LIGO SURF Project Proposal

An Updated Technique on Extracting Cosmological Redshifts

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1 Introduction:

The Hubble-Lemaitre Constant H_0 is an important quantity in cosmology because it characterizes the rate at which the Universe is expanding, and it can be measured from a cosmological distance-redshift relation. However, two classical methods of measuring H_0 have led to seemingly inconsistent results, known as the "Hubble tension". One method uses type Ia supernovae (whose redshifts are provided by their spectra) as "standard candles" to infer the (luminosity) distance, while the other method relies on the acoustic features in the Cosmic Microwave Background (whose redshift corresponds to the surface of last scattering and is well-calculated) as a "standard ruler" to measure the (angular-diameter) distance. The tension has triggered people's interests in searching for alternative methods of constraining H_0, and it turns out that gravitational-wave (GW) observations is a promising candidate.

It has been well realized that a GW signal can serve as a "standard siren", as one can easily obtain the source's luminosity distance from the signal's amplitude. If one can also somehow infer the source's redshift, it will then allow for a measurement H_0. One way to achieve so is to identify the host galaxy with an EM counterpart, and this method has been successfully demonstrated by the GW170817 event [1]. However, it may not be guaranteed that an EM counterpart can always be found (e.g., the line of sight to the source may lie in the Galactic plane). Thus a way of inferring the redshift using the GW signal alone would be of great significance. One such possibility is to use the internal modes of a neutron star.

Under certain conditions the neutron stars cause tidal effects on each other which excite modes within the neutron stars. The following technique was used by [4], except they only considered the effects of the specific f and g modes, our analysis will focus primarily on the r-modes within the neutron stars. We will choose to focus primarily on the R-mode because it is now thought to have a considerably strong supplemental effect on the merger for the possible detectable frequency range of future generation detectors. For a given binary neutron star inspiraling gravitational wave data we are able to measure the r-mode resonance which allows us to find the redshifted spin frequency of the binary. This spin frequency can be mapped to the spin parameter referred to as $\chi = S/M^2$, where $S \sim f_{spin} M R^2$ is referring to the spin angular momentum. The mass is redshifted by a factor of $(1 + z)$. This measured value of χ is really shifted by a factor of $1/(1 + z)^2$. With this redshifted spin parameter we can compare it to the Point Particle

Orbit which also gives us a measurement of χ, this measurement of the spin parameter experiences no redshift. By comparing the two measurements of χ we are able to deduce what the redshift value z would be for a given binary. We will finally use the Fisher Matrix technique to determine how well we can measure the cosmological redshift z.

2 Objectives:

Our project aims to revise an already existing method for measuring cosmilogical redshifts without using the electromagnetic spectrum. We will be creating a theoretical model of the phase evolution of BNS mergers that includes the added physics needed to describe the effects of the r-mode resonance on phase evolution. Once our model is complete we will then analyse how well we could possibly measure the desired parameters by using the Fisher Matrix technique. In order for this work to matter it has to be applicable for future generation gravitational wave observatories which is why we have to analyze how well we would be able to measure the paramaters of a given inspiral using the Fisher Matrix technique.

3 Approach:

Our research will be entirely theoretical for this coming summer. We will not be needing any equipment or other resources to conduct our research project. We build off of the results of [2] which shows us how we can extract information about a binaries inspiral waveform, which we then look to [4] as a guide on how to utilize this information about the binary to extract the cosmoligical redshift using modes within the neutron stars of the merger, and we incorporate the new physics of the specific r-modes from [3] into the results from Messenger et. al.

4 Project Schedule:

This is a bulleted timeline of our summer research project:

- (6/16) LIGO SURF Program starts
- (7/1) Reproduce the point particle cutler analysis
- (7/8) Incorporate the f-mode Analysis
- (7/15) Incorporate the effects of the R-Modes
- (7/21) Combine the effects of both r & f modes and characterize the effects of them individually and combined over different parameter space of the companion.

- (7/28) Investigate whether it is possible to relax previous assumptions about the system (known EOS of NS for example)
- (8/3) Look at other new inertial modes and their effects
- (8/7) Submit 1st draft of final report
- (8/8) Begin working on Final Presentation
- (8/14) Finish final report
- (8/21) End of summer program

References

[1] B. P. Abbott and et al. "A gravitational-wave standard siren measurement of the Hubble constant". In: *Nature* 551.7678 (Nov. 2017), pp. 85–88. DOI: `10.1038/nature24471`. arXiv: `1710.05835 [astro-ph.CO]`.

[2] Curt Cutler and Eanna E Flanagan. "Gravitational waves from merging compact binaries: How accurately can one extract the binary's parameters from the inspiral waveform?" In: *Physical Review D* 49.6 (1994), p. 2658.

[3] Eanna E Flanagan and Etienne Racine. "Gravitomagnetic resonant excitation of Rossby modes in coalescing neutron star binaries". In: *Physical Review D* 75.4 (2007), p. 044001.

[4] Chris Messenger and Jocelyn Read. "Measuring a cosmological distance-redshift relationship using only gravitational wave observations of binary neutron star coalescences". In: *Physical review letters* 108.9 (2012), p. 091101.