BIRKELAND CENTRE
FOR SPACE SCIENCE

Instrumentation for TGF detection

M. Marisaldi, UiB, 23/05/2019

UNIS
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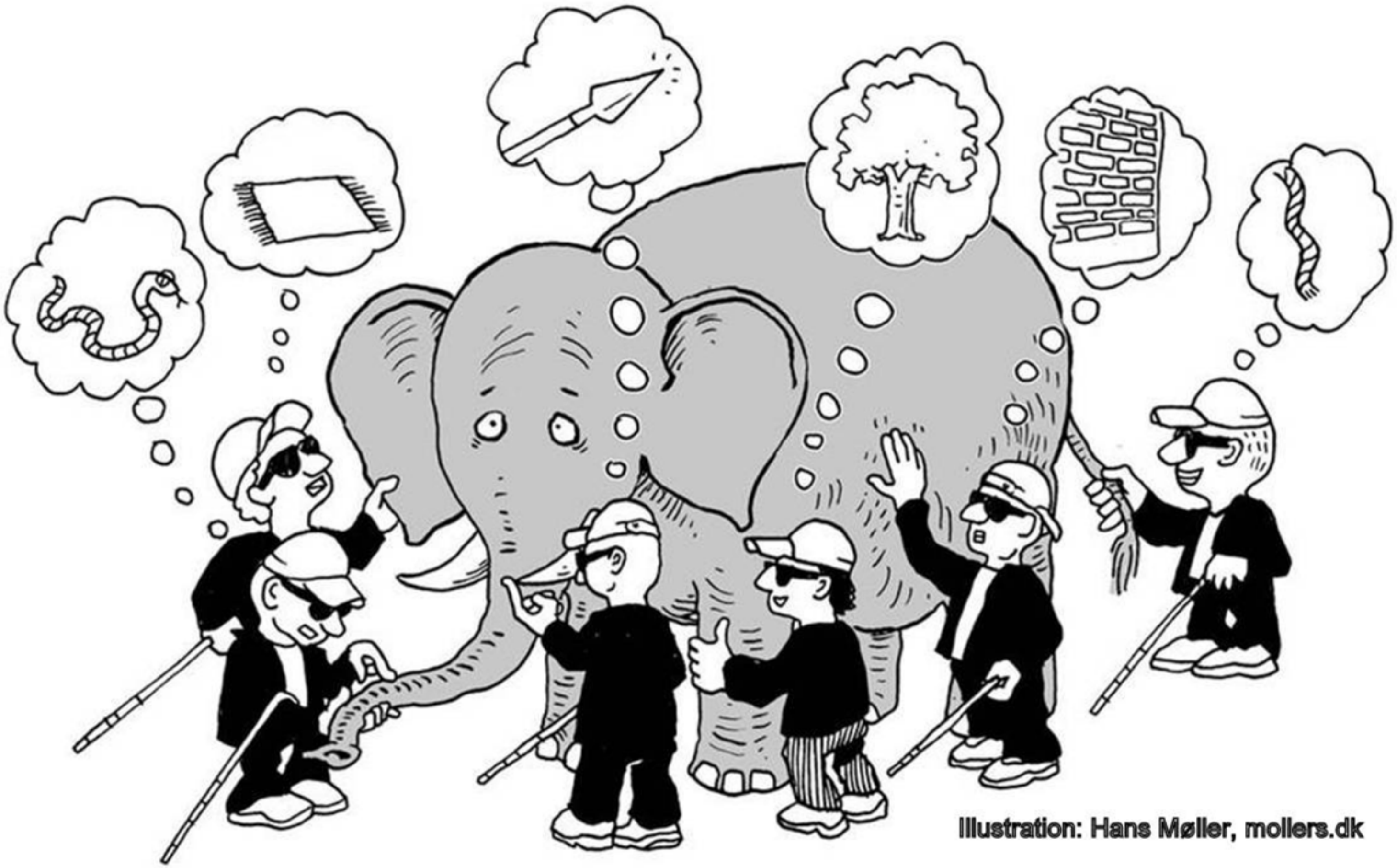
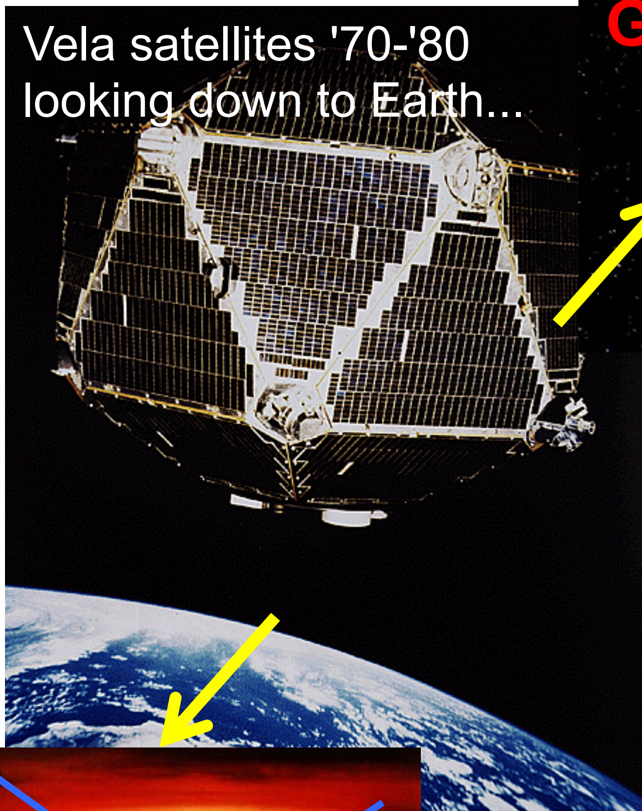
Det skapende universitet

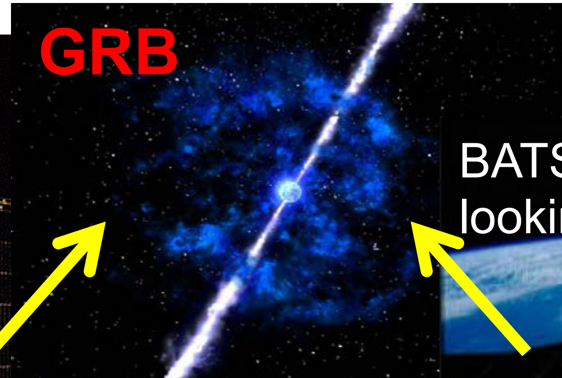
What do we really know about ~~elephants~~ TGFs?

