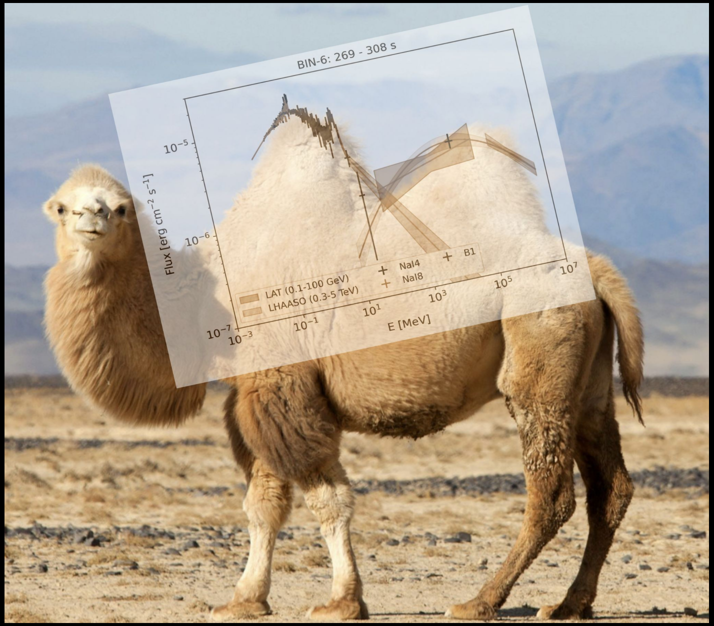
Camel on BOAT: Observation and characterization of the second spectral component in GRB 221009A



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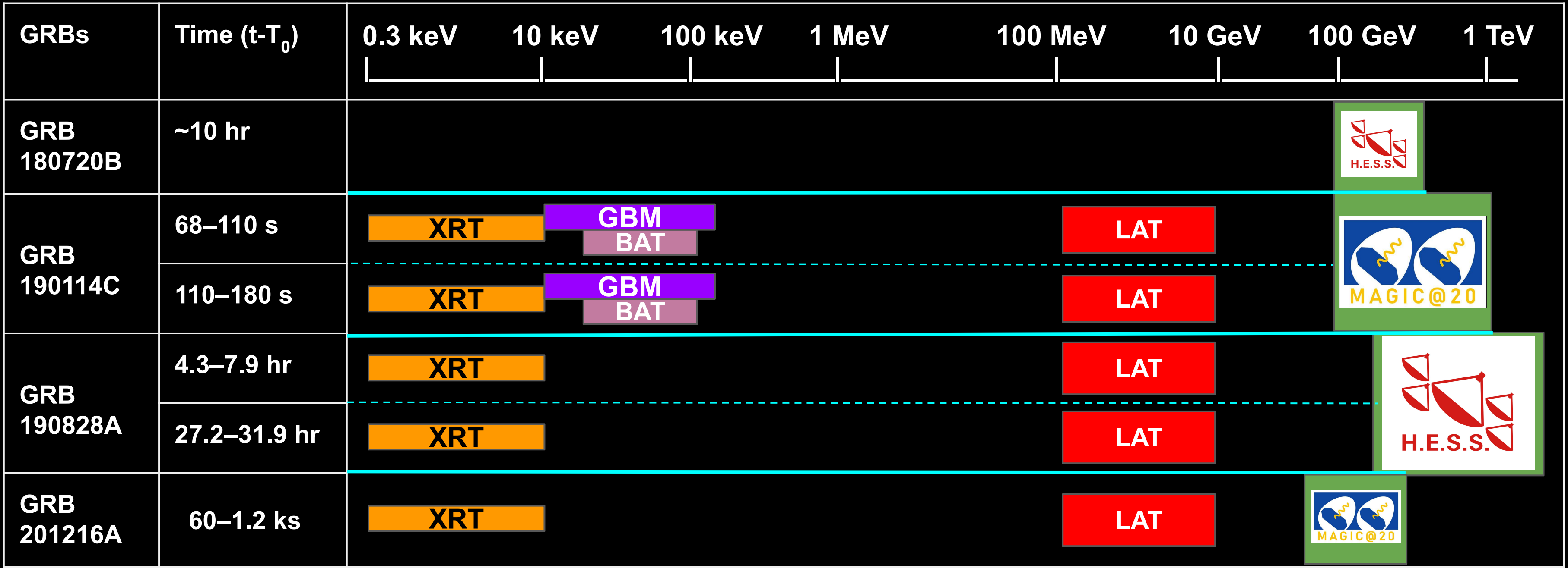
GSSI
GRAN SASSO SCIENCE INSTITUTE

Based on:
- Banerjee, Macera, Oganesyan+ 2025; A&A, 701, A68 (2025)
- Macera, Banerjee+; A&A 700, A88 (2025)

TeVPA 2025, Valencia

TeV GRBs



XRT | BAT | GBM | LAT | IACTs

MAGIC Collaboration:
Nature v. 575, p. 455–458 (2019)
Nature v. 575, p. 459–463 (2019)
H.E.S.S. collaboration, Nature, 2019
H.E.S.S. collaboration, Science, 2021
MAGIC Collaboration, MNRAS, 2024

