

# Search and candidates of TGF in SPI experiment of INTEGRAL observatory

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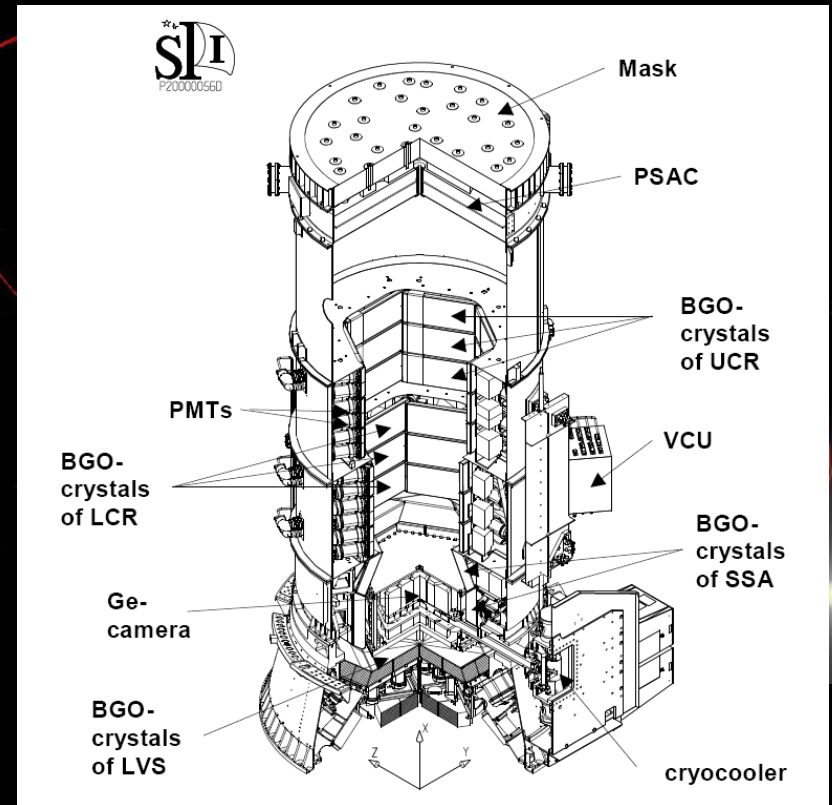
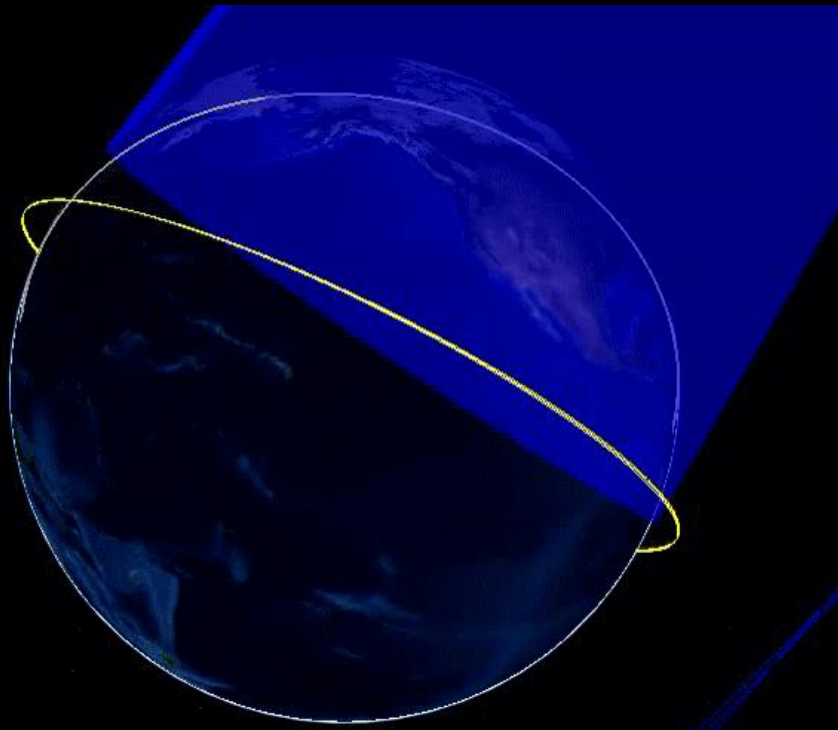
# Main properties of TGF

- TGF are generated in upper atmosphere at atmospheric breakdown on runaway electrons and accompanied by thunderstorm activity (A.V. Gurevich et al., Phys. Lett., A 165, 463, 1992).
- Short duration (less than millisecond)
- Hard spectrum, up to 45 MeV
- 30% of TGF registered by GBM/Fermi and 10% of TGF registered by RHESSI are identified with lightning
- Lower limit of global TGF frequency is 50 / day from RHESSI observations (D. Smith et al., v307, p1085, 2005)

## Some problems of TGF registration

- Low significance (a few dozens of photons per event)
- Distortion of energetic spectrum and fluence of TGF due to dead time losses and pile-up effect
- Two-thirds of events are not identified with lightning
- Electron and positron beams can be registered from TGF in addition to photons (M. Briggs et al., Geophys. Res. Lett., 38, L02, 808, 2011)