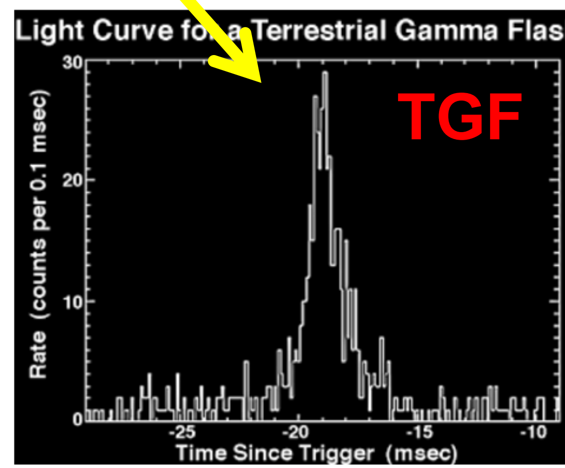


Credits: Michael Briggs, EGU 2014
Hamid Rassoul, Bergen, 2019

The discovery of TGFs

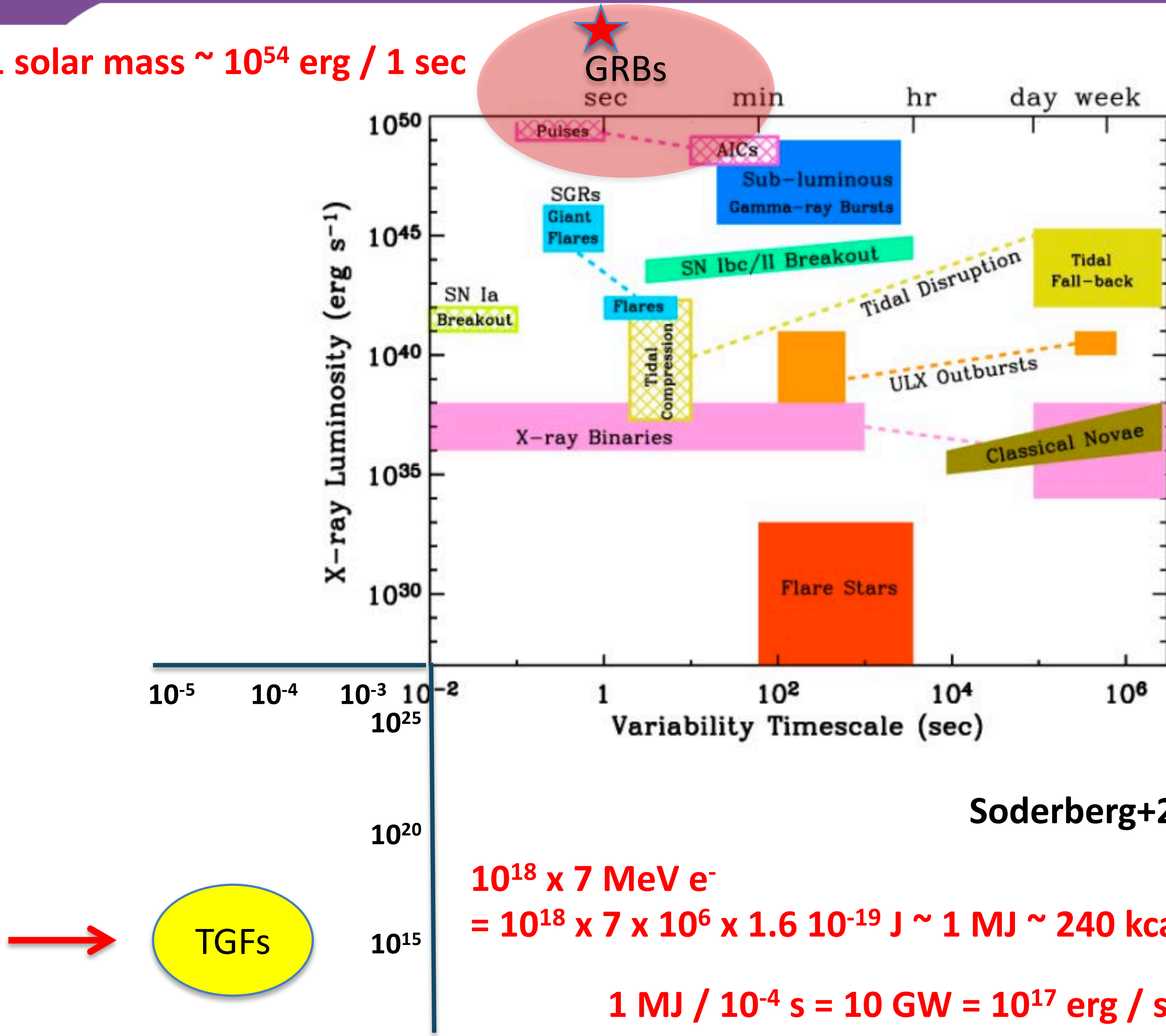






The transient high-energy universe (including Earth)

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



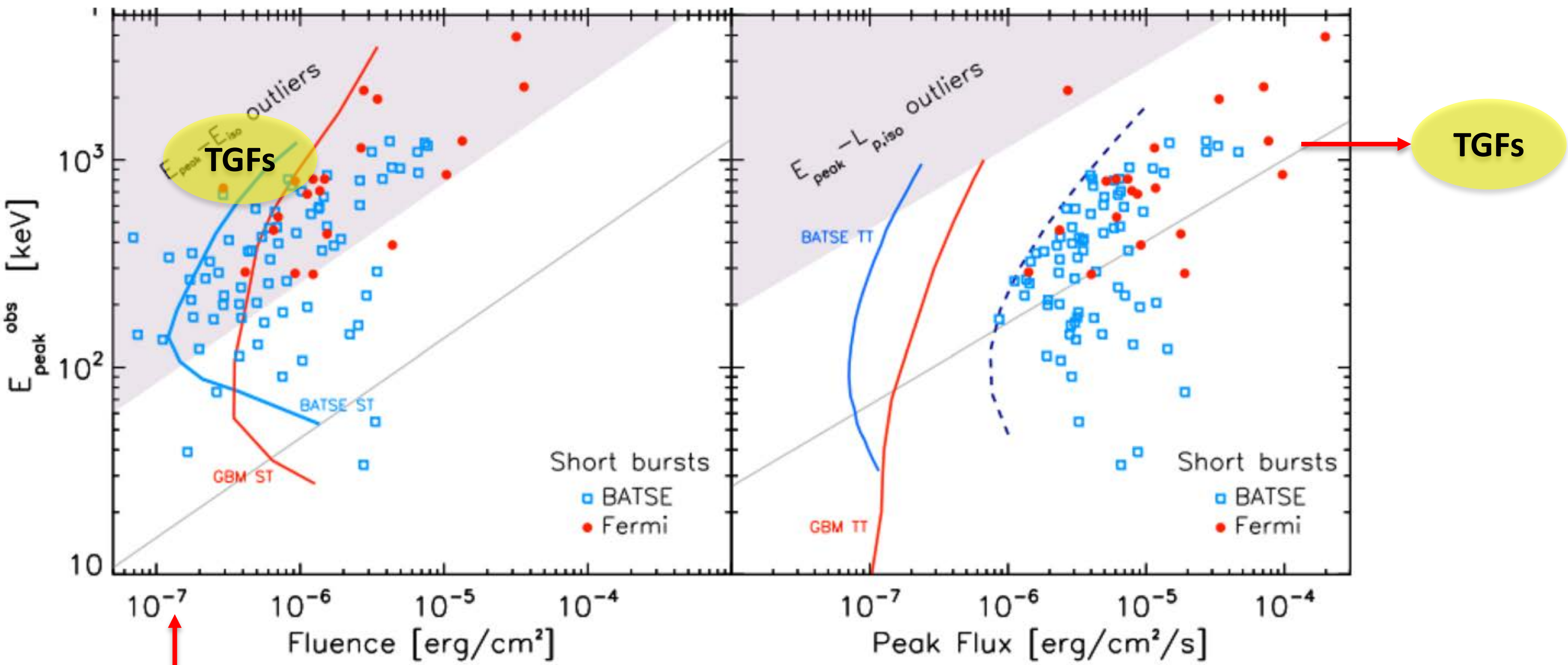
Soderberg+2009

10^{18} x 7 MeV e^-

= 10^{18} x 7 x 10^{6} x 1.6 10^{-19} J ~ 1 MJ ~ 240 kcal = 1

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

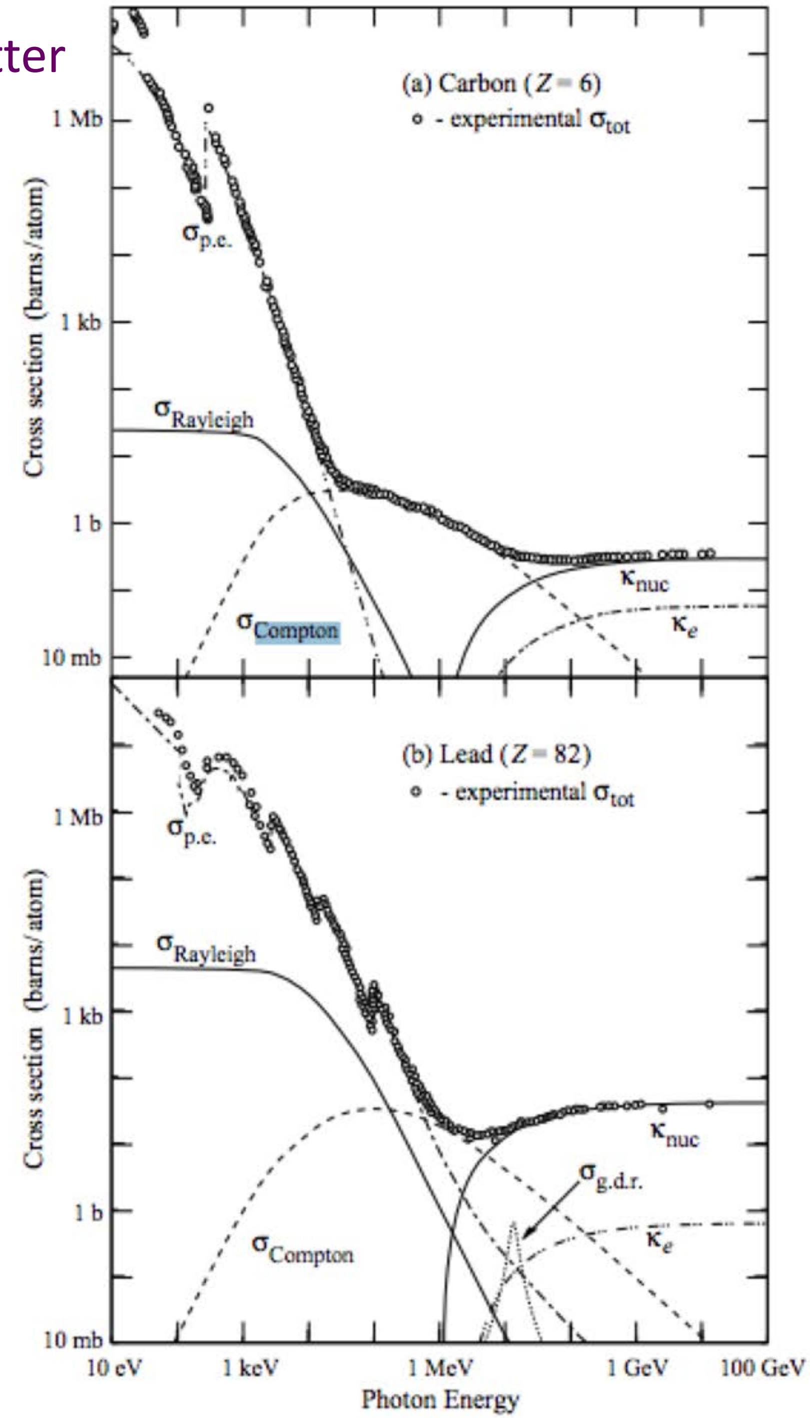
Why BATSE could detect TGFs



0.1 ph/cm^2 x ~1 MeV ~1.6 10^{-7} erg/cm^2

Basic ingredient #1: Interaction of photons in matter

- Three distinct regimes, depending on which interaction type is dominant
- The cross section is material dependent → strong constraints on detectors material choice
- E< ~200 keV: photoelectric effect is dominant
- ~200 keV < E < ~10 MeV Compton effect is dominant
- E > ~10 MeV pair production is dominant



pdg.lbl.gov

Basic ingredient #2: effective area

- Effective area of a detector is the geometrical area that an ideal detector with detection efficiency 1 would have in order to detect the same number of counts as detected by the real detector