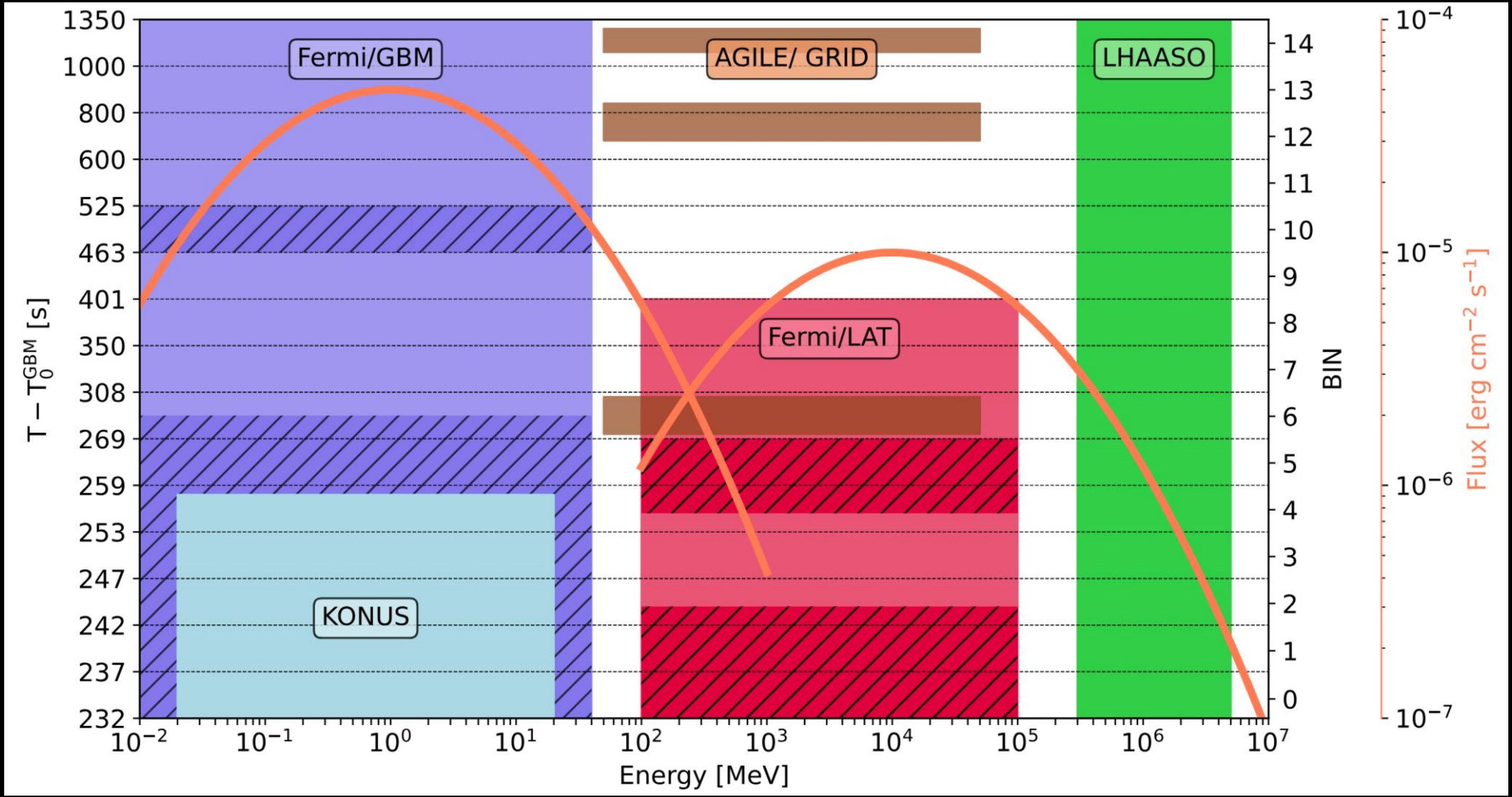
TeV GRBs

GRBs	Time ($t-T_0$)	0.3 keV	10 keV	100 keV	1 MeV	100 MeV	10 GeV	100 GeV	1 TeV
GRB 180720B	~10 hr	?	?		?	?		H.E.S.S.	
GRB 190114C	68–110 s	XRT	GBM / BAT		?	LAT (~3σ)		MAGIC@20	
	110–180 s	XRT	GBM / BAT		?	LAT (~5σ)		MAGIC@20	
GRB 190829A	4.3–7.9 hr	XRT	?		?	LAT (U.L.)		H.E.S.S.	
	27.2–31.9 hr	XRT	?		?	LAT (U.L.)		H.E.S.S.	
GRB 201216A	60–1.2 ks	XRT	?		?	LAT (U.L.)		MAGIC@20	

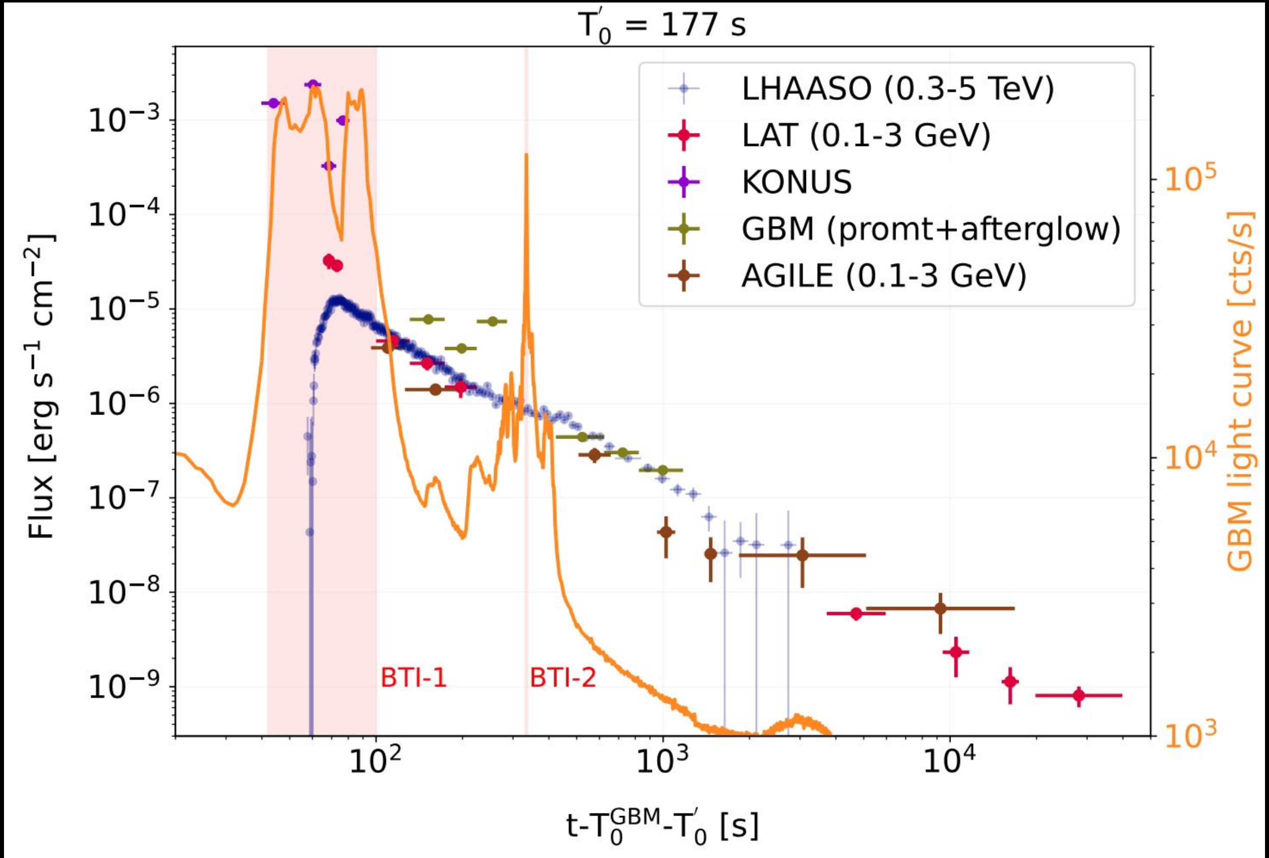
XRT | BAT | GBM | LAT | IACTs

MAGIC Collaboration:
Nature v. 575, p. 455–458 (2019)
Nature v. 575, p. 459–463 (2019)
H.E.S.S. collaboration, Nature, 2019
H.E.S.S. collaboration, Science, 2021
MAGIC Collaboration, MNRAS, 2024

GRB 221009A; MWL data



GRB 221009A; BOAT (Brightest Of All Time*)



z~ 0.15

LHAASO Collaboration, Science (2023)

Tavani et al 2023 ApJL 956 L23, 2023

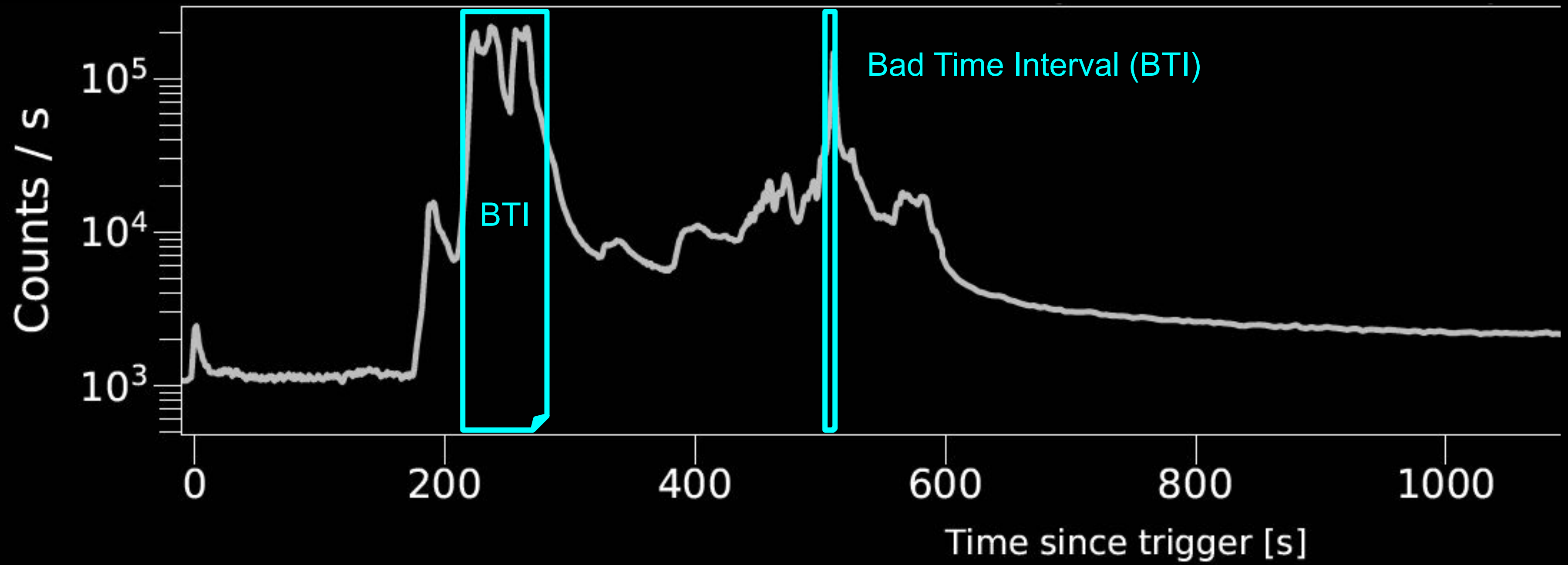
Bissaldi et al 2023: https://pos.sissa.it/444/847/