# INTEGRAL Observatory



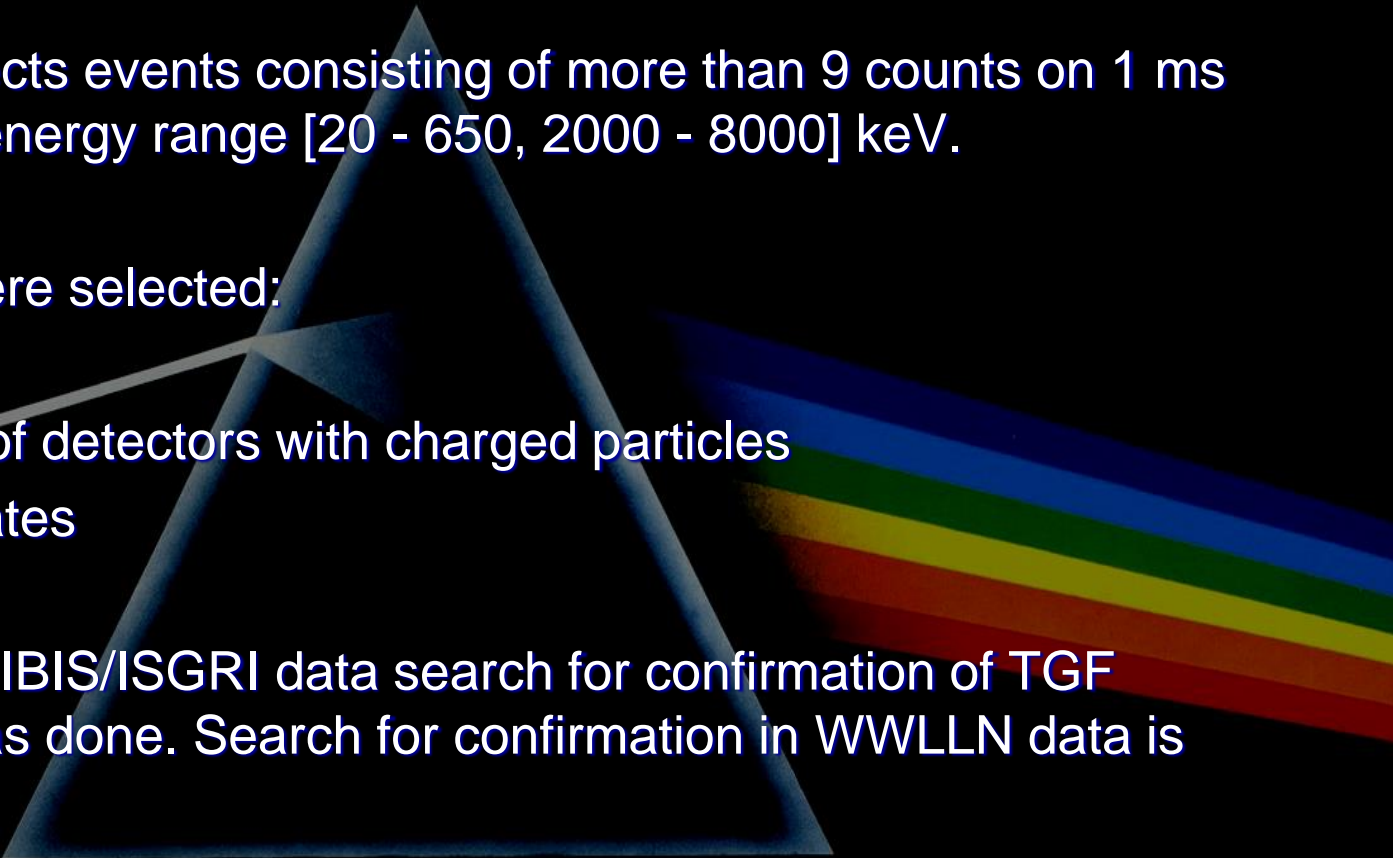
## Features of INTEGRAL observatory

Highly elliptical orbit (150 000 km in apogee)  
Full Earth in the field of view  
Absence of dead time losses and pile-up effect

## Gamma-Spectrometer SPI/INTEGRAL

Consists of 19 Ge detectors  
Energy range - [20-8000] keV  
Spectral resolution - 2.5 keV (1.3 MeV)  
Field of view at zero sensitivity -  $30^\circ$

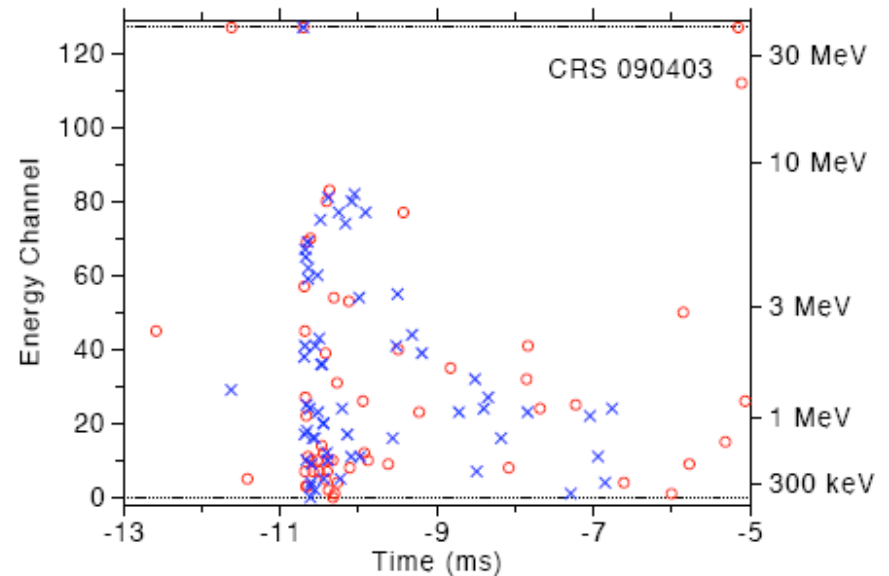
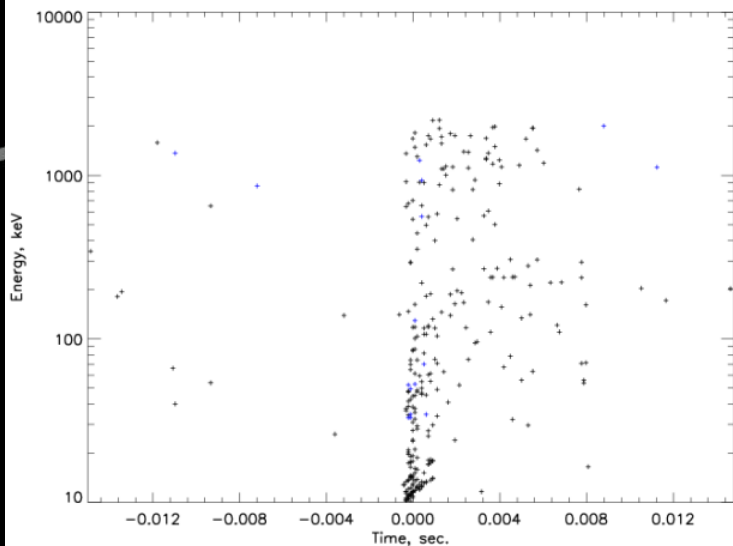
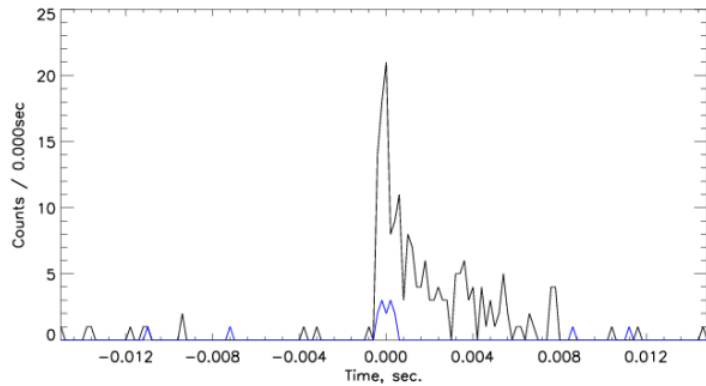
# Searching TGF in SPI / INTEGRAL data

