Detection of a spectral break in the extra-hard component of GRB 090926A

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Summary: GRB 090926A is one of the four brightest gamma-ray bursts observed by Fermi. We report here the first measurement ever of a spectral break in the extra high energy component of a gamma-ray burst [1].

We report on the observation of the bright, long gamma-ray burst, GRB 090926A, by the Gamma-ray Burst Monitor (GBM) and Large Area Telescope (LAT) instruments on board the Fermi Gamma-ray Space Telescope. GRB 090926A clearly shows a short spike in the light curve that is present in all detectors that see the burst,suggesting that there is a common region of emission across the entire Fermi energy range. In addition, we report here for the first time the detection with good significance of a high-energy spectral break (or cutoff) in the extra power-law component around 1.4 GeV in the time-integrated spectrum. If the spectral break is caused by opacity to electron-positron pair production within the source, then this observation allows us to compute the bulk Lorentz factor for the outflow, rather than a lower limit.

GRB 090926A light curve

- MET: $T_0 = 275631628.99$ s
- Redshift: $z = 2.106$ (GCN 9942, VLT)
- $T90 = 15.3 \pm 0.2$ s (50 keV–300 keV)
- High energy emission delay ~ 3.3 s
- Highest energy γ at $T_0 + 26$ s : E=21 GeV