Frederiks et al 2023 ApJL, 949, L7 (2023)

Lesage et al 2023, ApJL 952 L42

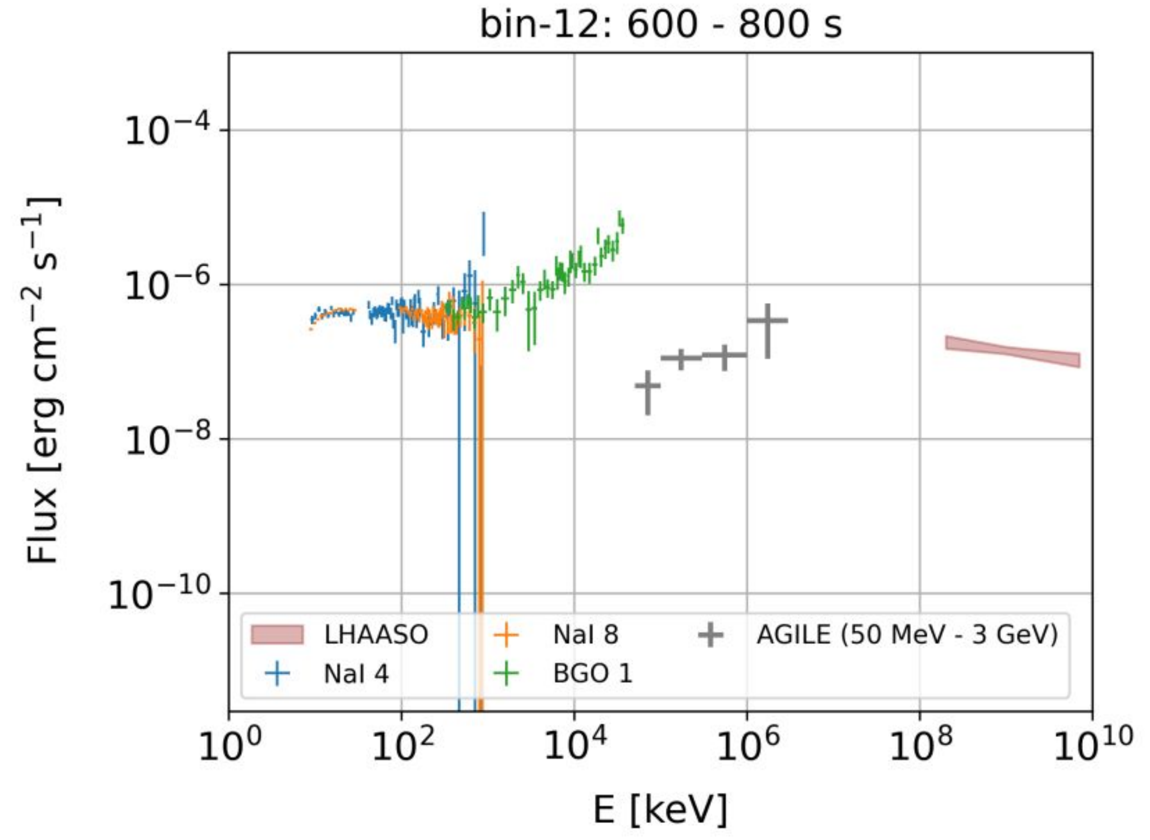
*Burns et al 2023, ApJL 946 L31

GRB 221009A: GBM light curve



Lesage et al 2023, ApJL 952 L42
Burns et al 2023 ApJL 946 L31
Ravasio et al 2023, Science

MWL spectrum; 600-800 s (after $T_{0,\ GBM}$)



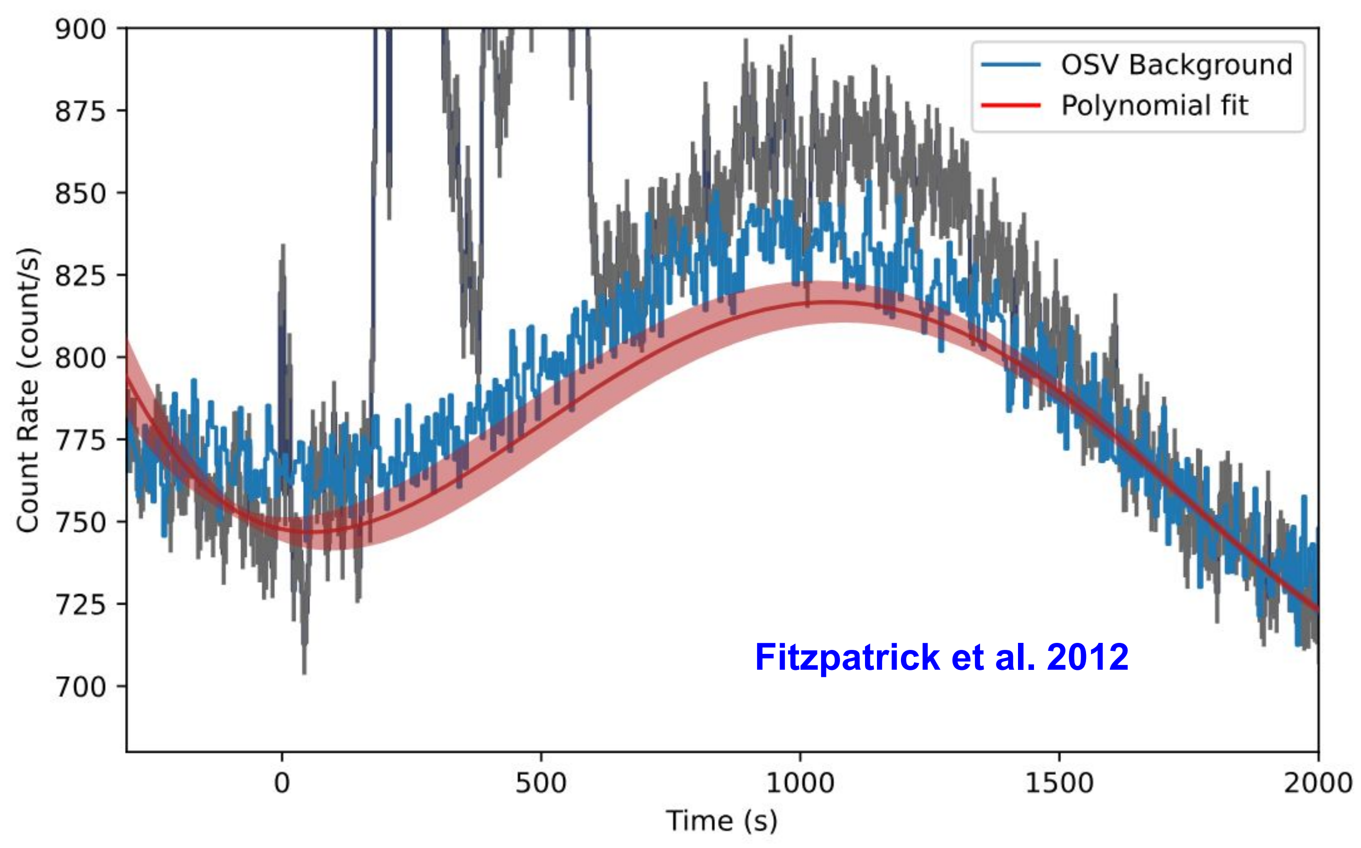
LHAASO Collaboration, Science (2023)