- Several observations of the Earth were performed by INTEGRAL observatory in 2006 and 2012 with total duration of 500 ks. Aim of observations is Cosmic X-ray Background (CXB) measurement by the Earth occultation technique.
  - Algorithm selects events consisting of more than 9 counts on 1 ms time scale in energy range [20 - 650, 2000 - 8000] keV.
  - 604 events were selected:
    - fluctuations
    - interactions of detectors with charged particles
    - TGF candidates
  - In JEM-X and IBIS/ISGRI data search for confirmation of TGF candidates was done. Search for confirmation in WWLLN data is planned
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# Interactions with charged particles (I)

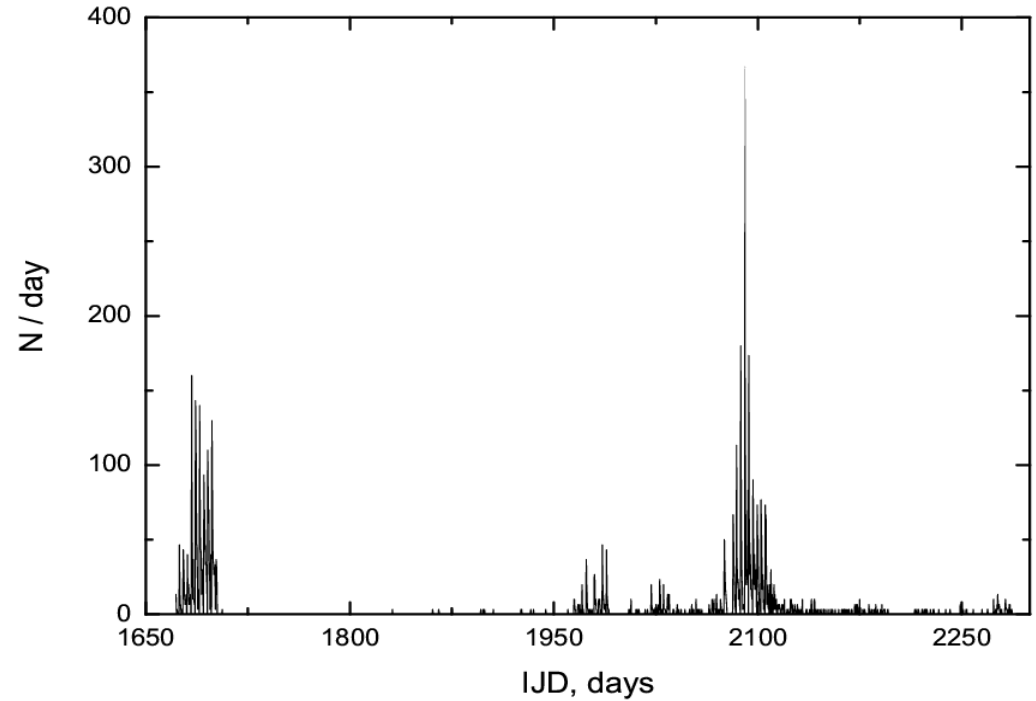
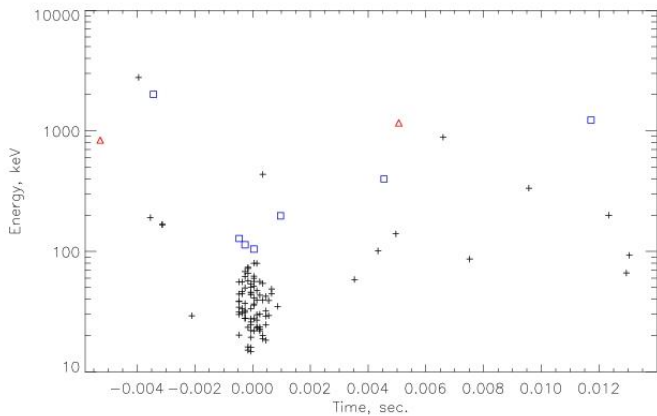
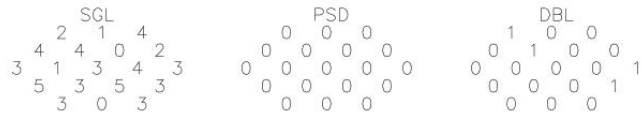
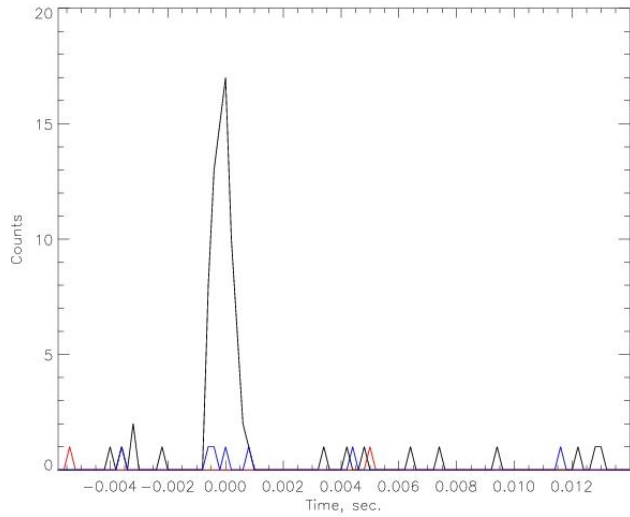
s=77.0; d=4.1; HR=1.6; UT=2006.01.25 02-28-6.2653792;  
IJD=2216.103604738016; SCW: 040100000041.001  
RA: 252.10609; DEC: -60.780574

