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Gravitational Waves in Cosmology

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Gravitational Waves in Cosmology, Hubble tension solution, and a discovery

Final Project

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Abstract

Gravitational waves (GWs) provide a novel and independent mechanism to probe cosmology. Over the past few years, research methods—primarily the bright siren and the dark siren approaches—have made significant progress in constraining the Hubble tension. Despite these advancements and improved accuracy from extended methods, the tension problem remains unresolved. Researchers now suggest that the solution to this tension might lie in new physics underpinning the H_0 constant, with some analyses observing an emerging "trend" in H_0 measurements. This project aims to explore the methodologies of GWs in cosmology, investigate potential solutions to the Hubble tension, and highlight recent gravitational wave discovery with implications for cosmology.

Keywords: gravitational waves, bright serin, dark serin, Hubble constant, Hubble tension.

1 Introduction

Gravitational waves (GWs) are distortions in the spacetime metric caused by the acceleration of massive astrophysical objects, travel at the speed of light and reveal information about their source dynamics. The remarkable gravitational wave event GW170817, observed through multi-messenger methods, marked the dawn of gravitational wave cosmology, where gravitational wave detections enabled independent methods to constrain the Hubble parameter H_0. To date, around 100 confirmed gravitational wave events have been detected, facilitating population inferences for binary systems. Several recent independent methods, such as quasar lensing and gravitational wave observations, have been proposed to constrain H_0 with high precision. However, the Hubble tension remains a significant challenge, with various proposed solutions questioning the ΛCDM model.

This research explores recent advancements and challenges in gravitational wave cosmology. The first analysis review focuses on progress in gravitational wave methods and their application in cosmology. The second analysis highlights evidence of potential new physics beyond the ΛCDM model, with quasar lensing observations offering possible insights into the Hubble tension. Finally, the discovery of the stochastic gravitational wave background is discussed in the third review, emphasizing its implications to cosmology. Highlighting these developments, we discuss methods to improve precision and accuracy, as well as recent discoveries with far-reaching implications for our understanding of the universe. This analysis aims to provide a comprehensive overview of these contributions to cosmology.

2 Analysis of the Topic

2.1 Reference 1: Cosmology with Gravitational Waves: A Review

2.1.1 Issue

From GW signals, the luminosity distance d_L can be directly measured if the redshift is obtained (Mastrogiovanni et al. 2024):

$$d_L = \frac{c}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_m (1+z')^3 + \Omega_\Lambda}}. \tag{1}$$

For a system containing one neutron star binary (NSB or BNS), the redshift and the host galaxy are identified by the electromagnetic (EM) signals, which in this context include short γ-ray bursts (GRBs) and kilonovae. In fact, such an observation is rare and remarkable (e.g., GW170817), and estimating the redshift is typically fulfilled through additional astrophysical assumptions for the remaining binary black holes (BBHs). [1]

The review sheds light on the two main methods—**Bright Sirens** and **Dark Sirens**—utilizing gravitational wave (GW) data in cosmology, alongside the latest advancements and refined measurements.

2.1.2 Methods

Bright Sirens Inevitable uncertainty in the luminosity distance estimation lies in the line of sight in the inspiral phase of the source, which can be leveraged by the subsequent EM observations that contain crucial information about the inclination angle of the orbital plane.

Dark Sirens When there is no EM counterpart for any binary system, an alternative method to infer the cosmological parameters with respect to the GW data is the Dark Siren method (referring to the lack of light waves). In this method, a galaxy catalog is used in alignment with the GW observations. In practice, by identifying the sky localization of the GW event, the Sloan Digital Sky Survey (SDSS) provides potential galaxies consistent with the GW signal localization area.

Two weak points are identified for this method:

1. Galaxy catalogs are incomplete due to the limits of the apparent magnitude of individual galaxies in different observing bands. 2. The poor sky localization for almost all events suggests thousands of potential host galaxies, thus leading to a less reliable method to constrain cosmology.

