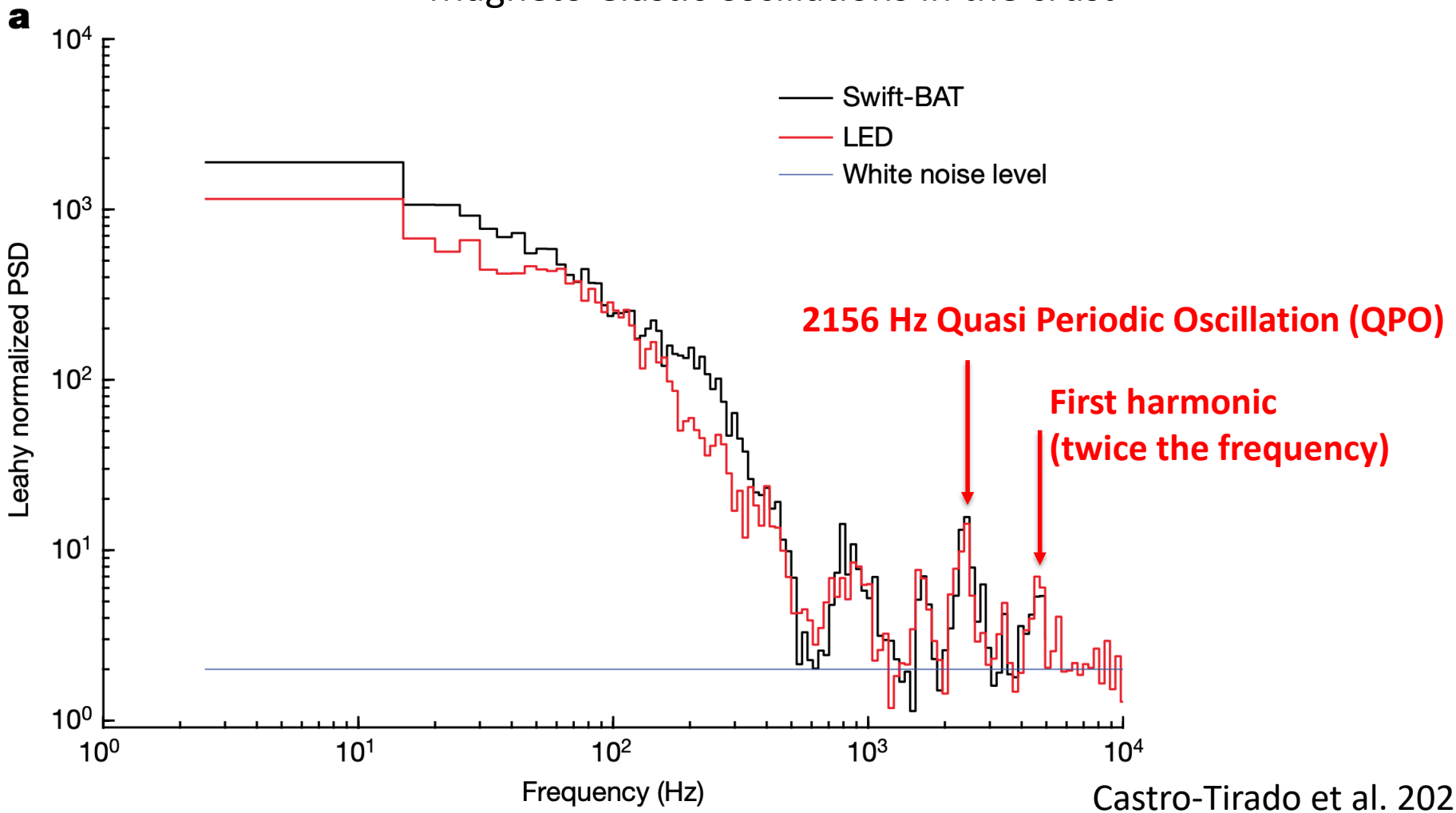
Two physical scenarios:

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



Castro-Tirado et al. 2021

Why ASIM?