	SGL		PSD		DBL					
0	0	2	3	0	0	0	0			
0	0	2	0	13	0	0	0	0	1	
0	2	13	17	4	0	0	1	0	1	0
1	1	8	3	0	0	0	1	0	0	0
0	0	0	2	0	0	0	0	0	0	0

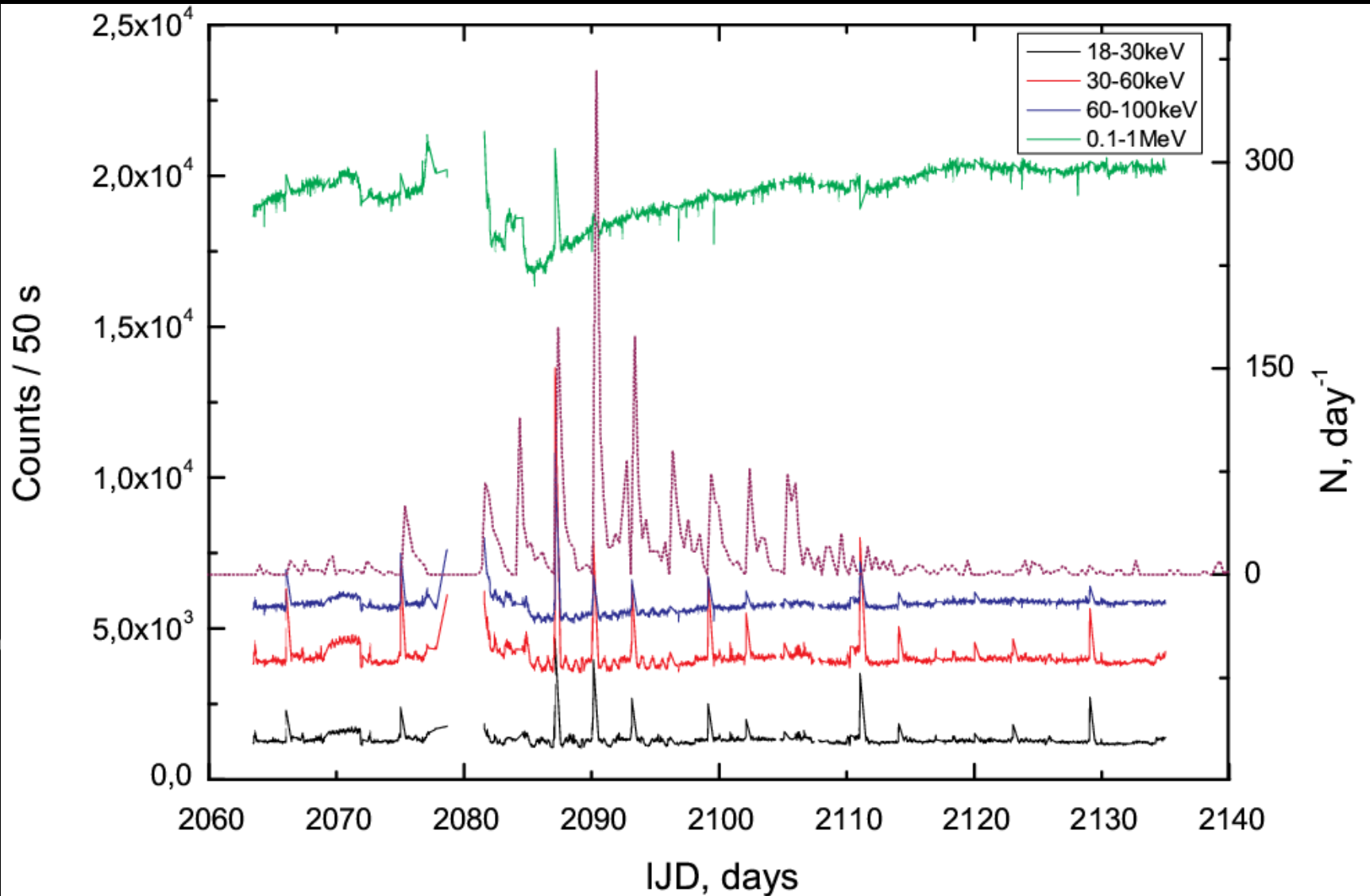


# Interactions with charged particles (II)

s=53.8; d=1.6; HR=0.0; UT=2004.08.04 15:37:43.843766;  
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RA: 109.93288; DEC: 66.776642



