MODELING HIGH ENERGY FERMI GRBS
INSIGHTS INTO SHORT GRB 090510

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ABSTRACT

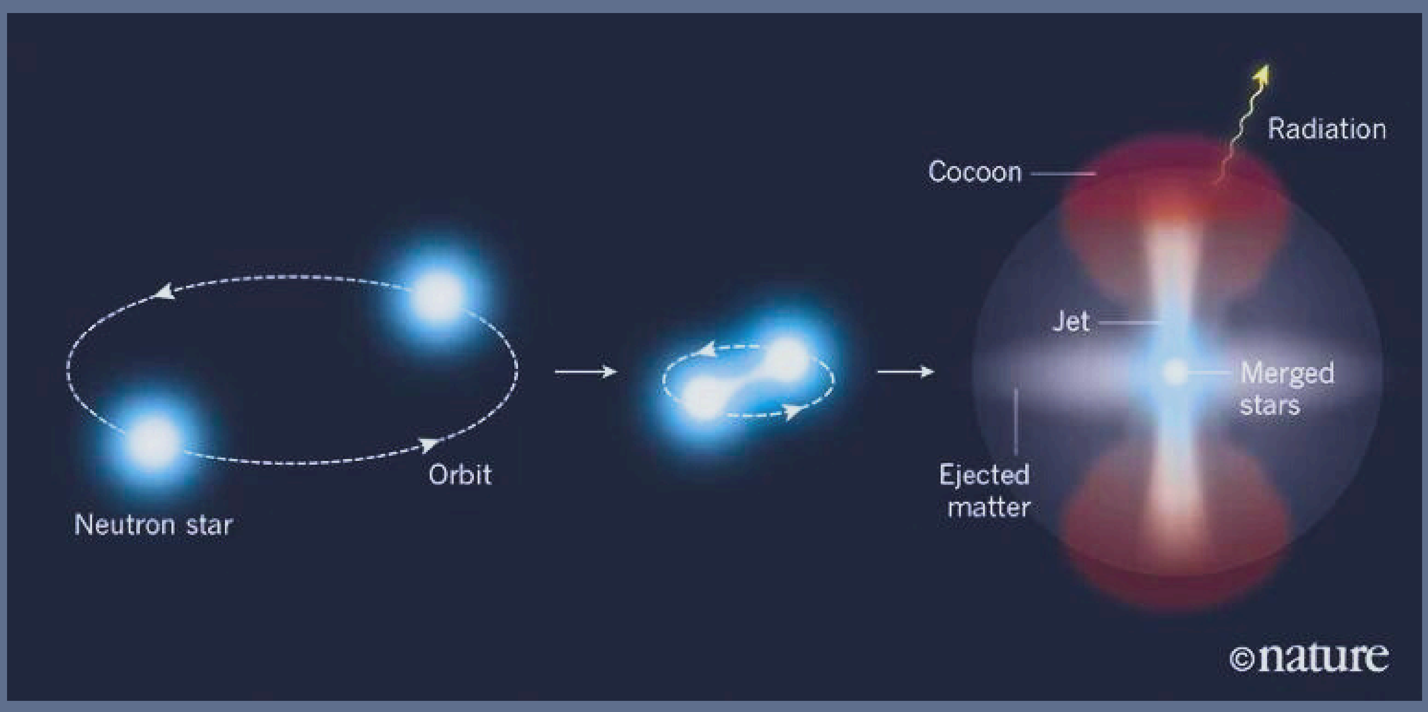
In this study, we examine the unique characteristics of GRB 090510, a short gamma-ray burst observed by Fermi-LAT, through General Relativistic Magnetohydrodynamic (GRMHD) simulations. Our aim is to accurately determine and compare key parameters such as the jet opening angle, energetics, Lorentz factor, jet structure, variability, and the progenitor details of the compact binary from observations and simulations. Multiple 2D and 3D models were tested. The results show that the simulated energetics and jet opening angles align well with observed values. This research lays the groundwork for ongoing efforts to refine theoretical models to better match observational data.

Gamma Ray Bursts (GRB)
- A brief introduction

- Short but intense flashes of high energy radiation detected in gamma rays
- Lasts from milliseconds to hundreds of seconds.
- Typical Radiation energy: 10^52 – 10^54 ergs

Progenitors;

- Short GRB: Originates from the merger of compact objects
- Long GRB: Progenitors are identified to be massive stars based on their association with a core-collapse supernova.