Tavani et al 2023
ApJL 956 L23, 2023

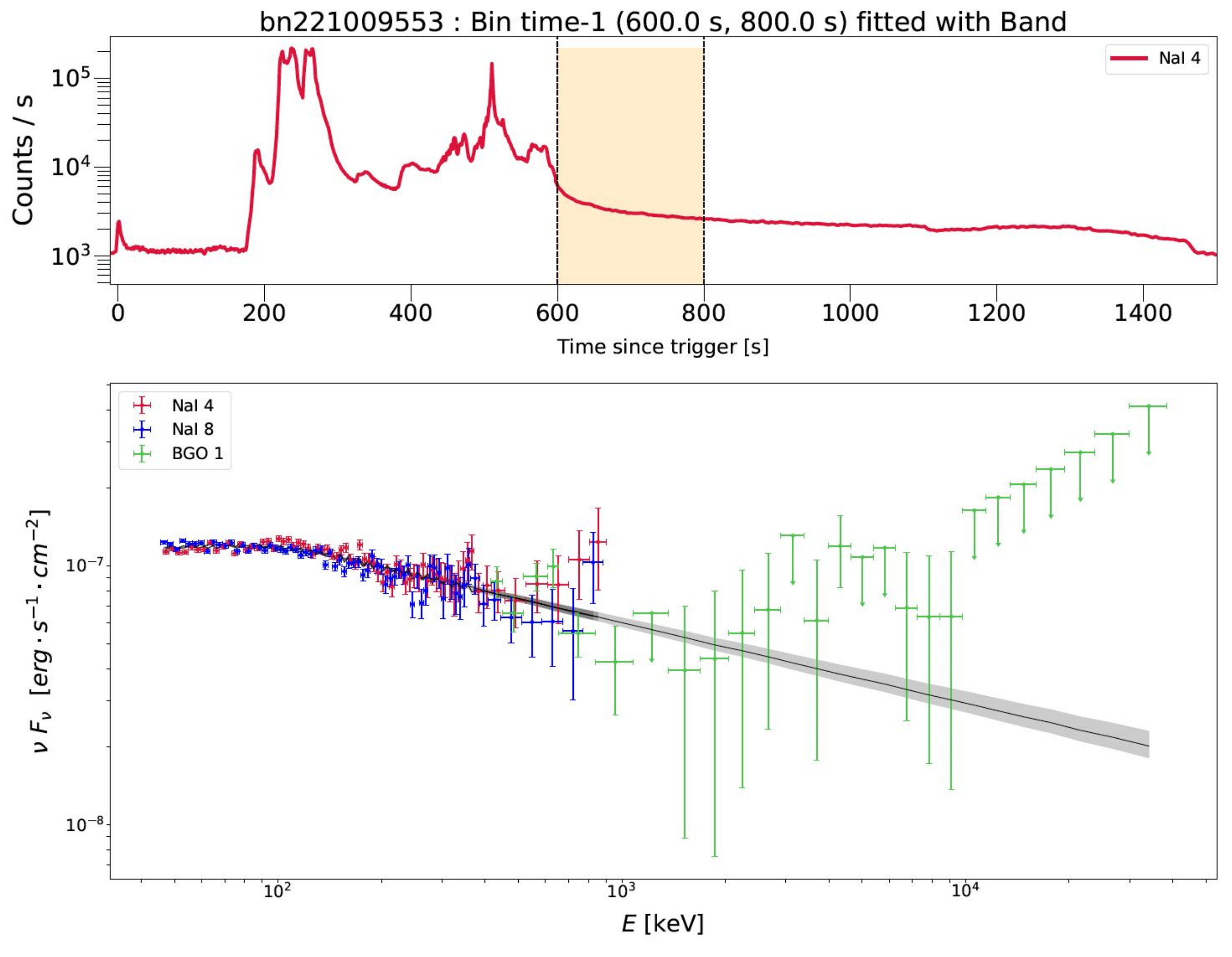
Lesage et al 2023, ApJL 952 L42

Burns et al 2023 ApJL 946 L31

Non standard GBM analysis:

