GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN
Istituto Nazionale di Fisica Nucleare

HIGH ENERGY FOLLOW-UP OF EXCEPTIONALLY LUMINOUS GAMMA-RAY BURSTS

3rd year PhD report

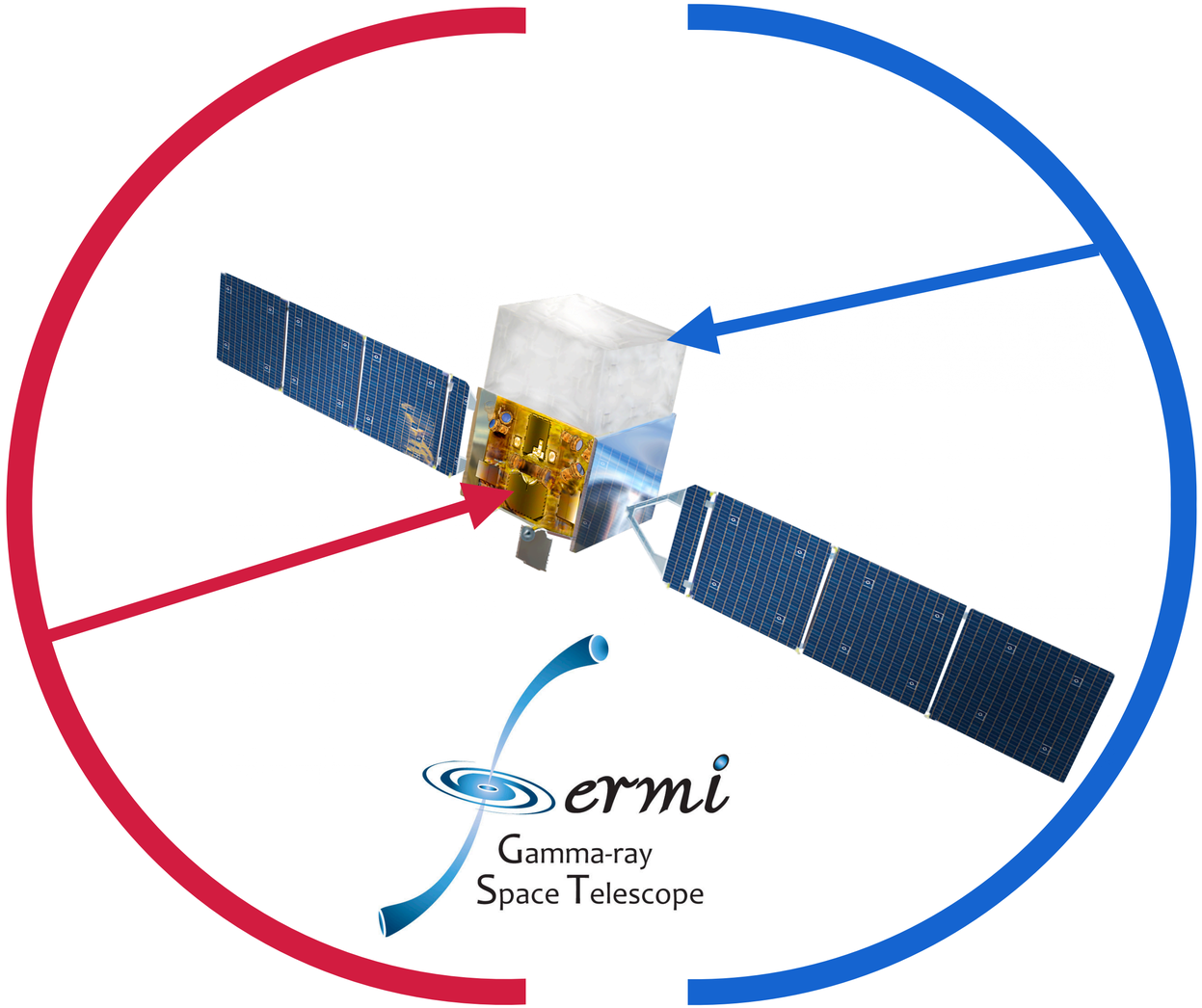
Alessio Mei
Astroparticle Physics PhD student

Supervisors:
G. Oganesyan, M. Branchesi, B. Banerjee

The main protagonist of (also) this research year

Gamma-ray Burst Monitor

- 12 NaI detectors (8-900 keV) and 2 BGO detectors (300 keV - 40 MeV)
- Good energy and temporal resolution (up to 64 ms)
- Provides triggers for GRB prompt emission



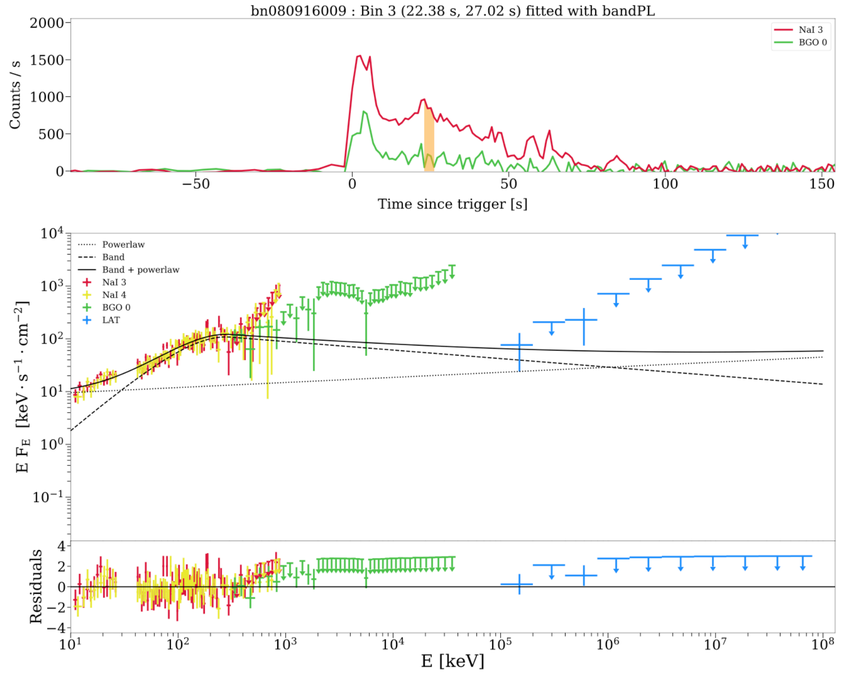
Large Area Telescope

- Particle tracker measures γ direction, calorimeter measures E_γ and image the shower
- Large sky coverage ($\sim 20\,\%$)
- Poor angular resolution (PSF ~ 1 deg @ 1GeV)
- Sensitive in the high energy range (30 MeV - 300 GeV)

GBM data analysis

GBM

- I developed a python-based tool able to analyse GBM data and produce light curves and (time-resolved) spectra
- It is based on the **GTBURST** pipelines
- In combination with **XSPEC**, it can provide also (time-resolved) spectral analysis
- It can now handle an automatic analysis of large samples of sources in the *Fermi*/GBM catalog.



Applied to:

- Analysing the BOAT GRB
- Testing physical models on the GRB prompt spectra at high energies (with Samanta)
- Unveiling the GRB progenitor origin
- Testing empirical correlations of GRBs with measured redshift
- Studying the soft extended emission in GRB prompt emissions

