光球面放射の数値シミュレーションから明らかにする米徳関係の起源

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Yonetoku Relation

Tight correlation between $E_p - L_p$

$$L_p = 10^{52.43 \pm 0.037} \times \left[ \frac{E_p (1 + z)}{355 \text{ keV}} \right]^{1.60 \pm 0.082}$$

Yonetoku + 2004; 2010

Important for application to cosmology

Powerful diagnostic for emission mechanism
Photospheric Emission in GRB jet

Dynamics of Jet have significant effect on the radiation signature

Dynamics of Jet and Radiation transfer must be solved

Previous Studies

steady outflow or 1D model

approximated treatment for radiation

This Study

Radiation transfer calculation based on 3D hydrodynamical simulation

See also Lazzati 2016, Parsotan + 2017
Calculation of relativistic jet breaking out of massive progenitor star

Progenitor star

16TI (Woosley & Heger 2006)

\[ M_* \approx 14 \text{M}_{\odot} \]

\[ R_* \approx 4 \times 10^{10} \text{cm} \]

@presupernova phase

Jet parameter

\[ L_j = 10^{49}, 10^{50}, 10^{51} \text{ erg/s} \]

\[ \theta_j = 5^\circ \]

\[ \Gamma_j = 5 \]

\[ \Gamma_h = 500, 900 \]

\[ R_{inj} = 10^{10} \text{cm} \]

3 models with different power

Radiative transfer calculation

Propagation of photons are calculated until they reach optically thin region
fiducial model \( L_j = 10^{50} \text{ erg/s} \)
fiducial model $L_j = 10^{50}$ erg/s
Steady jet
jet-stellar interaction

fiducial model \( L_j = 10^{50} \text{ erg/s} \)

\( \log \gamma \) t=0098 sec

\( \Theta_{\text{obs}} \)

E_p & L_p decline as \( \Theta_{\text{obs}} \) increases
Dependence on jet power

$L_j = 10^{49}$ erg/s

$L_j = 10^{50}$ erg/s

$t = 40s$

$L_j = 10^{51}$ erg/s

Ito + 2017, submitted
Dependence on jet power

\[ L_j = 10^{51} \text{ erg/s} \]
\[ L_j = 10^{50} \text{ erg/s} \]
\[ L_j = 10^{49} \text{ erg/s} \]

\[ \Theta_{\text{obs}} = 0^\circ \]
\[ \Theta_{\text{obs}} = 5^\circ \]
\[ \Theta_{\text{obs}} = 10^\circ \]

\textbf{L}_p \text{ and } \textbf{E}_p \text{ are systematically higher for higher } L_j
Dependence on jet power

$E_p$ & $L_p$ decline as $\Theta_{\text{obs}}$ increases

lateral structure of jet induces the viewing angle dependence
Yonetoku relation

Blue: \( L_j = 10^{51} \text{ erg/s} \)
Green: \( L_j = 10^{50} \text{ erg/s} \)
Red: \( L_j = 10^{49} \text{ erg/s} \)

Remarkable match with observations
Evidence of photospheric emission as dominant radiation process
Yonetoku relation: viewing angle dependence

- Blue: $L_j = 10^{51}$ erg/s
- Green: $L_j = 10^{50}$ erg/s
- Red: $L_j = 10^{49}$ erg/s

$\theta_{obs} = 0 - 2^\circ$

- $t_{dur} = 20s$
- $t_{dur} = 40s$
- $t_{dur} = 60s$
- ALL ($t_{dur} = 110s$)
Yonetoku relation: viewing angle dependence

\[ \theta_{\text{obs}} = 3 - 5^\circ \]

Blue : \(L_j = 10^{51}\) erg/s
Green : \(L_j = 10^{50}\) erg/s
Red : \(L_j = 10^{49}\) erg/s

\[ t_{\text{dur}} = 20s \quad \nabla \nabla \nabla \\
 t_{\text{dur}} = 40s \quad \triangle \triangle \triangle \\
 t_{\text{dur}} = 60s \quad \circ \circ \circ \\
 \text{ALL} (t_{\text{dur}} = 110s) \quad \square \square \square \\
\]
Yonetoku relation: viewing angle dependence

Blue: $L_j = 10^{51}$ erg/s
Green: $L_j = 10^{50}$ erg/s
Red: $L_j = 10^{49}$ erg/s

$\theta_{obs} = 6 - 8^\circ$
Yonetoku relation: viewing angle dependence

Blue: $L_j = 10^{51}$ erg/s
Green: $L_j = 10^{50}$ erg/s
Red: $L_j = 10^{49}$ erg/s

$\theta_{\text{obs}} = 9 - 11^\circ$
Origin of viewing angle dependence

Lateral structure developed during propagation

Fast Powerful core surrounded by decaying wing
Time resolved Yonetoku relation

Lu + 2012
15 GRBs with time resolved Ep and redshift

Yonetoku Relation holds regardless of the time interval
High polarization (>10%) at large $\Theta_{\text{obs}}$

DOP(%) = ($I_+ - I_-$) / ($I_+ + I_-$)

$L_j = 10^{49}$ erg/s
$L_j = 10^{50}$ erg/s
$L_j = 10^{51}$ erg/s

Ito + 2017 in prep.
Summary

- Jet structure developed during propagation causes notable time variability
- Central engine activity can be directly observed in the light curve; engine activity is not smeared out during the propagation
- Structure of jet broadens the thermal spectrum; multi-color effect, bulk Comptonization at shock; possible origin of Band spectrum
- Yonetoku relation is an inherent feature of phosphoric emission; This relation holds regardless of the jet power; evidence of photospheric emission as a dominant radiation mechanism
- Prediction of high polarization at large viewing angle