Multiwavelength observations of GRB 110731A

GeV emission from Onset to Afterglow

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on behalf of the Fermi–LAT collaboration

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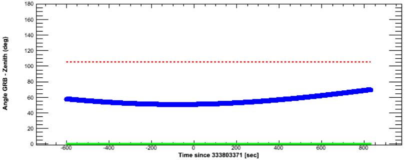
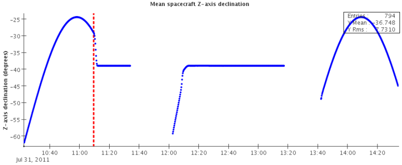
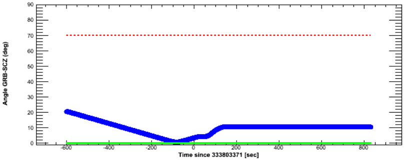
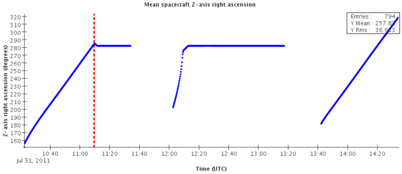
Outline. . .

- Observations
  - *Fermi* Autonomous Repoint Request
  - *Fermi* data quality and automatic science processing
  - *Swift*, GROND and MOA
- *Fermi* prompt emission results
  - Light curves
  - Spectral analysis
- Multi–wavelength Afterglow study
  - Multi–wavelength light curves
  - Broadband SEDs
  - Forward shock in a wind model





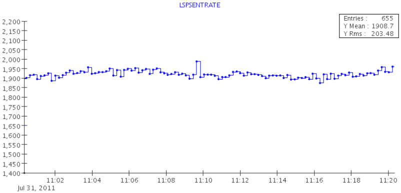


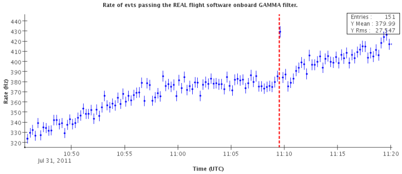


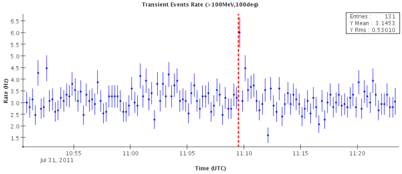
Fermi Autonomous Repoint Request

- GBM Trigger at 11:09:29.94 UT (T_0)
- Burst well in the field of view $\sim 6^{\circ}$
- Earth limb far away (little contamination)
- South Atlantic Anomaly gap only ∼30 minutes after the burst
- Optimal observations for 2.5 hours

Data Quality and Automatic Science



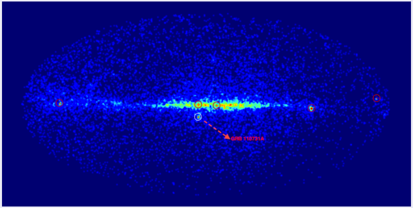




Data processing sequence

- GRB observed in `LSPSENTRATE` at 14:45 UT
- Data processing started at 15:40 UT
- GRB is observed in `GAMMA` filter rate,
- 'Transient' class event rate,
- 'Diffuse' class event rate above 100 MeV !
- *Burst Advocate* tool: automated LAT analysis emailed with GRB detection at 16:36:04 UT
- LAT GCN 12218 at 18:13:26 UT

Standard ASP results over 6 hours



Multi–wavelength observations

Swift observations

- BAT trigger at 11:09:30.45 UT$\sim T_0 + 0.5$ s
- *Swift* slewed immediately to the burst: XRT and UVOT observations from $\sim T_0 + 56$ s
- XRT observations for 24 days: exposure of 600 s in Window Timing mode and 75 ks in Photon Counting mode.
- UVOT observations: short exposure with the v filter during the settling phase, 'finding chart' exposure with the White filter lasting 147 s and usual procedure of cycling through its 3 visible filters.
- Swift/UVOT (Ra, Dec) = (280.50413, -28.537167) deg. $\pm$ 0.5 arcsec. (90%)