GW-Only Data Gravitational waves are sensitive to the "redshifted mass"(Mastrogiovanni et al. 2024):

$$\mathcal{M}_{\rm obs} = (1 + z)\mathcal{M}_{\rm source}. \tag{2}$$

By providing an independent method to constrain the mass, the redshift can be estimated. However, there is a complete degeneracy between the GW mass and redshift, which can be handled by the two methods:

1. Neutron Star Equation of State (EOS): For a binary system containing a compact object with neutron star progenitors, the latter experience a tidal deformability imprinted in the observed GW signal as they approach their companion. To break the mass and redshift degeneracy, the tidal deformation is used(Mastrogiovanni et al. 2024):

$$\psi^{\rm tidal}(f) = \sum_{a=1,2} \frac{3\lambda_a(1+z)^5}{128\eta} \left[-\frac{24}{\chi_a}\left(1 + \frac{11\eta}{\chi_a}\right)\frac{x^{5/2}}{M_z^5} - \frac{5}{28\chi_a}\frac{x^{7/2}}{M_z^5}\left(3179 - 919\chi_a - 2286\chi_a^2 + 260\chi_a^3\right)\right]. \tag{3}$$

The redshift z can be determined by measuring the redshifted mass M_z from the gravitational wave signal and estimating the source-frame mass M using the tidal deformability parameter λ_a, which depends on the neutron star's mass and the assumed equation of state (EOS). Once M is obtained, the redshift is calculated using the relation in equation (2). Events with a high signal-to-noise ratio (e.g., GW170817) had good constraints on the NS deformability and allowed tighter EOS constraints.

2. Merger Rates Method: A prior knowledge about the dark siren mass distribution and the merger rate can provide a good estimation of the redshift. For a population of GWs, each detected event is characterized by parameters θ. The posterior on the cosmological hyperparameters $\mathcal{H} = \{H_0, \Omega_m, \Omega_\Lambda, \dots\}$ is given by:

1. For binary black hole systems, an expected electromagnetic "flare" could arise from their very dense origins, such as Low-Mass X-Ray Binaries (LMXBs). However, no such case has been detected due to the limitations of current telescopes. Some signals, like GW190521, have candidates for a flare in an active galactic nucleus, but none have been confirmed.

$$p(\mathcal{H}|\mathcal{D}) = \frac{p(\mathcal{D}|\mathcal{H})p(\mathcal{H})}{p(\mathcal{D})}. \tag{4}$$

Assuming independent observations, the likelihood $p(\mathcal{D}|\mathcal{H})$ is the product of single-event likelihoods $p(d_i|\mathcal{H})$. Each single-event likelihood depends on the population-level parameters $\mathcal{H}$, the source parameters (e.g., binary masses M and redshift z), and the redshifted mass $M_z = (1+z)M$.

The prior $p(M, z|\mathcal{H})$ commonly factorizes as:

$$p(M, z|\mathcal{H}, \Lambda) = Cp(M|\Lambda)\frac{R(z;\Lambda)}{1+z}\frac{dV_c}{dz}, \tag{5}$$

where $\frac{dV_c}{dz}$ is the differential comoving volume, $p(M|\Lambda)$ is the mass prior, $R(z;\Lambda)$ is the merger rate as a function of redshift, and C is a normalization constant. The parameters Λ describe the mass and redshift distributions as well as the merger rate.

This method has three applications, two of which rely on the mass distribution, and the third uses the merger rate density $R(z;\Lambda)$. These methods exploit assumptions about the compact object density rates, making the method model-dependent. The three approaches are:

1. Black Hole Mass Function: This method has the potential to constrain the Hubble parameter H_0 at $z \approx 0.8$.

2. Neutron Star Mass Function: Due to the narrow mass range of neutron stars, this method is applied exclusively to BNS systems and is expected to achieve better constraints with the next generation of GW detectors, such as the Einstein Telescope.

3. Merger Rate as a Function of Redshift: Using the dark siren merging rates $R(z;\Lambda)$, the redshift is implicitly defined if the merger rate peaks at a specific redshift. For example, BBH formation peaks at $z \approx 2$, which is expected to follow a low-metallicity star formation history. Future third-generation GW interferometers are expected to provide redshift scales for this method.

The GW-only methods face challenges due to systematic biases from inaccurate models. For BBHs, an incorrect model of the merging rate as a function of cosmic time can introduce biases. For neutron stars, uncertainties in the EOS hinder precise measurements and introduce biases in measuring H_0. Achieving sub-percent accuracy requires improved modeling and simulations.