A schematic showing short GRB formation and resulting jet structure from two neutron star mergers

Modeling GRBs using GRMHD Simulations

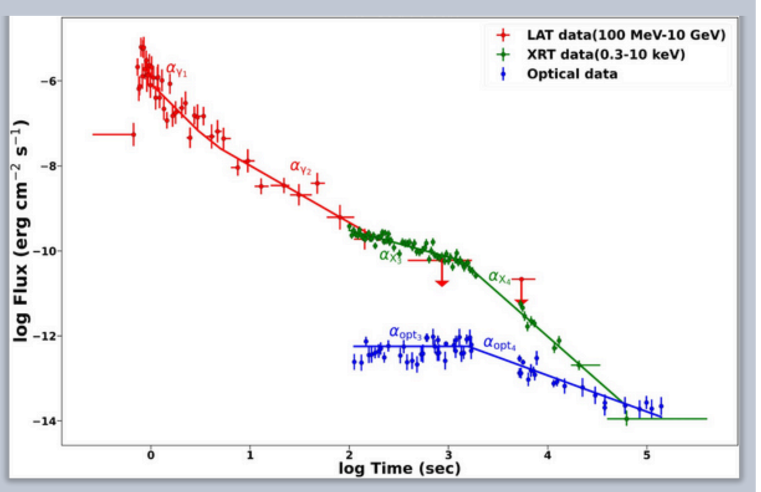
We explore the properties of relativistic jets produced by an accreting system around a Kerr-black hole (we have chosen the blackhole mass to be 3 Msun throughout these simulations). Jets of magnetized, Poynting-dominated plasma are launched from the engine on the cost of rotational energy of the black hole [*Blandford-Znajek mechanism*]

Code used: ***GRMHD code HARM*** [Gammie et al. 2003; Noble et al. 2006; Sapountzis & Janiuk 2019]. The code follows the flow evolution by numerically solving continuity, energy-momentum conservation, and induction equations in the GRMHD scheme

Combining Observations with simulations

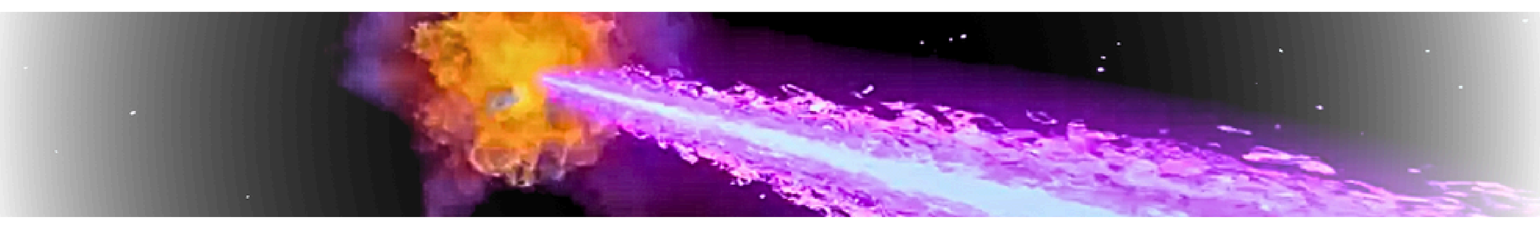
- Understanding properties like jet opening angle, variability, Lorentz factor & Energetics is crucial for uncovering emission mechanisms and jet structure, but observational limitations pose significant challenges.

- Integrating simulations with observations enhances our ability to model GRB jets more accurately, improving predictions for both observed and unobserved bursts. In this work, We focus on a short GRB with multi-wavelength observation; GRB 090510; using GRMHD short GRB simulations to explain the observed properties of 090510.



Multi wavelength lightcurve of GRB090510

GRB 090510
T90 - 0.6s; Redshift: 0.903
Total bolometric Luminosity: 4x 10^53 ergs/s
Jet opening angle from observation : 8.24 +- 2.0



Simulation setup

We perform multiple 2D and one 3D simulations with multiple accretion disk configurations and magnetic field strengths.

The goal of each of these simulations is to produce a jet with an opening angle ~8 degrees with a luminosity of the order ~10^53 and minimum variability timescales in the order of 30ms while maintaining jet stability for ~0.6s which is the T90 of GRB090510. All these parameters were calculated from detailed spectral and temporal analysis of GRB 090510 data from Fermi and Swift Observatories.

