CLUSTERING ANALYSIS OF GRAVITATIONAL WAVE EVENTS FROM NEUTRON STAR AND BLACK HOLE MERGERS OBSERVED BY LIGO AND VIRGO

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ABSTRAK

LUTFI SYAHREZA LUBIS. Analisis Penggerombolan pada Peristiwa Gelombang Gravitasi dari Gabungan Bintang Neutron dan Lubang Hitam yang Diamati oleh LIGO dan Virgo. Dibimbing oleh RAHMA ANISA, AAM ALAMUDI, dan HUSIN ALATAS.

Penelitian ini menganalisis penggerombolan 93 peristiwa gelombang gravitasi (2015–2020) dalam *Gravitational-Wave Transient Catalog 3* (GWTC-3) yang dirilis oleh kolaborasi LIGO-Virgo pada tahun 2021. Dataset terdiri atas kejadian *binary black hole* (BBH), *binary neutron star* (BNS), dan *neutron star–black hole* (NSBH). Studi ini bertujuan mengidentifikasi substruktur pada *compact binary coalescences* melalui penerapan teknik penanganan multikolinearitas dan *unsupervised learning*. Analisis difokuskan pada sembilan parameter, yaitu massa primer, massa sekunder, *chirp mass*, *redshift*, massa total, massa akhir, *signal-to-noise ratio* (SNR), *effective spin*, dan jarak. Dua metode penanganan multikolinearitas, *Principal Component Analysis* (PCA) dan *Uniform Manifold Approximation and Projection* (UMAP), digunakan sebagai tahap praproses data sebelum penggerombolan. Penggerombolan dilakukan menggunakan algoritma K-Means dan DBSCAN, sedangkan evaluasi kualitas gerombol dilakukan dengan *Silhouette Score* dan *Density-Based Clustering Validation* (DBCV). Hasil penelitian menunjukkan bahwa kombinasi UMAP dan K-Means memberikan performa terbaik dengan nilai *Silhouette Score* tertinggi (0,729) yang membentuk tiga gerombol yang terpisah dengan baik. Ketiga gerombol ini secara konsisten dibedakan oleh parameter massa, jarak, SNR, dan *effective spin*, yang dikategorikan sebagai gerombol parameter tinggi, sedang, dan rendah. Temuan ini menegaskan bahwa penanganan multikolinearitas berperan penting dalam meningkatkan performa penggerombolan dan mengungkap pola tersembunyi pada data peristiwa gelombang gravitasi.

Kata kunci: gelombang gravitasi, LIGO, multikolinearitas, penggerombolan, Virgo.

ABSTRACT

LUTFI SYAHREZA LUBIS. Clustering Analysis of Gravitational Wave Events from Neutron Star and Black Hole Mergers Observed by LIGO and Virgo. Supervised by RAHMA ANISA, AAM ALAMUDI, and HUSIN ALATAS.

This study investigates the clustering of 93 gravitational-wave events (2015–2020) in the *Gravitational-Wave Transient Catalog 3* (GWTC-3), released by the LIGO–Virgo Collaboration in 2021. The dataset contains of binary black hole (BBH), binary neutron star (BNS), and neutron star–black hole (NSBH) events. The aim is to uncover substructures in compact binary coalescences using multicollinearity handling techniques and unsupervised learning. The analysis targets nine key astrophysical parameters: primary mass, secondary mass, chirp mass, redshift, total mass, final mass, signal-to-noise ratio (SNR), effective spin, and distance. Principal Component Analysis (PCA) and Uniform Manifold Approximation and Projection (UMAP) were employed as data preprocessing steps prior to clustering. Clustering was performed using the K-Means and DBSCAN algorithms, while cluster quality was evaluated using Silhouette Score and Density-Based Clustering Validation (DBCV). The results indicated that the combination of UMAP and K-Means achieved the best performance, producing the highest Silhouette Score (0,729) and forming three well-separated clusters. These clusters are consistently distinguished by mass, distance, SNR, and effective spin, and can be categorized as high, medium, and low parameter groups. These findings highlighted that handling multicollinearity plays an important role in improving clustering performance and revealing hidden patterns in gravitational wave event data.

Keywords: clustering, gravitational waves, LIGO, multicollinearity, Virgo.

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PREFACE

Praise to Allah subhanaahu wa ta'ala for His blessings, allowing this scientific work to be completed. This research work, conducted since November 2024 to August 2025 is an undergraduate thesis titled "Clustering Analysis of Gravitational Wave Events from Neutron Star and Black Hole Mergers Observed by LIGO and Virgo".

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May this scientific work benefit those in need and contribute to the advancement of knowledge.

Bogor, August 2025

Lutfi Syahreza Lubis

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