Technical Report: *Sambandha* Multi-messenger Correlator

Overview

This submission presents a sophisticated multi-messenger astronomical event correlation system - **Sambandha** that efficiently matches events across different detection modalities (**gravitational waves**, **gamma-ray bursts**, **neutrinos**, etc.) using advanced **spatial-temporal indexing** and **adaptive scoring algorithms.**

vercel link : https://space-landing1.vercel.app/

python server git repo : https://github.com/madanVedansh21/kd-tree_-ctrl-hack

web server git repo : https://github.com/madanVedansh21/space-landing

Key Technical Innovations

Scalable Data Processing Architecture

- **Intelligent Column Detection:** Automatically maps variable **CSV formats** to standardized schema using flexible column name matching
- **Robust Data Cleaning:** Handles missing data gracefully with **timezone-aware temporal processing** and comprehensive data validation
- **Dynamic Schema Adaptation**: Supports diverse input formats while maintaining consistent internal representation

High-Performance Matching Engine

- **KD-Tree Spatial Indexing**: Implements efficient spherical coordinate matching using **3D Cartesian conversion** and **chord distance calculations**
- **Binary Search Temporal Queries**: Utilizes sorted time arrays for O(log N) temporal candidate selection
- **Dual-Stage Filtering**: Combines spatial and temporal pruning to **minimize computational complexity from O(N²) to near-linear scaling**

Adaptive Correlation Scoring

- **Multi-Component Analysis**: Evaluates temporal, spatial, and signal significance components with exponential decay functions

- **Dynamic Weight Normalization**: Automatically adjusts scoring weights based on available data components. Formula used:**normalized_weight[component] = weight[component] / sum(weights[available_components])**
- **Reliability Assessment**: Incorporates data completeness into confidence calculations
- **Missing Data Estimation**: Provides intelligent fallback calculations when primary metrics are unavailable

Advanced Astrophysical Modeling

- **Angular Separation Calculations**: Precise spherical geometry computations with error circle overlap detection
- **Signal Strength Normalization: Z-score** based significance assessment across heterogeneous datasets
- **Position Error Estimation:** Dataset-specific error modeling for incomplete positional data

Performance Characteristics

- Efficient cross-dataset correlation discovery
- Scalable to large astronomical survey datasets
- Configurable temporal and spatial search windows
- Comprehensive output with schema-compliant CSV export
- Detailed statistical analysis and quality metrics