2.1.3 Findings

Bright Sirens The only event associated with an EM counterpart was GW170817, where a gamma-ray burst and kilonova were detected in large observation campaigns using ground-based and space-based telescopes. The host galaxy was identified as NGC 4993 using the well-constrained 3D sky localization. The observations enabled computing the recessional velocity, which allowed measuring the cosmological redshift $z = 0.0101 \pm 0.0005$.

The posterior luminosity distance of the signal was provided at 68% confidence level as $43.8^{+2.9}_{-6.9}$ Mpc, which, when combined with the galaxy redshift measurement, allowed the Hubble constant to be inferred as $H_0 = 70^{+12}_{-8}$ km/s/Mpc. Improved analyses, such as accounting for inclination angle degeneracy using afterglow observations, tightened the constraint to $H_0 = 68.4^{+4.1}_{-3.3}$ km/s/Mpc. **Measuring Hubble Constant**

The posterior luminosity of the signal was provided at the 68% confidence level as $43.8^{+2.7}_{-2.9}$ Mpc, which was combined with the galaxy redshift measurement, and then the Hubble constant was inferred to obtain a value of $H_0 = 70^{+19}_{-8}$ km s^{-1} Mpc^{-1}, as shown in Figure 1.

More enhanced analysis at the detector low-frequency bands provided more accurate measurements to a value of $H_0 = 70^{+12}_{-8}$ km s^{-1} Mpc^{-1} using lower spin priors.

Extended analysis to overcome the degeneracy of the inclination angle of the luminosity distance measurements used the afterglow observation of the associated jet. It was assumed that the jet is

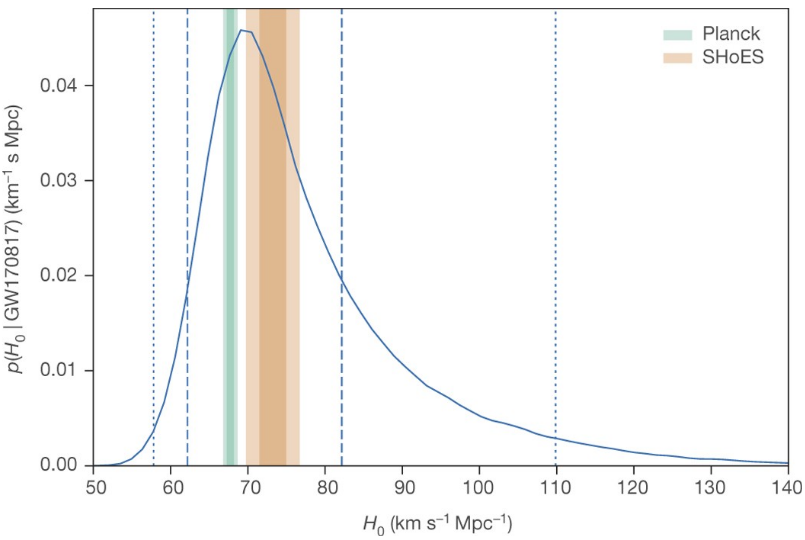

Figure 1. The posterior distribution of the Hubble constant from GW170817. The dashed lines correspond to the 68% confidence level, and the dotted line corresponds to the 95% confidence level. The orange and green shaded areas represent results from supernovae and CMB measurements. (Source: Nature, 2017).

perpendicular to the merger, providing a tighter constraint on measuring H_0, which improves the measurements to $H_0 = 68.4^{+4.7}_{-4.6}$ km s^{-1} Mpc^{-1}.

Dark Sirens Several works on this method have been proposed for different approaches. One analysis used the GWTC-2 catalog of the first and second observing runs, combined with the GLADE galaxy catalog using all-sky observations (see Figure 2).