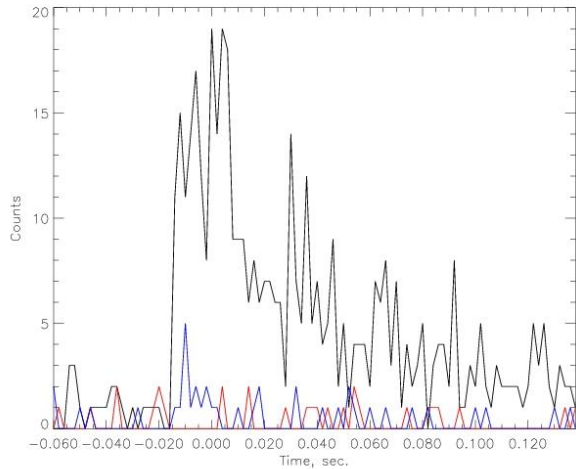
# Interactions with charged particles (II)



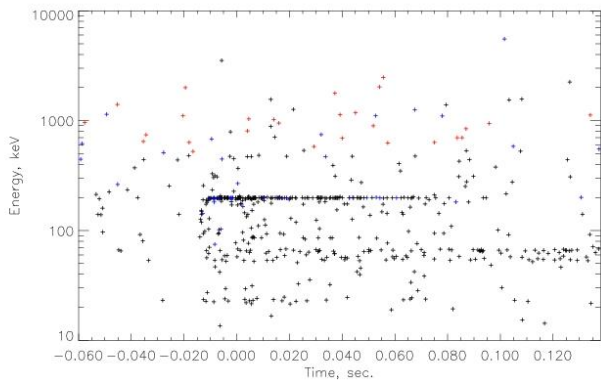
# Interactions with charged particles (II)

$70\text{Ge} + n > 71^m\text{Ge}$  (half-life  $\sim 20.4$  ms)  $> 71\text{Ge} + \gamma$  two-step transition  $175+23=198$  keV.  
 $72\text{Ge} + n > 73^m\text{Ge}$  (half life  $\sim 0.5$  s)  $> 72\text{Ge} + \gamma$  53.4 keV  
 $72\text{Ge} + n > 73\text{Ge}$   $> 72\text{Ge} + \gamma$  two-step transition  $53.4+13.3=66.7$  keV

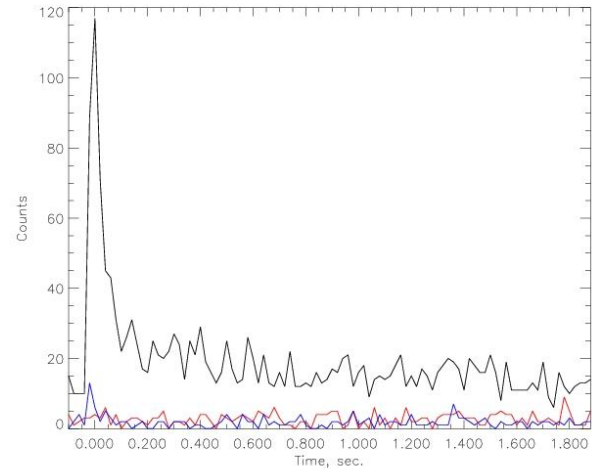
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 JD=2074.913041360150; SCW: spi\_oper\_\_035300670010.001.fits  
 RA: 265.74124; DEC: -25.937834



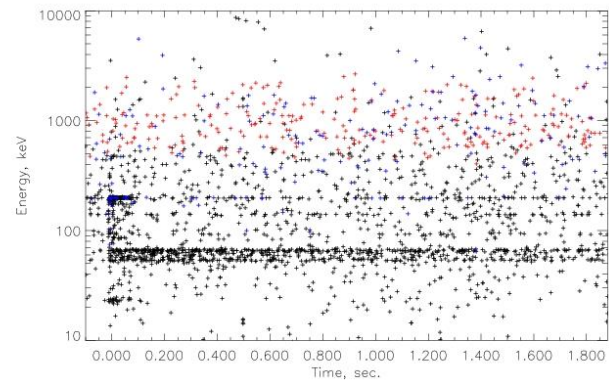
SGL	PSD	DBL
3 5 2 1 0 2 2	0 0 0 0 1	0 0 0 0 0
2 2 4 8 2 2	0 1 0 0 1 0	0 1 2 2 3 0
0 0 7	0 0 0	0 0 1



