Afterglow Linear Polarization Signatures from Shallow GRB Jets

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Gamma-Ray Bursts
Gamma-Ray Bursts
Formation of Structured Jets

[Image: Diagram showing the formation of structured jets with labels for Jet structure, Jet core, Extended NR material, Stellar envelope/merger ejecta.]
Power-law Jets

\[ \propto \Theta^{-a} \]

\[ \propto \Theta^{-b} \]

Gottlieb et al. 2021

Nakar (2020)
Beniamini et al. 2022
GRB 221009A - Observations

Image Credit:
NASA, DOE, Fermi LAT Collaboration
GRB 221009A - Observations

No Jet Break!

O’Connor et al. 2023
Shallow Jets

\[ \Gamma, E = \text{const} \]

\[ E \propto \Theta^{-a} \]
\[ \Gamma \propto \Theta^{-b} \]
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\[ \propto \theta^{-0.75} \]

\[ \propto \theta^{-0.8} \]

\[ \propto \theta^{-1.15} \]
Different Structures Can Fit the Light Curve!
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Reverse shock dominates optical emission at early times
Linear Polarization Can Differentiate Between Structures!
On-axis Jets

\[ \Gamma, E = \text{const} \]

\[ E \propto \Theta^{-a} \]
\[ \Gamma \propto \Theta^{-b} \]
On-axis Jets

Broken Power-law Jet

\( \theta_{\text{obs}} / \theta_c = 0.7 \)
Off-axis Jets

\[ \Gamma, E = \text{const} \]

\[ \theta_{\text{obs}} \]

\[ \theta_c \]

\[ E \propto \Theta^{-a} \]

\[ \Gamma \propto \Theta^{-b} \]
Off-axis Jets

Power-law Jet

$\theta_{obs}/\theta_c = 5$

$P_{\theta_{obs}}$ vs $t_{obs}$ [days]

$F_x(t) | \mu, J_y |

$\log_{10} (\mu)$ vs $t_{obs}$ [days]
Off-axis Jets

Power-law Jet

\[ a = 1 \]
Off-axis Jets
Let’s Go Back To GRB 221009A
GRB 221009A

\[ \epsilon(\theta) \text{ (ergs \cdot str}^{-1}) \]

\[ 10^{54} \]

\[ 10^{53} \]

\[ 10^{-3} \]

\[ 10^{-2} \]

\[ 10^{1} \]

\[ \theta \text{ [rad]} \]

Gill & Granot 2023

O'Connor et al. 2023
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8% difference in polarization degree

Reverse shock dominates optical emission at early times
Takeaway Points

• Understanding the structure of the jet can help us learn what processes it underwent before breaking out.

• Light curves alone cannot sample the jet structure as different structures can fit the same data.

• The polarization maximum is associated with a light curve break in both on axis and off axis jets.

• Adding a shallow structure to jet models decreases polarization which may explain observations better.

• The linear polarization signature of GRB AGs is sensitive to emission region geometry, which can help us discern between different models.