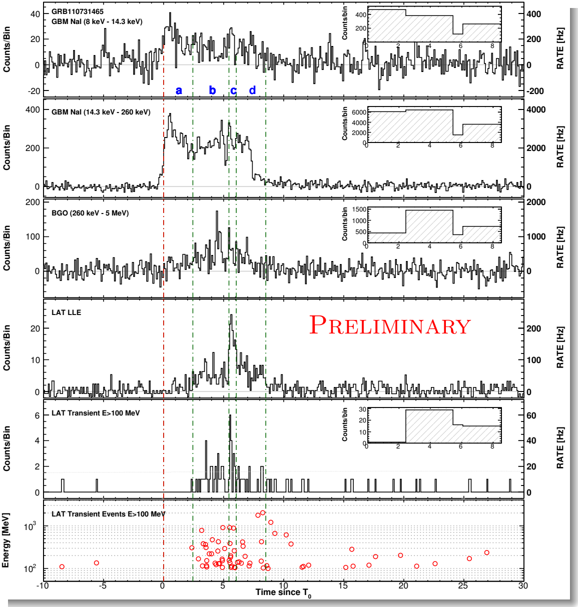
MOA observations

- observations began 3.3 min after the *Swift* trigger
- 61 cm Boller & Chivens telescope at the Mt John University Observatory (New Zealand)
- I and V band images with 60 s exposure times followed by 120 s exposures until for 105 min. after the trigger

GROND observations

- 2.2 m MPG/ESO telescope at La Silla Observatory, Chile
- Observations 2.74 d after the trigger with GROND, the seven-color imager
- Two 30-minute observation blocks were obtained
- Integration time of 4500 s in $g'r'i'z'$ and 3600 s in *JHK*

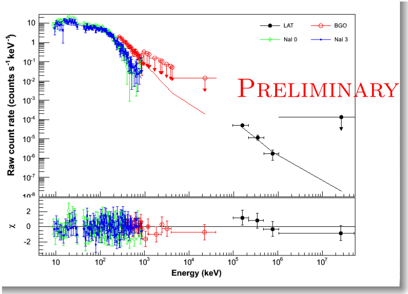
- Lots of good quality data
- Observations from T_0 to $T_0 + 2.7$ d
- More data exist: Konus–Wind, Suzaku, EVLA, MITSuME Ishigakijima, Chandra...
- Gemini–North redshift: $z = 2.83$ (GCN 12225)



- $T_{90,GBM} = 7.3 \pm 0.3$ s (50 keV to 300 keV)
- $\mathrm{T}_{90,\mathrm{LAT}} = 14.33^{-2.55}_{+16.79}$ s
- fluence (10 keV–10 GeV): $3.08 \pm 0.10\, 10^{-5}$ erg.cm^{-2}
- $E_{\mathrm{iso}} = 7.58^{+0.01}_{-0.01} \times 10^{53}$ erg (10 keV–10 GeV)
- high energy delayed on–set (E$>$ 100 MeV): $\mathrm{T}_{05,\mathrm{LAT}} = 2.51^{+0.27}_{-0.6}$ s
- peak in flux from $\sim$keV to $\sim$100 MeV at $T_0 + 5.5$ s
- Bayesian Blocks bins *a*,*b*,*c*,*d*: (0., 2.44, 5.44, 6.06, 8.52)
- FWMH of GBM pulses $\Delta t = 0.350 \pm 0.022$ s
- highest energy photon: 2.0 GeV event at $T_0 + 8.270$ s

Prompt phase spectral analysis (1)