s=5.2; d=1.8; HR=0.4; UT=2005.09.05 21:53:42.589441;  
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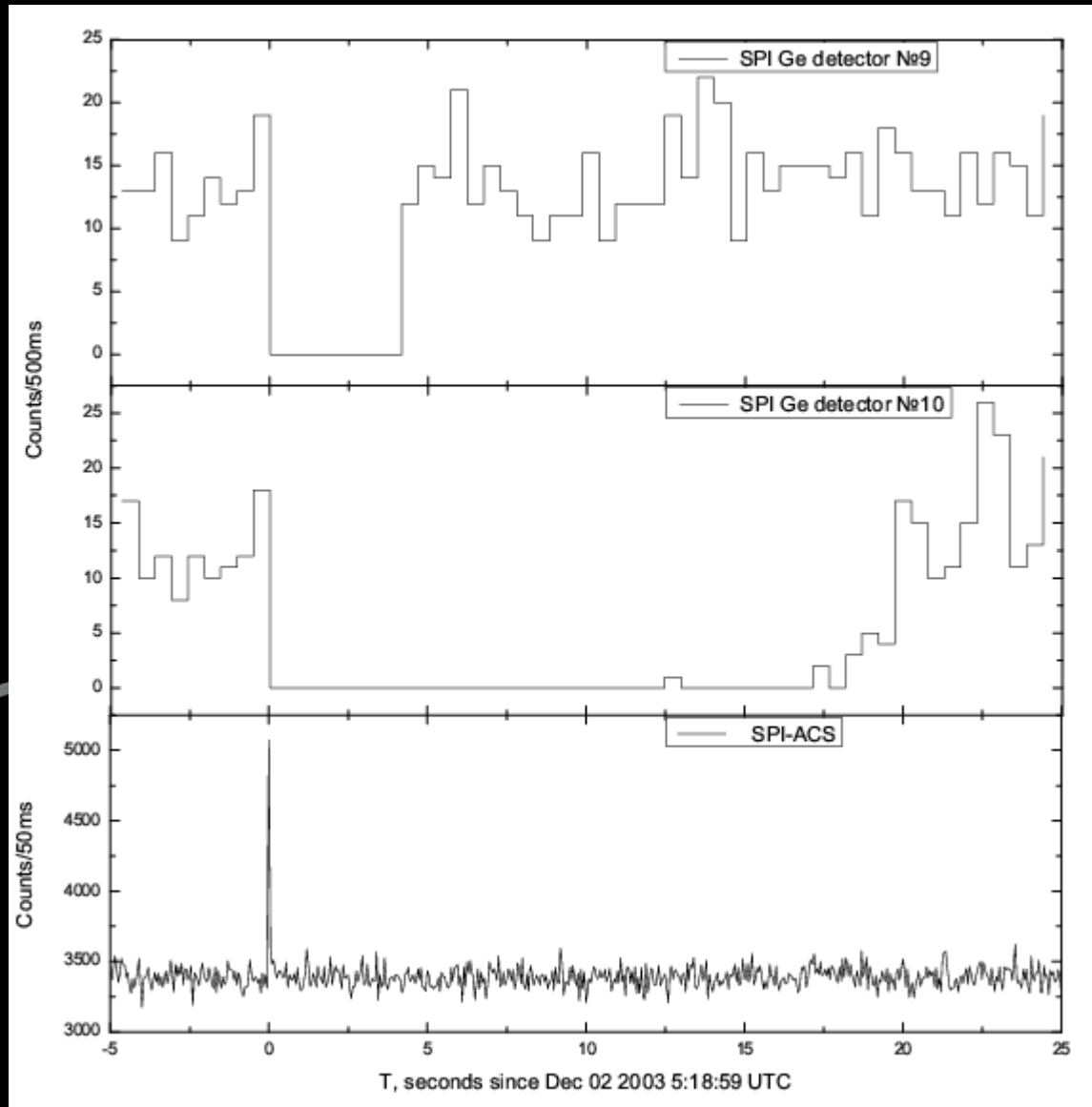


SGL	PSD	DBL
14 11 18 13 10 12	0 2 1 3 0 1 0	2 2 3 1 0 1 3
16 10 23 17 9	0 1 0 3 1 4 0	2 2 0 1 2 1
19 3 21 21	0 0 0 1 0 2 0	1 0 0 0 1
0 0 0	0 0 0	0 0 0



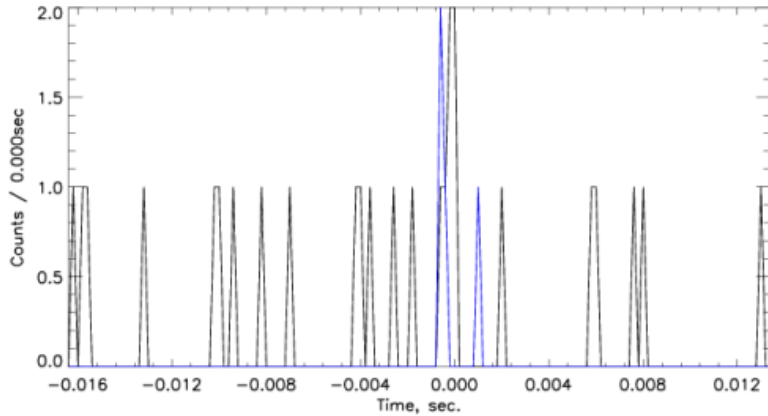
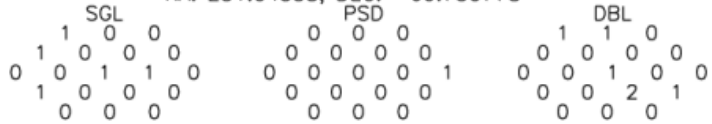