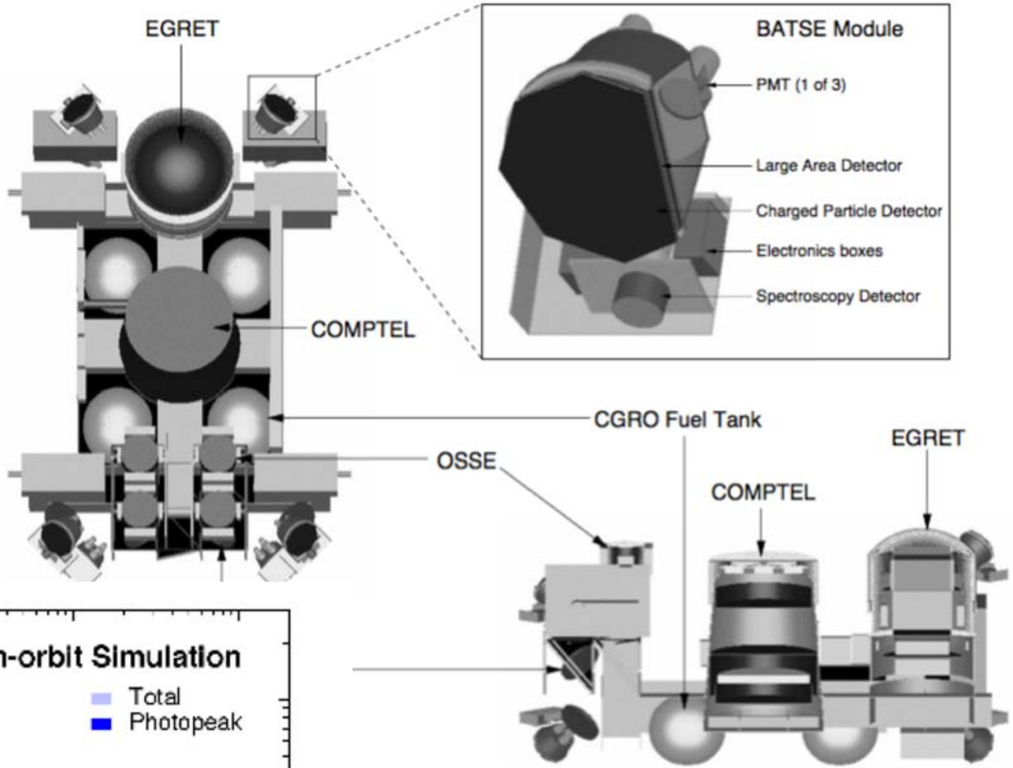
- For practical purposes:

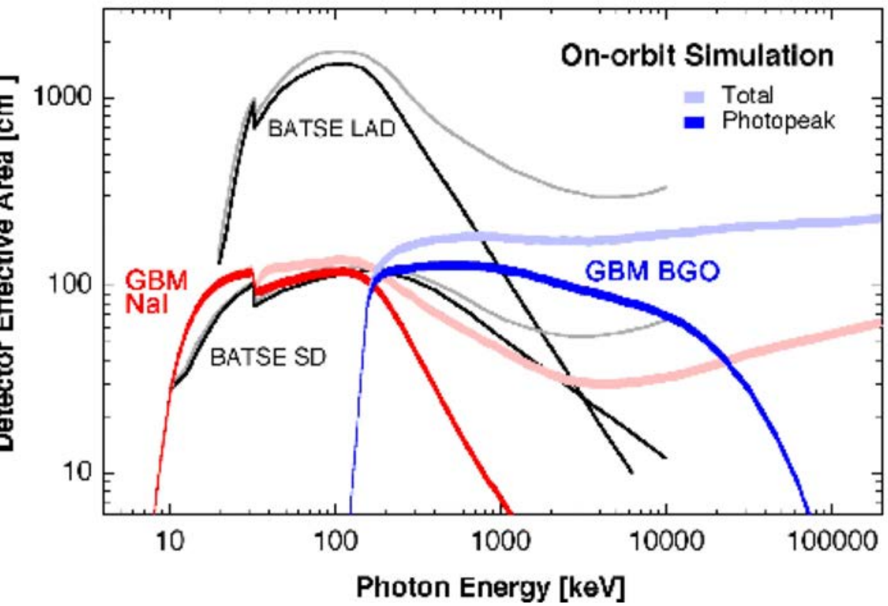
$$\underbrace{A_{eff}(E, \theta)}_{\text{Effective area}} = \underbrace{A_{geom}(\theta)}_{\text{Geometrical area}} \times \underbrace{\varepsilon(E,\theta)}_{\text{Interaction efficiency + Events selection}}$$

- Depends on photon energy and incidence angle
- Typically evaluated by MC simulations using the detector's mass model
- Can define different effective areas:

  total effective area (need assumptions on the incoming spectrum), photopeak effective area (strongly depends on type of interaction)

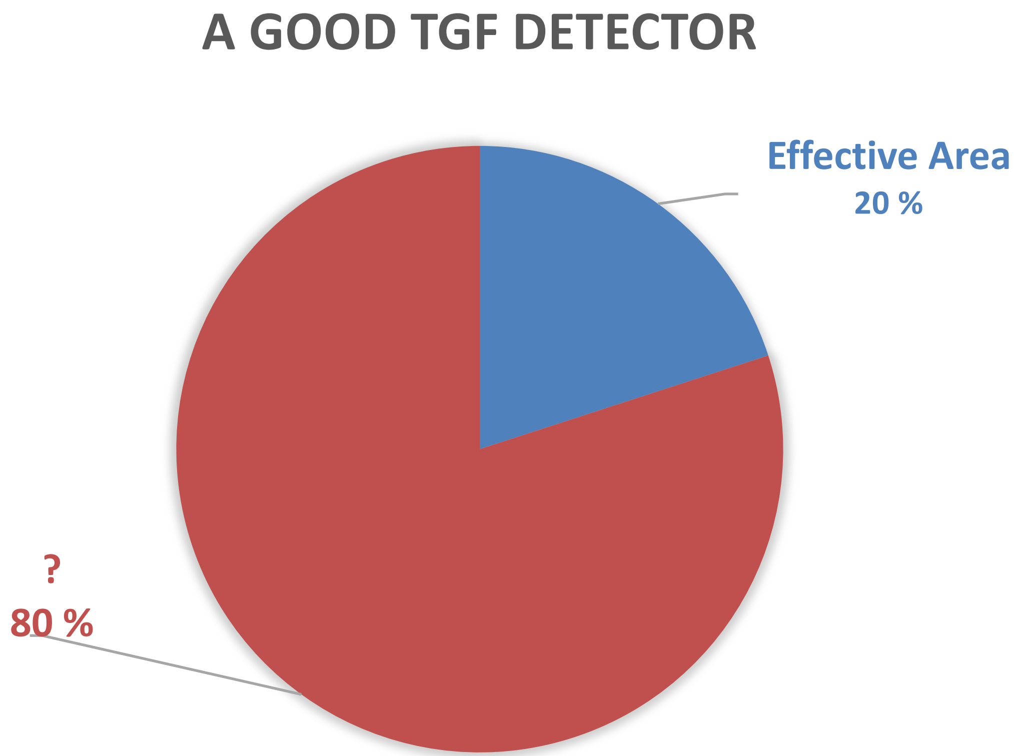
Why BATSE could detect TGFs



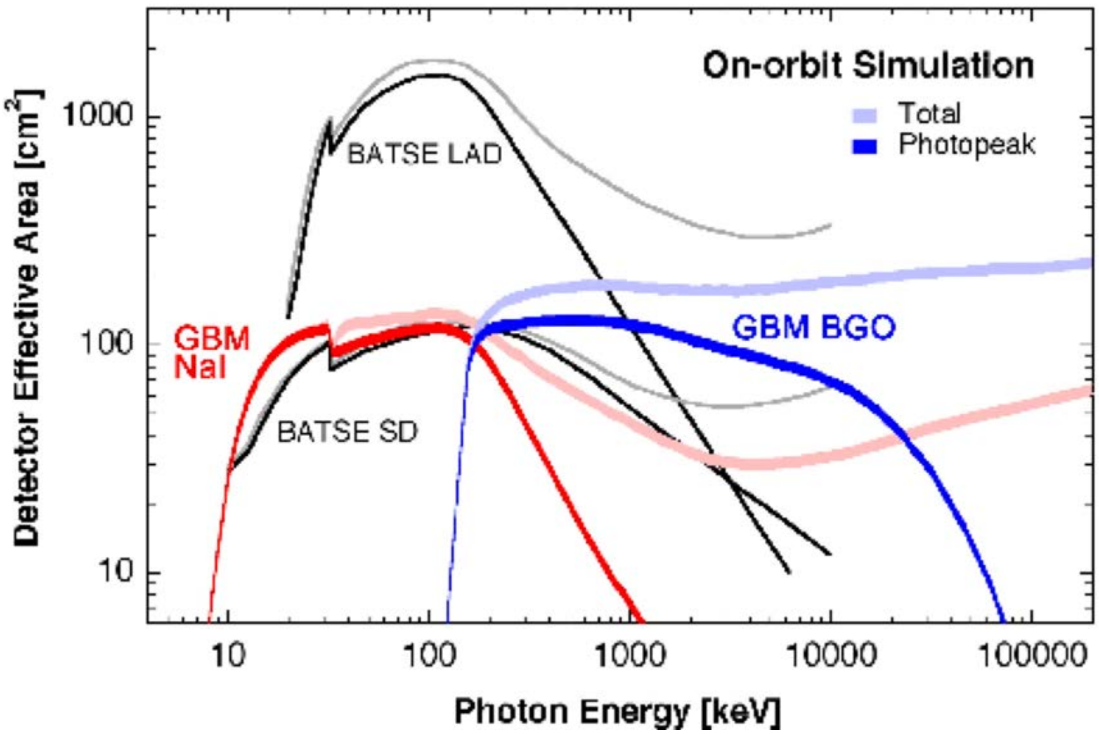


Shaw+2003

What makes it a good TGF detector?



