

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**.

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 $O(N^2)$ 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: **$\text{normalized_weight}[\text{component}] = \text{weight}[\text{component}] / \text{sum}(\text{weights}[\text{available_components}])$**
- **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