# Interactions with charged particles (II)

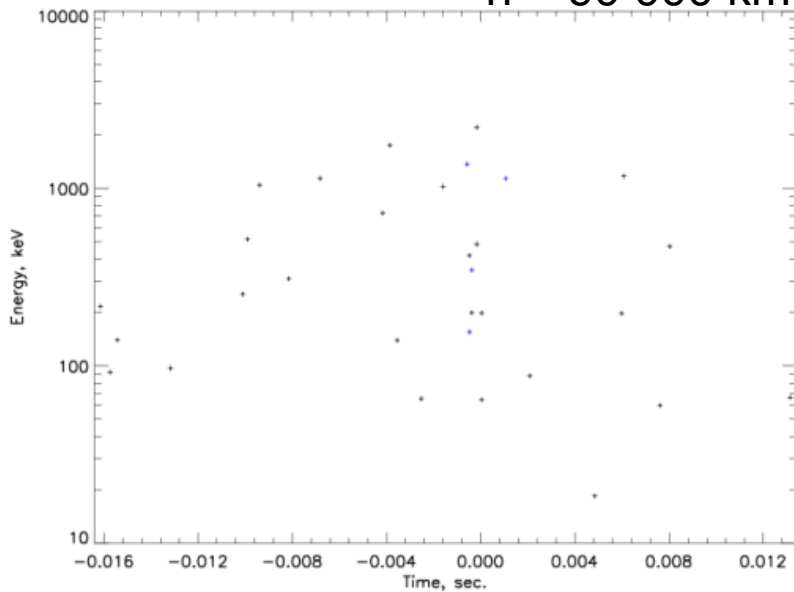


# TGF candidates

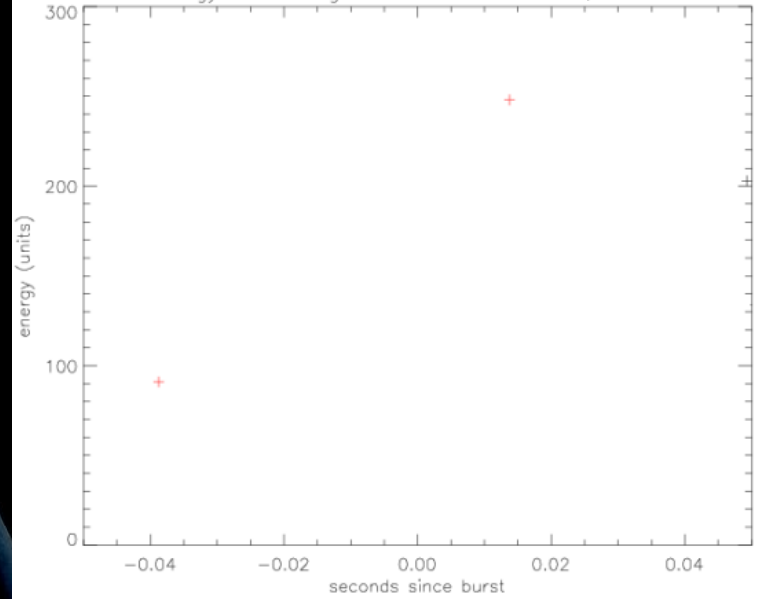
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RA: 251.04338; DEC: -60.730778



