Constraining the prompt emission region and the ejecta speed of the distant GRB 220101A

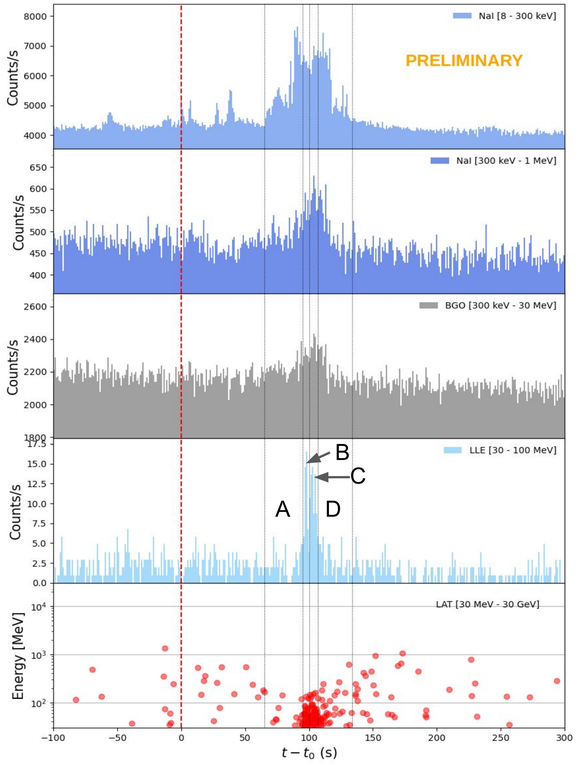
L. Scotton[1], F. Piron[1], N. Omodei[2], N. Di Lalla[2]
On behalf of the *Fermi*-LAT Collaboration
[1]Laboratoire Universe et Particules de Montpellier, CNRS/IN2P3
[2] Hansen Experimental Physics Lab, Stanford University

lorenzo.scotton@lupm.in2p3.fr

Abstract: GRB 220101A is the most distant gamma-ray burst detected by Fermi-LAT to date (z = 4.618). It is a very energetic event, with an equivalent isotropic energy E_{iso}~ 3.3x10^{54} erg. We jointly analysed Fermi-GBM and LAT data with two analysis chains and obtained consistent results. They reveal a spectral break below 100 MeV in the LAT Low Energy (LLE) range during the prompt emission, associated with second-time scale variability, which suggests that the spectral attenuation is caused by internal opacity to pair creation. Independently of the nature of the emission processes, we find that the keV and MeV emissions were produced co-spatially above and close to the photosphere, with a moderate Lorentz factor Γ_{bulk}~100. Here we present this study and compare our findings with other LAT-detected bursts with similar properties.

The event

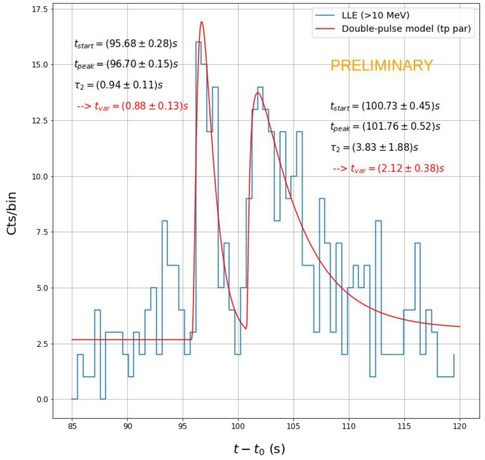
2022 January 1st at 05:10:11.5 UT
Burst with bright optical counterpart and high-energy emission
Farthest LAT-detected burst: z = 4.618
Very energetic event: E_{iso}~ 3.3 x 10^{54} erg



Variability

Fit of a double FRED function to two main LAT pulses
FRED function on a single pulse:

$$I(t) = \begin{cases} B, & \text{if } t \leq t_{start} \\ A \times \exp\left\{-\frac{1}{\tau_2}\left[\frac{(t_{peak}-t_{start})^2}{t-t_{start}} + (t-t_{start})\right]\right\} + B, & \text{otherwise} \end{cases}$$



Variability time scale t_{var} estimated as HWHM

$$t_{var} = \frac{\tau_2}{2} \times \sqrt{\left(\log(2) + 2\frac{t_{peak}-t_{start}}{\tau_2}\right)^2 - 4\left(\frac{t_{peak}-t_{start}}{\tau_2}\right)^2}$$

