Exploring Hubble's Constant through Gravitational Wave Parameter Estimation

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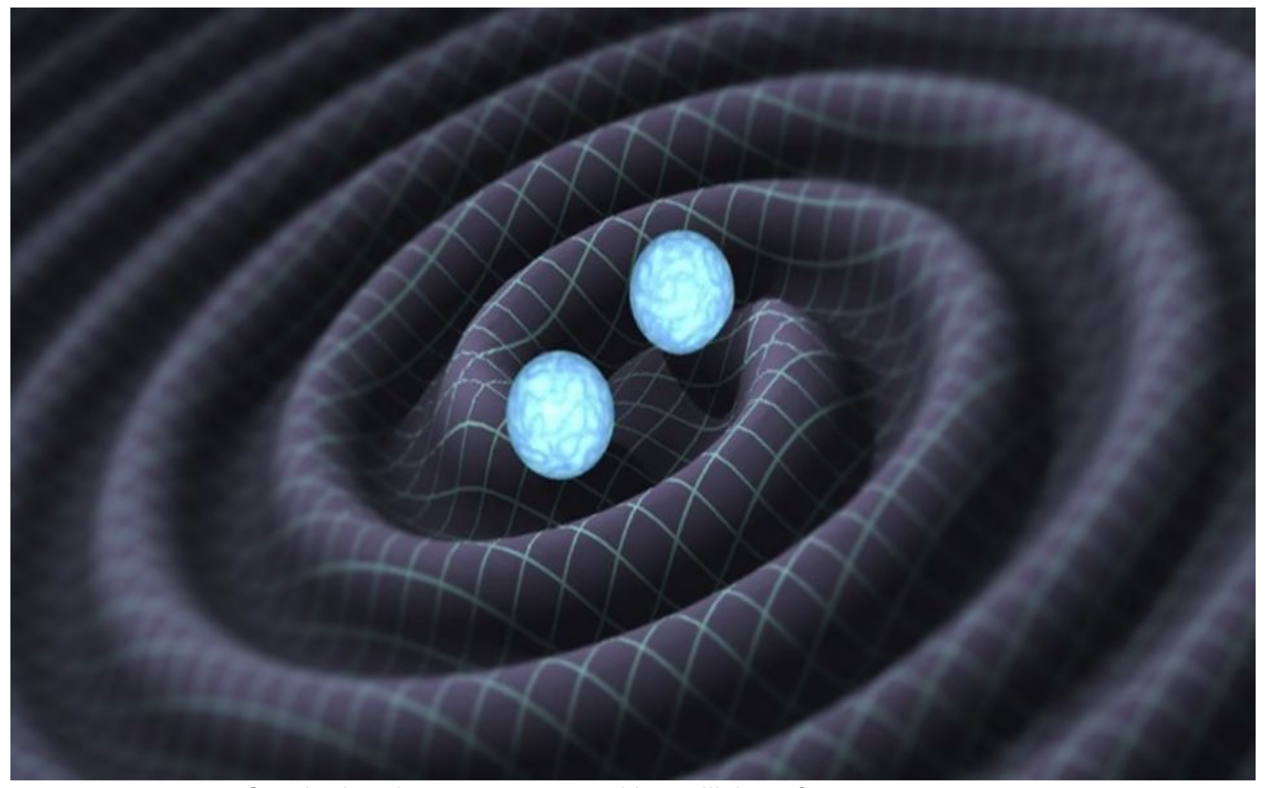
BACKGROUND

Our universe is in a constant state of expansion, a phenomenon where galaxies drift apart over time. This cosmic expansion is governed by Hubble's Law—a fundamental principle that describes the relationship between the velocity of galaxies and their distance from Earth. Hubble's Law reveals a remarkable insight: galaxies move away from us proportionally to their distance; the farther a galaxy is, the faster it is receding from us. This phenomenon is characterized by the Hubble constant (H0) which relates the velocity of galaxies relative to our observation point. This velocity can be determined by their redshift ,the stretching of light from distant galaxies due to cosmic expansion. Yet, there's more to the story. In the depths of space, extraordinary events create ripples in the fabric of spacetime known as gravitational waves (GWs).