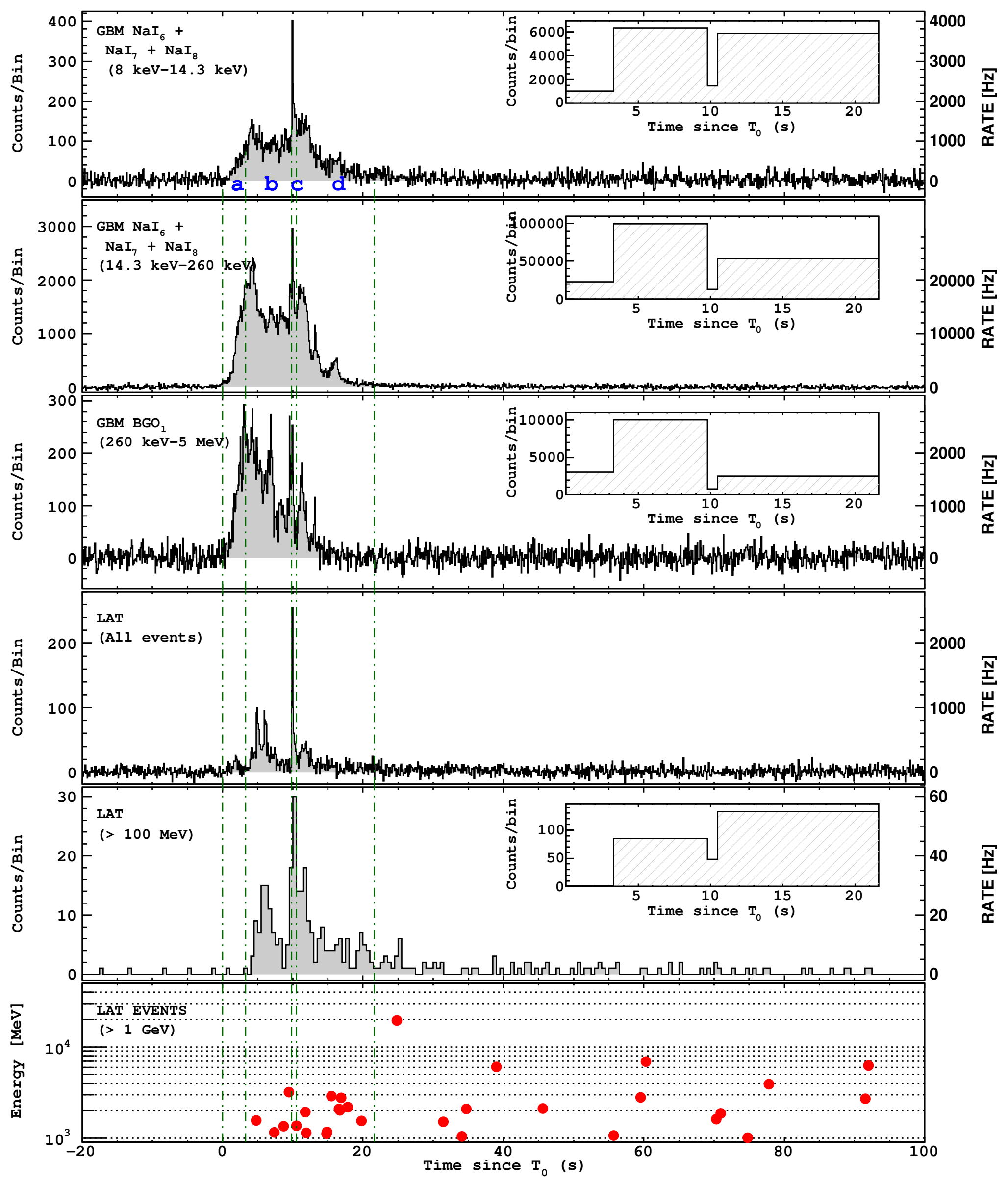

Figure 1: *GBM and LAT light curves of GRB 090926A. The fourth panel shows all LAT events that pass the on-board GAMMA filter. The first four light curves are background-subtracted and are shown for 0.1 s time bins. The fifth and sixth panels show LAT data transient class events for energies > 100 MeV and > 1 GeV using 0.5 s time bins.*