Accretion disk : Fishbone & Moncrief Torus
Magnetic Field : Poloidal Wire field configuration
Jet energetics parameter μ : Ratio of total energy flux to mass flux, reflecting the energy available per unit rest mass in the jet. μ is used in methodologies involving the calculation of jet opening angle, Lorentz factor, and minimum timescale variability as it's a direct quantifier of GRB jet in the case of Blandford Znajek emission process.

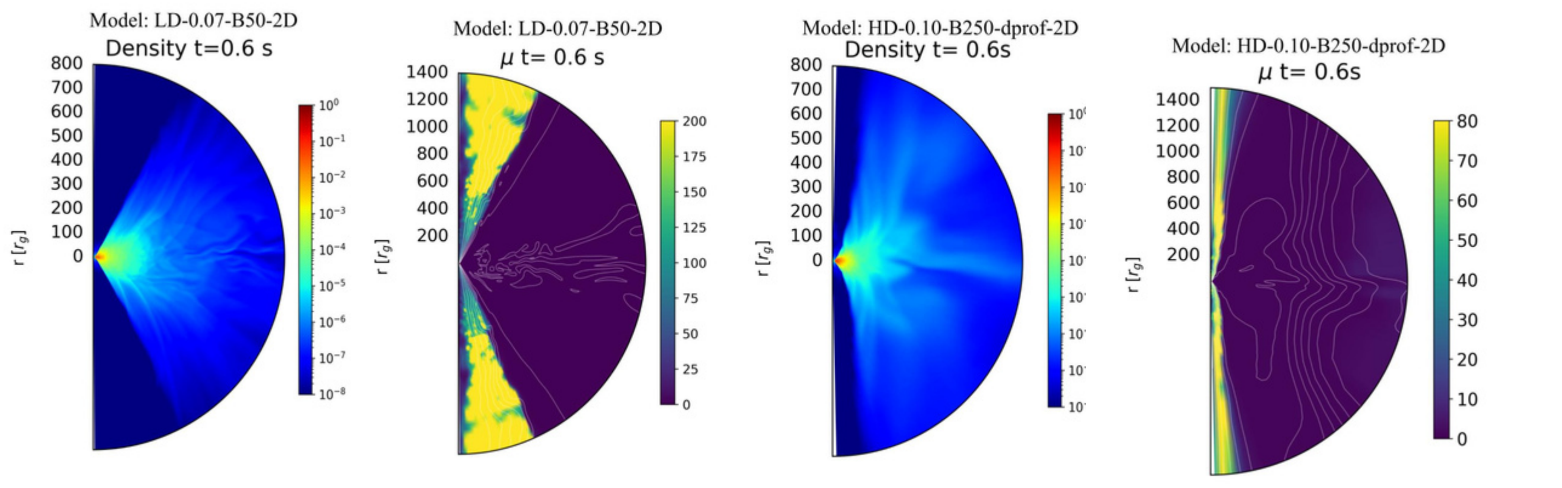
Dynamic Ejecta:

- Origin: Ejecta stripped off from the neutron stars (NSs) during the merger; This contributes to the jet collimation—a necessity for replicating the narrow jet observed in GRB 090510.
- Mass distribution: While the real distribution remains uncertain, we adopt a mass-density profile that includes both radial and angular distributions, inspired by the work of Gottlieb et al., 2022, which draws on theoretical studies and merger simulations.

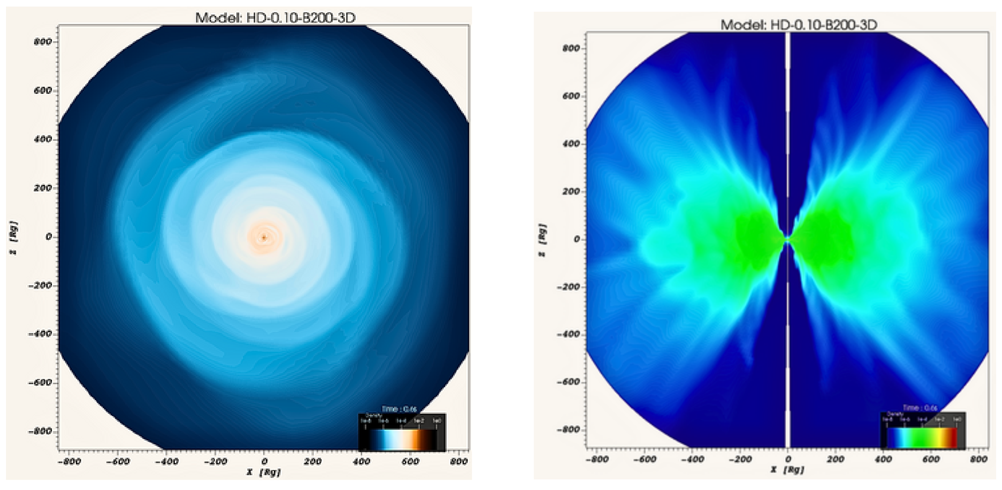
$$\rho(R_{\min} < r < R_{\max}, \theta) = \rho_0 r^{-\alpha}(0.1 + \sin^2\theta)^{\delta}$$

