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# Gamma-Ray Burst Jets in Circumstellar Material: Dynamics, Breakout, and Diversity of Transients

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Recent observations indicate that stripped-envelope core-collapse supernovae are often surrounded by dense circumstellar material (CSM). Motivated by this, we develop an analytic model to systematically study the dynamics of long gamma-ray burst (LGRB) jet propagation in various CSM environments. We derive a general expression for the jet head velocity ($\beta_\mathrm{h}$) and breakout time ($t_\mathrm{b}$) valid across Newtonian, relativistic, and intermediate regimes, accounting for a previously unrecognized dependence on $1-\beta_\mathrm{h}$. Our results highlight a fundamental distinction between jet propagation in massive stars, where $\beta_\mathrm{h} \ll 1$, and in extended CSM, where $1-\beta_\mathrm{h} \ll 1$. We establish an analytic success/failure criterion for jets and express it in terms of jet and CSM parameters, revealing a strong dependence on CSM radius. To quantify the relativistic nature of the jet-cocoon system, we introduce the energy-weighted proper velocity $\overline{\Gamma\beta}$. We identify three possible jet outcomes—(a) successful jets ($\overline{\Gamma\beta} \sim 10-100$), (b) barely failed jets ($\overline{\Gamma\beta} \sim 1$), and (c) completely failed jets ($\overline{\Gamma\beta} \sim 0.1$)—and constrain their respective jet/CSM parameter spaces. We show that in (b) and (c), large CSM radii can result in luminous fast blue optical transients via cocoon cooling emission. This theoretical framework provides a basis for future observational and theoretical studies to understand the link between LGRBs, intermediate GRBs, low-luminosity LGRBs, and their environments.

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