LAT–GBM joint spectral fit

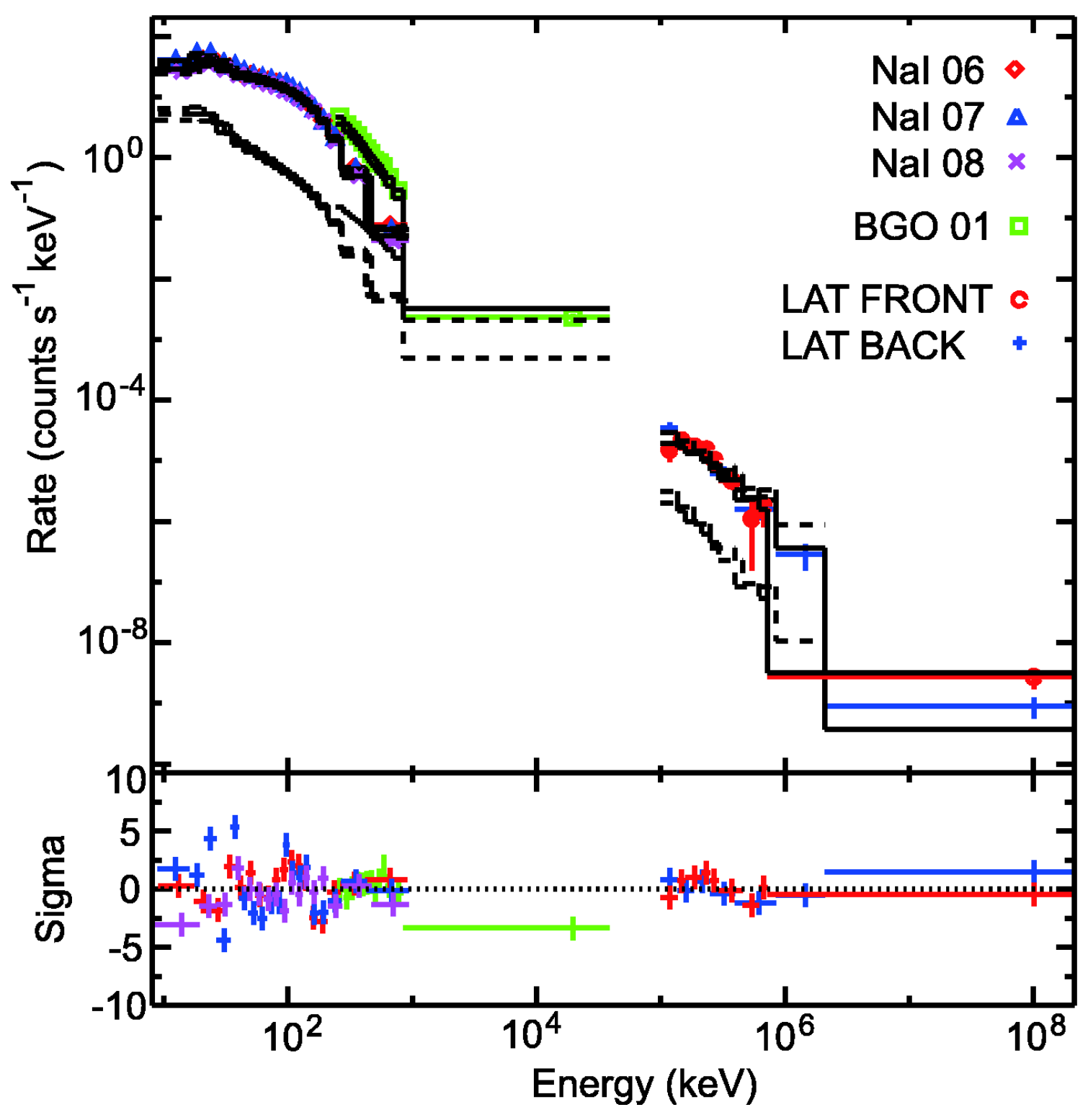

Figure 2: *GBM/LAT joint spectral fit for the prompt phase: count spectra and best-fit (top), the fit residuals (bottom).*

- A LAT–GBM joint spectral fit offers a lever arm on 7 decades in energy.
- Fit the full prompt phase from $T_0 + [3.3; 21.6]$ s.
- The Band plus cutoff power law (Band+CUTPL) model improves the Castor statistics by 40.5, what we estimated to be significant at $> 4\sigma$ using simulations.
- The fit residuals confirm the goodness of the fit.

Fitting model	Band	Band+PL	Band+CUTPL
Band function			
A (γ cm^{-2} s^{-1} keV^{-1})	0.176 ± 0.002	0.173 ± 0.003	$0.170\,^{+0.001}_{-0.004}$
$E_{\rm peak}$ (keV)	249 ± 3	256 ± 4	$259\,^{+8}_{-2}$
α (index 1)	-0.71 ± 0.01	-0.62 ± 0.03	$-0.64^{+0.02}_{-0.09}$
β (index 2)	-2.30 ± 0.01	$-2.59^{+0.04}_{-0.05}$	$-2.63^{+0.02}_{-0.12}$
Power-law			
B (10^{-10} γ cm^{-2} s^{-1} keV^{-1})	-	$3.17\,^{+0.35}_{-0.33}$	$5.80\,^{+0.81}_{-0.60}$
λ (index)	-	-1.79 ± 0.02	$-1.72^{+0.10}_{-0.02}$
$E_{\rm piv}$	-	1 GeV (fixed)	1 GeV (fixed)
High-energy cutoff			
E_F (GeV)	-	-	$1.41\,^{+0.22}_{-0.42}$
Flux (γ cm^{-2} s^{-1})	42.2 ± 0.1	43.5 ± 0.3	43.3 ± 0.2
Flux (10^{-5} erg cm^{-2} s^{-1})	1.18 ± 0.01	1.15 ± 0.02	1.13 ± 0.02
C-STAT / DOF	1395.1 / 579	1287.8 / 577	1247.3 / 576
Δ(C-STAT)†	-	107.3	40.5

† *with respect to the preceding model (column).*

Table 1: *LAT–GBM joint spectral fitting results for the prompt phase. The (Band+CUTPL) is the statistically preferred model ($> 4\sigma$).*

- The LAT/GBM joint fit is mandatory, LAT data alone cannot constrain the energy cutoff.
- A long awaited result: the first measurement of a spectral cutoff in the extra high energy component of a gamma–ray burst, the cutoff energy is E=$1.41^{+0.22}_{-0.42}$ GeV.