But...



- BATSE has 10x the effective area of Fermi GBM
- BATSE detected 79 TGFs in 9 years

- While Fermi GBM detects about 800 TGFs / year!
- Why???

The data acquisition strategy

- Two main data acquisition strategies:
  - Continuous acquisition (if telemetry budget allows it): all counts are collected and sent to ground
  - Triggered acquisition: data are collected and sent to ground only if a trigger condition is satisfied

If N_C in a time window Δt exceeds a certain threshold N_T --> a trigger is issued

$$N_C > N_T = n\sqrt{N_B}$$

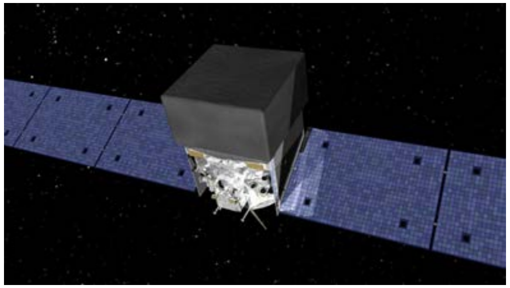
Where n ≈ 5, N_B number of background counts in Δt

- In practice a trigger logic can be much more complicated
- The key parameter is the time window Δt: it must be close to the duration of the transient that we want to detect in order to allow for the maximum sensitivity

CGRO - BATSE

Triggered: Min Δt = 64 ms
9 TGFs / year
Can trigger only on very bright TGFs!

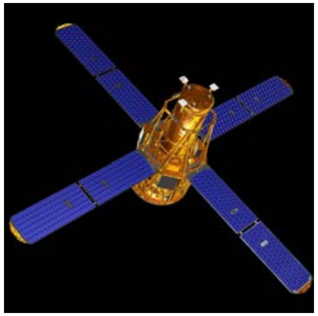
Fermi - GBM



Triggered: Min Δt = 16 ms
100 TGFs / year

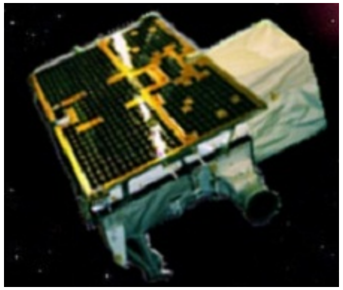
Continuous data acquisition since 2012:
800 TGFs / year

RHESSI



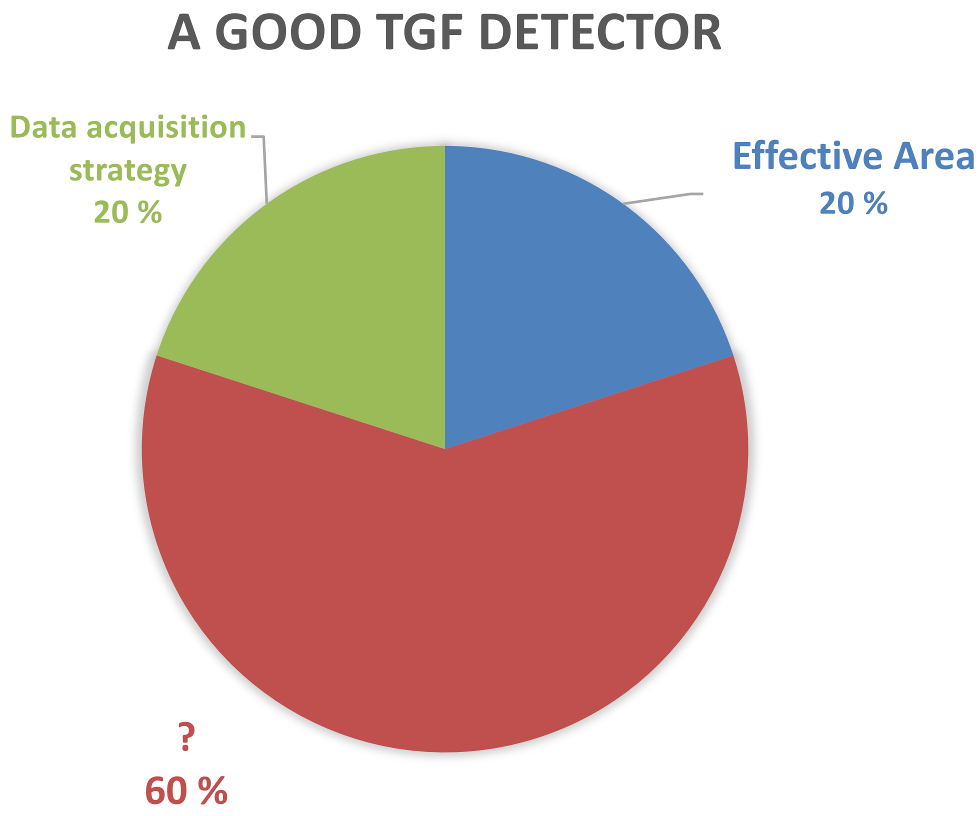
Continuous data acquisition
350 TGFs / year

AGILE

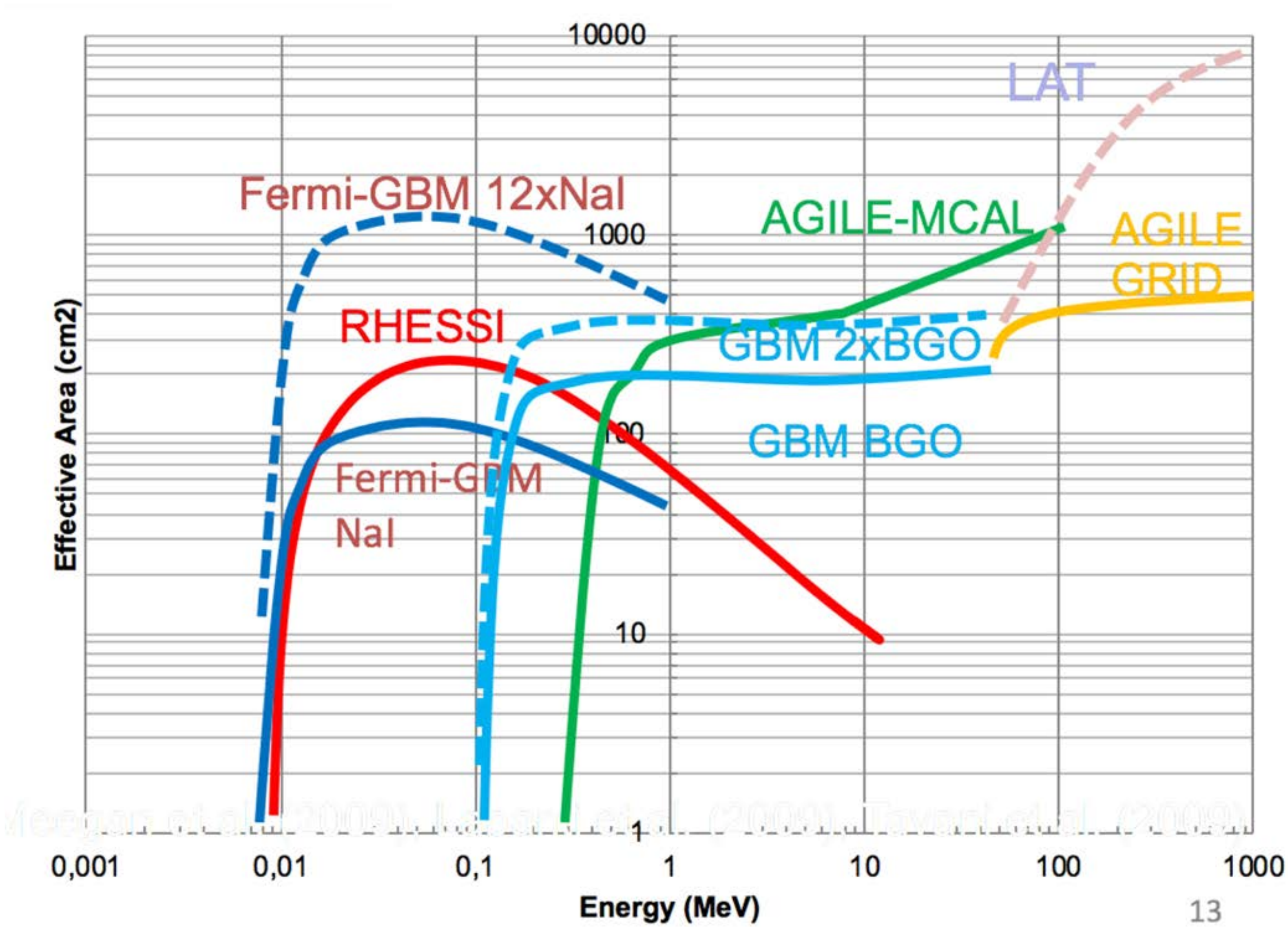


Triggered: Min Δt = 0.3 ms
1000 TGFs / year

What makes it a good TGF detector?