COMING SOON

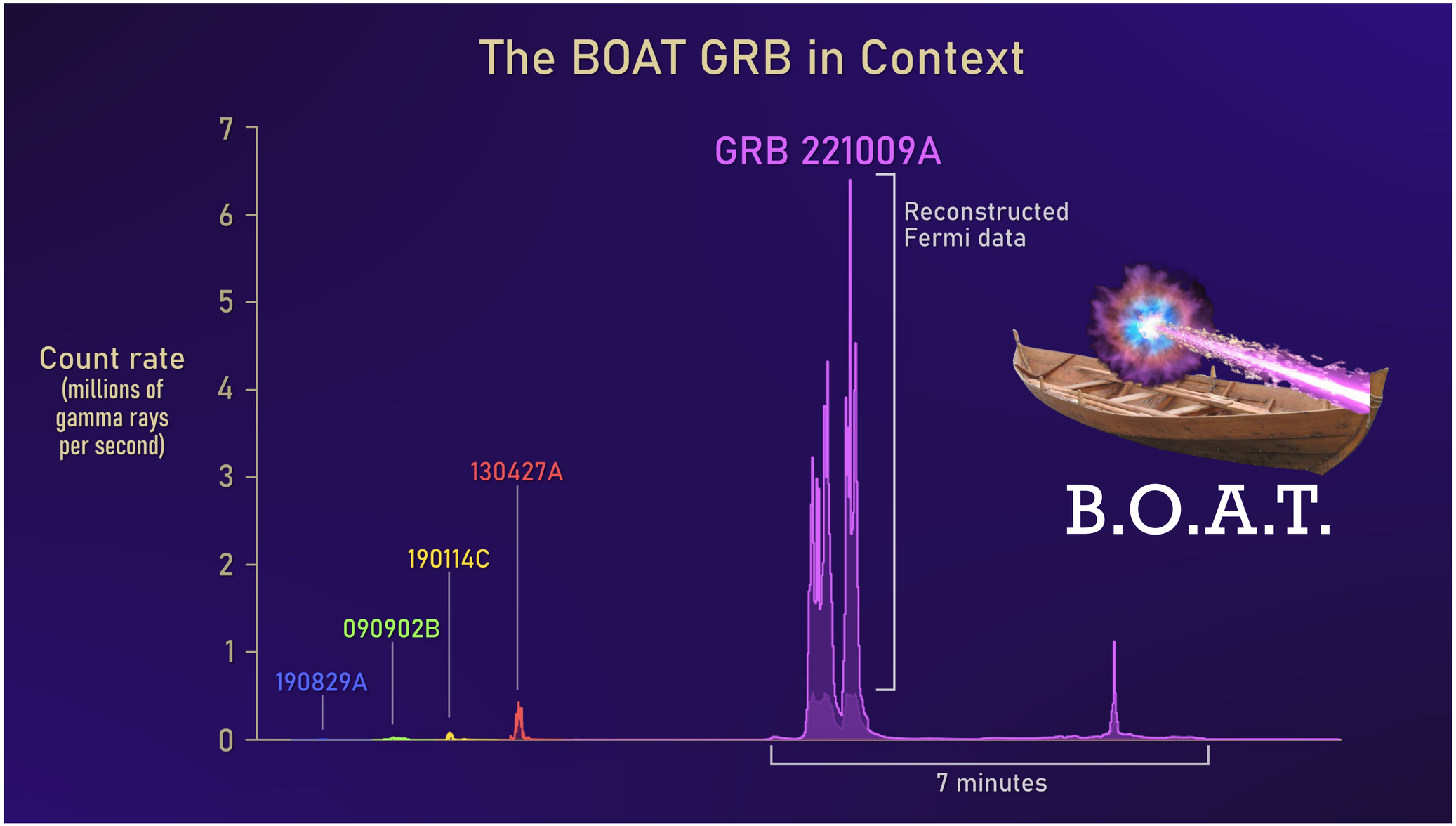
2021: a year of bright GRBs!

https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

Fermi GBM Burst Catalog (fermigbrst) Bulletin README

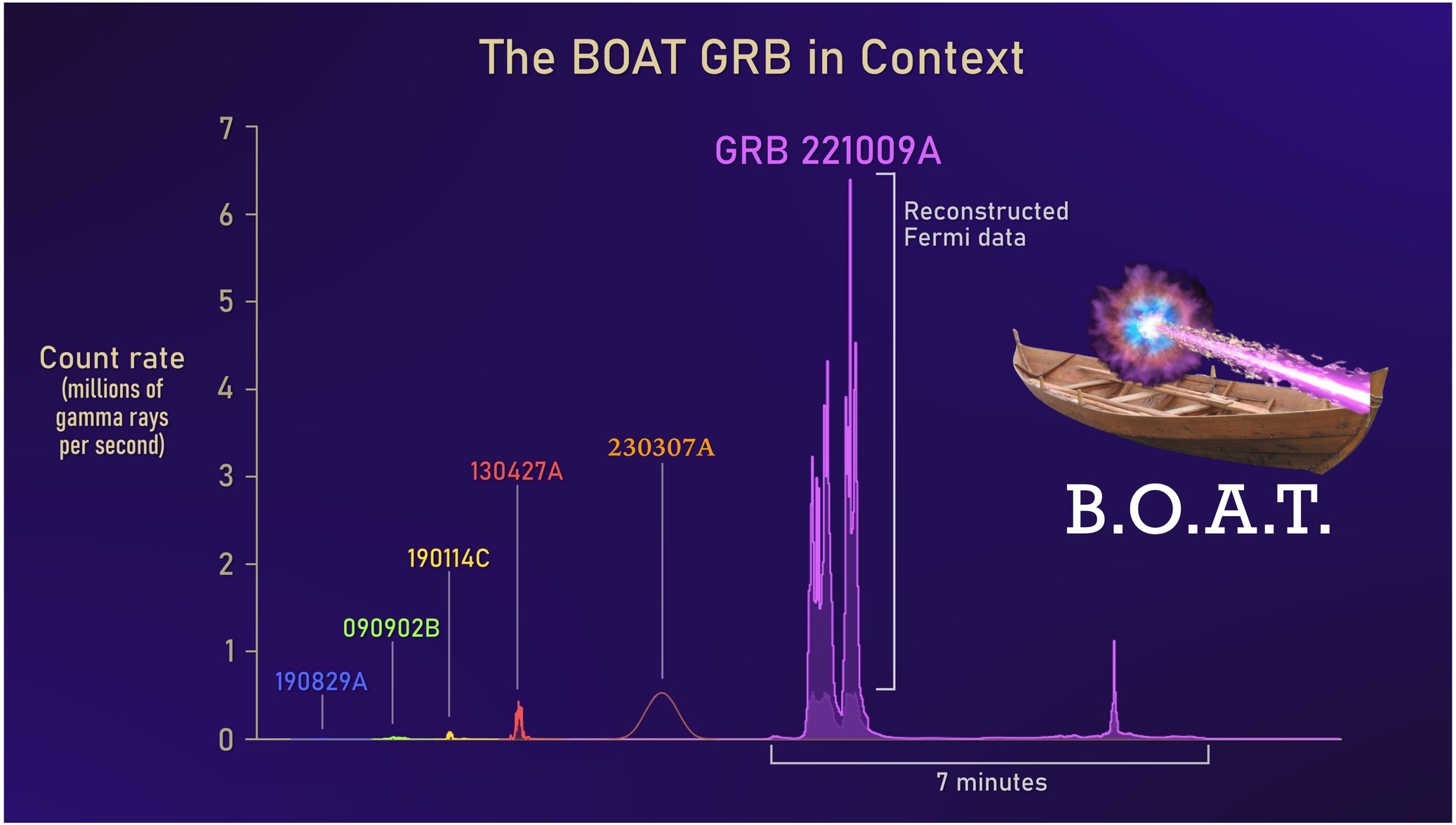
Select All	Services	name	trigger time	t90 [s]	fluence [erg/cm^2]	flux 1024 [photon/cm^2/s]
	D	GRB090626707	2009-06-26 16:58:45.464			
	D	GRB210518545	2021-05-18 13:04:09.640	6.400	2.4604e-02	374860.0000
	D	GRB130427324	2013-04-27 07:47:06.420	138.242	2.4620e-03	1051.8600
	D	GRB160625945	2016-06-25 22:40:16.275	453.385	6.4256e-04	216.8460
	D	GRB171010792	2017-10-10 19:00:50.576	107.266	6.3279e-04	120.1400
	D	GRB160821857	2016-08-21 20:34:30.039	43.009	5.2221e-04	123.0790
	D	GRB211211549	2021-12-11 13:09:59.651	34.305	5.0118e-04	324.8990
	D	GRB190114873	2019-01-14 20:57:02.626	116.354	4.4325e-04	246.8640
	D	GRB190530430	2019-05-30 10:19:08.903	18.432	3.7062e-04	160.5450
	D	GRB210619999	2021-06-19 23:59:25.604	54.785	3.0248e-04	238.6250
	D	GRB180720598	2018-07-20 14:21:39.654	48.897	2.9853e-04	124.5480

2022: the year of the brightest GRB!



Credit: NASA's Goddard Space Flight Center and Adam Goldstein (USRA)

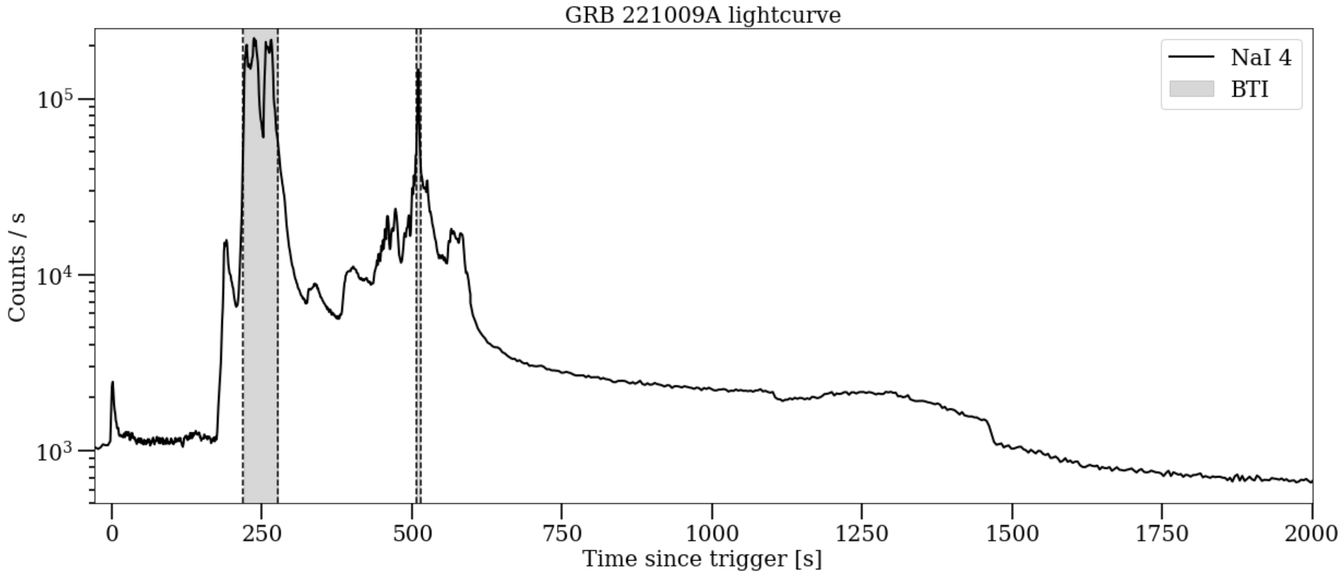
2022: the year of the brightest GRB!



