Identifying potential Binary Neutron Star merger events from the Fermi GBM Gamma-Ray Burst Catalog

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Introduction

The advent of multimessenger astronomy has changed our understanding of Gamma-Ray Bursts (GRBs), since events like GRB 170817A have confirmed the link between short GRBs (sGRBs) and neutron star mergers. This study employs machine learning techniques to improve the identification of GRBs associated with compact mergers. Using a clustering algorithm, we analyzed the Fermi Gamma-Ray Burst Monitor (GBM) Catalog to isolate GRBs with characteristics similar to known kilonova-associated events: **GRB 170817A**[2] and **GRB 150101B** [3].

Methodology

DATA SAMPLE

3585 GRBs selected from the Fermi GBM Burst Catalog, which includes measurements of fluence, energy peak and T90.

PRE-PROCESSING

Application of a logarithmic transformation and standardization to ensure all features contribute equally.

DIMENSIONALITY REDUCTION:

Explored three techniques –PCA, t-SNE, and UMAP– to simplify the dataset while retaining key features, reducing it to two dimensions.

CLUSTERING ANALYSIS

Used the K-Means algorithm to identify groups of GRBs with similar characteristics.

Clustering Results

- The clustering analysis identified **five** subpopulations of GRBs.
- **UMAP** emerged as the best method based on clustering evaluation metrics.
- **Cluster 2** was identified as a potential subpopulation of KN candidates, as it includes both known merger-associated GRBs (Fig. 1).
- A comparison with the sGRB catalog of W. Fong (2022) [1] showed that most sGRBs detected by *Fermi* were grouped within Cluster 2, reinforcing its association with compact object mergers.