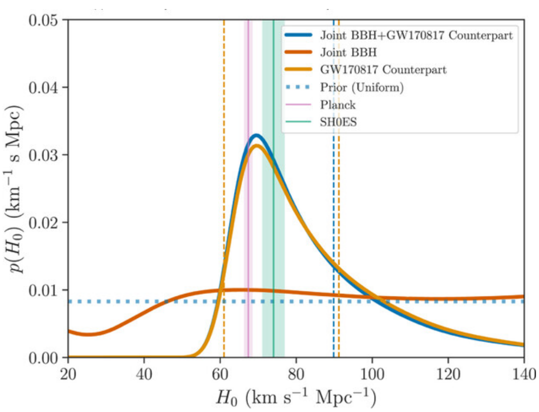

Figure 2. The updated posteriors of the Dark serin method along with combining the data with the bright serin. Purple area refer to Plank collaborations and the green area is the Supernova measurements

More recent events from the third observing run observations used an updated dark siren method, which employed a more complex model of the mass distribution and 47 events. With a combination of GW170817 measurements, the BBH mass distribution was used to yield a result of $H_0 = 68.7^{+17.0}_{-7.8}$ km s^{-1} Mpc^{-1}. The mass distribution of BBHs plays a relevant role in assessing systematics in H_0, where the BBH mass is modeled as a power law. Using 46 dark sirens, the measurement resulted in $H_0 = 67^{+8}_{-6}$ km s^{-1} Mpc^{-1}, and combining it with GW170817 improved the estimate to $H_0 = 68^{+8}_{-6}$

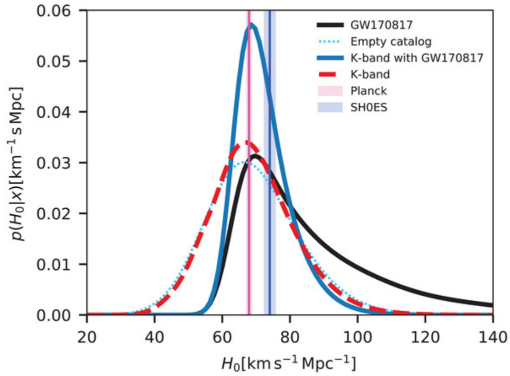

Figure 3. The updated posterior of galaxy catalog method using different frequency bands. Purple area refer to Plank collaborations and the green area is the Supernova measurements

km s^{-1} Mpc^{-1}. See Figure 3.

In cases where the galaxy catalog is incomplete, methods dependent on the merging rate and the mass distributions of BBHs are utilized.

BBH Mass Spectrum Results

Analysis using 42 BBHs from the third observing run (GWTC-3) applied three different population models for the mass distribution of BBHs: the power-law plus Gaussian and the broken power-law models were preferred. by combining the 42 estimations with GW170817, the Hubble constant was found to be $H_0 = 68^{+8}_{-6}$ km s^{-1} Mpc^{-1}, which improves the measurement by approximately 17% compared to GW170817 alone (Mastrogiovanni et al. 2024).

I summarized the results in table 1 combining all the methods along with the corresponding Hubble constant measurements.

Table 1. Hubble Constant Measurements Using Different Methods

Method	**Details**	**Hubble Constant (H_0)**
	Bright Sirens	
GW170817	EM counterpart	70^{+19}_{-8} km/s/Mpc
	Improved with inclination angle (VLBI)	$68.4^{+4.7}_{-4.6}$ km/s/Mpc
	Dark Sirens with Galaxy Surveys	
GLADE catalog	6 BBHs + GW170817	$68.7^{+17.0}_{-7.8}$ km/s/Mpc
GLADE+ catalog	46 dark sirens + GW170817	68^{+8}_{-6} km/s/Mpc
DESI catalog	High completeness to $z = 1$	$72.8^{+11.0}_{-7.6}$ km/s/Mpc
	Dark Sirens with Mass Spectrum	
Power-law + Gaussian	Population model (BBH masses)	50^{+37}_{-30} km/s/Mpc
Broken power-law	Population model (BBH masses)	44^{+52}_{-24} km/s/Mpc
	Combined Methods	
Bright + Dark Sirens	GW170817 + 42 BBHs (mass model)	68^{+12}_{-8} km/s/Mpc

2.1.4 Relevance

Despite being a relatively new field with limitations, GWs enable probing of higher redshifts and the early universe. Unlike electromagnetic (EM) waves, GWs traverse vast cosmic distances with minimal interaction with matter, preserving pure information about their origins and providing unique insights into their sources.