Credit: NASA's Goddard Space Flight Center and Adam Goldstein (USRA)

The BOAT: some milestones

- On Oct 9, 2022 the BOAT triggered Fermi/GBM and Swift/BAT.



- An unprecedented follow-up campaign started: BOAT triggered everything!

1 2023GCN.33418....1D 2023/03
GRB 230307A: Detection by GRBAlpha
Dafcikova, M.; Ripa, J.; Pal, A.; Werner, N. *and 47 more*

2 2022GCN.32995....1L 2022/11
Optical polarization observation of GRB 221009A
Lindfors, E.; Nilsson, K.; Liodakis, I.; Kasikov, A. *and 1 more*

3 2022GCN.32949....1N 2022/11
GRB 221009A: Japanese VLBI Network observation
Niinuma, K.; Yonekura, Y.; Fujisawa, K.; Motogi, K. *and 1 more*

4 2022GCN.32809....1R 2022/10 cited: 1
GRB221009A: LBT optical imaging
Rossi, A.; Maiorano, E.; Malesani, D. B.; CIBO Collaboration *and 2 more*

5 2022GCN.32805....1K 2022/10
Improved IPN localization for GRB 221009A (BepiColombo-MGNS light curve)
Kozyrev, A. S.; Golovin, D. V.; Litvak, M. L.; Mitrofanov, I. G. *and 34 more*

6 2022GCN.32788....1B 2022/10
GRB 221009A: Second epoch of NuSTAR data
Brethauer, Daniel; Margutti, Raffaella; Racusin, Judith; Grefenstette, Brian *and 10 more*

7 2022GCN.32780....1A 2022/10
GRB 221009A: A type I BdHN of exceptional energetics
Aimuratov, Y.; Becerra, L.; Bianco, C. L.; Cherubini, C. *and 11 more*

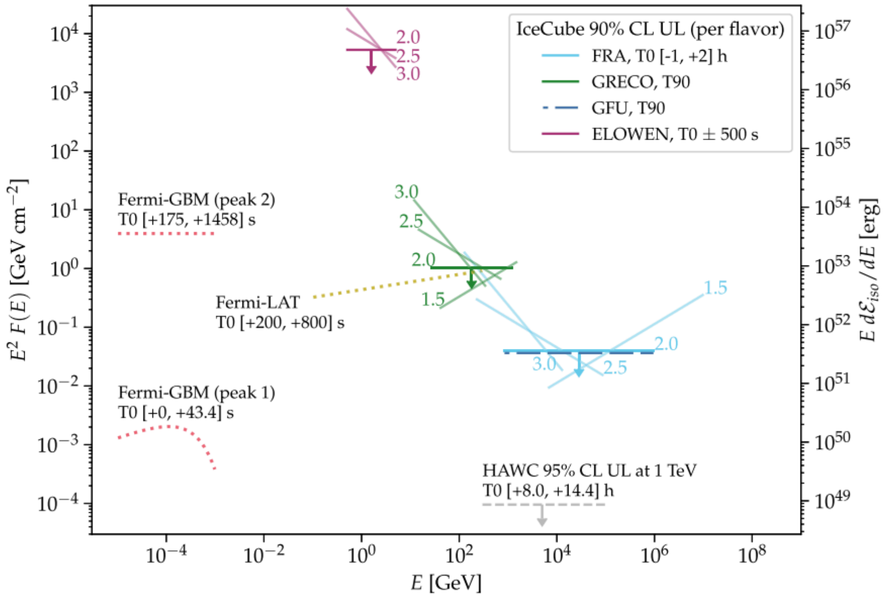
8 2022GCN.32752....1B 2022/10
GRB221009A: RTT-150 optical observations
Bikmaev, Ilfan; Khamitov, Irek; Irtuganov, Eldar; Gorbachev, Mark *and 2 more*

9 2022GCN.32749....1R 2022/10
GRB221009A: Gemini-South Optical Afterglow Detection
Rastinejad, J.; Fong, W.

10 2022GCN.32745....1G 2022/10
GRB221009A: Ionospheric disturbance observed in India
Guha, A.; Nicholson, P.

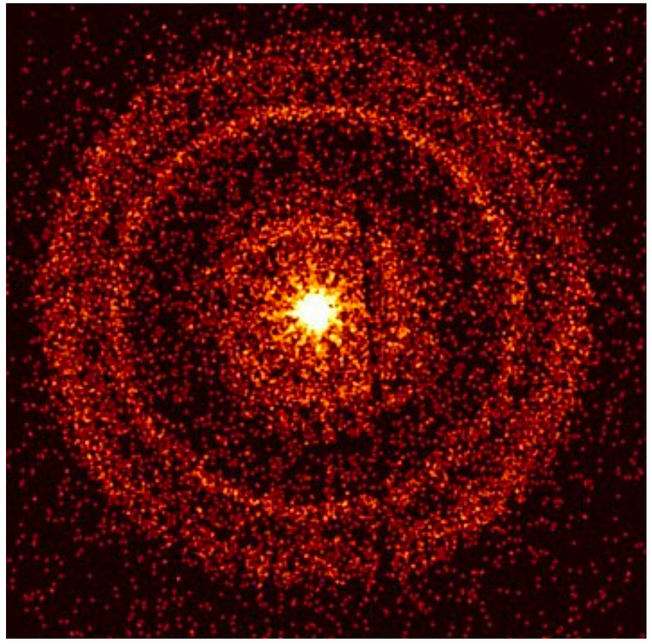
The BOAT: some milestones

- IceCube & KM3Net did not find any evidence of high energy neutrinos coming from this source.



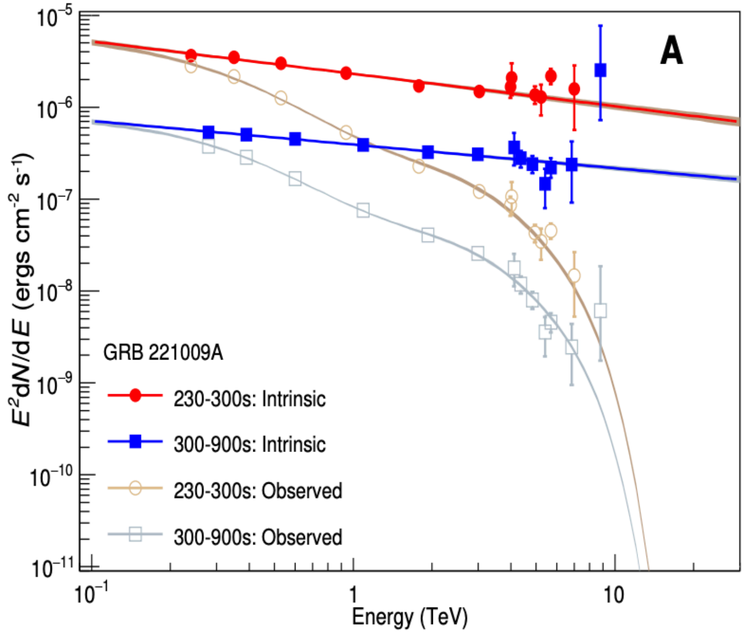
IceCube Collab. 2023

- XMM-Newton observed expanding X-ray rings generated by scattering in Galactic dust clouds

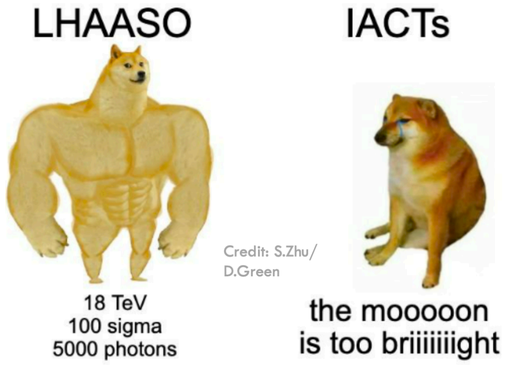


Tiengo et al. 2023

- LHAASO observed several >100 GeV photons and one 13 TeV photon after ~200s from the burst trigger