These GWs, first predicted by Einstein's theory of general relativity, are born from cataclysmic events, such as the collision of black holes or neutron stars. Detecting these waves, a century after Einstein's prediction, has revolutionized our understanding of the cosmos. GWs provide us with unique insights into their sources. In this research, we employ the valuable information carried by gravitational waves (GWs) to explore a novel method for estimating Hubble's constant.

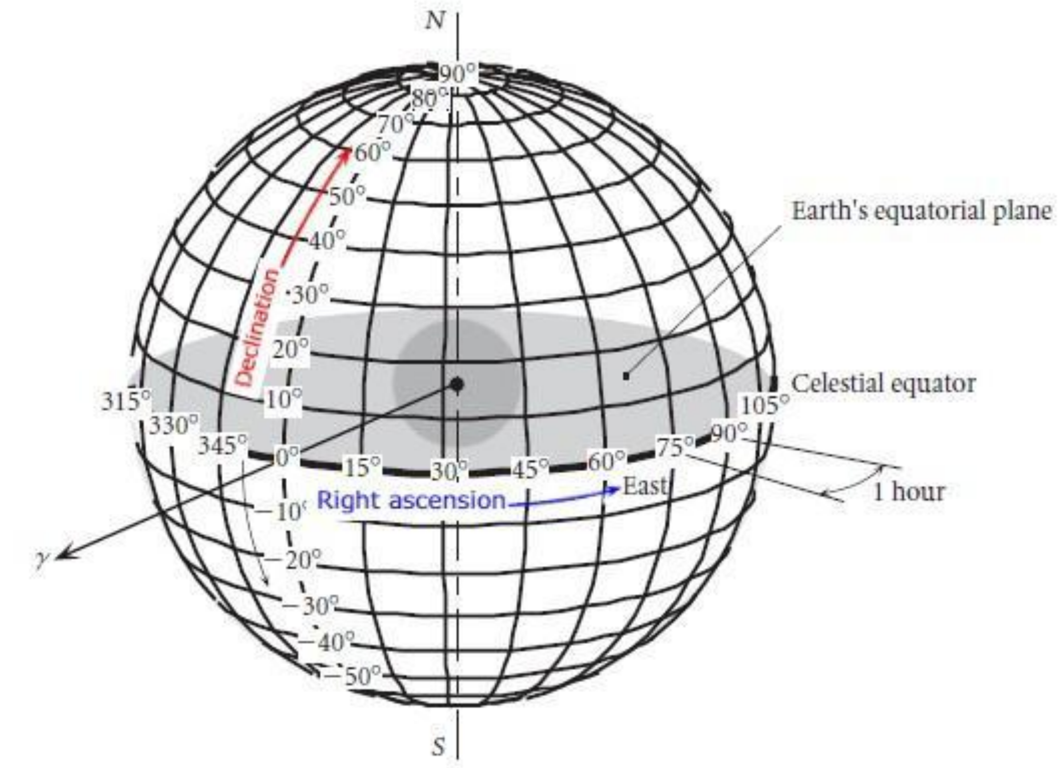


Gravitational waves generated by collision of two neutron stars

METHODS

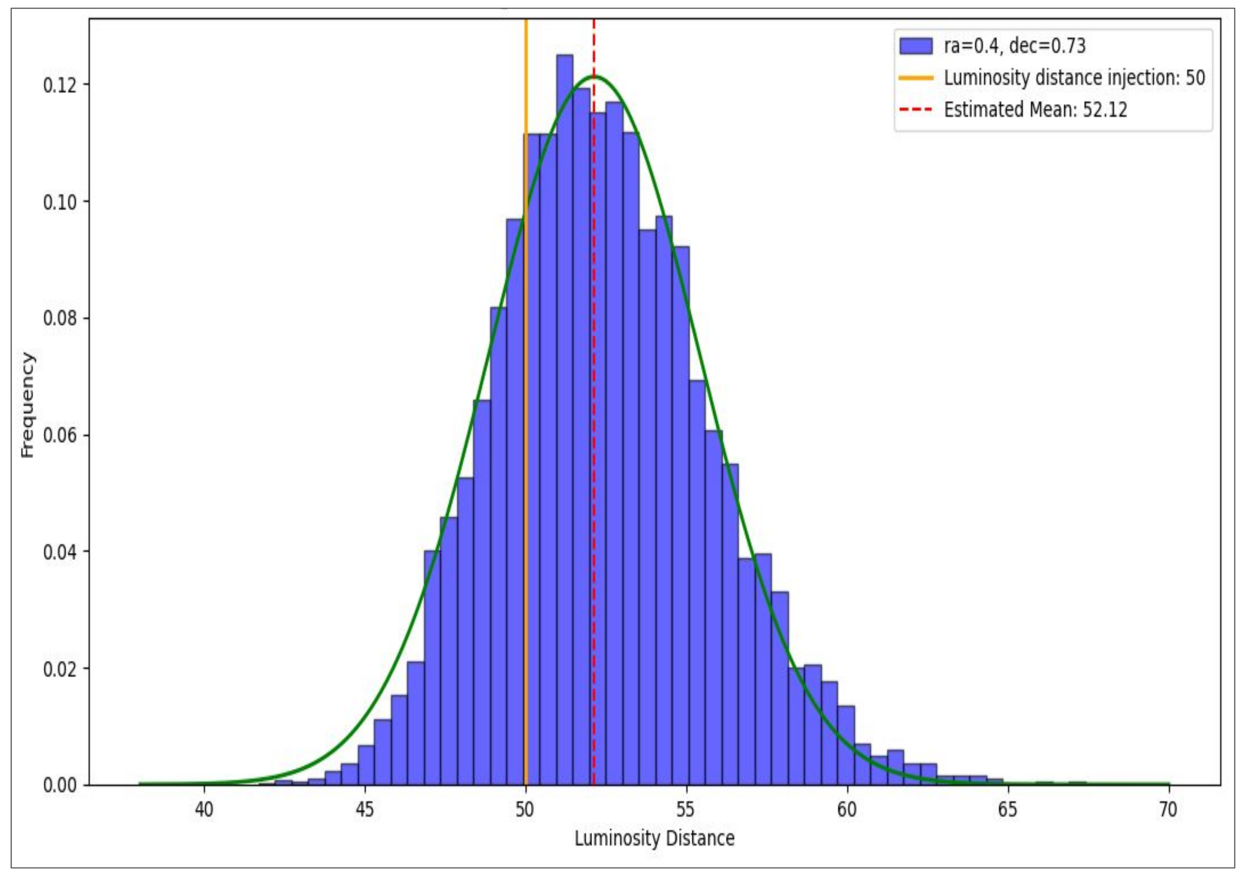
Our study involved running multiple simulations of gravitational wave events occurring at various positions in the sky, specified by their right ascension (RA) and declination (DEC) coordinates.
To facilitate this, we utilized a Python library called Bilby. With it, we generated synthetic gravitational wave events, inject their signals into interferometers—sensitive instrument designed to detect GW by measuring the tiny changes in the length of its arms, and then performs parameter estimation of the signal to obtain information about this event.

Two crucial parameters were the luminosity distance and redshift (z). The luminosity distance, represented by a probability distribution with a peak representing the most probable distance, played a key role. We calculated the Hubble constant (Ho) using the formula Ho = cz/D, where Ho is the Hubble constant, c is the speed of light, z is the redshift, and D is the luminosity distance, for each simulated gravitational wave event. We then compared these calculated Ho values across various simulations to assess their alignment with the actual Hubble constant of 66.67 km/s/Mpc.



