Physical Origin of GeV emission in the early phase from GRB 170405A: clue from emission onsets with multi-wavelength observations

Makoto Arimoto (Kanazawa University), Katsuaki Asano (ICRR/Univ. of Tokyo) on behalf of the Fermi-LAT collaboration

17th, October 2018
Outline

• Introduction: GeV emission from GRBs
  ✓ Delayed emission
  ✓ Extended emission

• GRB 170405A
  ✓ Lightcurve
  ✓ Spectrum

• Discussion
  • Bulk Lorentz factor
  • Synchrotron emission from the forward shock?

• Summary
Anatomy of Gamma-ray bursts

- Internal shock (prompt emission)
- External shock (afterglow)
- Interstellar medium (ISM)
- Relativistic outflow

Germinal emission: 8 - 260 keV
260 keV - 5 MeV
> 100 MeV
> 1 GeV

Delayed GeV emission

Extended emission

Abdo+2009
Ghisellini+ 2013
Nava+ 2014
What causes the GeV emission?

- Synchrotron emission in the forward shock?
  - Ghisellini+2010, Kumar+2010
- Inverse Compton (IC) emission in the internal shock?
  - Razzaque+ 2004
- IC emission in the reverse shock?
  - Granot & Guetta 2003
- Hadronic emission?
  - Dermer+ 2003

can easily explain both
- the delayed emission
- the extended emission
GRB 170405A: Prompt emission

- Simultaneous detection w/ Swift
- $z = 3.51$
  (GCN #20990)

Delayed (sub-)GeV emission

$\sim 30$ s

Few GeV photons
($> 1$ GeV)
Spectrum

\[ E_{\text{cut}} \sim 50 \text{ MeV} \]

\[ \Delta \text{PG}_{\text{stat}} \sim 40 \]

\[ \rightarrow >4 \sigma \]
Extended emission/Afterglow

- **LAT X-ray**: $\alpha = -1.8 \rightarrow -1.1 \rightarrow -1.9$
- **Optical**: $\alpha = -1.7$
- **LAT**: $\alpha = -1.1$

Flux density [Jy] vs. Time from the trigger [s]
Spectral Energy Distribution

At least, the spectral behavior cannot be explained by the single component.
Bulk Lorentz factor from opacity

From the pair production opacity

\[ \Gamma \sim \left[ \sigma_T \left( \frac{d_L}{c \Delta t} \right)^2 E_{\text{piv}} f(\lambda) F(\lambda) (1 + z)^{-2\lambda - 2} \left( \frac{E_{\text{cut}} E_{\text{piv}}}{m_e^2 c^4} \right)^{-\lambda - 1} \right]^{1/(2 - 2\lambda)} \]

\[ \Delta t \sim 2 \text{ s} \]

\[ E_{\text{cut}} \sim 50 \text{ MeV} \]

\[ \Gamma \sim 370 \]
Optical onset from the forward shock scenario

\[ t_{onset} = \left[ \frac{3E_{FS}(1 + z)^3}{32\pi n_{ISM} m_p c^5 \Gamma^8} \right]^{1/3} \]

- \( E_{FS} = 3 \times 10^{54} \eta^{-1} \) erg
- \( n_{ISM} = 1 \) cm\(^{-3}\)
- \( z = 3.51 \)

If \( \Gamma \sim 370 \), \( t_{onset} \sim 200 \) s.

- Optical flux @ 200 s (Sari+98)
  \( F_v \sim 50 \) mJy for adiabatic jet with \( \varepsilon_e = \varepsilon_B = 0.01 \)

Optical emission originates from the forward shock
Physical Origin

\[ \sim 200 \text{ s} \]

Start of the FS emission

Ghisellini+2010, Kumar+2010

Not FS!
Physical Origin

\(~ 200 \text{ s} \)

Start of the FS emission

Ghisellini+2010, Kumar+2010

GRB170405A counters that the temporally extended GeV emission originates from the synchrotron emission of the forward shock!!

Not FS!
Summary

- Optical-X-ray-GeV observation for GRB170405A shows
  - Different time onsets in the optical and GeV bands
  - High-energy cutoff appears in the prompt phase
  - $\Gamma_{\text{max}} \approx 370$, which can reasonably explain the \textit{optical} onset, which is caused by the external forward shock
  - \textit{Delayed GeV emission is not likely to be the external forward shock}

- \textit{Multi-wavelength observation} is a key to understanding the emission mechanism of GeV emission
  - After Fermi10, we need to be more active for multi-wavelength campaign.