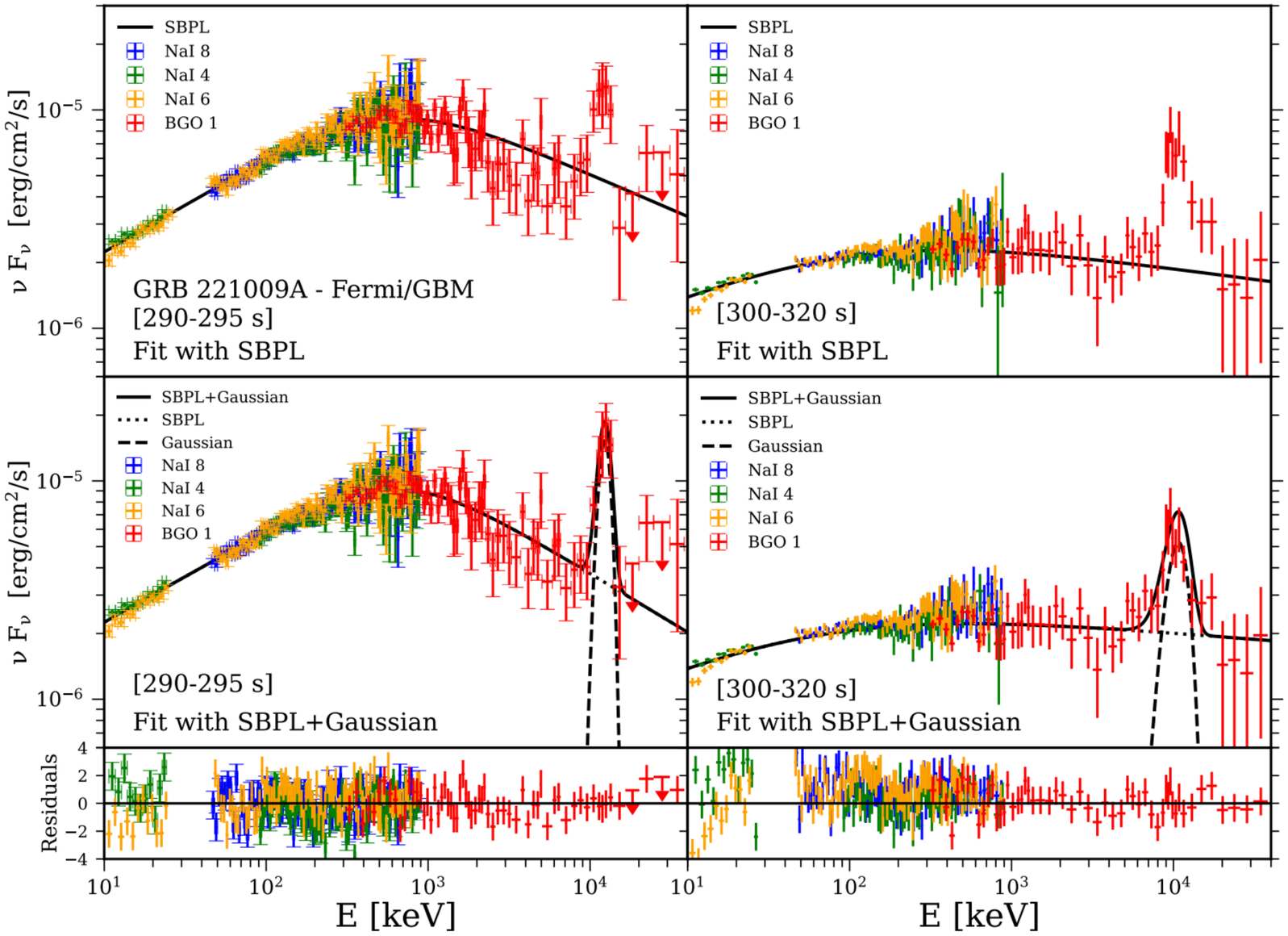


LHAASO Collab. 2023



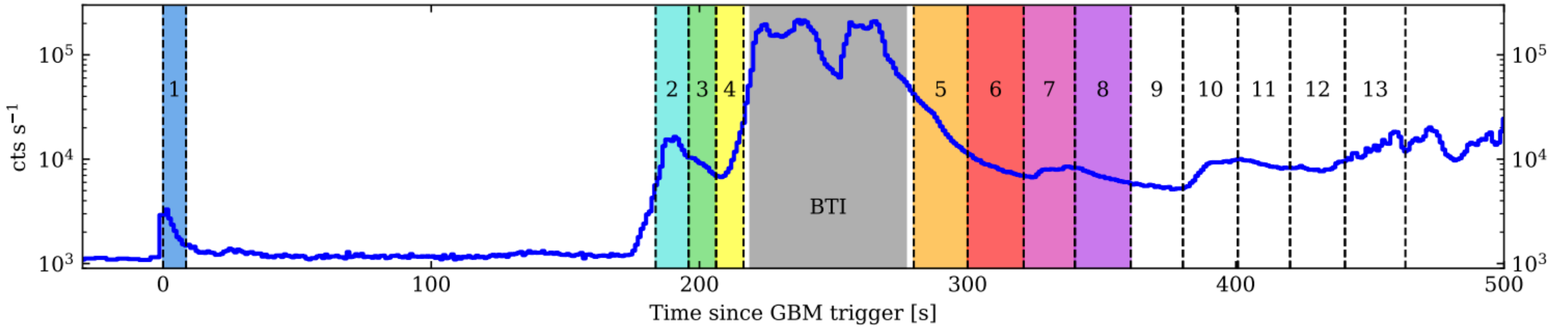
The first emission line in a GRB spectrum

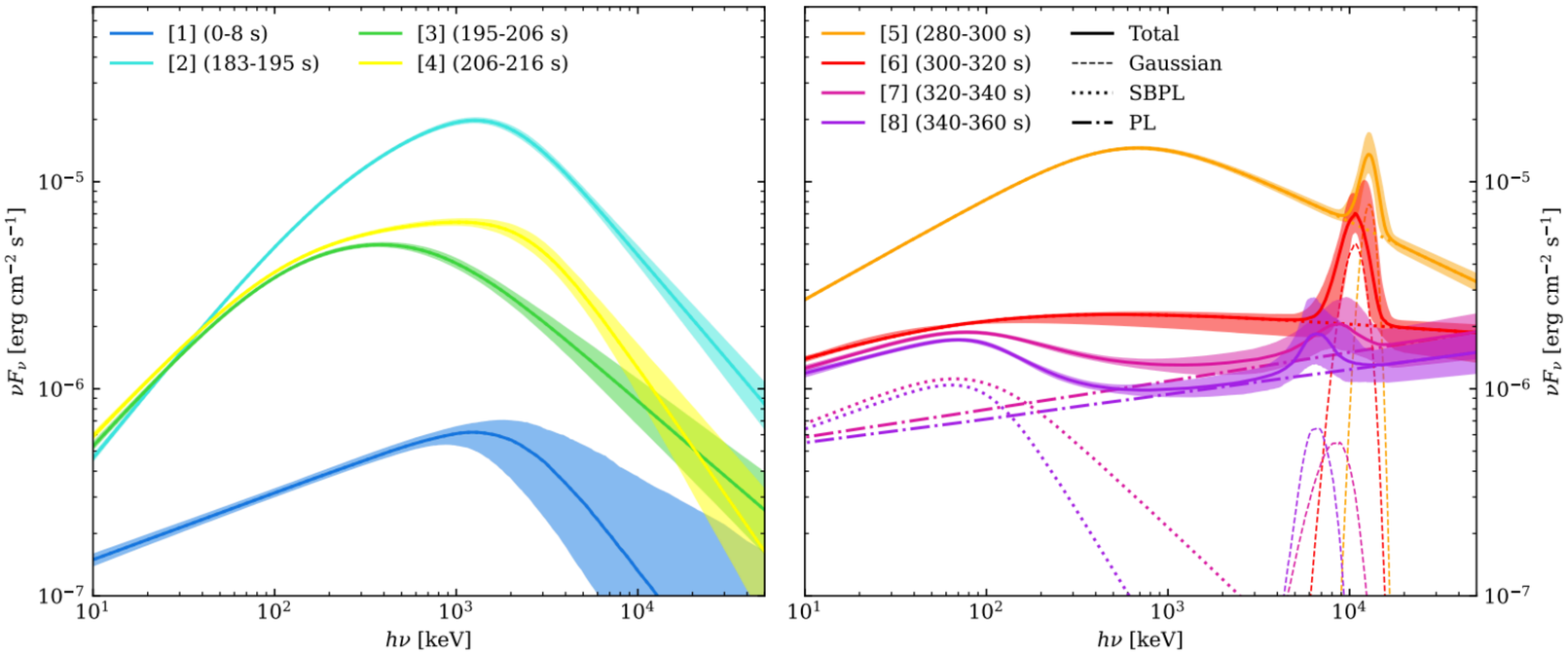
Ravasio M.E., Salafia O.S., Oganesyan G., **Mei A.** et al. 2023, under review Science