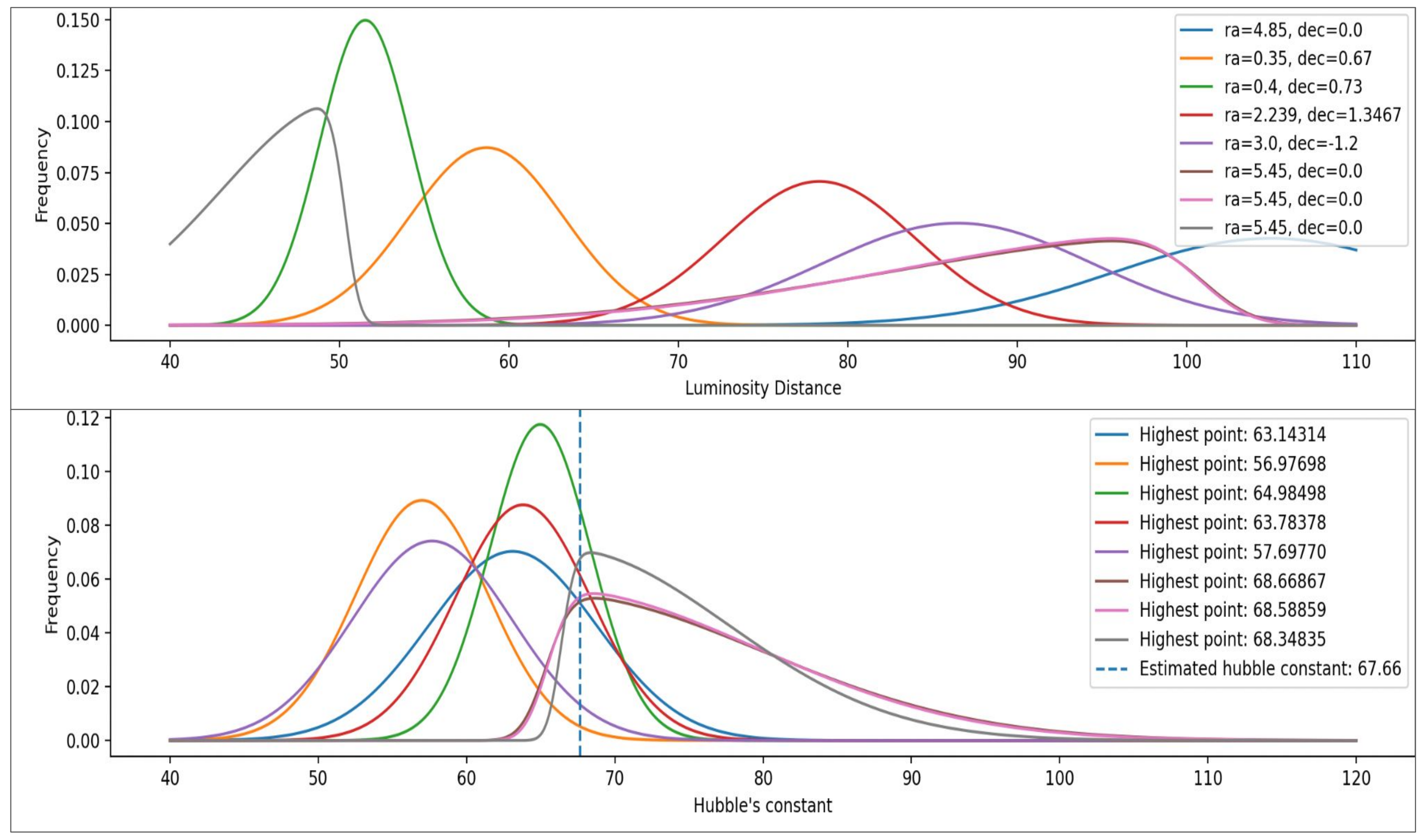
Celestial coordinates, right ascension and declination

Results



Luminosity distance distribution of one event

This graph illustrates the luminosity distribution for a single event where the injected (simulated) value is 50 Mpc and the peak (the most likely value for the luminosity distance of this event) is 52.12 Mpc.
This distribution is obtained from the parameter distribution analysis done by Bilby and the green plot represents the best fit function for the histogram distribution.



Distribution of luminosity distances and their respective hubble's values

This second graph depicts the distributions of simulated events occurring at various positions in the sky, along with their corresponding Hubble's constant distributions.
The event located at position ra = 5.45, dec = 0.0 was simulated three times, each with different parameters. In the first run, the injection distance was set to 100 Mpc, in the second run, it was set to 50 Mpc, and in the third run, the area of localization for the gravitational wave event was broader. Remarkably, all three simulations yielded a consistent estimate of Hubble's constant.

Conclusion

We observe in the first graph the luminosity distance distribution for a single event, where the injected value of 50 Mpc closely aligns with the peak at 52.12 Mpc, demonstrating the reliability of our parameter estimation process. While this alignment holds for 6 out of 8 events, slight deviations appear in events with RA values of 0.35 and 3.0. Such variations are expected in simulations of gravitational wave events, influenced by factors like chosen parameters, localization precision, instrument sensitivity, and limitations. However, these discrepancies are not significantly distant from the actual Hubble constant value. Rather than a concern, they present opportunities for exploration, enriching our understanding of diverse cosmic scenarios within our simulated data.

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