Time resolved spectral analysis

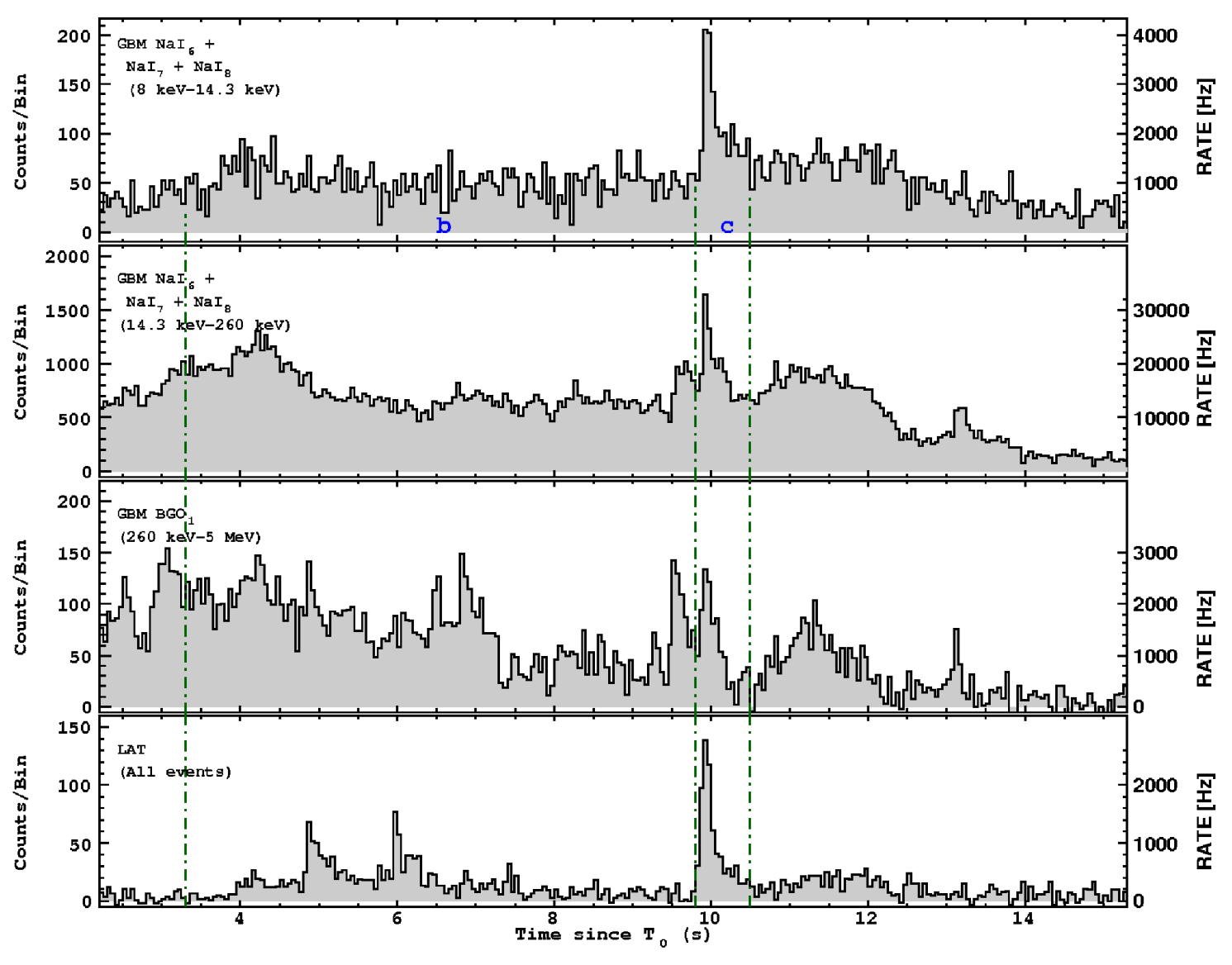

Figure 3: *Zoom on the light curve around time interval c for a 0.05 s time binning.*

- The light curve shows a high peak in flux at $T_0{+}10$ s, across all the detectors, i.e. from the keV to the GeV energy range, and a variability time scale $\Delta T = 0.15 \pm 0.01$ s.
- We ran a time resolved spectroscopy in the 4 time intervals defined in figure 1, including the flux peak by itself ($T_0 + [9.8; 10.5]$ s).