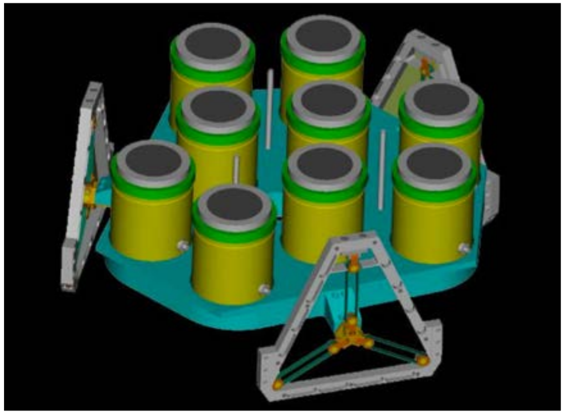


Detector material and system architecture

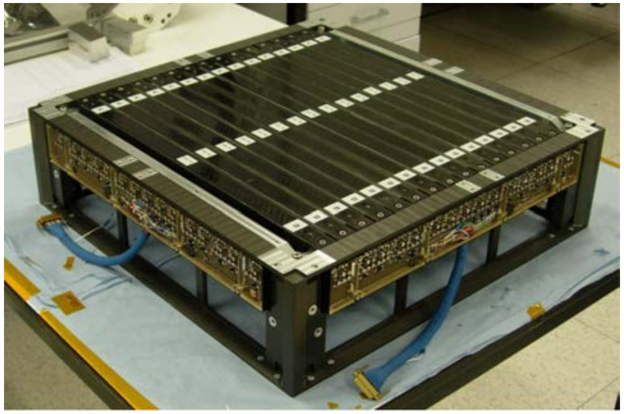


Detector material and system architecture

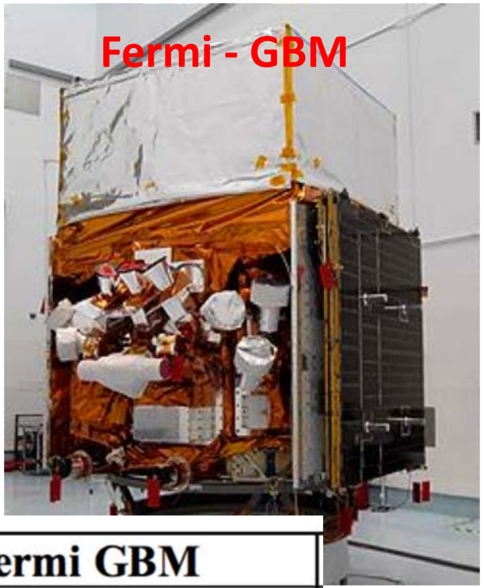
RHESSI - GeD



AGILE - MCAL

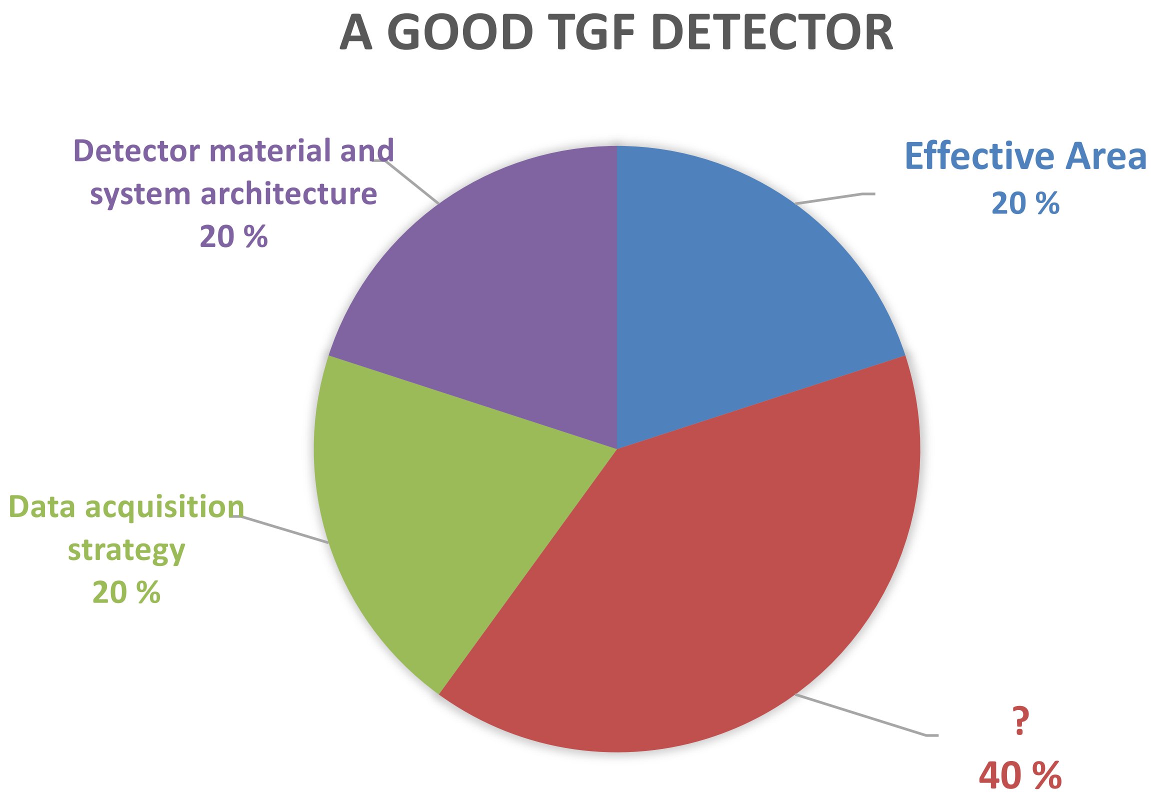


Fermi - GBM



	RHESSI	AGILE MCAL	Fermi GBM
Operative since	2002	2007	2008
Orbit inclination and altitude	38° 600 km	2.5° 540 km	26° 540 km
Detector type	HPGe	CsI(Tl) scintillator with solid state readout	NaI(Tl) and BGO scintillator with PMT
Energy range	0.015 – 20 MeV	0.35 – 100 MeV	0.015 – 40 MeV
Effective area for typical TGF spectrum	260 cm^2	220 cm^2	160 cm^2 (1xBGO)
Acquisition type	continuous	triggered	continuous
TGFs/year	~340	~800	~800

What makes it a good TGF detector?

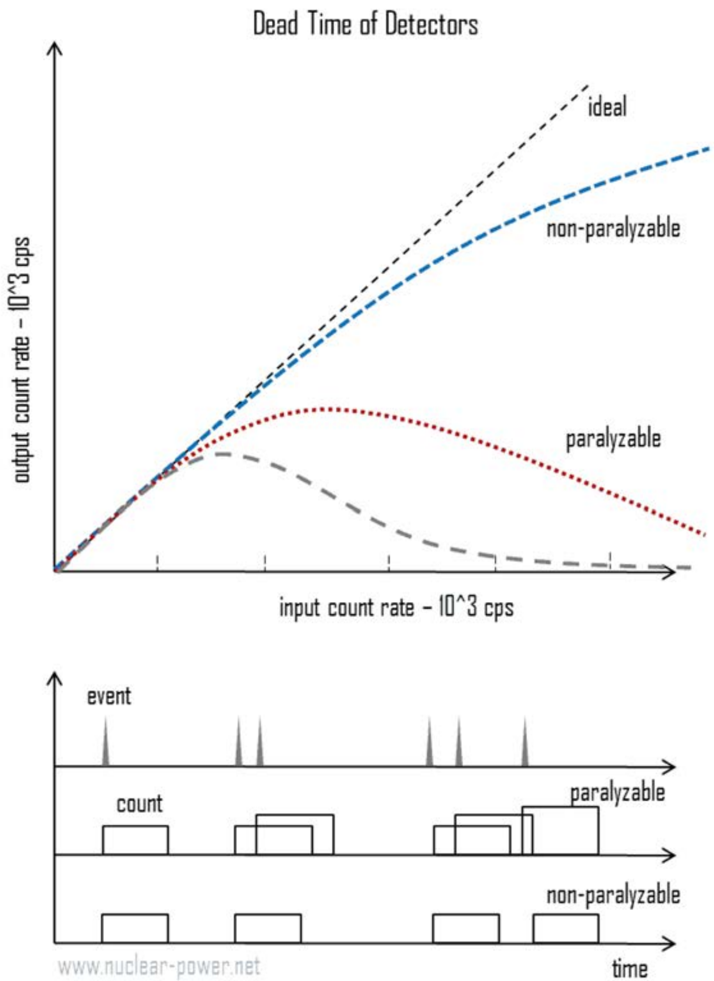


The front-end electronics (FEE)

