Two-Step Localization Simulation

This project simulates pre-merger localization of gravitational-wave (GW) events and evaluates how different telescope coordination strategies affect detection time. We simulate dynamically updated sky-maps, telescope movement, and detection protocols to compare the performance of three methods: **Partial Communication**, **No Communication**, and our proposed **Two Step Localization Method**.

Simulation Overview

1. Sky-Map Generation

- For each simulated event, four sky-map update times are randomly chosen within defined pre-merger intervals: 50--60 s, 40--50 s, 20--40 s, and 1--20 s.
- At each update time `t_u`, the GW signal frequency and SNR are calculated.
- Sky-maps reflect progressively more accurate localization (shrinking 90% probability area) as merger approaches.
- Sky-maps are based on existing LVK BBH, BNS, and NSBH events, scaled for simulation.

2. SNR and Frequency Modeling

- SNR is computed using the GW strain model and noise power spectral densities (PDS) from LVK runs (O3, O4, O5).
- Masses of the source components are fixed to 1.4 $M_\odot$.
- The GW frequency and phase evolution are modeled up to 2PN order.
- The event distance is sampled uniformly in volume, subject to max range per run: 140 Mpc (O3), 160 Mpc (O4), 325 Mpc (O5).

3. Telescope Movement

- Telescopes begin moving at the first useful sky-map update time.
- Way-points are spaced by the FOV radius to ensure full coverage.
- Each telescope moves to nearby way-points maximizing local detection probability.
- Movement updates dynamically as new sky-maps become available.

4. Event Detection Modeling

- Each simulation run includes one event placed probabilistically in the final sky-map.
- Both telescopes begin from random starting locations.
- If the event lies outside the 90% probability area, detection is considered impossible.

Detection Methods Compared

1. Partial Communication Method

- Telescopes share information on areas already searched but **do not** inform each other when the event is detected.
- Only the main telescope's detection time is recorded.

2. No Communication Method

- No coordination at all: telescopes search independently.
- Auxiliary telescope detection does not affect the main telescope.

3. Two Step Localization Method (Proposed)

- If the auxiliary telescope detects the event, it communicates the location to the main telescope.
- The main telescope is then directed straight to the event.

Telescope Models

- **Main Telescope:** Swope telescope (7 deg^2 FOV)
- **Auxiliary Telescopes:**
- ULTRASAT-like (204 deg^2 FOV, 0.5 deg/s max velocity, 5 deg/s^2 acceleration)
- BIG model with FOVs of 100, 200, 400, and 1000 deg^2

Technical Details

- Scan time per field: 15 sec
- Sky-maps updated when slew time reaches a new `t_u`
- Event position fixed in the final sky-map; sky-maps only valid when 90% area < 4π steradians

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Dependencies

A `requirements.txt` file should be included with packages like:

```
numpy
scipy
matplotlib
healpy
astropy
pandas
```

Running the Simulation

Coming soon: a `main.py` entry point that will handle:

- Event generation
- Sky-map synthesis
- Telescope motion simulation
- Time-to-detection comparison

Citation and References

This work references data and models from:

- LIGO O3/O4/O5 noise curves
- ULTRASAT mission proposal
- ZTF instrument specs
- LALSuite

License

For questions, open an issue or contact the project maintainer.