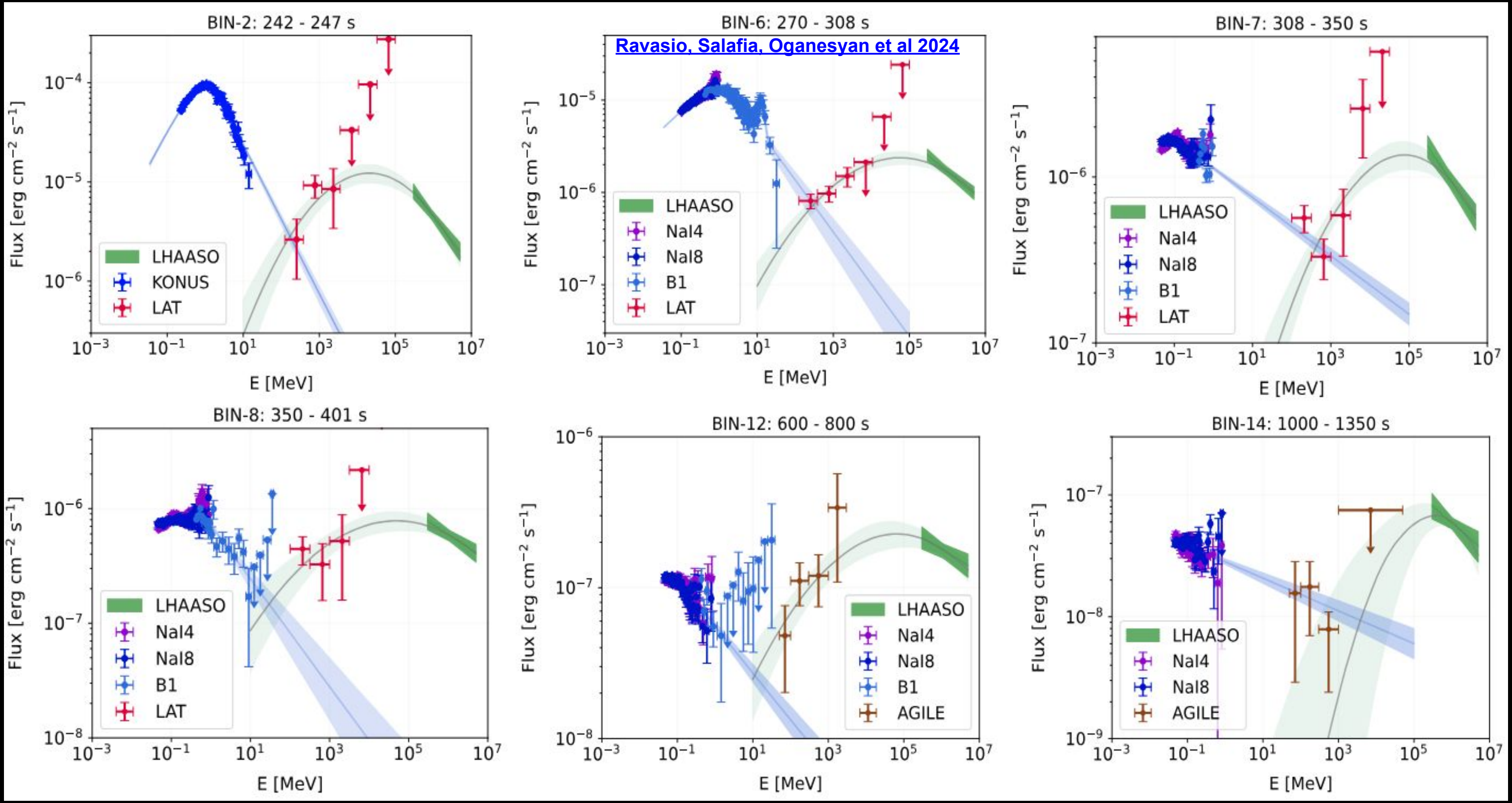


See also
Talk by
Oganesyan@16:45, Wednesday
Gamma-ray/ Galactic



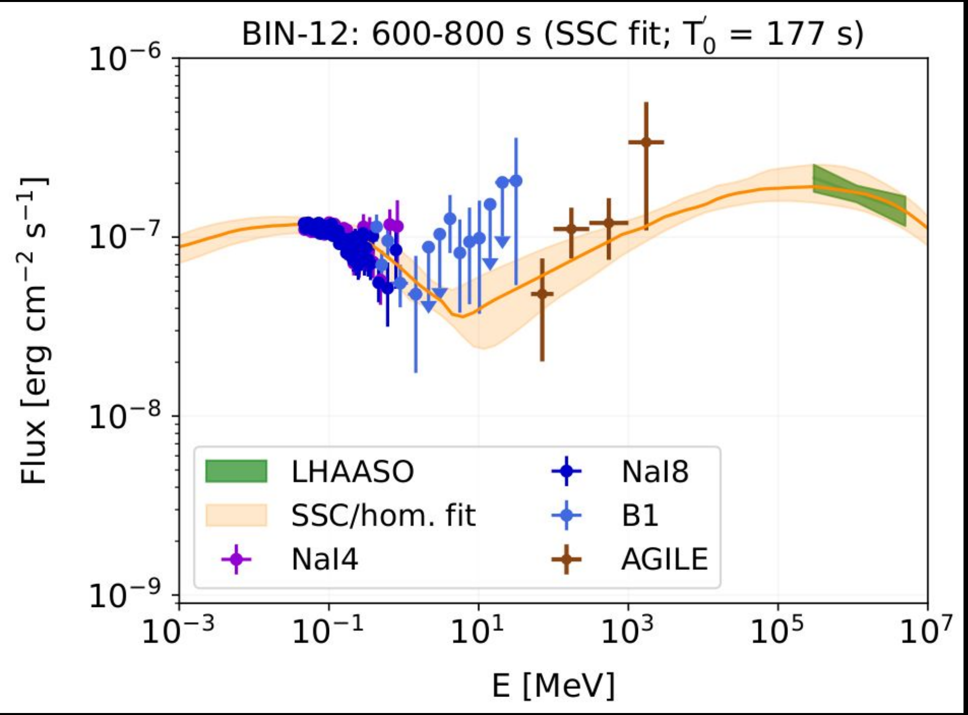
bn221009553 : Bin time-1 (600.0 s, 800.0 s) fitted with Band
NaI 4
Counts / s
Time since trigger [s]
NaI 4
NaI 8
BGO 1
νF_ν $[erg \cdot s^{-1} \cdot cm^{-2}]$
E [keV]

Time resolved spectra of GRB 221009A



Homogeneous medium

SSC: LeHaMoC; Stathopoulos et al 2023



Miceli and Nava 2022 (+references therein)

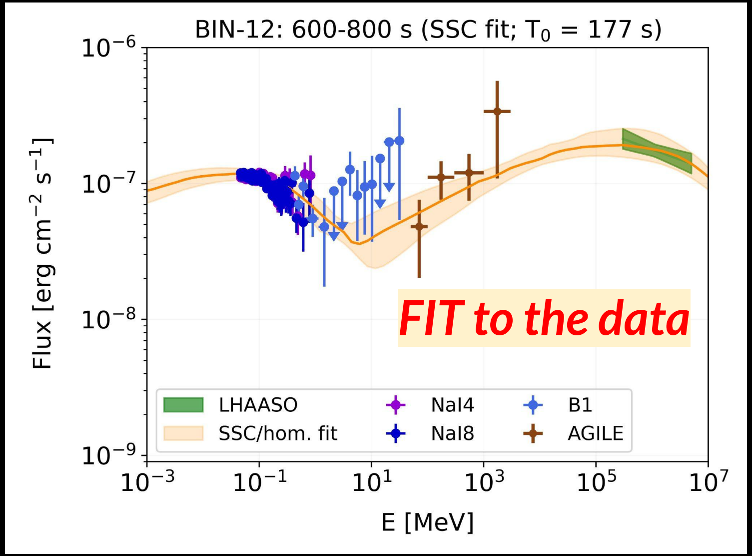
Parameters	Priors	Posteriors
$\log_{10}(\mathrm{B})$ [G]	(-5; 2)	$-1.3^{+0.8}_{-0.4}$
$\log_{10}(\gamma_m)$	(0; 5)	$1.5^{+0.9}_{-1.0}$
$\log_{10}(\gamma_{max})$	(4; 8)	$6.3^{0.1}_{-0.2}$
$\log_{10}\mathrm{l_e}$	(-7; -1)	$-2.8^{+0.6}_{-0.4}$
p	(2; 3)	$2.6^{+0.1}_{-0.4}$
$\log_{10}\mathrm{D}$	(1; 4)	$2.5^{+0.1}_{-0.3}$

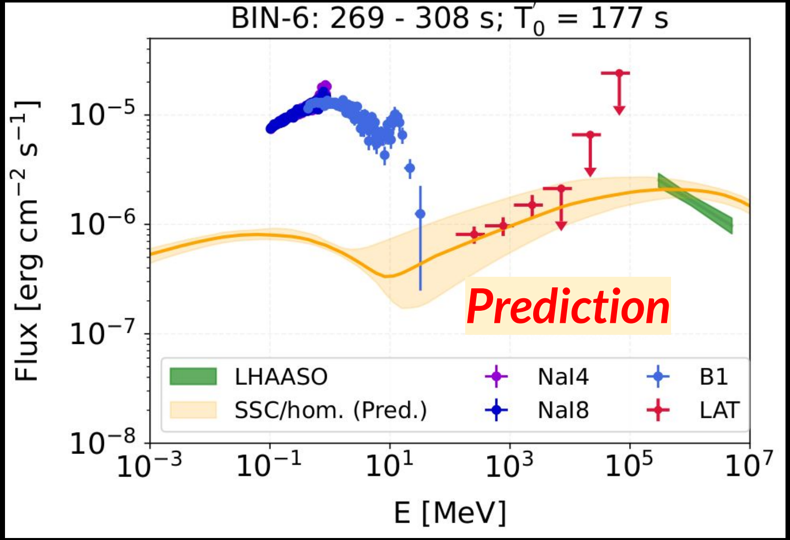
Extract microphysical parameters from BIN-12

Homogeneous medium

Miceli and Nava 2022 (+references therein)

SSC: LeHaMoC
Stathopoulos et al 2023



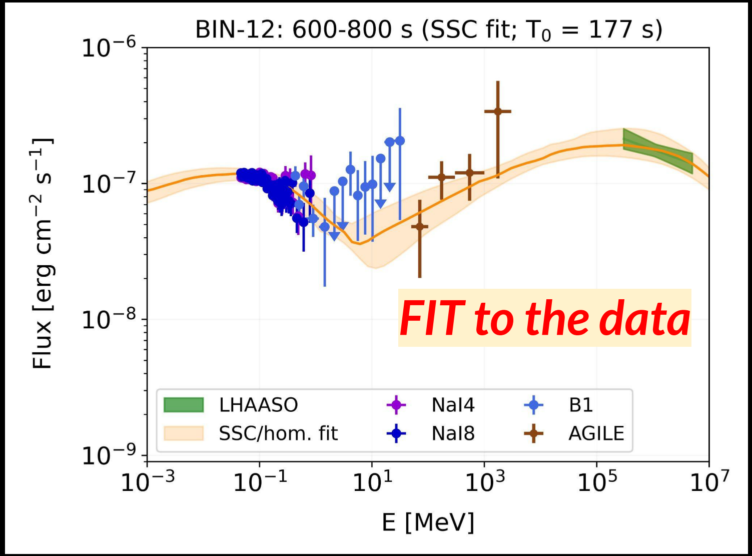


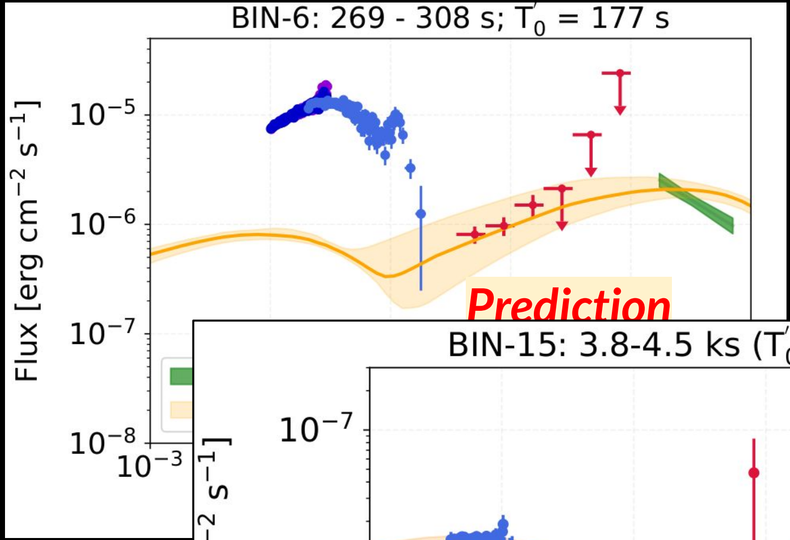
Extract microphysical parameters from bin 12