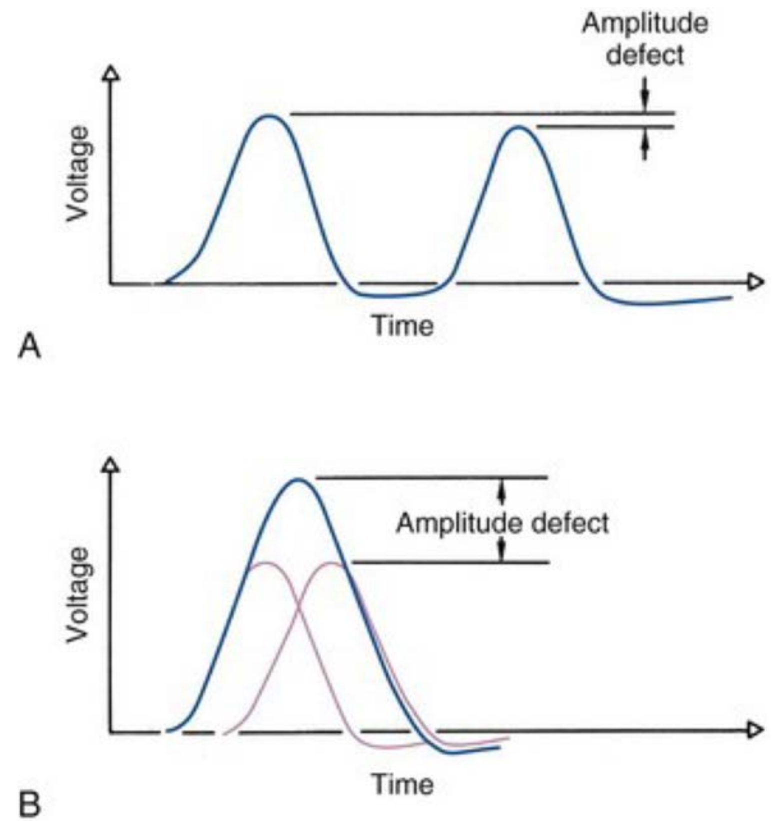
- FEE takes care of the first conversion of a charge pulse (output of a PMT or a solid-state detector), into a voltage signal that can subsequently be measured
- The FEE can be responsible for several instrumental effects that can significantly affect the measurements
- This is particularly true for TGFs, which deliver gamma-ray fluxes above the design limits of most detectors designed for astrophysics
- ALL TGFs observing missions so far are, to some extent, affected by instrumental effects driven by the FEE
- Misinterpretation of these instrumental effects can lead to wrong scientific conclusions (e.g. Pulse alteration leads to incorrect energy spectra reconstruction)

Tipycal instrumental effects

Dead time

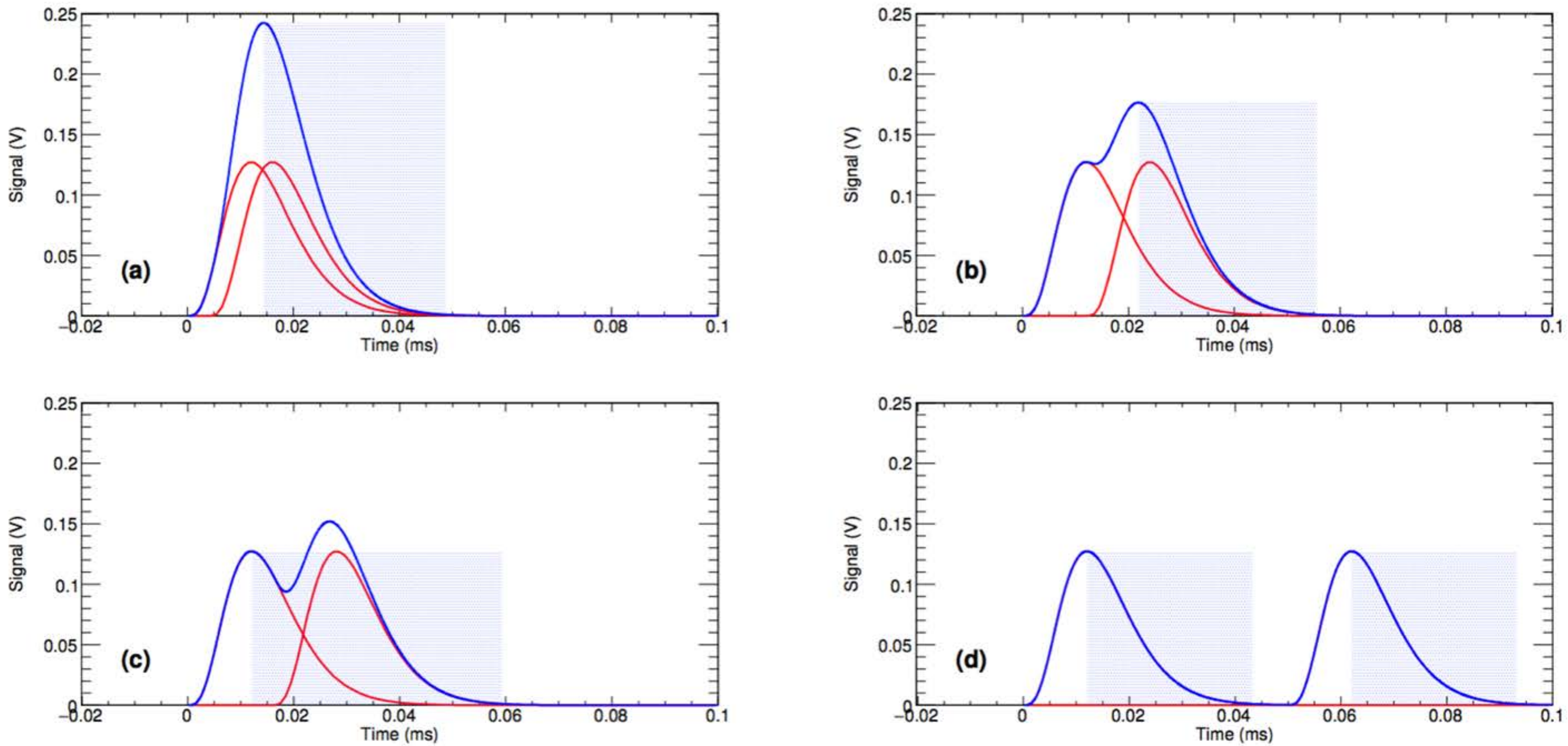


Pulse pile-up



Radiologykey.com

Tipycal instrumental effects (the real world)



AGILE MCAL FEE (Marisaldi+2019)

Tipycal instrumental effects (the real world)