Time bin	t_{var} (s)
B: T_0 + [95, 100] s	0.88 ± 0.13
C: T_0 + [100, 107] s	2.12 ± 0.38

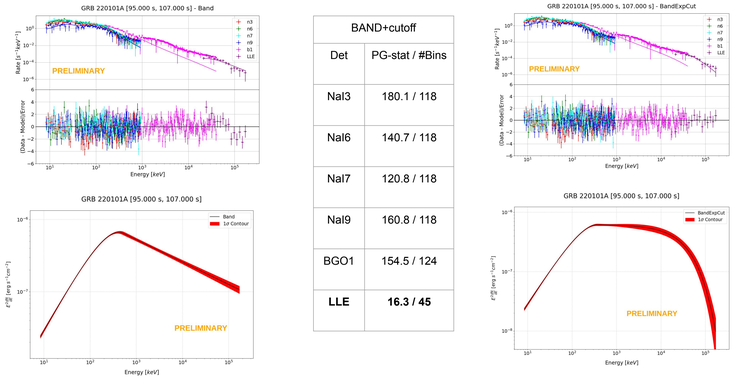
Joint analysis on main LAT pulses

pyXSPEC analysis on GBM+LLE data

BAND	
Det	PG-stat / #Bins
NaI3	178.7 / 118
NaI6	144.9 / 118
NaI7	119.9 / 118
NaI9	161.5 / 118
BGO1	157.3 / 124
LLE	**71.9 / 45**

BAND+cutoff	
Det	PG-stat / #Bins
NaI3	180.1 / 118
NaI6	140.7 / 118
NaI7	120.8 / 118
NaI9	160.8 / 118
BGO1	154.5 / 124
LLE	**16.3 / 45**

*Triangles correspond to 2σ upper limits



3ML analysis on GBM+LLE and GBM+LLE+LAT data, and consistency with pyXSPEC analysis

		Time Bin B: T_0 + [95, 100]s			Time Bin C: T_0 + [100, 107]s		
		GBM+LLE		GBM+LLE(<100 MeV)+LAT	GBM+LLE		GBM+LLE(<100 MeV)+LAT
		pyXSPEC	3ML	3ML	pyXSPEC	3ML	3ML
Band	E_{cut} [MeV]	22 ± 8	22 ± 6	31 ± 8	70 ± 24	72 ± 25	68 ± 18
	TS_{cut}	41	36	40	26	20	34
ISSM	E_{cut} [MeV]	40 ± 10	36 ± 10	40 ± 12	10^6 (at limit)	100 ± 40	89 ± 26
	TS_{cut}	23	21	24	0	10	19

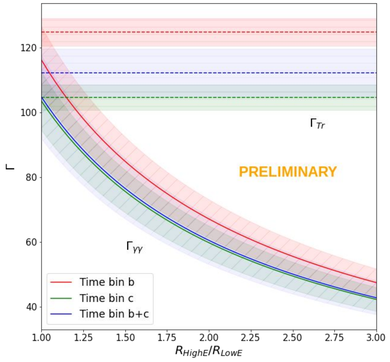
Conclusion: detection of high-energy cutoff regardless of the non-thermal emission model

Estimate of the prompt emission region and Bulk Lorentz factor

Moderate Γ_{bulk} ~ 100 estimated following Yassine et al. 2017 and Hascoët et al. 2012

Time bin	R_{LE} [10^{14} cm]	R_{PH} [10^{14} cm]	Γ_{BULK}	Γ_{TR}
B	1.27 ± 0.29	1.81 ± 0.51	116 ± 10	125 ± 4
C	2.43 ± 0.61	2.55 ± 0.68	104 ± 9	105 ± 4
B+C	1.76 ± 0.73	2.46 ± 0.91	105 ± 13	112 ± 8

GRB	z	$E_{cut,obs}$ (MeV)	$E_{cut,ref}$ (MeV)	Γ_{bulk}	Reference
090926A	2.1062	370 -50/+60 (time bin c)	1150 -155/+186	decrease from 230 to 100	Yassine et al. 2017
100724B	unknown	20-60 (time-resolved)	-	between 100 and 400 depending on z	Vianello et al. 2018
160509A	1.17	80-150 (time-resolved)	170-330	time evolution between 100 and 400	Vianello et al. 2018
170405A	3.510	50 (prompt phase)	225	170-420	Arimoto et al. 2020
220101A	4.618	40 (brightest LLE peaks)	230	105 (preliminary)	This analysis



Conclusion: the radii at which the low and high-energy emissions are produced are near the photospheric radius