2.2 Reference 2: Hubble Tension: The Evidence of New Physics

2.2.1 Issue

The review paper explores the persistent discrepancies in Hubble constant measurements, discussing the methods used to constrain H_0: the Cosmic Microwave Background (CMB) and recent independent observational methods used to estimate Hubble measurements. However, a significant discrepancy in the measurements of H_0 between the CMB and the local distance ladder is statistically significant and is referred to as "Hubble tension." Many international conferences have discussed this tension. In 2015, a poll at one such conference showed that 69% of participants believed there is new hidden physics contributing to the tension, while 50% attributed it to systematic unknowns in the observational data. As the precision of measurements has improved, researchers increasingly tend to believe that the H_0 tension arises from new physics beyond the ΛCDM model, the current cosmological framework that needs further exploration. The review discusses the potential for this solution, considering hundreds of studies dedicated to the Hubble tension and presenting evidence for it.

2.2.2 Methods

The enhanced and improved measurements of independent methods to measure H_0 have been provided, listed in table 2

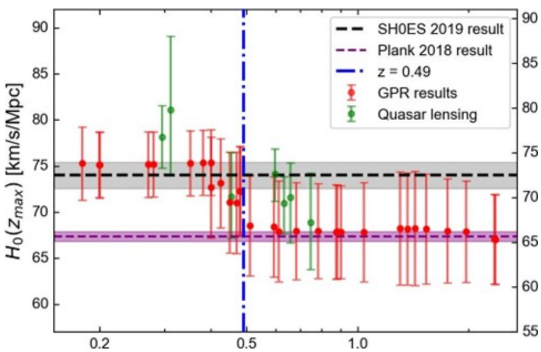

Figure 4. H_0 measurements using different independent recent methods. The purple regions ccorrespondes to SH0ES and the blue to Planck collaboration.(Hu and Wang 2023)

The solutions are divided into two categories to address the Hubble tension solution: This passage discusses two approaches to addressing the Hubble constant (H_0) tension:

1. **Sequential Scheme**: This approach proposes a new cosmological model first, and then uses early-time (e.g., Cosmic Microwave Background, CMB) or late-time (e.g., Cepheid) observational data to constrain cosmological parameters. While it aligns H_0 values with recent observations (e.g., SH0ES), it often increases the complexity of the model by introducing additional parameters(Hu and Wang 2023).
2. **Reverse-Order Scheme**: This approach starts with the standard ΛCDM model or a model-independent framework. It then analyzes existing late-time observations to explain anomalies in H_0 values, which might hint at new physics beyond the ΛCDM framework(Hu and Wang 2023).

Table 2. H_0 measurements with the 68% confidence level derived from recent observations.

Observation	H_0 (km/s/Mpc)
Quasar lens	$73.3^{+1.7}_{-1.8}$
Quasar lens	$74.0^{+1.7}_{-1.8}$
Quasar lens	$74.2^{+1.6}_{-1.6}$
Megamaser	69.3 ± 4.2
Megamaser	73.9 ± 3.0
GW	$74.0^{+16.0}_{-8.0}$
GW + EM	$70.3^{+5.3}_{-5.0}$
GW	$68.0^{+12.0}_{-7.0}$
GW	$67.0^{+6.3}_{-3.8}$
FRB	62.3 ± 9.1
FRB	$68.81^{+4.99}_{-4.33}$
FRB	$73.0^{+12.0}_{-8.0}$
FRB	70.6 ± 2.11
FRB	$71.5^{+10.0}_{-8.1}$
TRGB	69.8 ± 0.8
TRGB	69.6 ± 0.8
TRGB	69.8 ± 0.8

The sequential scheme tends to add complexity by increasing the parameter space, whereas the reverse-order scheme focuses on uncovering potential new physics(Hu and Wang 2023).

2.2.3 Findings

Evidence of new physics The quasar lensing method provided new evidence of hidden physics behind the tension, revealed by the strongly-lensed quasar time-delay (H0LiCOW). It showed a weakly significant ($\sim 1.7\sigma$) trend where H_0 decreases with increasing lens redshift, illustrated in figure 5. Although the trend's statistical strength is debated, it provides a diagnostic that may indicate systematic deviations from ΛCDM rather than errors in measurements(Hu and Wang 2023).