The first emission line in a GRB spectrum

Ravasio M.E., Salafia O.S., Oganesyan G., **Mei A.** et al. 2023





- Akaike Information Criterion (AIC) confirms the presence of the line with 6.6σ and 11.6σ in the [280-300 s] and [300-320 s] time-intervals, respectively

- Both the line peak energy E_{peak} and peak luminosity L_{peak} are decreasing over time. Instead, the width does not show any trend.

$$E_{peak}\ [\mathrm{MeV}] : 12.56 \pm 0.03 \rightarrow 6.12^{+0.74}_{-0.59}$$

$$L_{peak}\ [\mathrm{erg/s}] : (1.12 \pm 0.20) \times 10^{50} \rightarrow (2.1 \pm 0.10) \times 10^{49}$$

Looking for the line in other GRBs

- We looked for the presence of a MeV line in a sample of 6 GRBs:

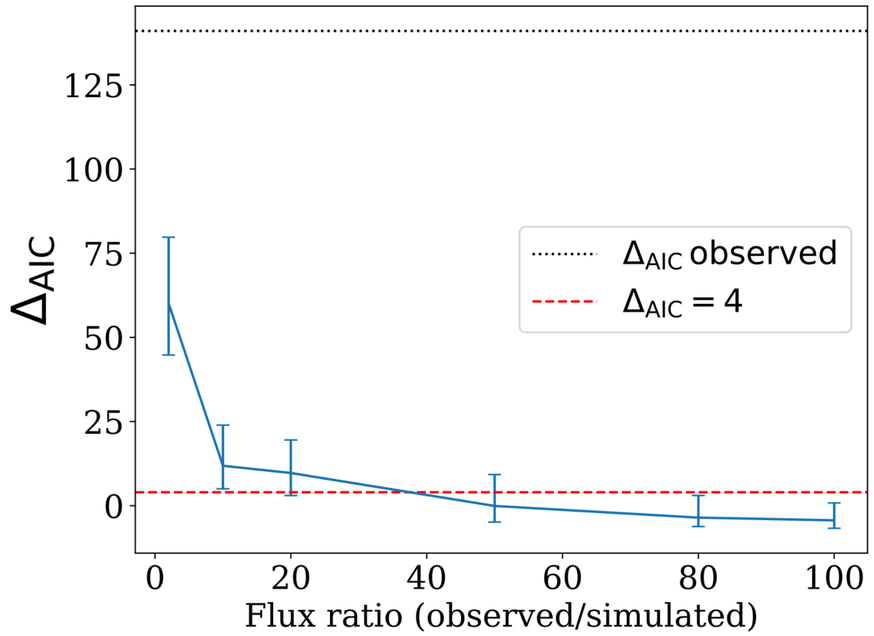
GRB 230307A
GRB 130427A
GRB 160625B

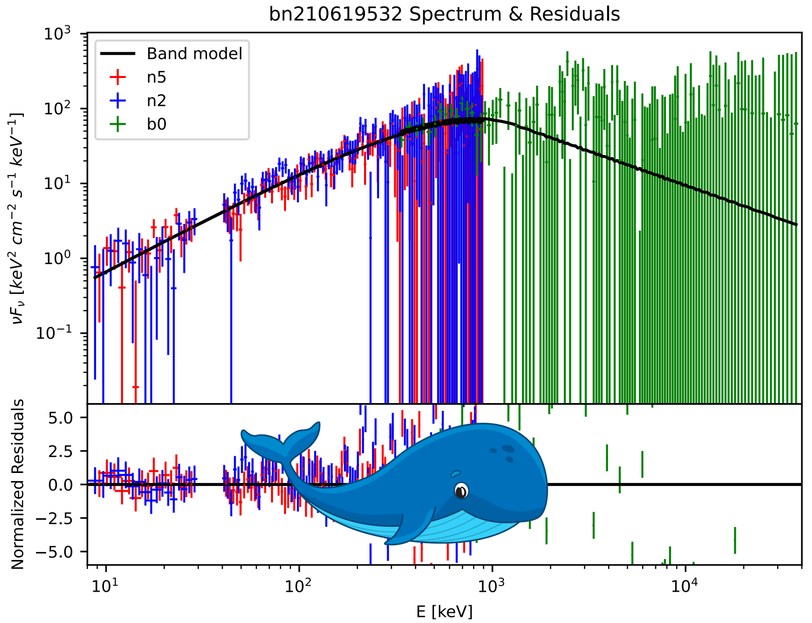
Brightest GRBs

GRB 170409A
GRB 171227A
GRB 130606B

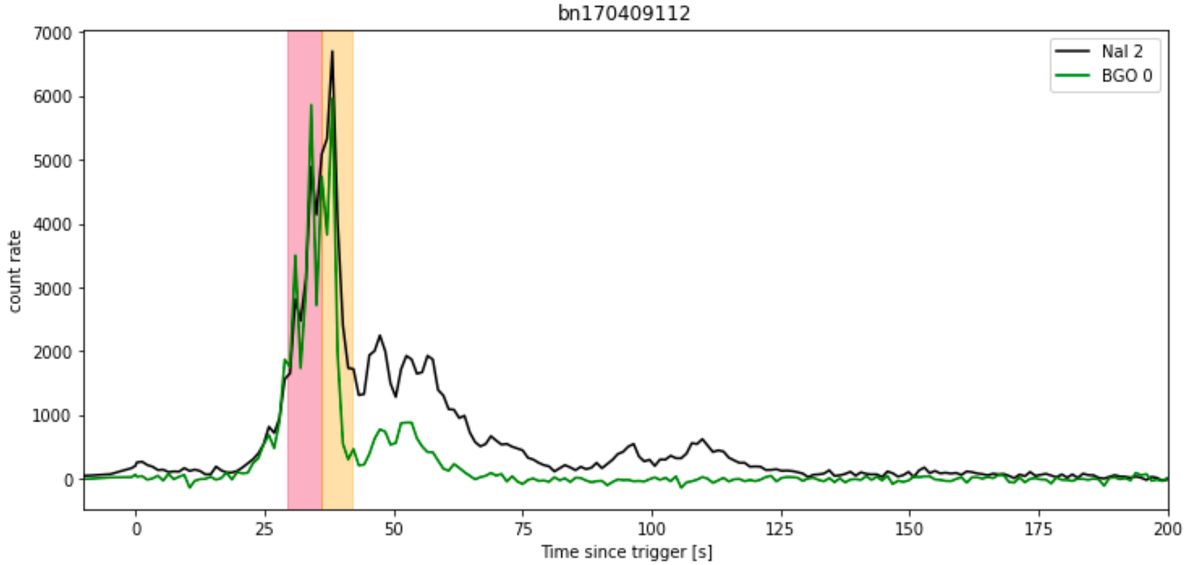
Best BGO viewing angle

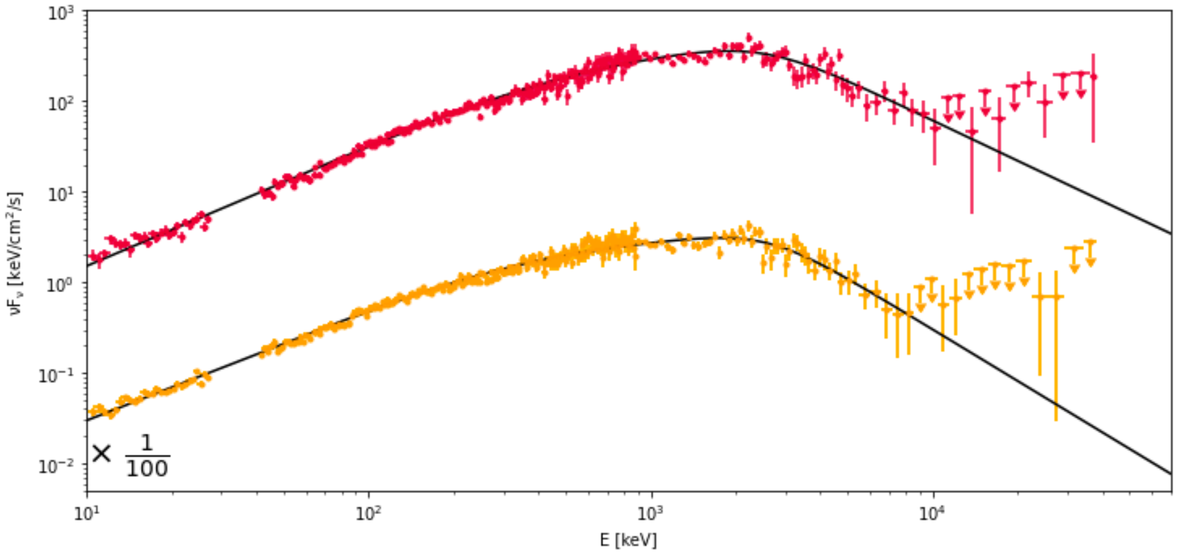
$\theta_{BGO} \lesssim 40^{\circ}$





Looking for the line in other GRBs





- We looked for the presence of a MeV line in a sample of 6 GRBs:

GRB 230307A
GRB 130427A
GRB 160625B

Brightest GRBs

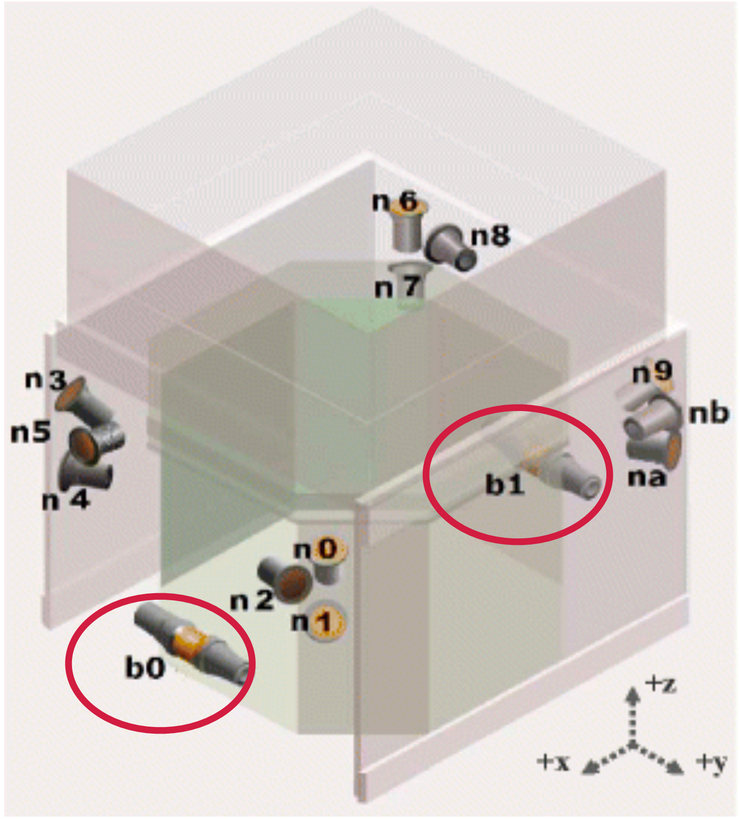
GRB 170409A
GRB 171227A
GRB 130606B

Best BGO viewing angle

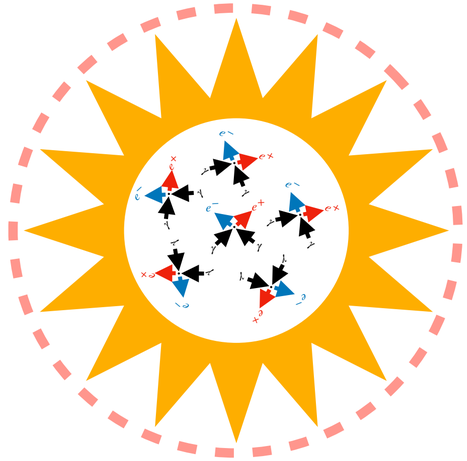
$\theta_{BGO} \lesssim 40^{\circ}$

What can produce a MeV line?

- Instrumental effects?



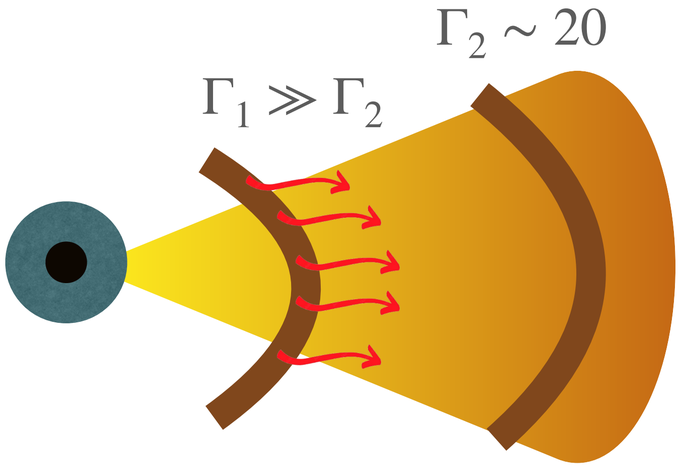
- Pair-annihilation blue-shifted line?

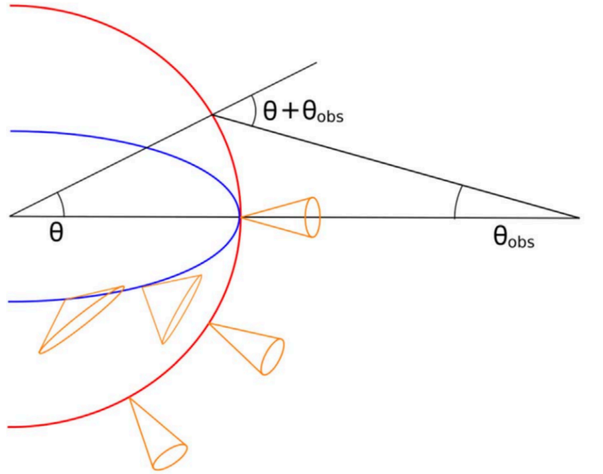


$$E'_{th,\gamma\gamma} = m_e c^2 = 0.511 \text{ MeV}$$

$$E_{th,\gamma\gamma} = \Gamma m_e c^2 \simeq 10 \text{ MeV} \rightarrow \Gamma \simeq 20$$

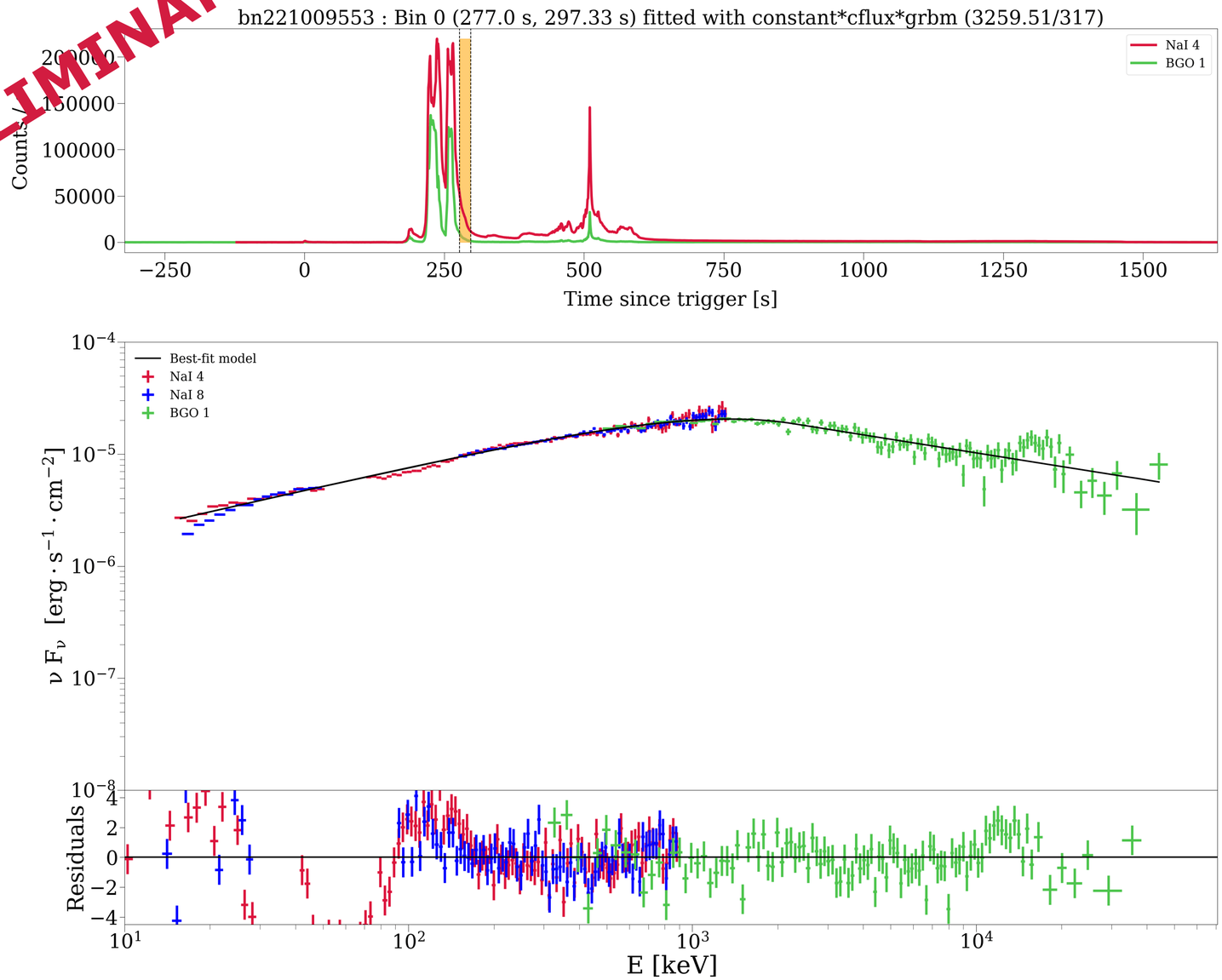
Usually $\Gamma_{GRB} \gtrsim 100$!!!