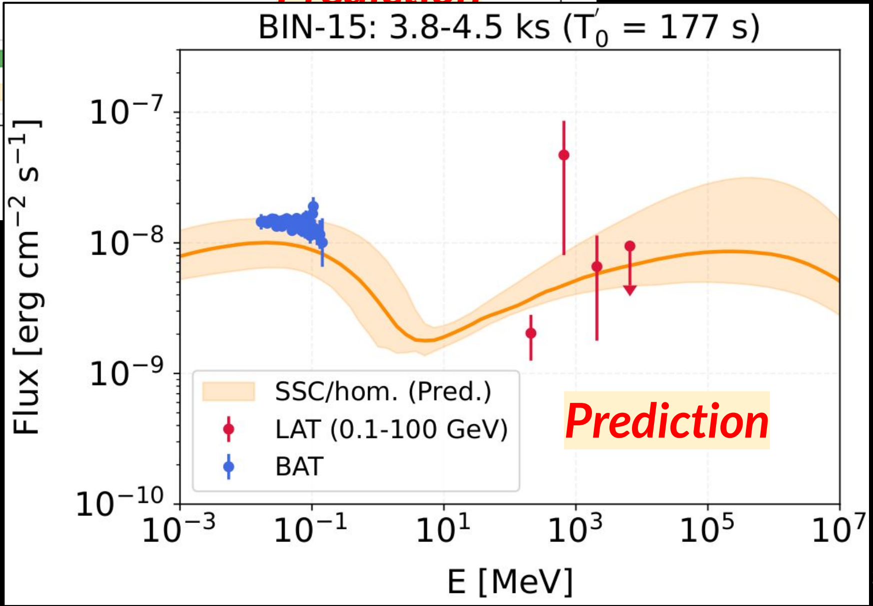
Homogeneous medium

Miceli and Nava 2022 (+references therein)

SSC: LeHaMoC
Stathopoulos et al 2023





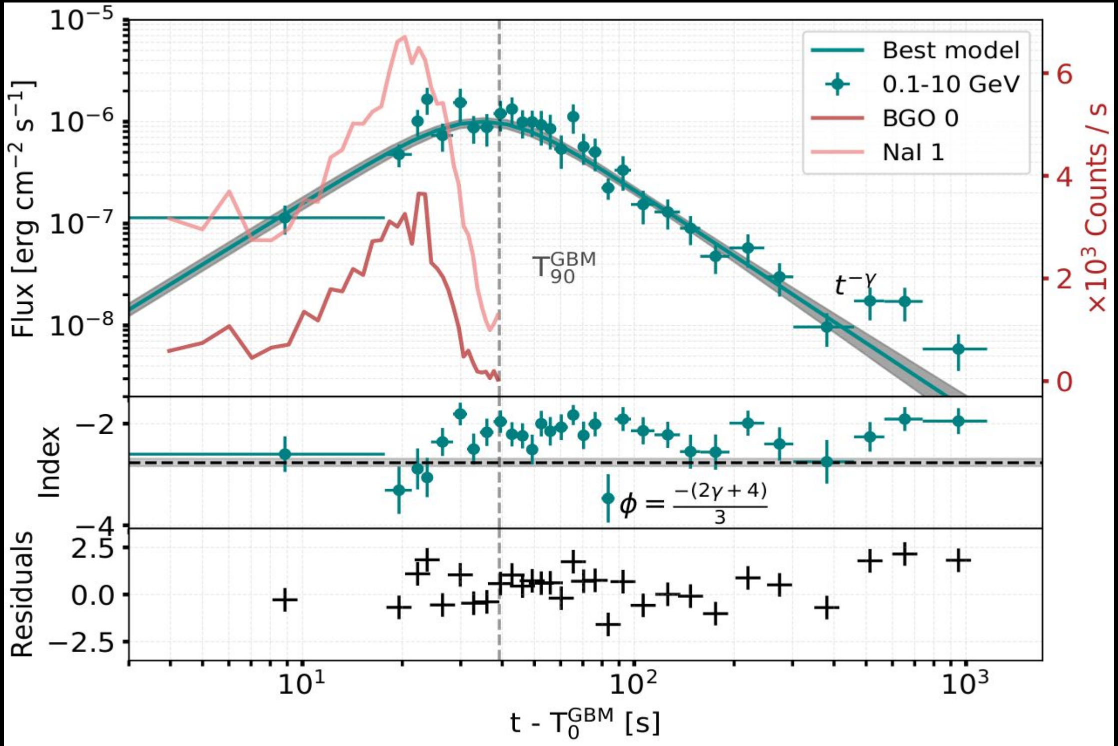


Extract microphysical parameters from bin 12

Nature of the early GeV emission

Macera et al 2025

GRB 221023A



- For some GRBs early GeV emission follows variability of prompt
  Zhang et al. 2011

- Early Afterglow or Prompt origin?
  Ghisellini et al. 2009,
  Kumar & Barniol Duran, 2009
  Maxham et al. 2011

- What is the contribution of the keV-MeV prompt?

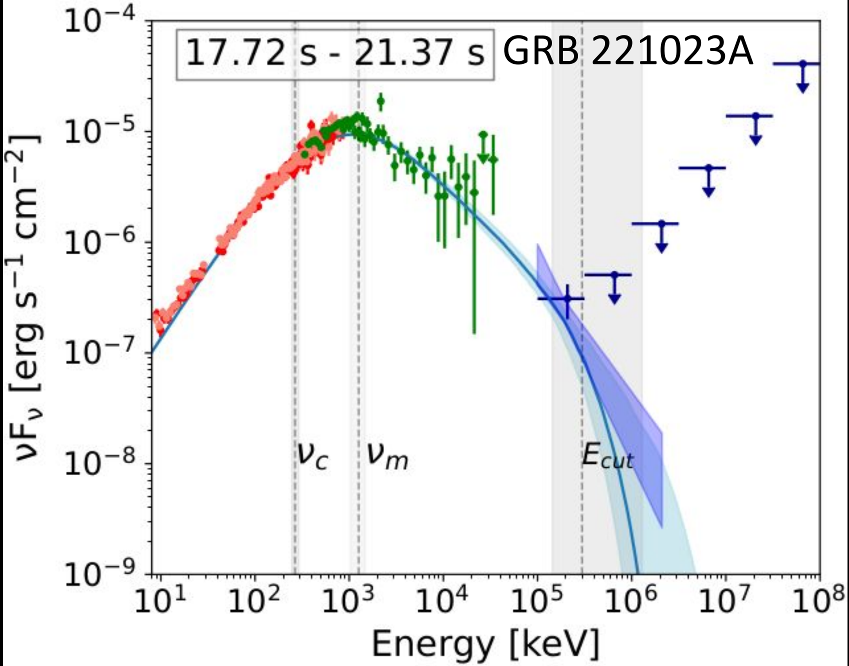
- Prompt second component?