Count spectrum BAND+PL model fit



Joint–fit results for the different models

Fitting model	BAND	BAND+PL	COMP+PL	COMP+COMP
E_0 [keV]	349^{+31}_{-28}	155^{+20}_{-13}	198.8^{+21}_{-18}	191.1^{+21}_{-18}
α	$-0.74^{+0.04}_{-0.04}$	$0.03^{+0.15}_{-0.12}$	$-0.14^{+0.10}_{-0.10}$	$-0.10^{+0.12}_{-0.12}$
β	$-2.31^{+0.03}_{-0.03}$	$-2.40^{+0.10}_{-0.20}$	–	–
extra component				
γ	–	$-1.96^{+0.09}_{-0.05}$	$-1.89^{+0.02}_{-0.02}$	$-1.79^{+0.03}_{-0.03}$
Cutoff Energy [MeV]	–	–	–	390^{+220}_{-120}
Fluence [10^5 erg cm^{-2}]	$3.33^{+0.05}_{-0.05}$	$3.08^{+0.10}_{-0.10}$	$2.50^{+0.10}_{-0.10}$	$2.44^{+0.05}_{-0.08}$
PG-STAT / DOF	440.7 / 354	405.5 / 352	409.0 / 353	390/ 352
ΔPG-STAT / DOF	–	35.2 / 2	31.7 / 1	50.7 / 2

Joint–fit from $T_{05,LAT}$ to $T_{95,GBM}$: $[T_0 + 3.0\text{ s}; T_0 + 7.56\text{ s}]$

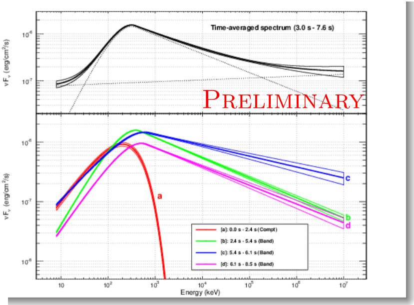
- very significant power–law extra–component: $\sim 5.5\,\sigma$
- hint of a high energy cutoff in the power–law extra–component: COMP+COMP improves the fit by $\sim 4\,\sigma$ over BAND+PL

→ pair creation hypothesis and variability : $\Gamma_{jet} = 530 \pm 10$

- single zone steady state model with homogneous photon distribution
- folding energy 390^{+220}_{-120} MeV, variability: $\Delta t = 0.428 \pm 0.025$ s

Prompt phase spectral analysis (2)

νF_ν for the best fit models



Joint–fit results for each time interval

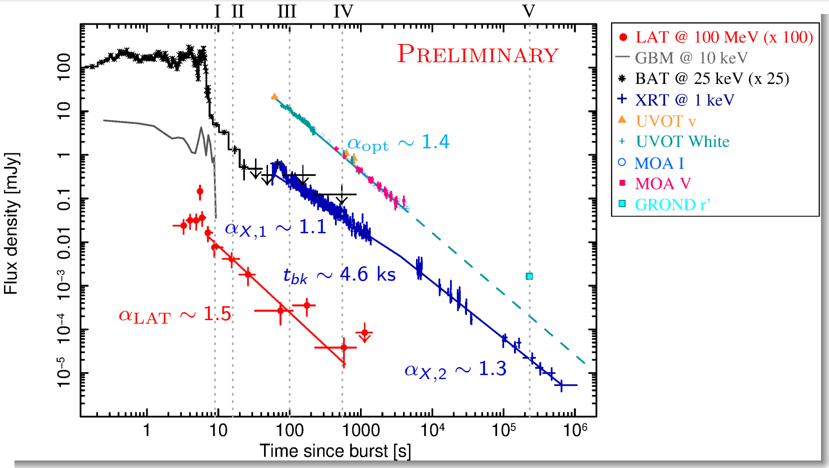
Time interval from T_0 [s]	a (0 2.44)	b (2.44 5.44)	c (5.44 6.06)	d (6.06 8.52)
Best model	COMP	BAND	BAND	BAND
E_0 [keV]	188^{+22}_{-17}	285^{+30}_{-26}	683^{+270}_{-180}	446^{+91}_{-72}
α/Index	$-0.92^{+0.05}_{-0.05}$	$-0.64^{+0.05}_{-0.05}$	$-1.15^{+0.05}_{-0.06}$	$-0.86^{+0.06}_{-0.06}$
β	–	$-2.34^{+0.04}_{-0.04}$	$-2.18^{+0.05}_{-0.06}$	$-2.31^{+0.04}_{-0.05}$
Fluence [10^{-5} erg cm^{-2}]	$0.58^{+0.05}_{-0.06}$	$2.05^{+0.04}_{-0.04}$	$0.59^{+0.03}_{-0.03}$	$1.10^{+0.04}_{-0.04}$
PG-STAT (DOF)				
BAND (354)	–	417.4	365.3	389.1
COMP (353)	378.6	–	–	–
BAND+PL (352)	–	397.9	363.2	375.4
COMP+PL (353)	–	399.7	365.3	380.2
COMP+COMP (352)	–	389.8	360.2	377.7