Inspired by that, subsequent researchers analyze the late-time cosmological data (e.g., SNe Ia, BAO, megamasers) by binning it into redshift intervals. They found a descending trend in H_0 with redshift, consistent with the H0LiCOW results. The observed trend was modeled using the mean redshift $\bar{z}$ of the bins(Hu and Wang 2023):

$$\bar{z} = \frac{\sum_i z_i/\sigma_i^2}{\sum_i 1/\sigma_i^2}, \tag{6}$$

where σ_i is the observational uncertainty at redshift z_i. This descent in H_0 is unlikely to arise purely from observational biases.

sample of Type Ia supernovae to describe H_0 evolution with redshift using the function:

$$g(z) = H_0(z) = \tilde{H}_0(1 + z)^a, \tag{7}$$

where $\tilde{H}_0$ and a are free parameters. They found that $a \approx 0.008$, indicating a slow evolution of H_0 with redshift. This approach reduced the H_0 tension by up to 66%, suggesting that the tension is not tied to a specific cosmological model or binning method.

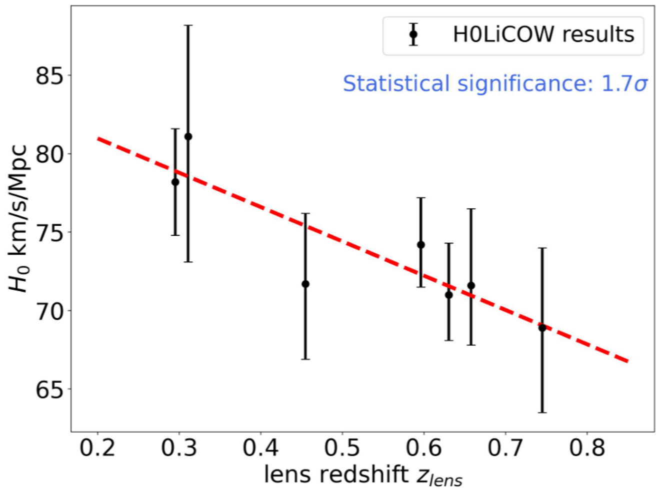

Figure 5. H_0 results of H0LiCOW measurments. Increasing the lens redshift gives smaller hubble constant values, with levels of 6σ.(Hu and Wang 2023)

2.2.4 Relevance

The reference is highly relevant to the most important problem in cosmology; it offers an overview about the latest research contributions to reveal the tension and the state of the experimental results.

2.3 Reference 3: Strong evidence for the discovery of a gravitational wave background

2.3.1 Issue

In 2023, the first discovery of stochastic gravitational waves detection has been announced by pulsar timing arrays (PTAs). The article highlights the discovery and its implications to astrophysics and cosmology. Binary pulsars are composed of a rotating magnetized neutron star and a compact companion. They have been used as a celestial clock system.

2.3.2 Methods

Pulsars emit regular pulses of radio-frequency electromagnetic waves as their magnetic axis periodically aligns with the line of sight to Earth. The stability of these pulses allows their precise timing to be used as a probe for gravitational waves(Caprini 2024).

Gravitational waves passing through spacetime induce a time-dependent variation in the spacetime metric, leading to a shift in the arrival times of these pulses. This effect, known as gravitational redshift, causes pulses to arrive slightly earlier or later than expected. By analyzing the timing of these pulses, it is possible to evidence external gravitational waves traveling between the pulsar and Earth(Caprini 2024).

2.3.3 Findingas

- **Confirmation of Stochastic Gravitational Wave Background:** The detected signal by Pulsar Timing Arrays (PTAs) is consistent with the incoherent superposition of gravitational waves from a population of supermassive black hole binaries.