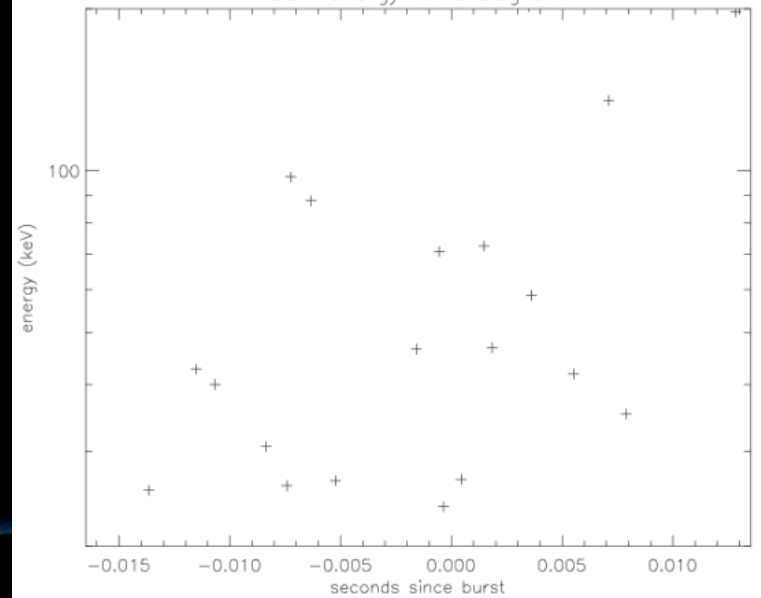
$h = 90\ 000\ \text{km}$



JEM-X energy-time diagram. Black - JEM-X1, Red - JEM-X2

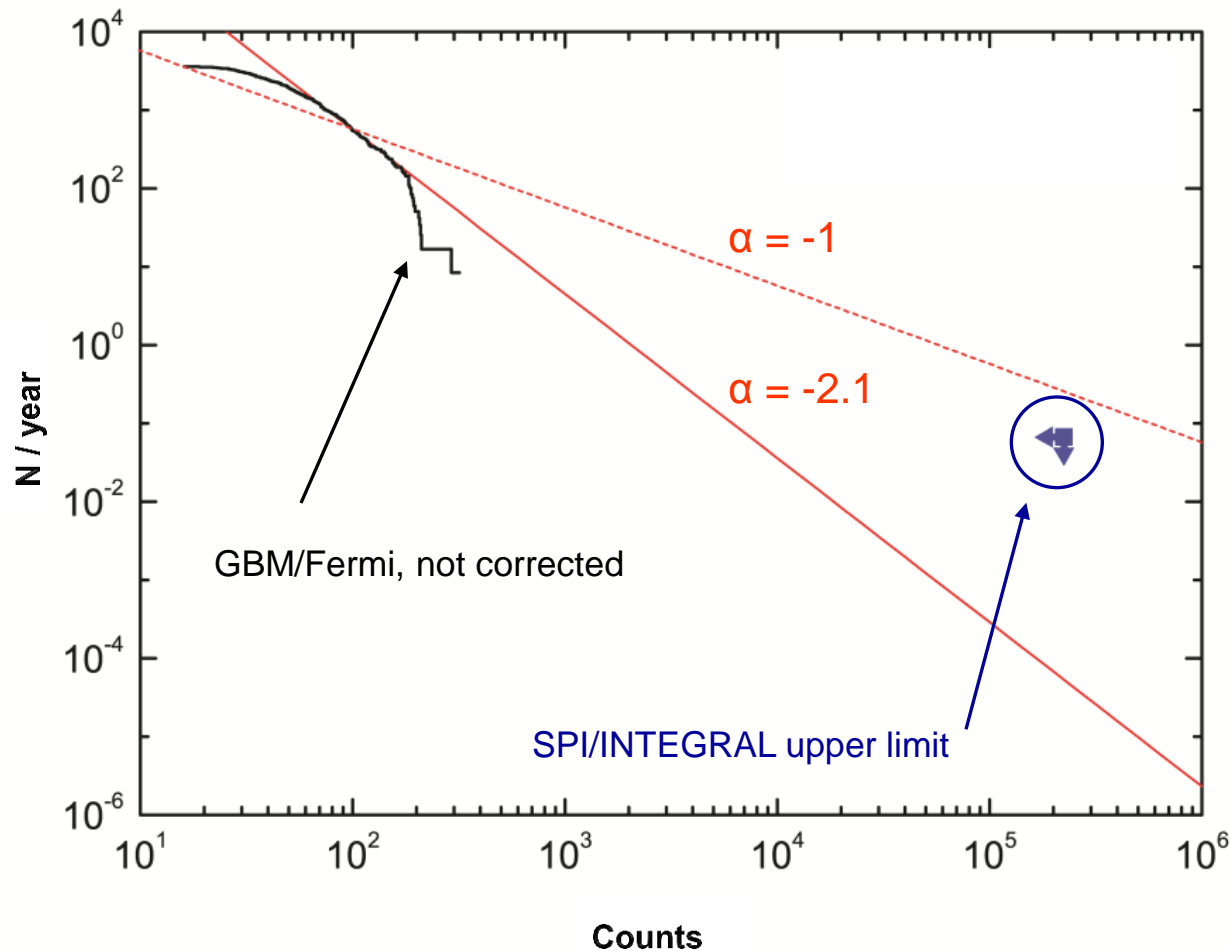


ISGRI energy-time diagram.

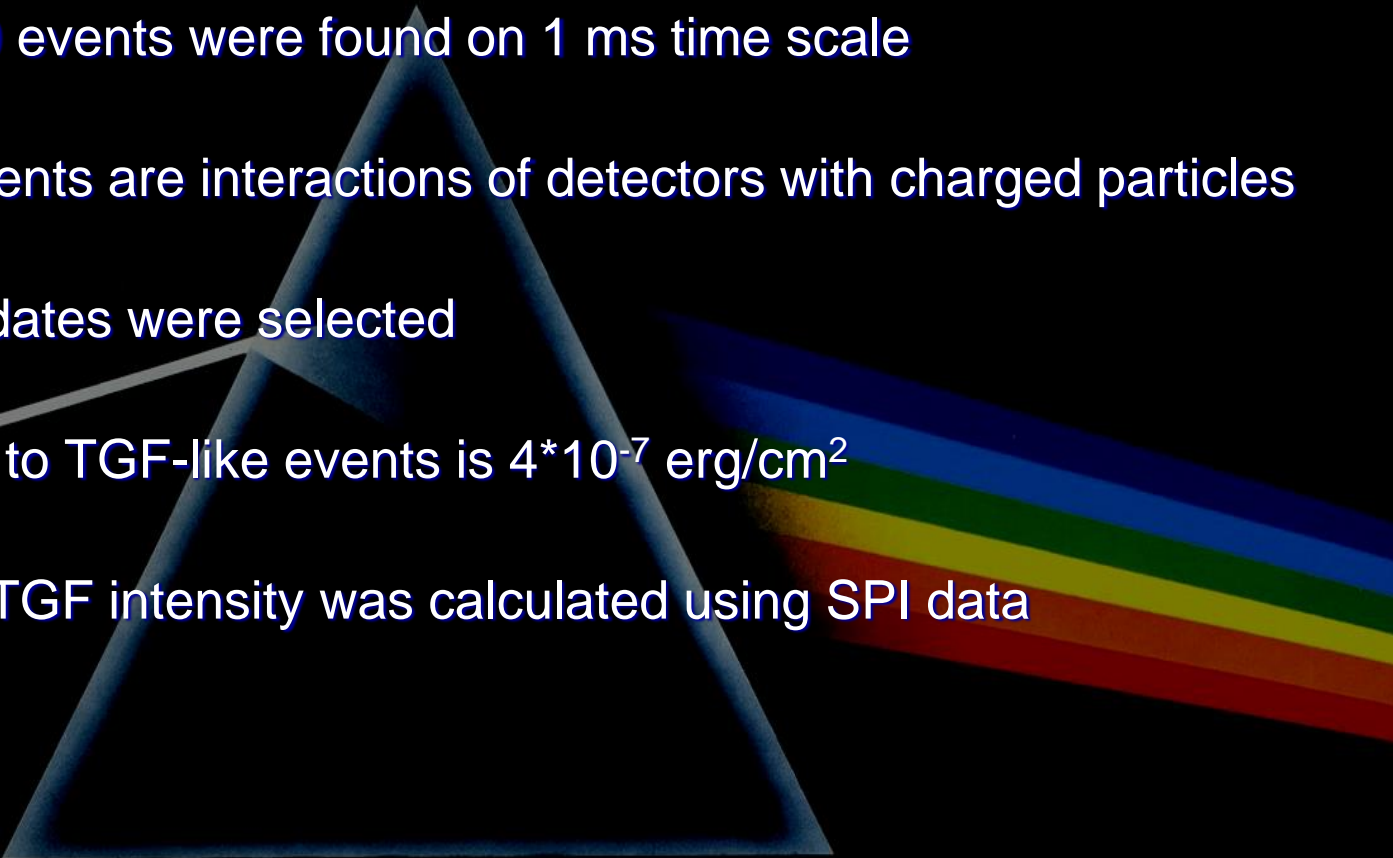


# Upper limits of TGF intensity

- SPI Trigger threshold in GBM units -  $2.25 \cdot 10^5$  counts
- SPI Trigger threshold - 9 counts / ms
- SPI Sensitivity -  $4 \cdot 10^{-7}$  erg/(cm<sup>2</sup> ms)



# Main results

- Data analysis of Earth observations made by INTEGRAL observatory in 2006 and 2012 was done
  - More than 600 events were found on 1 ms time scale
  - Most of the events are interactions of detectors with charged particles
  - 28 TGF candidates were selected
  - SPI sensitivity to TGF-like events is  $4 \cdot 10^{-7}$  erg/cm<sup>2</sup>
  - Upper limit of TGF intensity was calculated using SPI data
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**Thank you for your attention!**