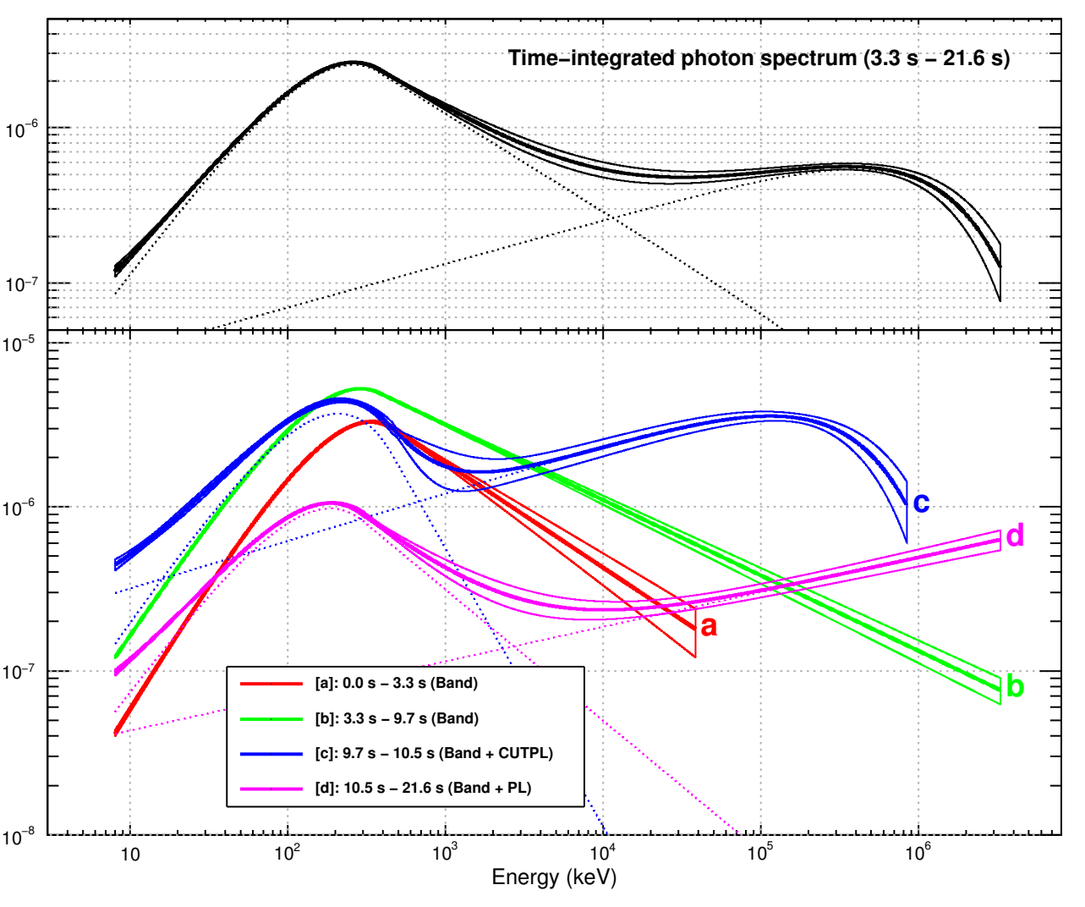

Figure 4: *Best-fit model for the time-integrated data (top) and the time-resolved spectroscopy (bottom), with $\pm 1\ \sigma$ error contours.*

- The time resolved spectroscopy shows that the high energy cutoff is significant in interval c (the flux peak) at a $\sim 4\sigma$ level: the cutoff energy is E= $0.40^{+0.13}_{-0.06}$ GeV.
- An evolution of the energy cutoff with time cannot be statistically proven but is possible.

Discussion

- GRB 090926A has a well defined flux peak at $T_0 + 10$ s: a short variability $\Delta T = 0.15 \pm 0.01$ s to be associated with a spectral cutoff at E= $0.40^{+0.13}_{-0.06}$ GeV.
- Under the assumption that the cutoff is due to $\gamma\gamma$ absorption within the jet [2], we're able to estimate the bulk Lorentz factor Γ_{jet} of the emission region for the time interval c:
  - a one-zone, steady emission model [3], leads to $\Gamma_{jet} \sim 700$
  - using a thin-shell, time dependent model [4], leads to $\Gamma_{jet} \sim 200$

References

[1] Ackermann M. et al., *Detection of a Spectral Break in the Extra Hard Component of GRB 090926A*, ApJ, 729, 114 (2011).

[2] Krolik, J. H., & Pier, E. A. , *Relativistic motion in gamma-ray bursts*, ApJ, 373, 277 (1991).

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[4] Granot, J. et al., *Opacity buildup in impulsive relativistic sources*, ApJ, 677, 92 (2008)