For a complete review see: **Nava, 2018** and the references therein

Results of the time-resolved spectral analysis

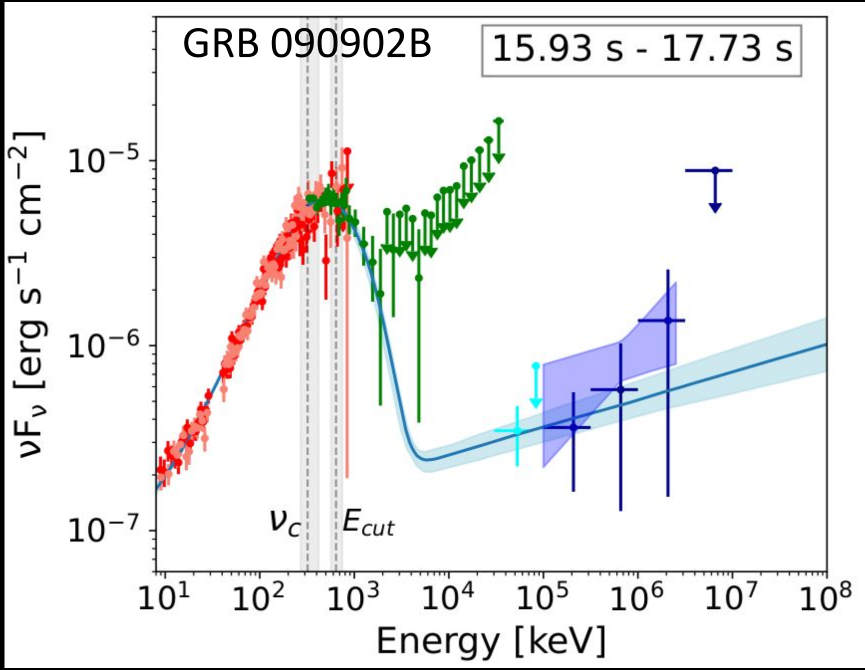
Sample divided in two groups

1 High-Energy emission dominated by synchrotron



2 High-Energy emission dominated by power law

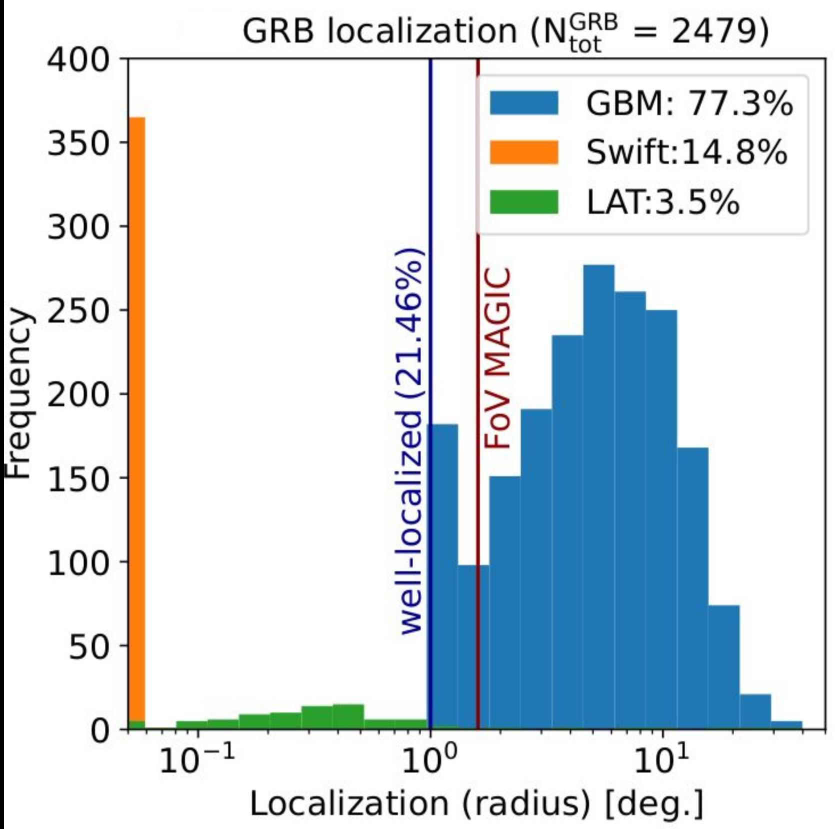
See also Ravasio et al 2023



How to catch and characterize early GeV/TeV emission: Observation proposal to IACTs

- LHAASO FoV and duty cycle (>90%) is excellent
  X LHAASO sensitivity is not adequate!
- Ground based telescopes have better sensitivity
  X requires slew (~20 s)
  X duty cycle is order of magnitude lower
- IACTs mostly follow-up BAT triggered GRBs (factor of 3 lesser than GBM triggers)
- **Way out: making tilled observation of poorly localized GRBs**

Talk by
[Macera@15:00, Tuesday]
Gamma-ray/ Galactic



Summary:

- GRB 221009A is a special case with clear double hump.

- The available MWL data makes it possible to put constraints on the micro-physical parameters.

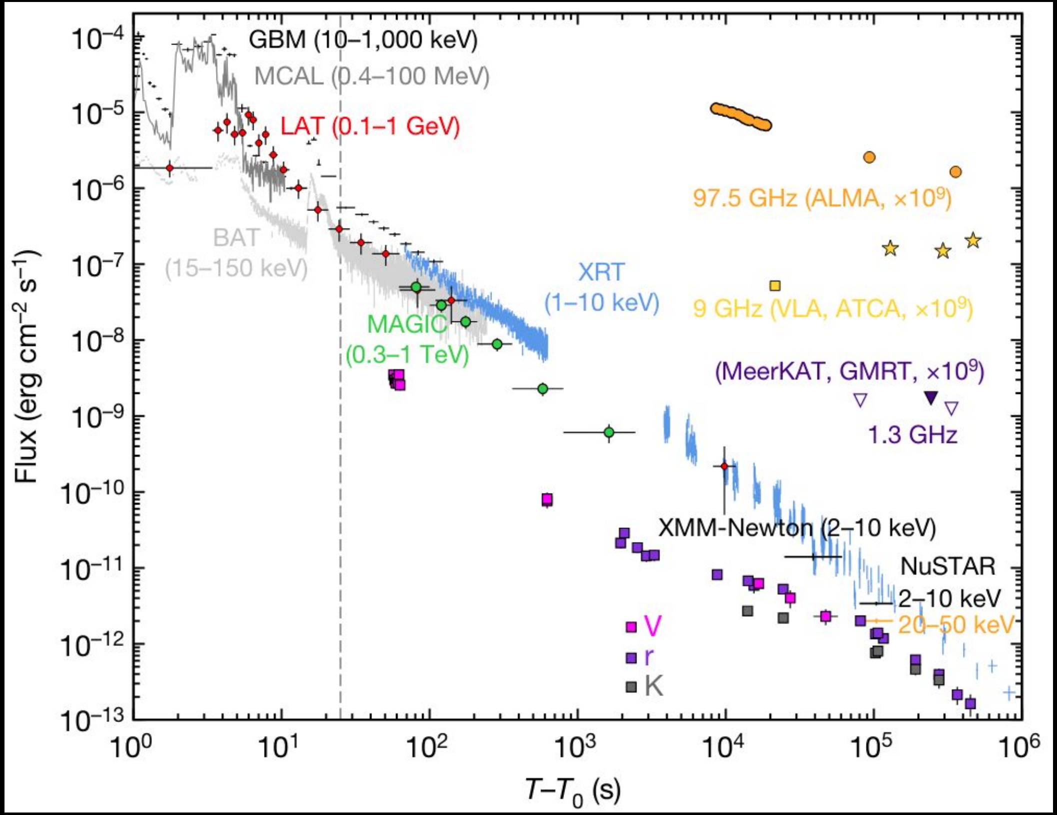
- GeV detections (LAT and AGILE) were crucial to establish the presence of the second component.

- Looking in to the MWL data of GRBs with GBM/LAT is important.

- Observational proposals are in place to detect early VHE emission in the future.

More!

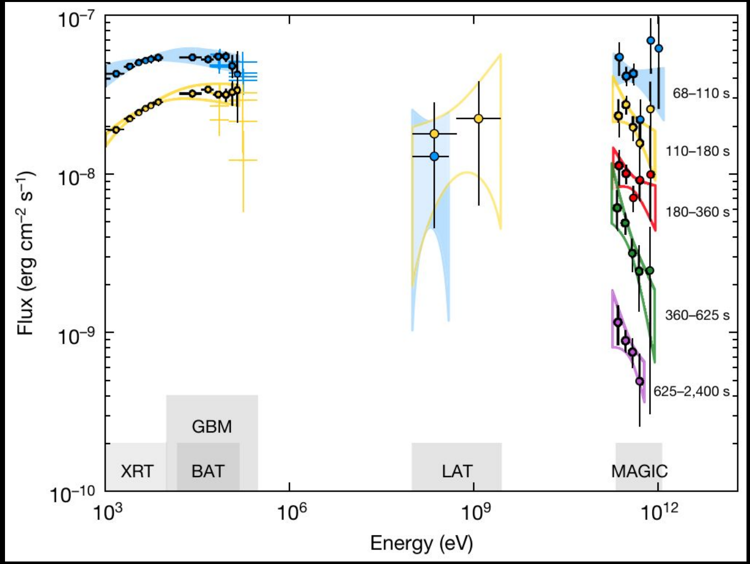
Why is it more informative?
GRB 190114C



MAGIC Collaboration:

Nature v. 575, p. 455–458 (2019) and
Nature v. 575, p. 459–463 (2019)

