Thermal Electrons in an Ultra-Relativistic Shock Shape the Optical Afterglow of GRB 250702F

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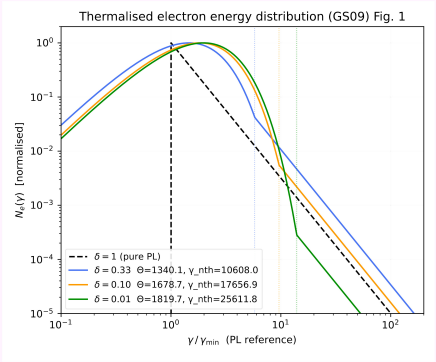
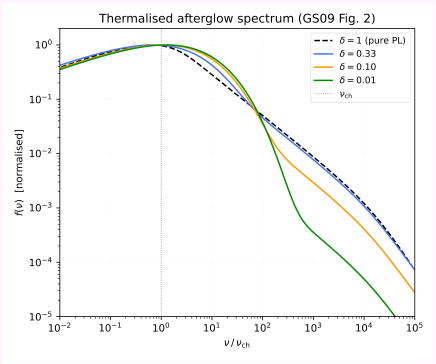
Maxwellian Electrons in GRBs

PIC simulations predict that shock-accelerated electrons are **not** purely power-law. A thermal (Maxwellian) peak always forms alongside the non-thermal tail.





Top: Hybrid electron energy distribution – Maxwellian peak plus power-law tail (δ = non-thermal fraction; figures after Giannios & Spitkovsky 2009, *MNRAS* 400, L75 – **GS09**).
Bottom: Resulting synchrotron spectrum: sharp cutoff above $\nu_{\rm th}$ (vs. pure power-law, dashed). As the shock decelerates, $\nu_{\rm th} \propto t^{-3/2}$ sweeps to lower frequencies – leaving a temporal fingerprint in the light curve.

GRB 250702F

GRB 250702F ($z = 1.520$, $E_{\rm iso} = 9.9 \times 10^{52}$ erg), detected by *Fermi*/GBM & *Swift*/BAT on 2025 July 2. The D50 robotic telescope (Ondřejov) began observations 27.8 s after trigger – catching the prompt pulses in the optical.

Flare A (30–100 s) tracks the γ-ray pulses. The GBM spectrum extrapolated to optical correctly predicts the D50 flux: the optical is the low-energy tail of the prompt emission across 5 decades.

Flare B (100–1400 s) shows a rise, plateau, and then an unusual steep-to-shallow decay transition, decoupled from X-ray flaring. Forward-shock and reverse-shock models fail to explain it. It is the fingerprint of the spectral break between the thermal cutoff and the non-thermal power-law sweeping through the optical band.

First direct observational evidence for the thermal electron component in a GRB optical afterglow.

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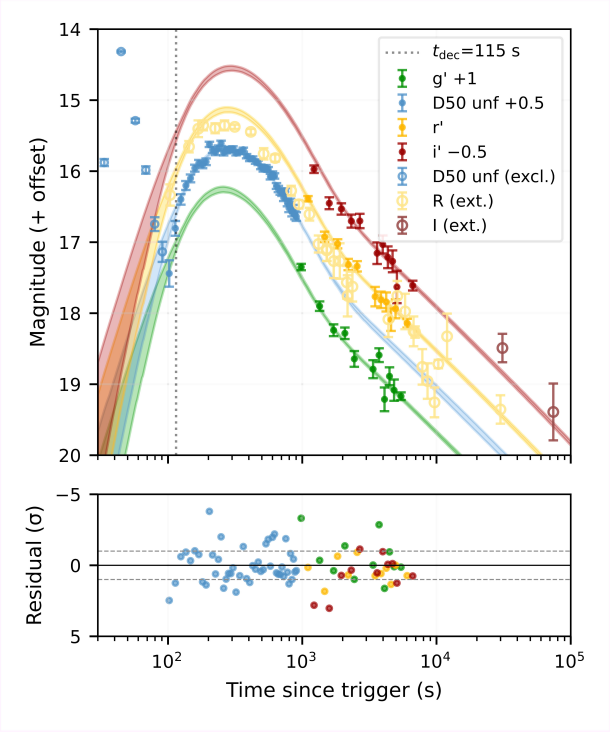
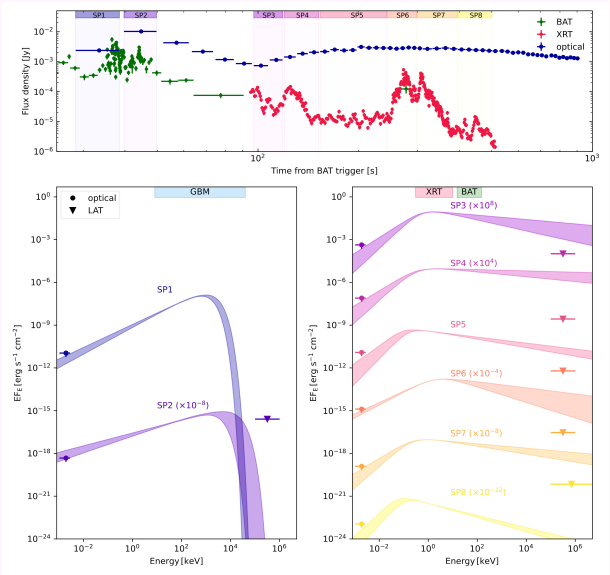
The Afterglow Fingerprint of Thermal Electrons



The rise and plateau of Flare B are ordinary afterglow dynamics. What is unusual is the subsequent steep decay ($\alpha \sim 1.8$) and its sharp recovery to a mild power-law decline ($\alpha \sim 0.8$).
The hybrid electron distribution produces a synchrotron spectrum with two regimes (see GS09 figures, left): a steep thermal cutoff just above $\nu_{\rm th}$, and a shallower non-thermal power-law at higher frequencies. As the shock decelerates, the spectral break between these two regimes sweeps through the optical band – the optical first probes the steep thermal cutoff, then transitions to the non-thermal power-law, reproducing the observed steep-to-shallow break.

Best-fit parameters ($\delta = 0.84$, $p = 2.05$, $\Gamma_0 \simeq 160$, $\gamma_{\rm th} \approx 900$, $\epsilon_B \approx 5 \times 10^{-4}$) are consistent with PIC simulation predictions.

Simultaneous Gamma-ray and Optical Analysis



Bottom left: GBM spectra (SP1, SP2) extrapolated to optical – consistent with D50 flux.
Bottom right: X-ray flares (SP3–SP8) fit jointly with XRT+BAT, peaks at 0.1–4 keV. Both are internal-dissipation events; the optical afterglow (Flare B) is physically distinct.

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