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On the Jet Structure of Gamma-ray Bursts through X-ray Light Curve Modeling

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INTRODUCTION

- Gamma-ray bursts (GRBs) are intense beams of electromagnetic(EM) radiation.
- Gravitational wave event GW170817 associated with GRB170817A has confirmed the progenitors of short GRBs are binary neutron star merger (Fig.1).
- Relativistic jet launched by the merger interacting with the ambient medium will produce an afterglow across the EM spectrum (Fig.3).
- Analyzing the afterglow light curves of GRBs can help us resolve the structure of these jets (Fig.2).

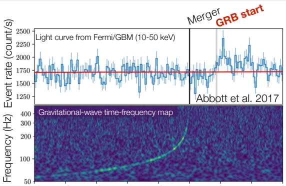


Figure 1.

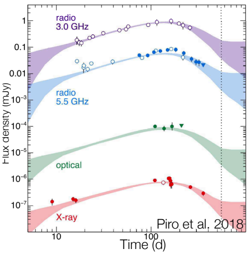


Fig.2 Afterglow light curve of GW170817

OBJECTIVE

Examine how future multi-messenger observations can help to solve the intrinsic structure of GRB jets.

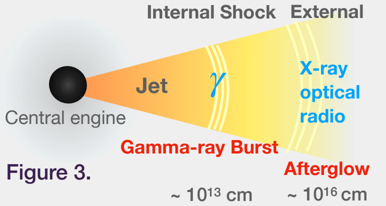


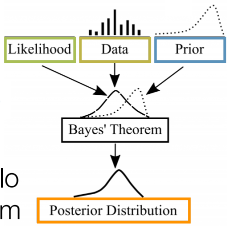
Figure 3.

METHOD

Bayesian Inference

Given a dataset D = {x$_1$, x$_2$, …, x$_n$}:

Bayes rule: $P(\theta\,|\,D) = \dfrac{P(D\,|\,\theta)\,P(\theta)}{P(D)}$



We adopt Marcov Chain Monte Carlo (MCMC) sampling method to perform parameter estimation.

Posterior distributions are the probability density functions of parameters given the observed dataset.

Parameter estimation

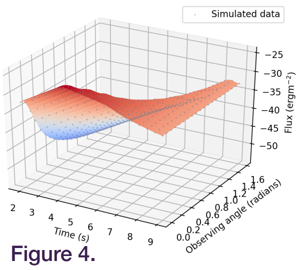


Figure 4.

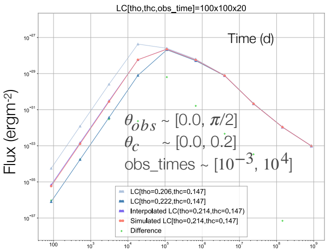


Figure 5.

We create a multi-dimensional grid of light curves by simulating each model parameter across a certain range in the parameter space and store them. Fig. 4 shows the simulated light curves over different observing angles (θ_{obs}).

For each MCMC sample, instead of calculating the likelihood from model, we replaced it with a **new function that interpolates between the adjacent parameter values stored in our high-dimensional grid (Fig.5)**.

CURRENT PROGRESS

Figure 6 is the input X-ray light curve generated from our GRB afterglow model[(a)] with noise added to mimic the true observation.

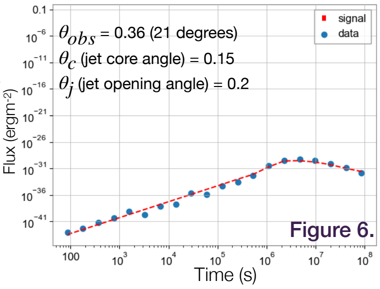
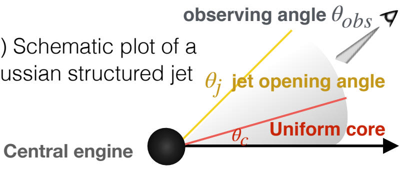


Figure 6.

(a.) Schematic plot of a gaussian structured jet



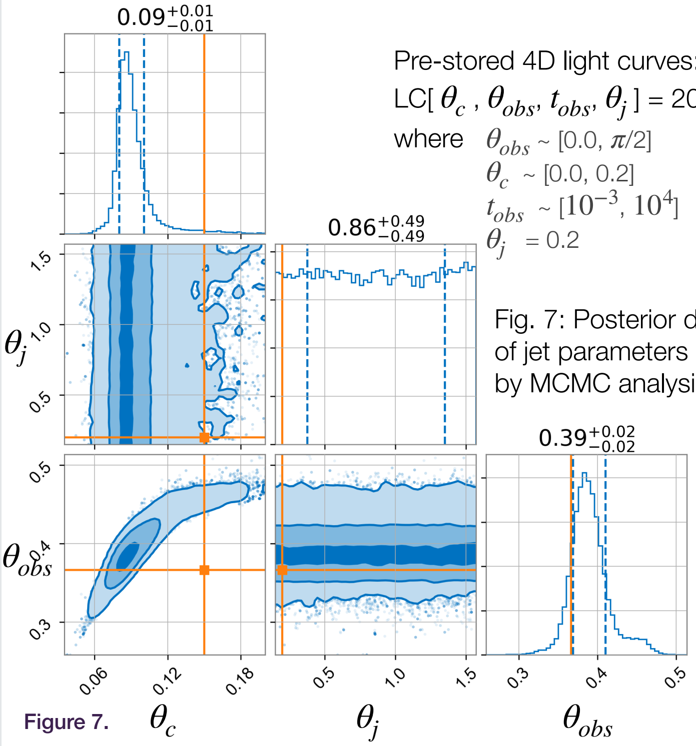


Figure 7.

Pre-stored 4D light curves:
LC[θ_c , θ_{obs}, t_{obs}, θ_j] = 200x200x20x1,
where θ_{obs} ~ [0.0, π/2]
θ_c ~ [0.0, 0.2]
t_{obs} ~ $[10^{-3}, 10^4]$
θ_j = 0.2

Fig. 7: Posterior distribution of jet parameters obtained by MCMC analysis.

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DISCUSSION

- Posterior distributions of θ_c and θ_{obs} show our code has the ability of recovering the injected parameter values (θ_j was not found due to the lack of information in the 3D grid).
- Accuracy of the interpolation function should be improved to allow a full parameter estimation.
- Constraint from gravitational wave observation, such as observing angle and distance, will be included during the parameter estimation.
- More jet models will be investigated in the future.

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