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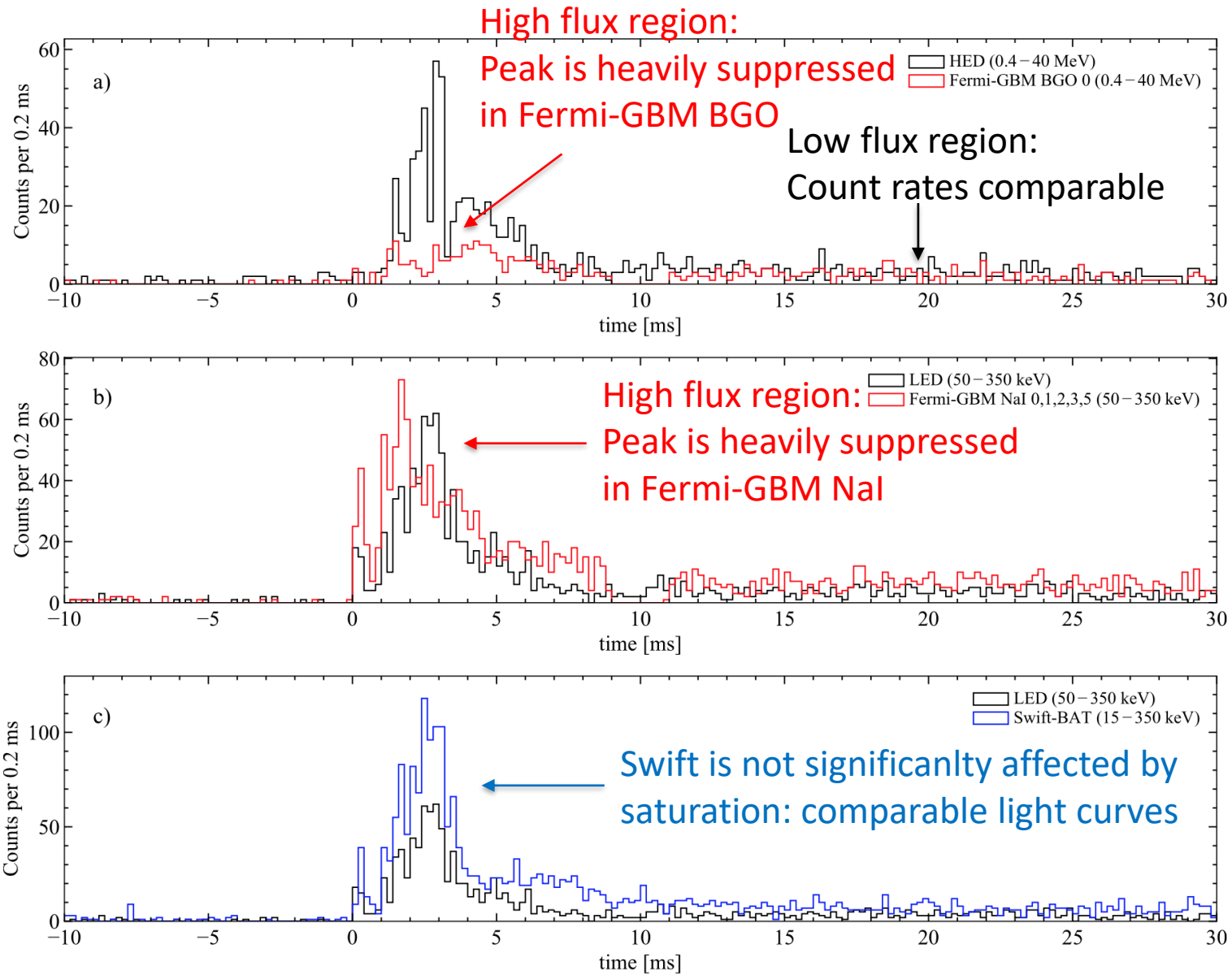

A great scientific achievement...

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

- 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 cout 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!

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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

The discovery of GRBs and TGFs

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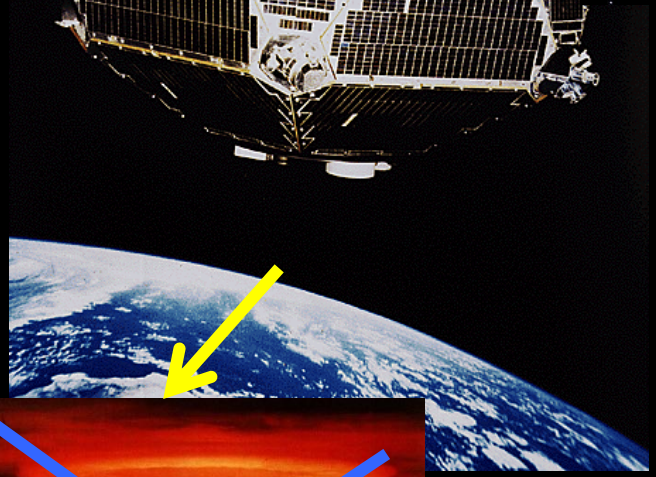
Vela satellites '70-'80 looking down to Earth...