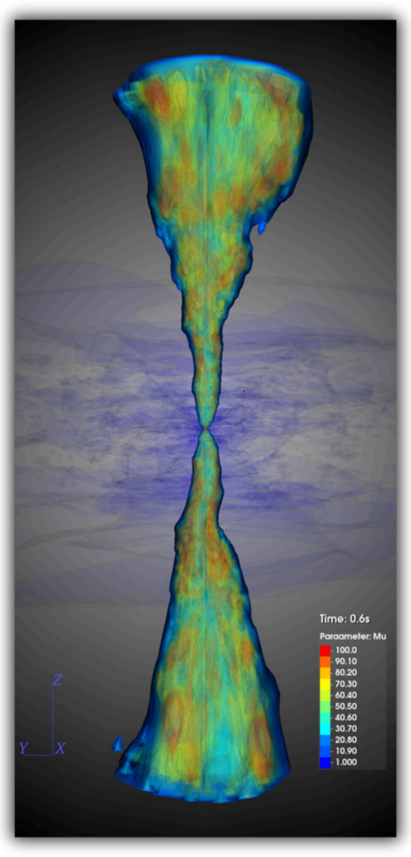
- Ejects is unmagnetized & for model *HD-0.10-B250-dprof-2D*, Dynamic ejecta mass Mej = *0.006Msun* that expands homologously with a velocity of *0.15c*

Results



Snapshots of density and jet energetics parameter, μ for two 2D models at 0.6s. Model Hd-0.10-B250-dprof-2D has the dynamic ejecta addition while Model LD-0.07-B50-2D is without dynamic ejecta. Both models produce a luminosity of the order 10^53 ergs, yet they exhibit distinctly different jet structures; notably, the model with dynamic ejecta features a considerably narrower jet.





Snapshots of density distributions on the equatorial and toroidal planes for the 3D model *HD-0.10-B200-3D* at 0.6 seconds
The right panel displays the jet energetics parameter, μ providing insights into the energy distribution and structural details of the simulated short GRB. Note that this model does not include dynamic ejecta.

Model	M_{disk} $(M_\odot)$	β, a	L_{Bz} $(10^{53}$ ergs/s)	θ_{jet}	t_{var} (ms)
LD-0.07-B50-2D	0.07	50, 0.950	3.0	20.2	1.1
HD-0.10-200-3D	0.10	200, 0.950	4.0	12.90	6.95
HD-0.10-B250-dprof-2D	0.10	250, 0.935	2.75	8.32	1.5

This table presents key parameters from three selected models, including accretion disk mass (M_disk), plasma β (ratio of magnetic to gas pressure), black hole spin (a), Blandford-Znajek luminosity (L_BZ), jet opening angle, and minimum variability timescale (t_var). These models illustrate the variability in outcomes based on different configurations and the impact of incorporating dynamic ejecta, representing a subset of the numerous simulations conducted in this study.

Conclusion

- Detailed analysis shows GRB 090510 possesses a narrow jet with millisecond variability and high energetics compared to other short GRBs. Using GRMHD simulations, we effectively modeled jets with similar energetics, opening angles, and variability timescales to those observed in GRB 090510.
- Introducing dynamic ejecta into our simulations has improved jet collimation, aligning closer to the observed narrow opening angles of GRB 090510. This step was crucial given the burst's unique properties.
- Current efforts include advancing 3D simulations with varied ejecta profiles to more accurately reflect observed characteristics.
- Our combined approach of observation and simulation offers deeper insight into jet structures. Future work will expand to include a broader range of multi-wavelength GRB observations from the short GRB catalog.