- Being conservative: best model is COMP in *a* and then BAND
- Hints of the power–law extra–component at 2–3 σ level in *b*, *d*
- LAT fluence is always 20–40% of the GBM fluence
- Why is the extra–component so weak in the flux peak in *c* ?

→ Do we see the transition from the prompt to the afterglow ?

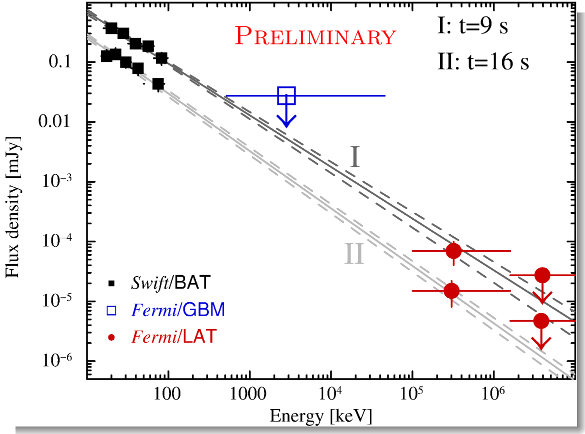
  - growing power–law extra–component through the burst,
  - becomes high energy extended emission during the afterglow ?

Multiwavelength light curve



Multi–wavelength observations: Opt.–GeV

- LAT flux peaks at $T_0 + 5.5$ s and then decays smoothly: detection up to $[T_0 + 227$ s; $T_0 + 853.9$ s$]$.
- Epochs I and II connect the prompt emission to the afterglow: contamination ?
- Epoch III shows X–ray flares, make it difficult to study (used for verification only)
- Epoch IV: optical flux decays faster than X–ray flux ($\alpha_{opt} \sim 1.4 > \alpha_{X,1} \sim 1.1$)



spectral index

- $\beta_I = 0.87^{+0.07}_{-0.11}$
- $\beta_{II} = 0.95^{+0.07}_{-0.11}$

temporal properties

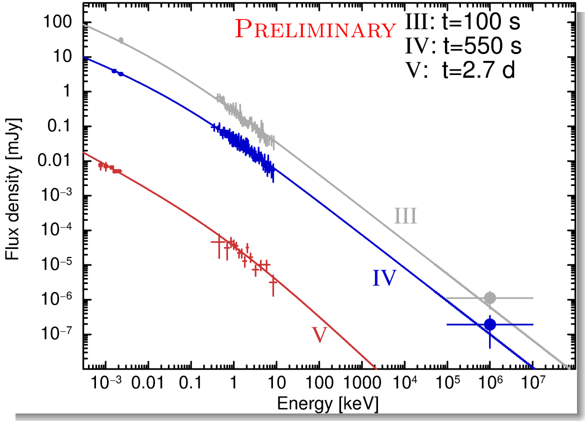
- $\alpha_{\mathrm{BAT}} = 2.3 \pm 0.3$
- $\alpha_{\mathrm{LAT}} = 1.55 \pm 0.21$