GRB

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



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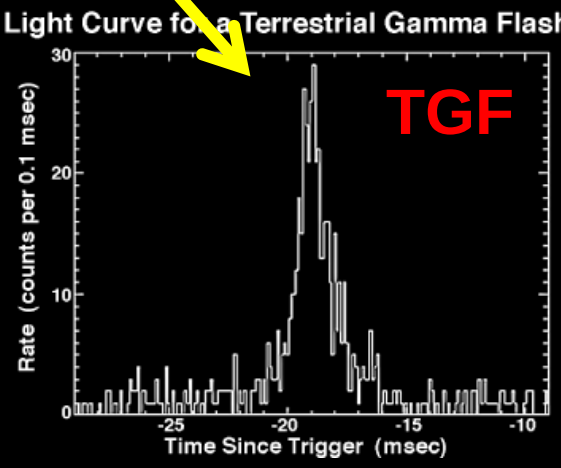

Expect the unexpected...

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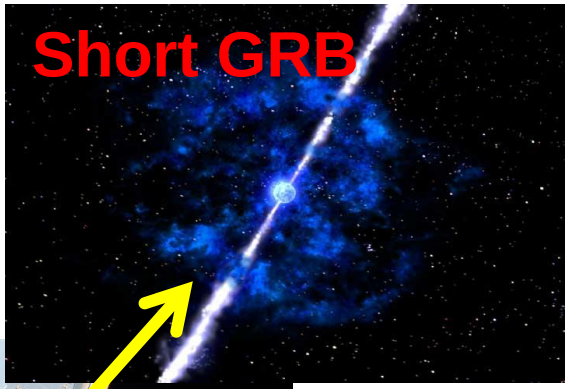
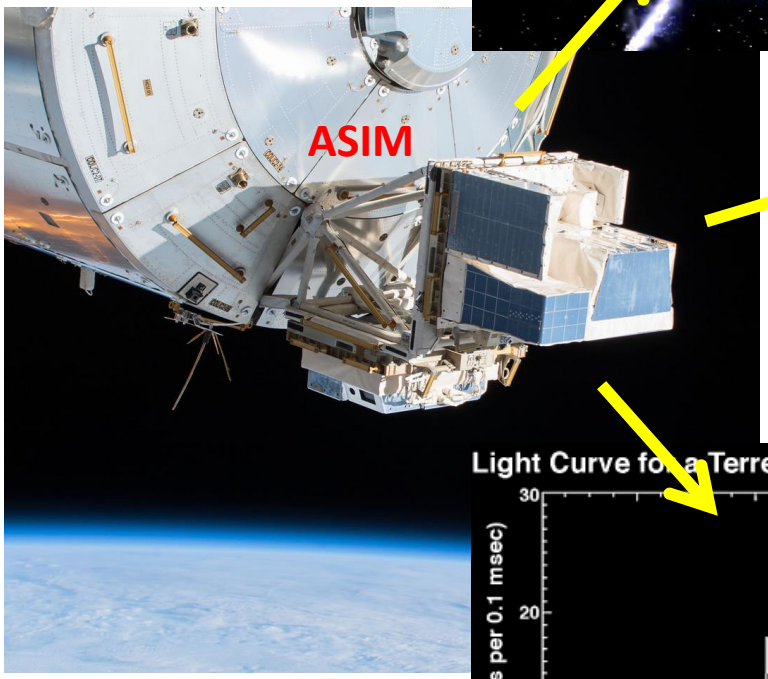
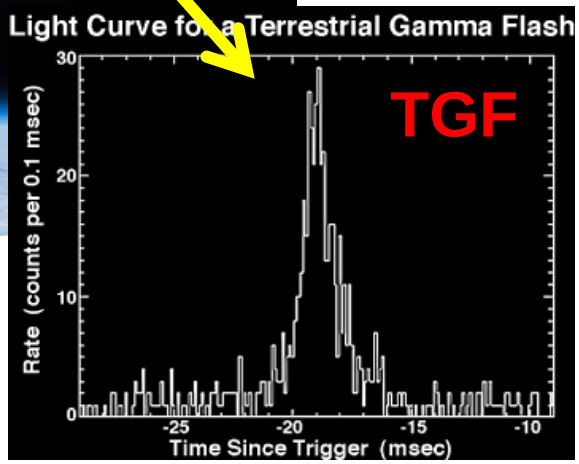
'Kind of' expected





Unexpected: discovery!



Expected by design

Up for more discoveries...

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