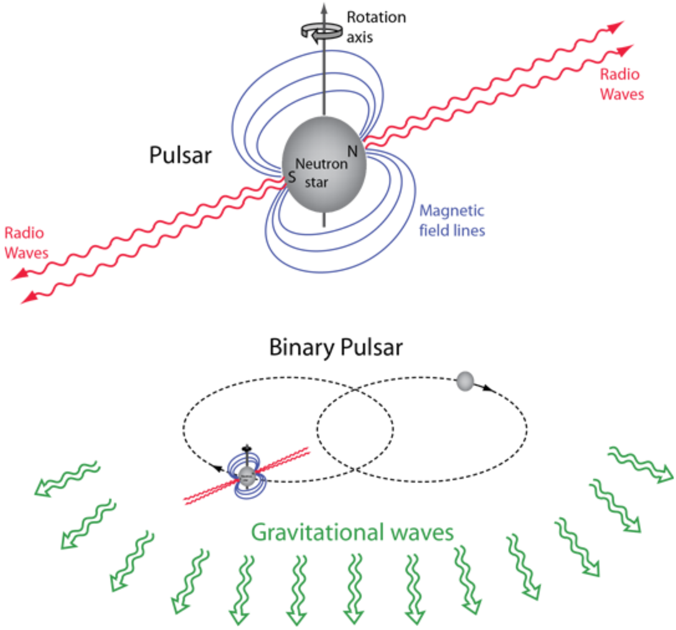

Figure 6. Diagram of a spinning neutron star and the binary pulsar with a compact object. Copyright:Hyperphysics website.

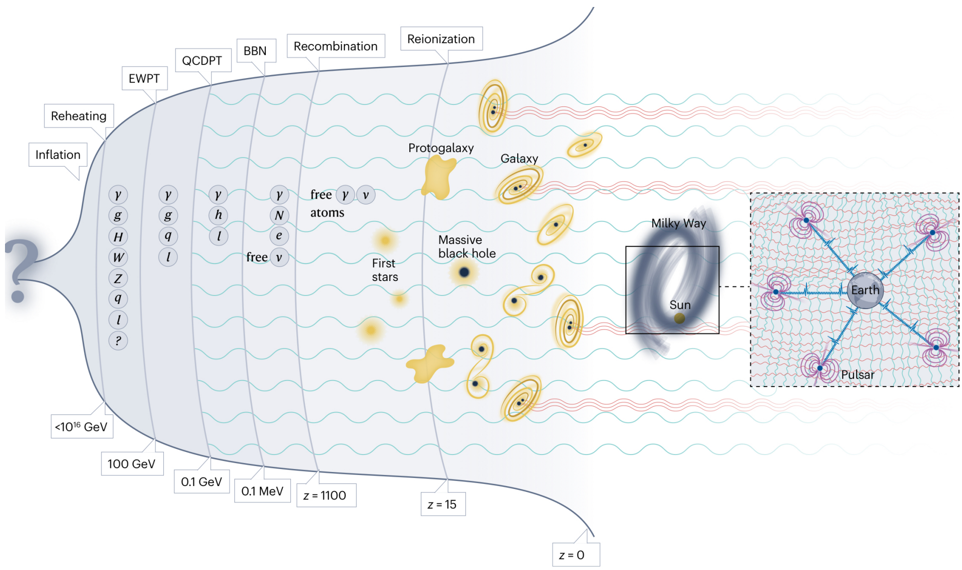

Figure 7. Gravitational wave sources and the Universe's evolution in the pulsar timing array frequency band. By monitoring the times of arrival the EM pulse of a network of pulsars in the Milky Way, pulsar timing arrays detect a stochastic gravitational wave background (1–50 nHz) through produced a quadrupole correlation pattern in the timing residuals observed in earth. These waves arise from supermassive black hole binaries or early Universe processes, such as phase transitions or cosmic mergers or at the epoch of the quantum chromo dynamics phase transition (QCDPT).(Caprini 2024)

- **Astrophysical Implication:** The detection provides the first observational evidence that supermassive black hole binaries do not stall at parsec separations but evolve toward merger, driven by dynamical processes.
- **Cosmological Implications:** The detection could trace primordial gravitational wave signals, offering insights into high-energy physics phenomena such as quantum chromodynamics phase transitions, cosmic inflation, or grand unification beyond the standard model of particle physics.

2.3.4 Relevance

The reference highlights a significant discovery with cosmological implications. The stochastic gravitational wave backgrounds have a speculated origin, just like the CMB. It might be a primordial signal picked up, with a characteristic frequency pointing to a generation of quantum chromodynamics phase (when the universe was a few microseconds old) with a potential to probe the universe with higher-energy scale. Furthermore, it is compatible with the sourcing process at higher energy beyond the standard model of particle physics, (e.g, topological defects, left over from phase transitions possibly connected to the grand unification; or inflation, the period of accelerated expansion at the origin of the entire observable Universe.). This for sure has many exciting opportunities to probe beyond our limit and knowledge in cosmology!