→ time decays are roughly consistant

SEDs early epochs

- Simple power–law fit from X–ray to γ–ray over 5 orders of magnitude
- Spectral index compatible with the measured X–ray spectral index β_X at later times
- Temporally extended GeV emission is compatible with afterglow emission

  → requires an afterglow on–set time before $\sim T_0 + 8$ s



broken power–law (IV)

- $\beta_{opt,IV} = 0.45^{+0.09}_{-0.07}$
- $\beta_{X,IV} = 0.95^{+0.09}_{-0.07}$
- $E_{break} = 0.04^{+0.03}_{-0.01}$ kev

broken power–law (V)

- $\beta_{opt,V} = 0.66^{+0.03}_{-0.03}$
- $\beta_{X,V} = 1.16^{+0.03}_{-0.03}$
- $E_{break} \sim 0.8$ kev

SEDs late time

- Simple power-law fits statistically acceptable, but large residuals for late times
- Broken power–law fits with tied parameters to test models
  - joint fit of epochs IV and V, cross–check with epoch III
  - $\beta_{opt}=\beta_X$-0.5, $E_{break} \sim \sqrt{t}$, and tied host extinction and absorption

$\Rightarrow$ Broken power–law parameters favor a wind model with slow–cooling spectrum

Global picture

- Prompt: delayed high energy emission, growing extra power–law component, temporally extended GeV emission
  - similar to other bright LAT bursts: GRB 090510, GRB 090902B, GRB 090926A
  - $\sim 4\ \sigma$ cutoff at ~ 400 MeV (weaker than for GRB 090926A): $\Gamma_{jet} = 530 \pm 10$ (internal shocks)
  - origin of the extra–component could be early afterglow emission from the forward shock

- Afterglow: jet in a wind environment with a slow–cooling spectrum
  - epochs I and II: single power–law fit from X to GeV, fast–cooling regime $\nu_c < \nu_m$ (e^- synch. freq.)
    $\rightarrow$ temporally extended GeV emission compatible with afterglow emission
  - epoch III: re–brightening, X–ray flares, hard to study, change from fast– to slow–cooling regime
  - epochs IV, V: optical decays faster than X, smoothly broken power–law fit with $\beta_{opt} = \beta_X - 0.5$ and $E_{break} \sim \sqrt{t}$
    $\rightarrow$ parameters compatible with a wind environment, slow–cooling spectrum: $\beta_X = (2/3)\alpha_X + 1/3$, $\beta_{opt} = (2/3)\alpha_{opt} - 1/3$, $\nu_{opt} < \nu_c < \nu_X$
  - epoch V: steeper decrease of X–ray flux explained by cooling break,$\nu_c \sim \sqrt{t}$, approaching the X–ray band after $t_{break} \sim 4.6$ ks

Conclusions

- Paper to be submitted soon (contact authors: J. Bregeon, D. Gruber, D. Kocevsky, S. Razzaque, E. Troja, G. Vianello)
  - temporally extended GeV emission is compatible with afterglow emission
  - afterglow indicates a jet in a wind environment and a slow–cooling spectrum, with the following model parameters:
    - low magnetic field $\epsilon_B \sim 10^{-2}$
    - low radiative efficiency $\epsilon_E \sim 10^{-3}$
    - 5 times larger kinetic energy than gamma-ray energy, $E_k \sim 3 \times 10^{54}$ erg
    - bulk Lorentz factor: $\Gamma_{jet} \sim 500$
  - the coasting bulk Lorentz factor $\Gamma_{jet} \sim 500$ from the afterglow model is compatible with the value/lower limit obtained from the $\gamma\gamma$ opacity argument in the internal shocks of the prompt phase

- Lots of high quality data, very nice joint *Fermi*–*Swift* observations
- More can certainly be done with these data, and more data on this burst are available
- Many Thanks to the *Fermi*, *Swift*, GROND and MOA teams