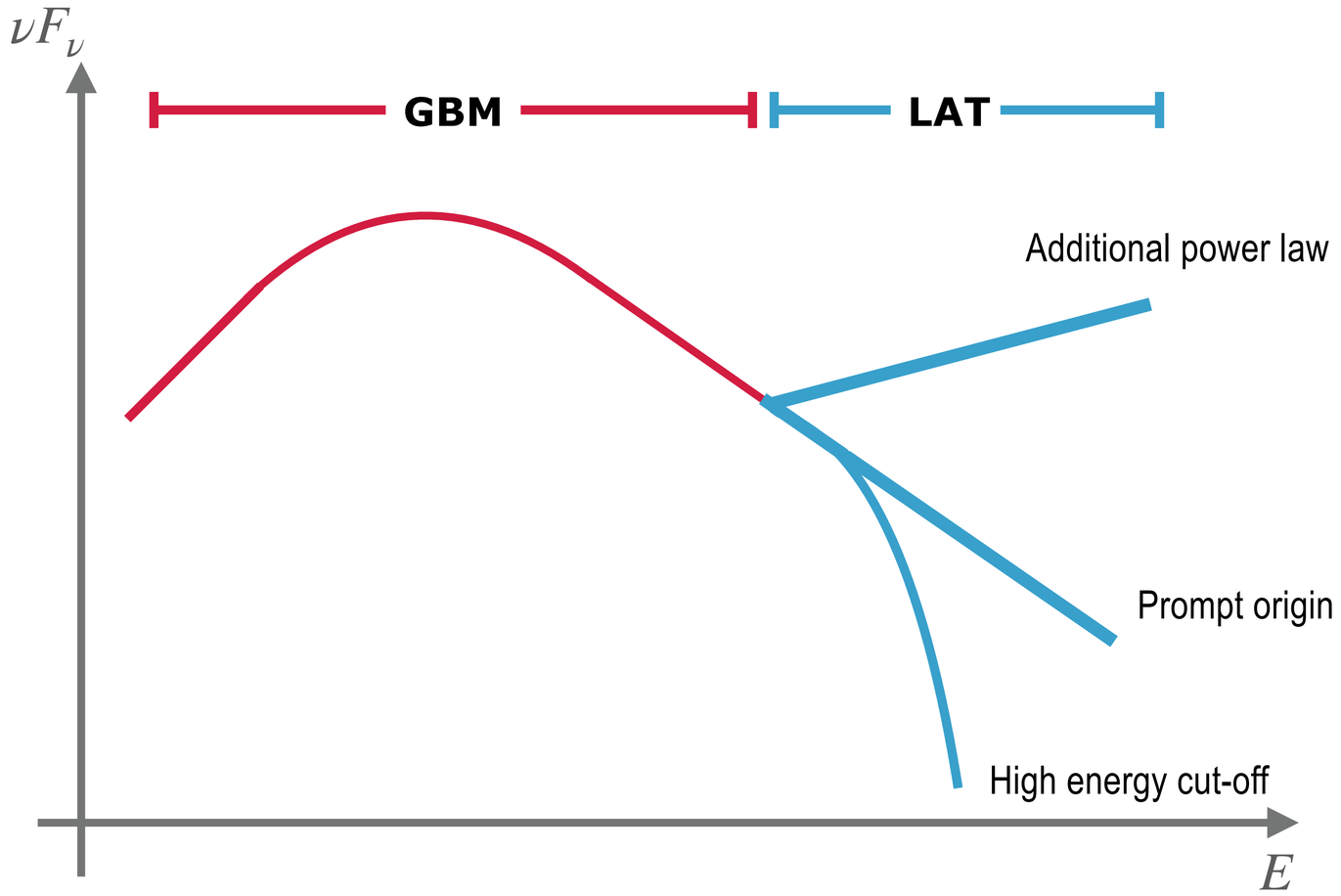


We are not done with the BOAT 🥲

PRELIMINARY



HE component in prompt emission phase



HE component in prompt emission phase

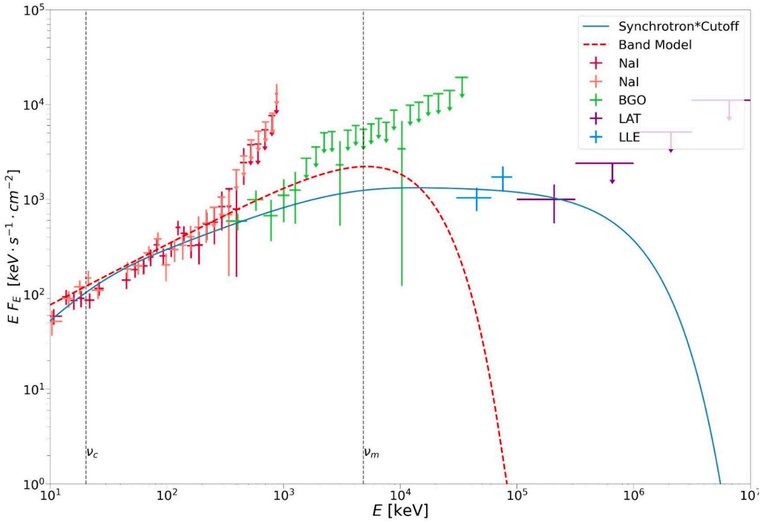
Time resolved analysis of 80 spectra and 14 GRBs

GBM + LLE + LAT

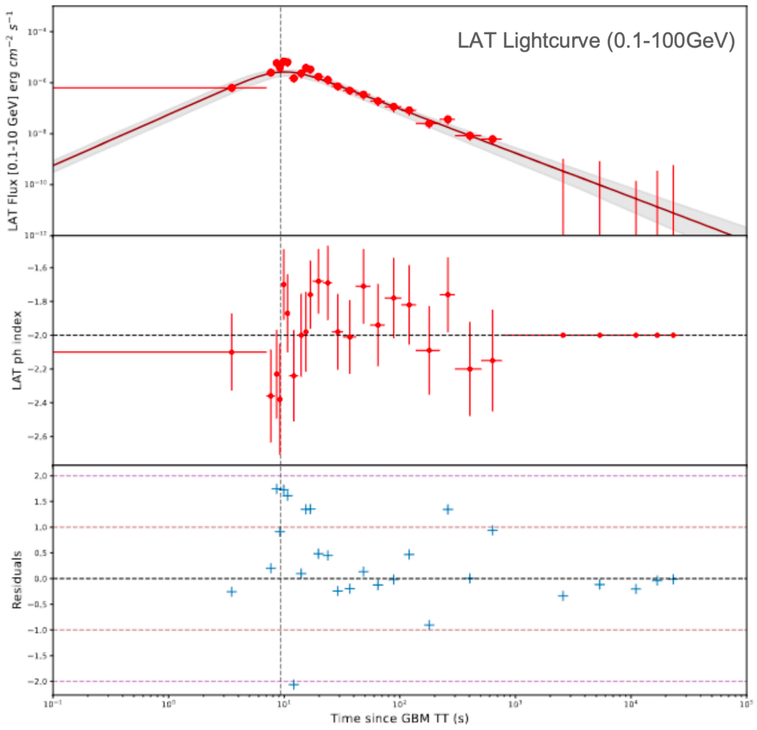
+ Physical model for Prompt emission

Only synchrotron

GRB080916C

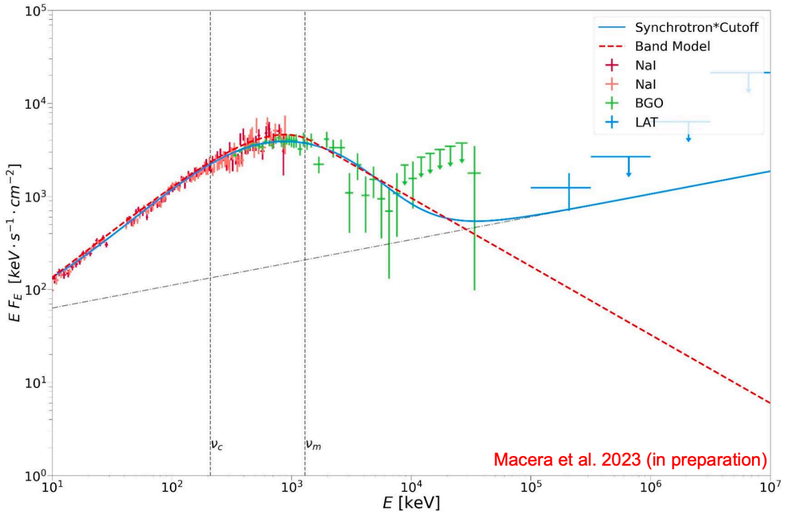


GRB090902B



Synchrotron + power law

GRB221023A



The fourth observational run (O4)

- May 24, 2023: LIGO officially started the run
- Virgo will join in March 2024, KAGRA still under commissioning
- LIGO alone reaches a range of 150 Mpc
- ~50 BBH observed so far, no BNS!