3 Discussion

I must confess that the choice of topic, along with references having different outlines, was perhaps not the best decision. However, it is worthwhile to discuss each topic individually.

1. **Discussion on the Refrence 1:**
   - The analysis provided above, provided a summary for all the methods have been proposed using the current GWs data. What we can conclude from Table1 that the bottleneck of using the current GWs as a reliable tool to probe cosmology (Also as a distance ladder) is the challenge of introducing EM observations, which is the rare case scenario, and we left with the low precision Dark serins.
   - The methods introduce above have potential to strongly constrains the Hubble constant H_0 with a good results. However, there is a loooot of experimental works needs to be handled ...and, at this stage of data, I can safely say there is a "big fuss" about how tranformative the GWs tool for cosmology.
   - More importantly, the review did not discuss other cosmological parameters other than H_0, making these methods tight to the Hubble constant. In fact, it was noted that such observations can't constrains other cosmological parameters such as Ω_m and Ω_Λ.
2. **Discussion on Refrence 2**
   - The "Classification scheme" of Hubble tension of previous work was divided into 5 main majors and 19 subcategories, giving insight to the direction of the theoretical research to the solution of Hubble tension. other review paper have consider it, and it was not discussed in this review paper. The bizarre behavior of H_0 might be evidence for hidden physics, However, there is no cosmological models for such a claim sofar.
   - The descending trend shown in figure 5 shows increasing in the error bars, which might be a statistical result of "choice-analysis" and not significant.
   - Which approaches do I found more promising ? It's true that the review paper have shown me that I need to look more, and due to the knowledge gap I have (The statistical framework, General relativity and advanced math), (also the time), I could not cover the issue in well manner. Still, I do believe that the other approaches (The reverse order scheme) is less arduous

process. By looking beyond, and these "evidence" might be a real hint for hidden information that need to be discovered.

3. **Discussion on Refrence 3:**
   - This article has the most limitations among the three references, it actually left me with a lot of questions than answer. First, why the Nanographs team believes that the signals are originated from supermassive black-holes (Astrophysical origin)?. What are the theoretical studies about these stochastic gravitational waves and which cosmological scenarios is the most promising source?.
   - The article was a motivation for the discovery, and did not discuss the methods behind it. The residual time lensing array, and the correlation results needed extended references and studies.

4 Conclusion and Prospects

The recent independent methods using new observational data have offered good estimations for the Hubble constant. However, research directions, such as the reverse scheme, are more promising to resolve the tension, especially by studying observed trends in the behavior of H_0 in some independent measurements. The tension problem is significant, introducing new "unpleasant" results for cosmologists and challenging the ΛCDM model. Yet, no significant evidence has been provided or strong theoretical interpretation, and the research is still going .

From the review papers, I gained a comprehensive analysis of the role of gravitational waves (GWs) in cosmology, their implications, and each method used, along with their limitations and challenges. Furthermore, I gained a good introduction to the research directions addressing the Hubble tension problem, supported by a set of significant studies and research approaches. As Dr. Walid once said, "It's good to start with review papers for such general topics." However, one thing these readings left me with is the realization of the large knowledge gap I have, which can be improved by sticking to scientific methods, further reading, and, most importantly, curiosity.

Could the next gravitational waves observations reach higher redshifts and achieve higher sensitivity with associated multi-messenger detections? We don't know; that's for the third-generation detectors and the next generations to discover!

The descending trend in $H_0(z)$ offers a new "diagnostic" for the Hubble tension, suggesting a promising path to resolve the H_0 tension without requiring early-time modifications. Future advancements in both observations and theory will be crucial to confirm these findings and explore physics beyond ΛCDM.

Would I choose this topic again? Yes. I chose these references specifically because I wanted to read them, but I now realize that I should have chosen one concise topic to build a stronger piece of research. First, the "aim" needed to be clearer and more focused, and second, the references should have been more related and consistent with the issue.

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