$z \sim 0.42$



Sample selection

Macera, BB + A&A 2025

- <u>At least three</u> significant temporal bins (>5 σ detection) simultaneous with Fermi-GBM
- GRBs with and without redshift up to year 2023
- At least 20 photons within 10° of region of interest around the GRB location
- GBM + LLE (when possible) + LAT

Sample 1

Time resolved spectral analysis of 14 GRBs, 80 spectra

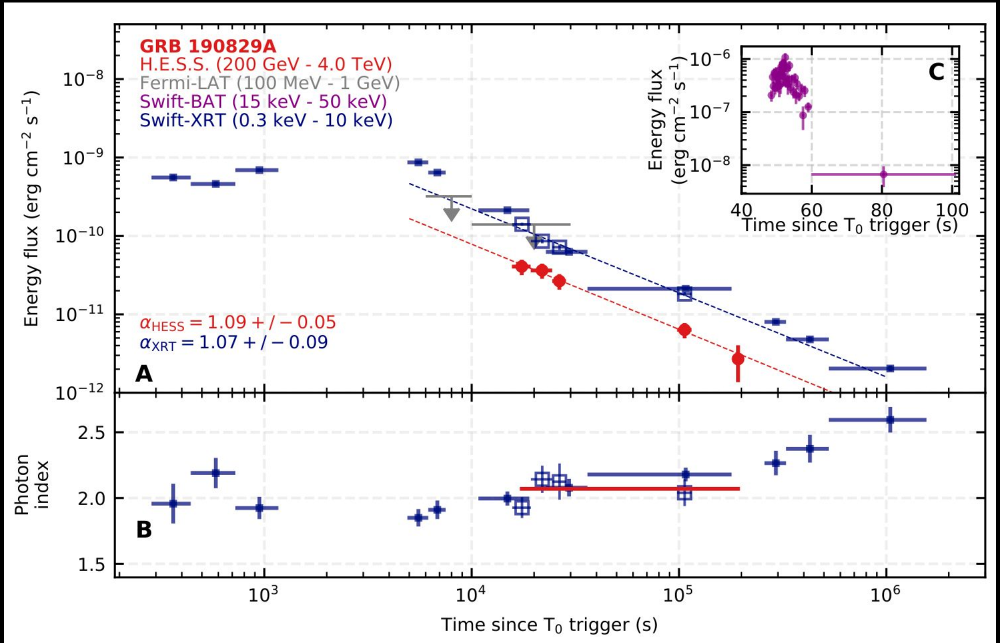
- <u>One</u> significant temporal bins (>5 σ detection) simultaneous with Fermi-GBM
- GRBs with and without redshift up to year 2023
- At least 20 photons within 10° of region of interest around the GRB location
- GBM + LLE (when possible) + LAT

Sample 2

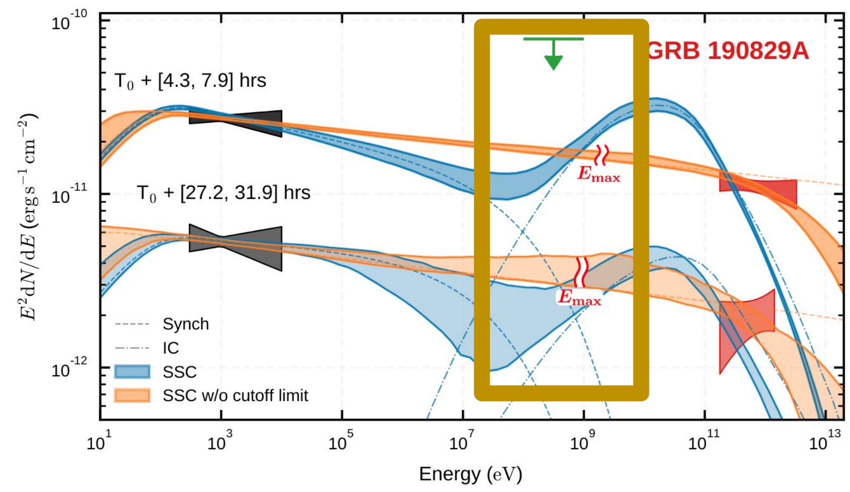
Spectral analysis of 66 GRBs

Total of 80 GRBs analysed in the energy range 8 keV - 10 GeV

Why is it more informative?
GRB 190829A



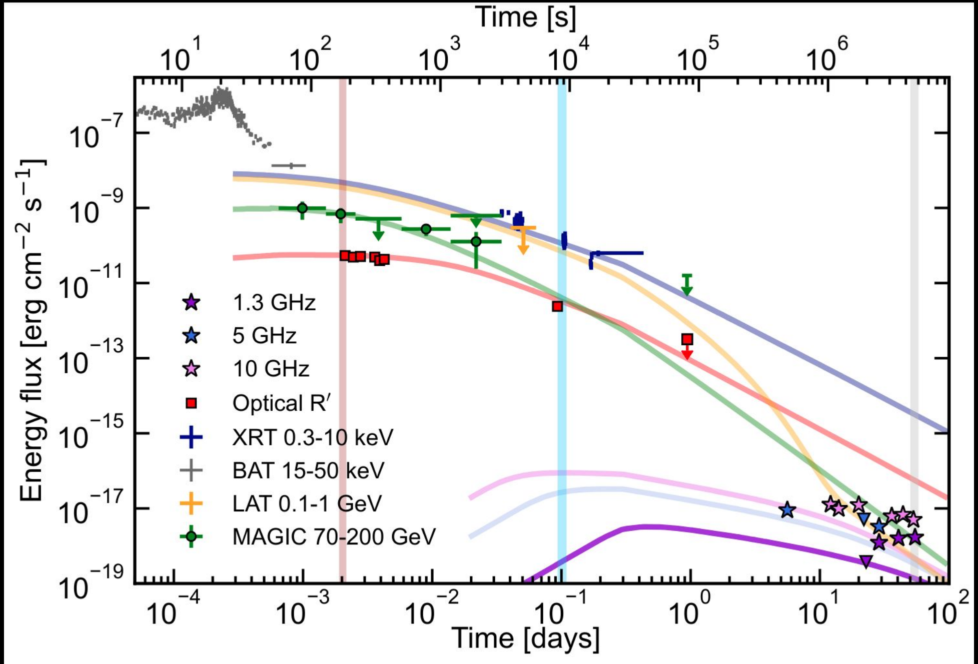
H.E.S.S. Collaboration 2021

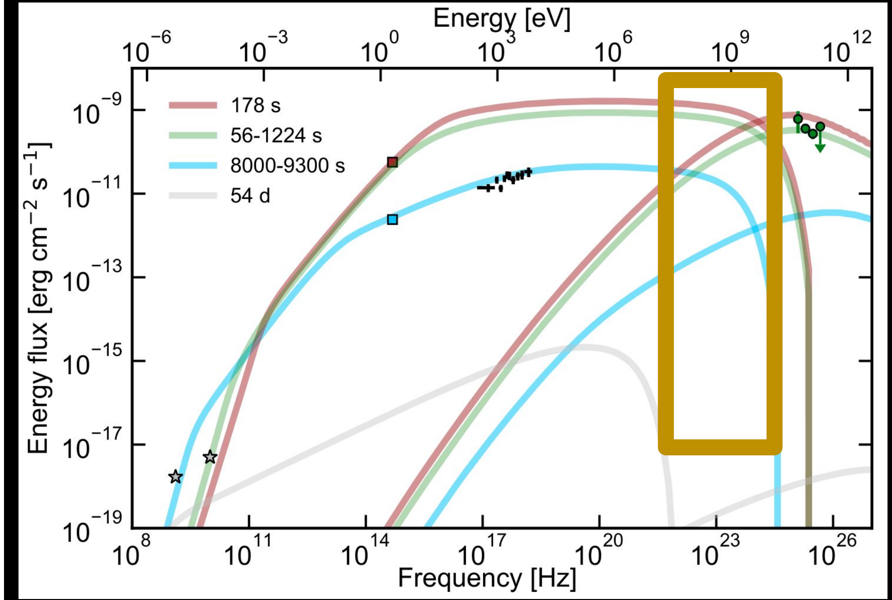


z~ 0.08

Why is it more informative?
GRB 201216C

MAGIC Collaboration 2024





z~ 1.1