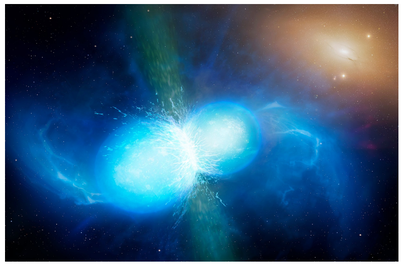
Challenge:

Looking for

Oddballs

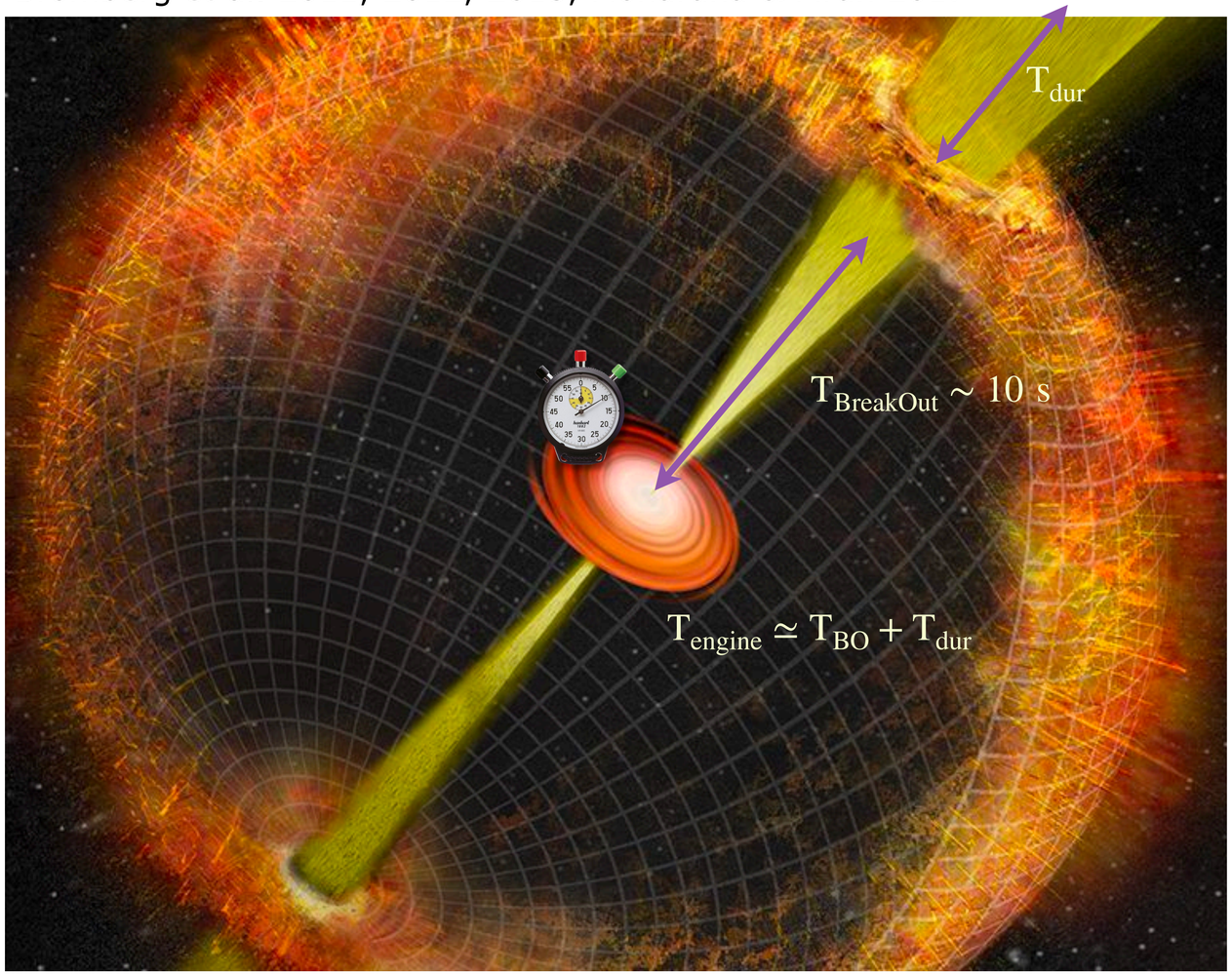
In offline search

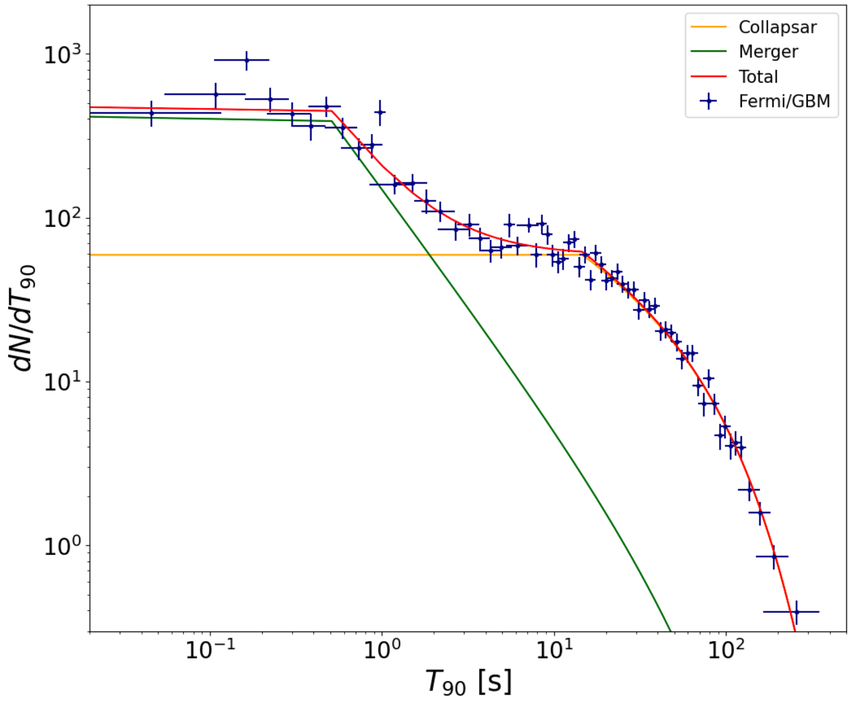
(Like GRB 211211A, GRB 230307A)

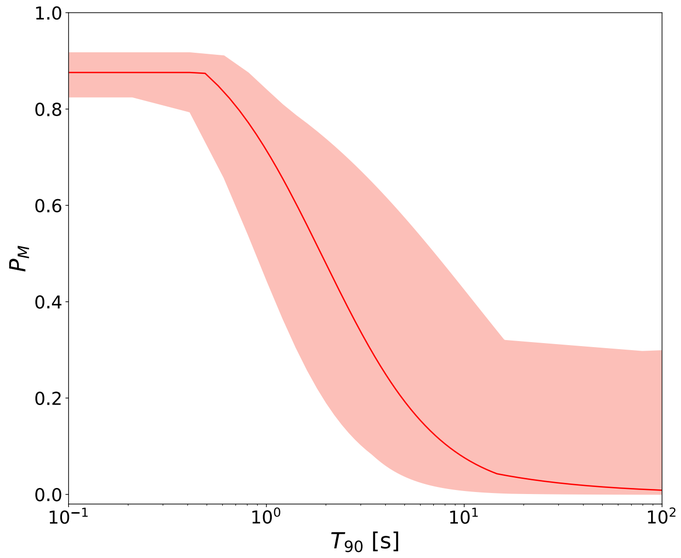


Searching for a new progenitor observable

Bromberg et al. 2011, 2012, 2013, Moharana & Piran 2017







Summary

GBM automatic analysis tool applied to :

- BOAT GRB prompt analysis, were we discovered the first MeV emission feature in a GRB spectrum and searched for others in the catalog.
- A catalog of bright LAT sources, to systematically analyse which emission contribution is observed in LAT using physically-motived models.
- The Fermi/GBM catalog (and a sub-sample with measured redshift), to look for a new observable able to give precious hints on the progenitor nature.

What's next?

- Systematic analysis of GRB soft extended emission
- Very likely the next **crazy** GRB!

- ***Mei A.*** *, Banerjee B., Oganesyan G., Salafia O.S. et al. 2022. DOI:10.1038/s41586-022-05404-7*
- ***Mei A.*** *, Oganesyan G., Tsvetkova A., Ravasio M.E. et al. 2022. DOI:10.3847/1538-4357/aca091*
- *Ravasio M.E., Salafia O.M., Oganesyan G.,* ***Mei A.*** *et al. 2023. DOI: 10.48550/arXiv.2303.16223*
- *Macera S., … ,* ***Mei A.*** *et al. 2023 in prep.*