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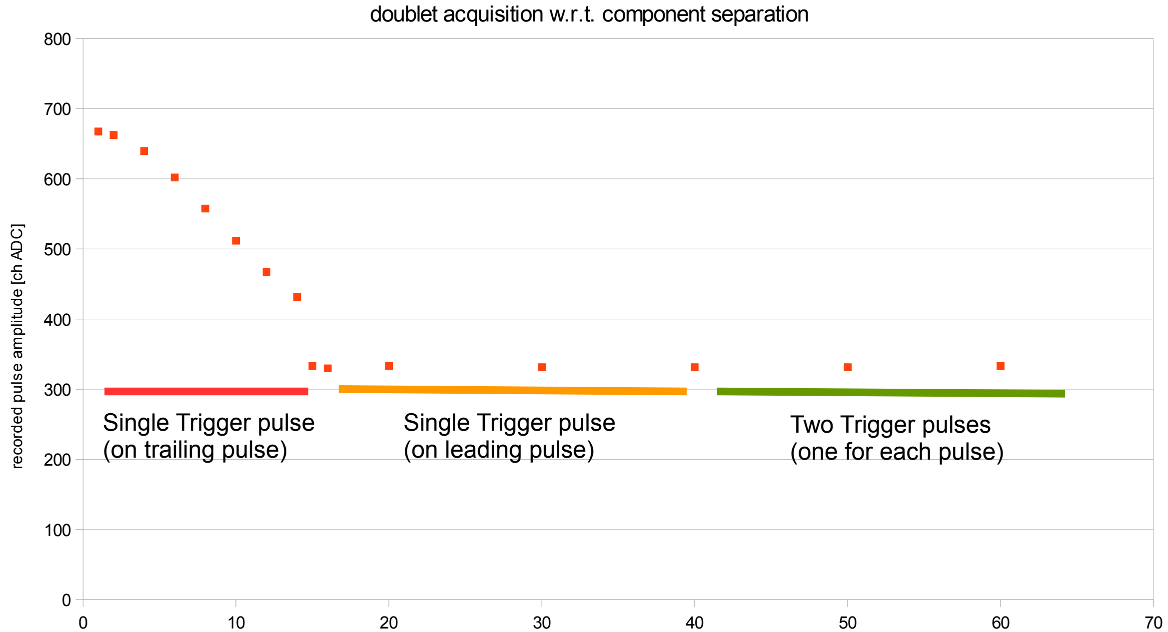
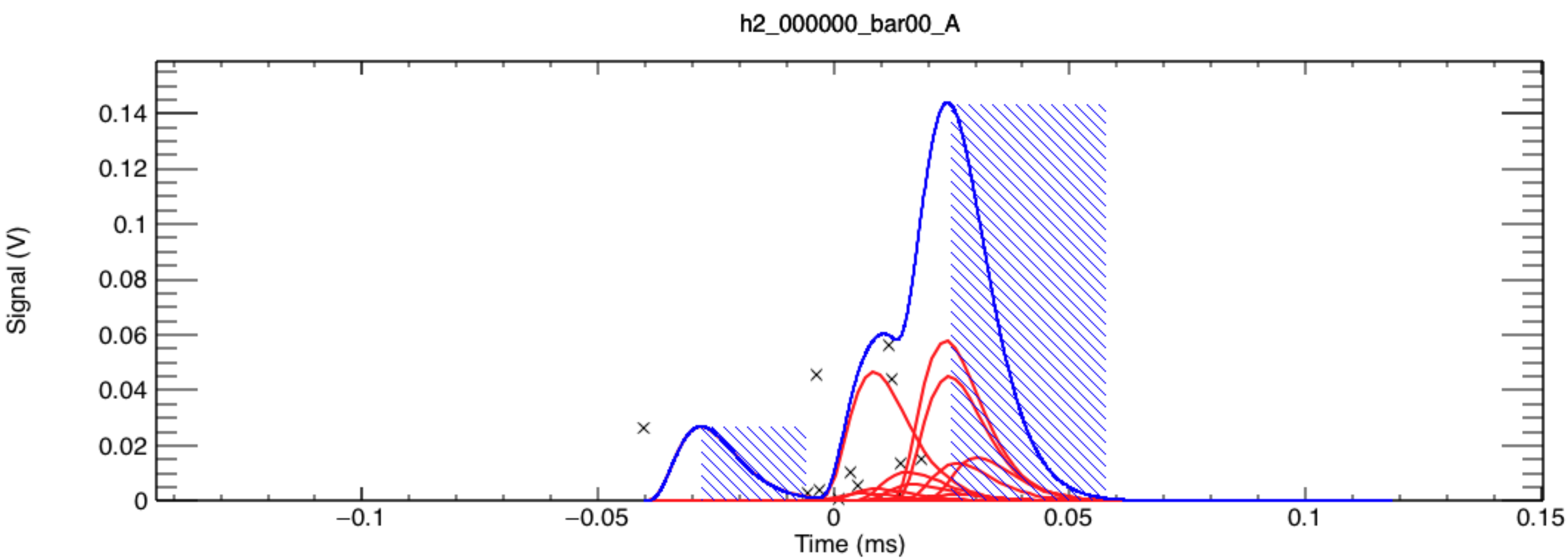
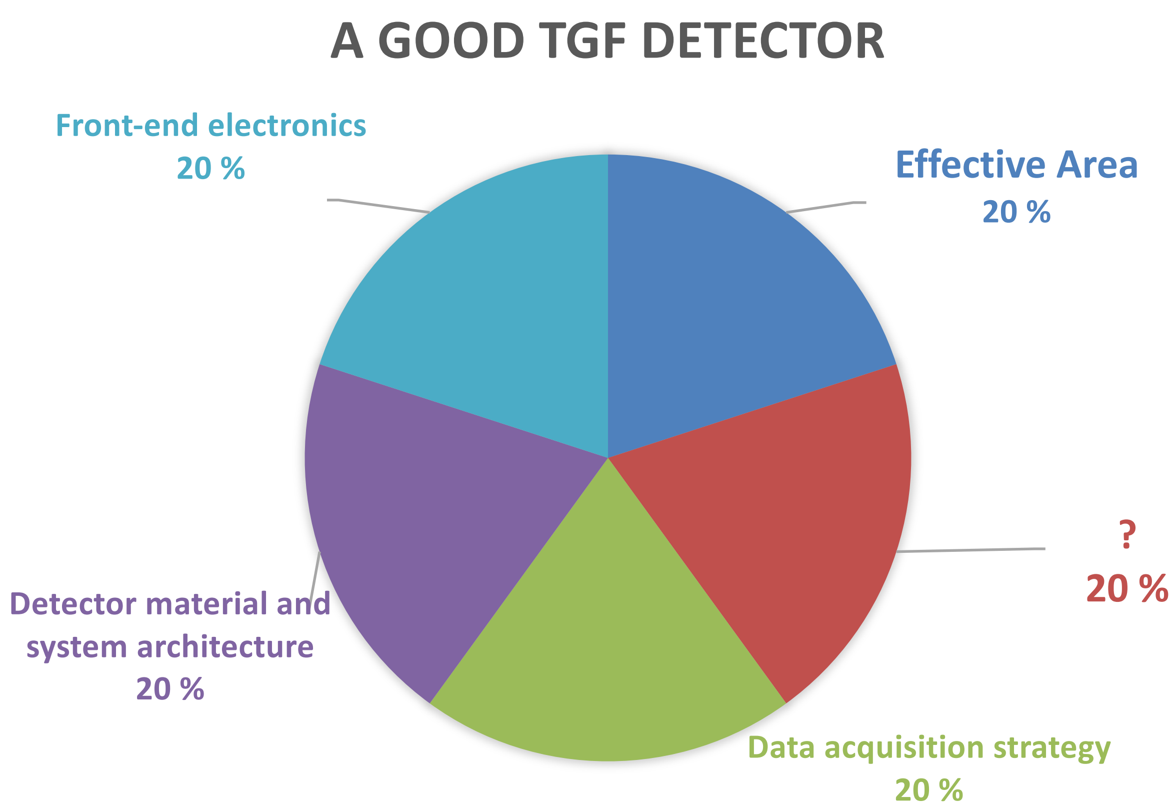
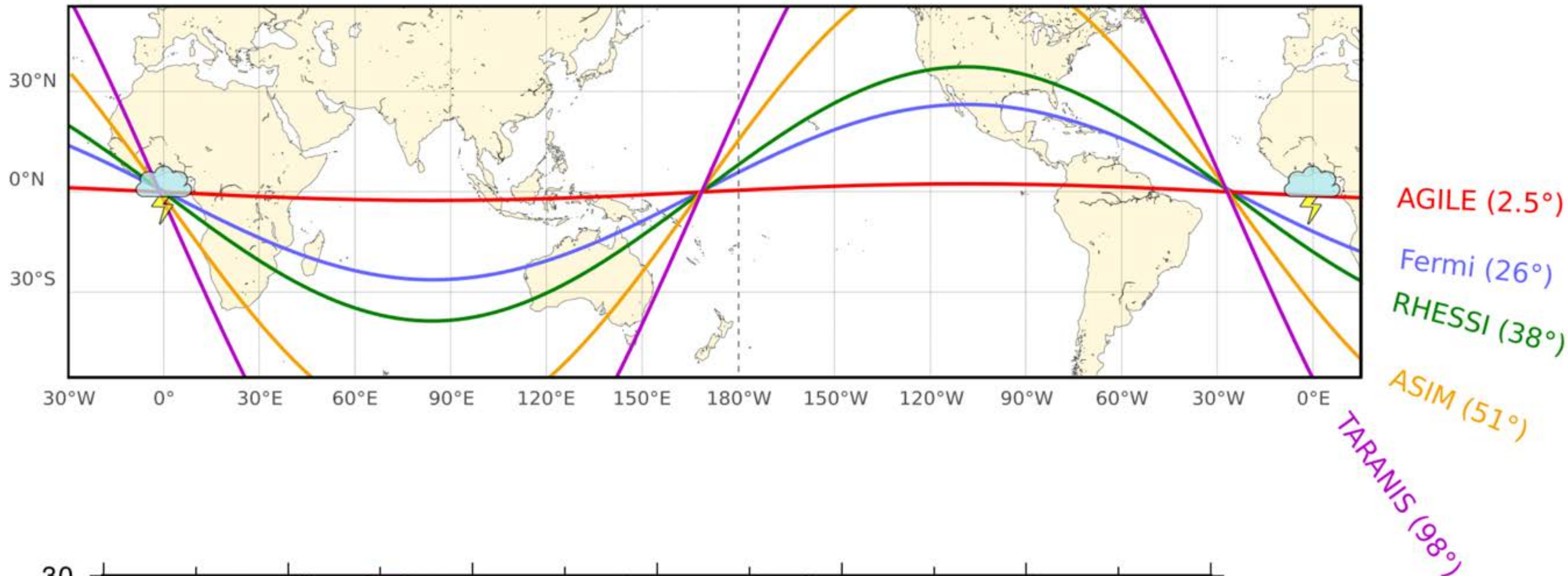


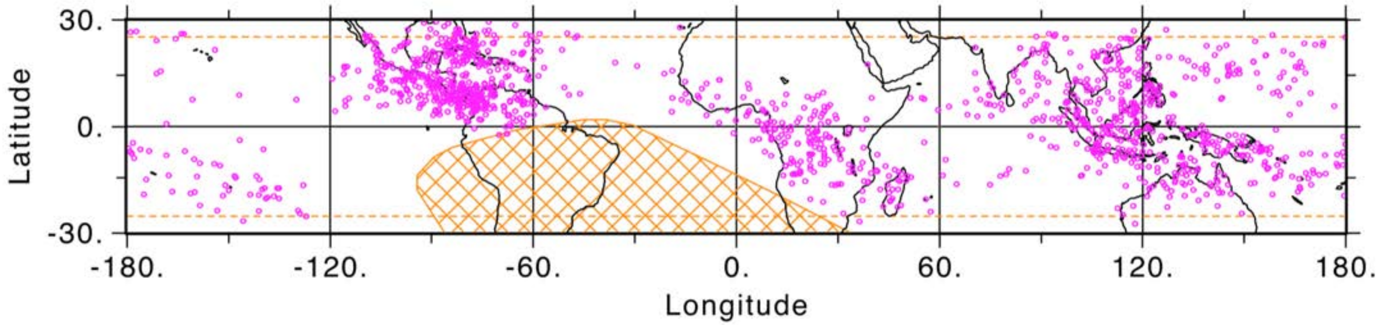


What makes it a good TGF detector?