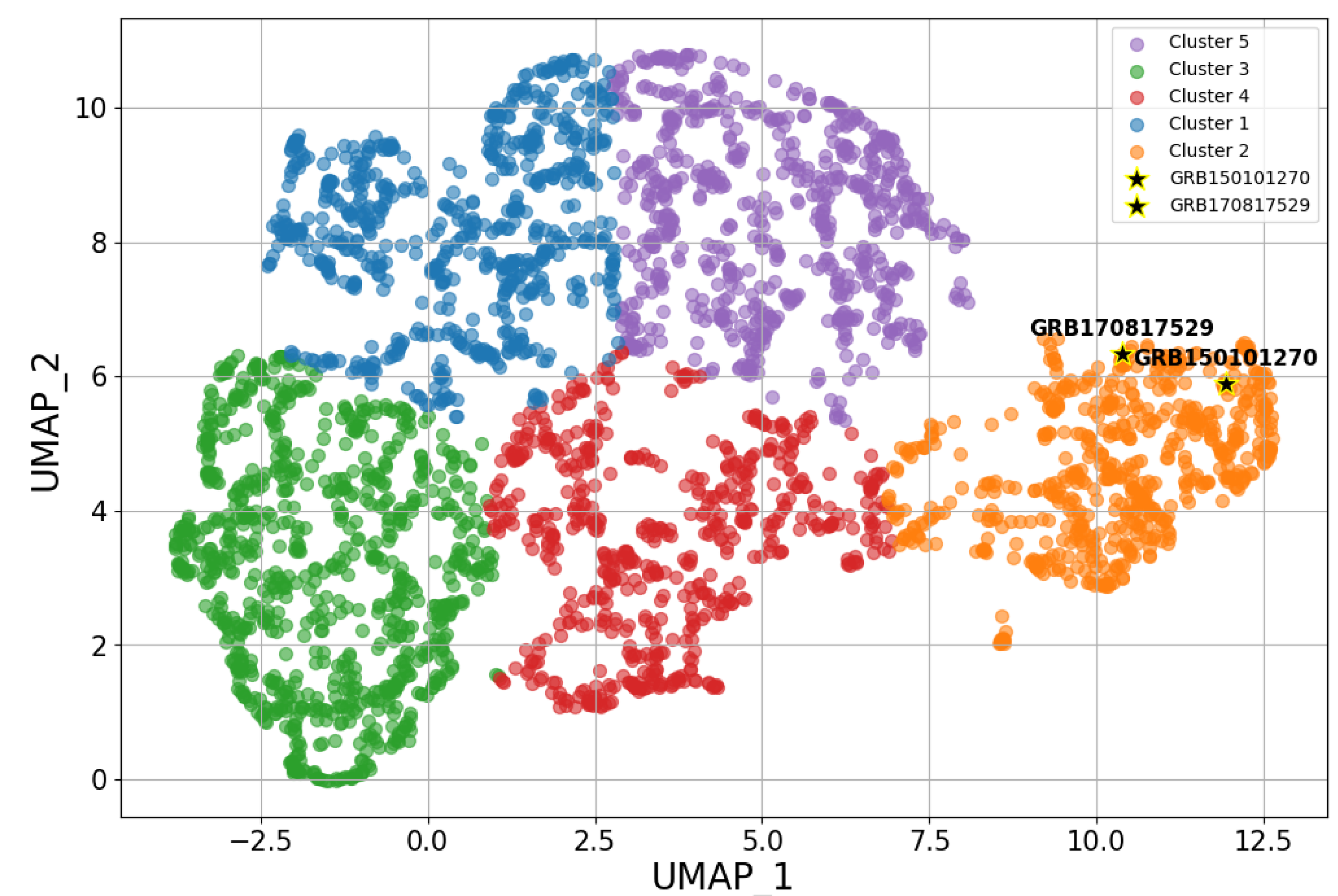

Figure 1. UMAP-based results for the n=5 selection clustering.

- We identified a **golden sample** of sGRBs that exhibits characteristics consistent with compact-object mergers, X-ray afterglow and a reliable redshift measurement.
- A comparison with KN candidates from Troja's review of Swift-detected GRBs [4] validated our results. All their KN candidates observed by Fermi are included in our cluster, highlighting the robustness of our clustering method by identifying the same events across instruments with distinct detection capabilities.

	t_{90}^{a} (s)	fluence^{a} (10^{-7} *erg/cm*^{2})	E^{a}_{peak} (*keV*)	*redshift*
080905A	0.96±0.35	8.50±0.46	317±52	0.122
090510	0.96±0.14	33.7±0.41	4248±440	0.903
090927	0.512±0.231	3.03±0.18	195.22±69.05	1.37
131004A	1.15±0.59	5.10±0.19	118.12±24.42	0.71
150101B	0.48±0.10	0.76±0.11	208±109	0.09
170817A	2.48±0.47	2.79±0.17	215±56	0.009
160821B	1.09±0.98	1.95±0.2	38±27	0.161
191031D	0.25±0.02	39.68±0.15	681.54±32.55	0.5
210323A	0.96±0.78	10.92±0.30	1440.78±339.89	0.733

Table 1. Golden sample.

Host Galaxy Association

Additionally, we developed a host galaxy association pipeline to enhance the localization of nearby sGRBs, increasing the likelihood of identifying their kilonova counterparts and improving future searches for electromagnetic signals from compact object mergers.

Refining electromagnetic counterpart searches for **nearby events**, narrowing down candidate host galaxies.

Galaxy search limited to a **1 square degree** region around the Fermi GRB position to minimize false associations.

Application of a 40 kpc **offset constraint** to match observed sGRB-host galaxy separations.

Optimizing targeted follow-up by prioritizing likely host galaxies based on GRB properties, particularly for telescopes with limited fields of view.

Potential for **synergy with wide-field surveys** like LSST.

References

[1] Wen-fai Fong, Anya E Nugent, Yuxin Dong, Edo Berger, Kerry Paterson, Ryan Chornock, Andrew Levan, Peter Blanchard, Kate D Alexander, Jennifer Andrews, et al.
Short grb host galaxies. i. photometric and spectroscopic catalogs, host associations, and galactocentric offsets.
The Astrophysical Journal, 940(1):56, 2022.

[2] Adam Goldstein, Péter Veres, E Burns, MS Briggs, R Hamburg, D Kocevski, CA Wilson-Hodge, RD Preece, S Poolakkil, OJ Roberts, et al.
An ordinary short gamma-ray burst with extraordinary implications: Fermi-gbm detection of grb 170817a.
The Astrophysical Journal Letters, 848(2):L14, 2017.

[3] Eleanora Troja, Geoffrey Ryan, LUIGI Piro, Hendrik Van Eerten, SB Cenko, Y Yoon, S-K Lee, M Im, T Sakamoto, P Gatkine, et al.
A luminous blue kilonova and an off-axis jet from a compact binary merger at z= 0.1341.
Nature Communications, 9(1):4089, 2018.

[4] Eleonora Troja.
Eighteen years of kilonova discoveries with swift.
Universe, 9(6):245, 2023.