Mission profile (orbital inclination)





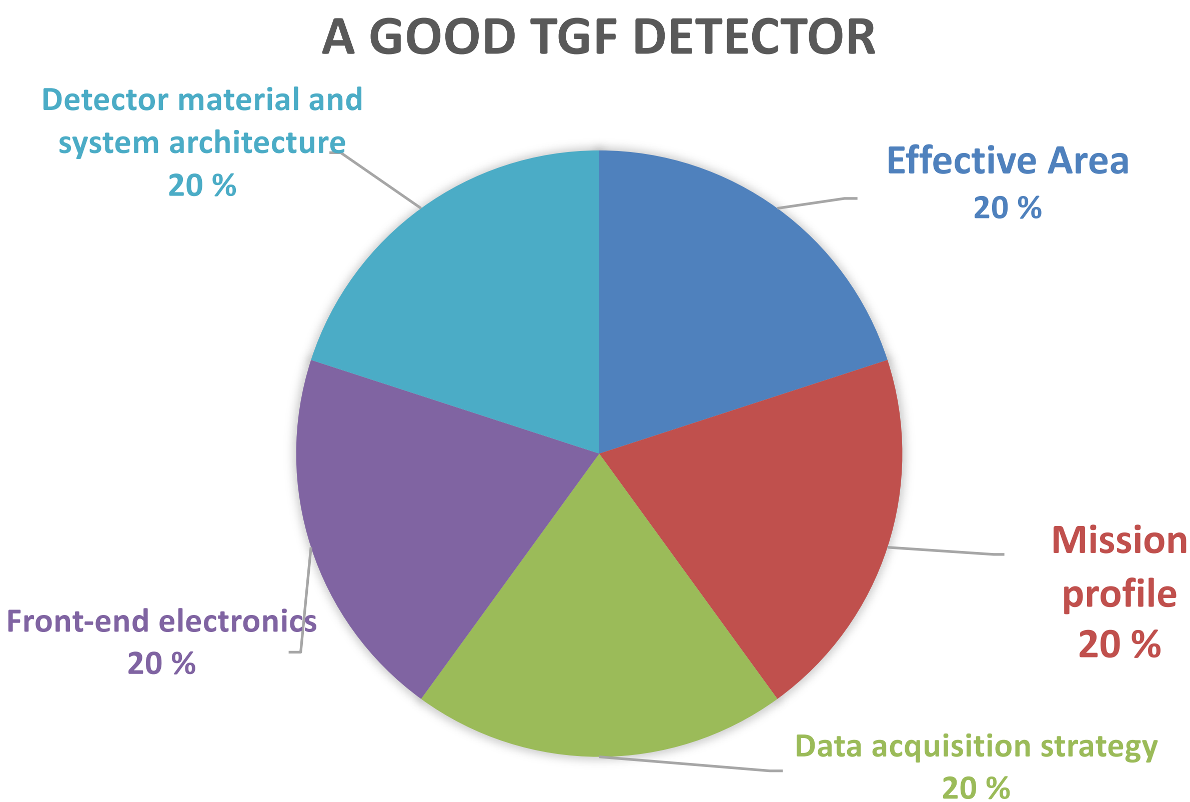
Roberts+2017

Mission profile (orbital inclination)

- All TGFs observing missions must be in LEO (the lower the better)
- Low orbital inclination:
  - Pros:
    - Fly over equatorial regions (high lightning activity)
    - High exposure → TGF surface detection density
    - Can revisit the same thunderstorm in consecutive passages
  - Cons: Cannot explore high-latitude regions

- High orbital inclination:
  - Pros: Explore high-latitude regions
  - Cons: Spend a lot of time on regions with limited lightning activity

What makes it a good TGF detector?



Who can detect TGFs?

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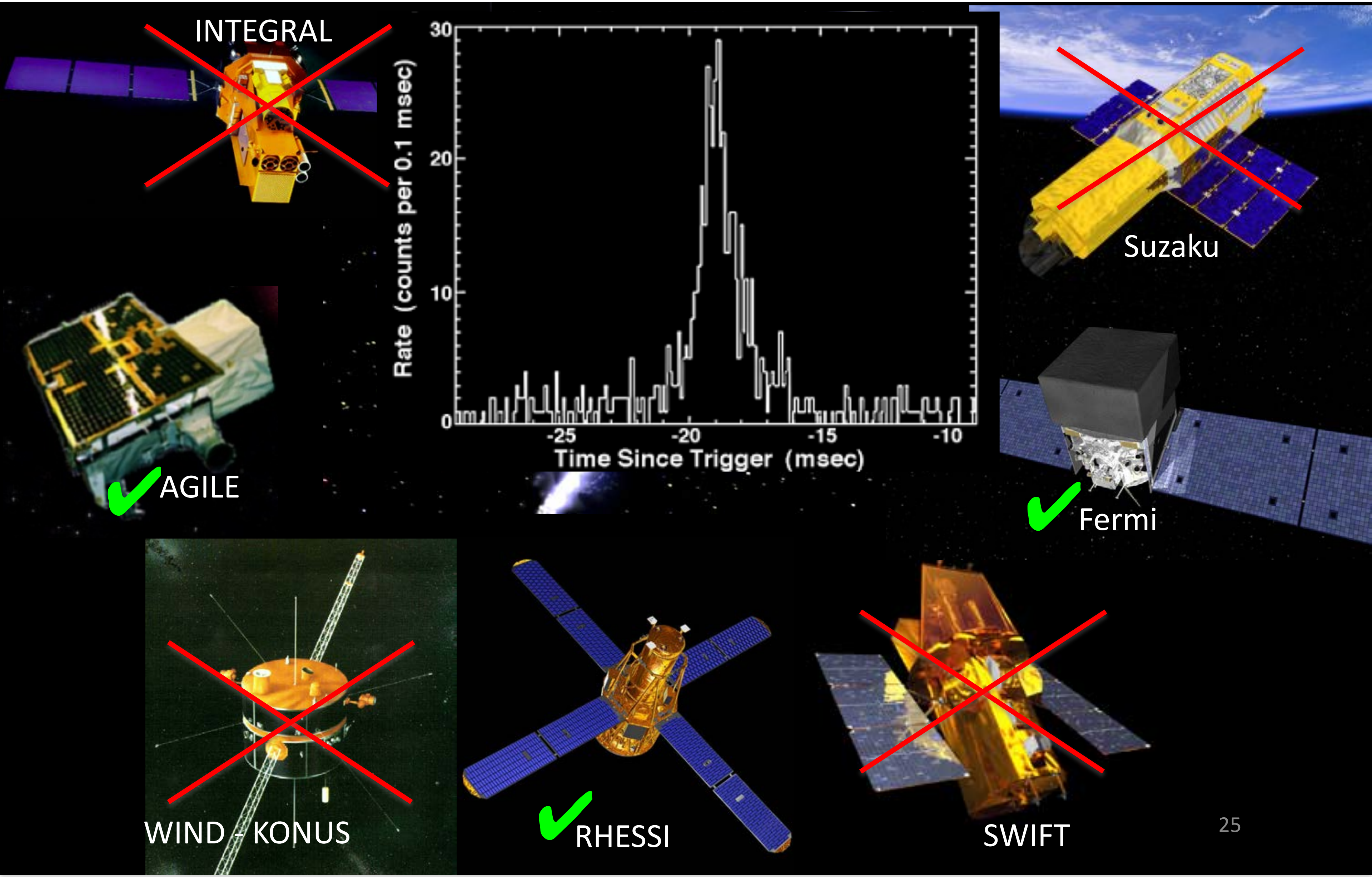
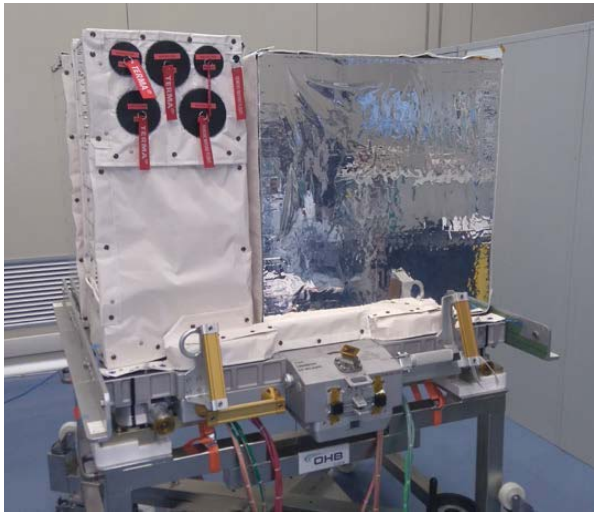


Is gamma-ray sensitivity enough?

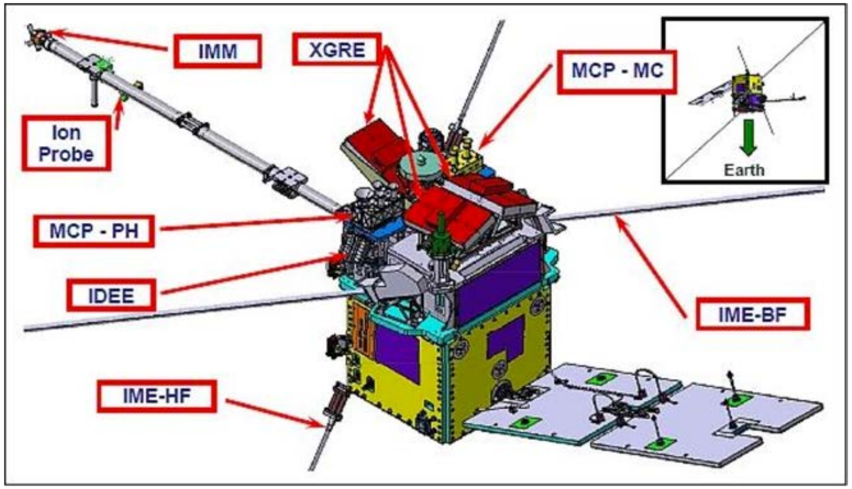
- Gamma-ray observations alone do not allow advancements in the TGF understanding anymore
- Coordinated observations of TGFs and lightning (in different wavelengths) are a must
- This can be achieved by correlation with ground-based observations (need microsecond level absolute timing accuracy), and/or by lightning instrumentation onboard the same space platform

ASIM



- X and gamma
- Optical (VIS e UV), cameras and photometers
- See presentation by N. Østgaard tomorrow

TARANIS



- X and gamma (+ electron discrimination)
- Optical, camera and photometers
- Radio receivers in various bands

Take home message

- A good TGF detector is a combination of several factors:
  - Detector material and geometry
  - System architecture (spatial segmentation, ecc...)
  - Front-end electronics performance (instrumental effects mitigation)
  - Read-out and data acquisition strategy
  - Mission profile

- In the real world one usually needs to make compromises (tradeoffs) between wishes (science requirements) and available budgets