[illegible]“2025[illegible]”

Report of Contributions

Contribution ID : **2** Type : **not specified**

Quantum Search for Gravitational Wave of Massive Black Hole Binaries

Matched filtering is a common method for detecting gravitational waves. However, the computational costs of searching large template banks limit the efficiency of classical algorithms when searching for massive black hole binary (MBHB) systems. In this work, a quantum matched filtering algorithm based on Grover’s algorithm is applied to the MBHB signals. It is demonstrated that the quantum approach can reduce the computational complexity from $O(N)$ to $O(\sqrt{N})$ theoretically, where N is the size of the template bank. Simulated results indicate that the quantum-enhanced approach significantly reduces computational costs. However, it is also found that the performance can degrade in some cases due to instability of the algorithm. This highlights the need for more robust and stable quantum search strategies. This paper is accepted by PRD.

Primary author(s) : GUO, Fangzhou (Hangzhou Institute for Advanced Study, UCAS;); HE, Jibo (University of Chinese Academy of Sciences)

Presenter(s) : GUO, Fangzhou (Hangzhou Institute for Advanced Study, UCAS;)

Contribution ID : **3** Type : **not specified**

Probing ultralight bosons with binary black holes

Clouds of ultralight bosons can form around spinning black holes through superradiance. In this talk, we shall discuss the dynamical evolution of such clouds in binary black hole systems. Focusing on comparable mass binaries, we demonstrate that the cloud can resonantly transfer between the two black holes and eventually form a common envelope during the late inspiral phase. We also study the implications on orbital dynamics and the signatures in gravitational waves, which provide a unique probe of the new physics.

Primary author(s) : Dr ZHANG, Jun (International Center for Theoretical Physics Asia-Pacific)

Presenter(s) : Dr ZHANG, Jun (International Center for Theoretical Physics Asia-Pacific)

Contribution ID : **5** Type : **not specified**

Shedding light on dark matter with gravitational waves: searches in the first part of the fourth observing run of LIGO-Virgo-KAGRA

Abstract:
Dark matter could compose ~80% of all matter in the universe, and yet it is completely invisible to us. Despite decades of experiments designed to detect dark matter, and numerous models for potential dark matter particles, no concrete evidence has been put forward to support the existence of beyond standard-model physics. Because of this, it is worth asking whether approaching the detection of dark matter from a different point of view, that is, via gravitational-wave interferometers, could provide some insight into explaining the origin of dark matter. In this talk, I will discuss searches for ultralight particle dark matters. While not designed to search for dark matter, gravitational-wave detectors can robustly probe a variety of dark-matter models simultaneously, without affecting their sensitivity to canonical gravitational-wave sources, and put competitive and sometimes even stronger constraints than those from other experiments designed to search for dark matter.

Primary author(s) : [illegible], [illegible] ([illegible])

Co-author(s) : Dr MILLER, Andrew L. (Utrecht University); GUO, Huaike (University of Chinese Academy of Sciences)

Presenter(s) : [illegible], [illegible] ([illegible])

Contribution ID : **6** Type : **not specified**

[illegible]

[illegible]0.1-10Hz[illegible]KHz[illegible]

Primary author(s) : WEI, Lian-Fu (SWJTU)

Presenter(s) : WEI, Lian-Fu (SWJTU)

Contribution ID : **7** Type : **not specified**

Variational inference for correlated gravitational wave detector network noise

Gravitational wave detectors like the Einstein Telescope and LISA generate long multivariate time series, which pose significant challenges in spectral density estimation due to the large number of observations as well as the presence of correlated noise. Addressing both issues is crucial for accurately interpreting the signals detected by these instruments. A variational inference method for spectral density estimation is applied to address correlated noise in gravitational-wave data. It uses a cosine-spline basis to represent the PSD, providing a flexible parametrization. To handle very long time series, the method employs a blocked multivariate Whittle likelihood approximation for stationary time series. Instead of MCMC, a surrogate posterior is optimized via stochastic-gradient variational Bayes and then sampled directly, thereby recasting complex posterior sampling into an optimization problem. The method is demonstrated by analyzing 2000 s of simulated Einstein Telescope noise, which shows its ability to produce accurate spectral density estimates and quantify coherence between time series components. This method is particularly effective in addressing correlated noise, a significant challenge in the analysis of multivariate data from collocated detectors.

Primary author(s) : Mr LIU, Jianan (University of Auckland)

Co-author(s) : Dr VAJPEYI, Avi; Prof. MEYER, Renate; Dr JANSSENS, Kamiel; Dr LEE, Jeung Eun; Dr MATURANA-RUSSEL, Patricio; Prof. CHRISTENSEN, Nelson; Dr LIU, Yixuan

Presenter(s) : Mr LIU, Jianan (University of Auckland)

Contribution ID : **8** Type : **not specified**

Probing spin-2 ultralight dark matter with space-based gravitational wave detectors in the mHz regime

Spin-2 ultralight dark matter (ULDM) is a viable dark matter candidate and it can be constrained using gravitational wave (GW) observations. In this paper, we investigate the detectability of spin-2 ULDM by space-based GW interferometers. By considering a direct coupling between spin-2 ULDM and ordinary matter, we derive the corresponding response functions and sensitivity curves for various time-delay interferometry channels and calculate the optimal sensitivity curves for future millihertz GW detectors. Our results demonstrate that the space-based detectors can place stringent constraints on the coupling constant of spin-2 ULDM, reaching alpha ~ 10^(-10) around a mass of m ~ 10^(-17) eV, surpassing current limits from ground-based detectors and pulsar timing arrays. Thus, the space-based GW detectors can serve as powerful tools not only for detecting GWs but also for probing fundamental properties of ultralight dark matter.

Primary author(s) : ZHANG, Jing-Rui (HIAS-UCAS)

Presenter(s) : ZHANG, Jing-Rui (HIAS-UCAS)

Contribution ID : **9** Type : **not specified**

Modeling and prediction of the foreground noise in space-based gravitational wave detections

The Galactic foreground noise presents a major challenge for space-based gravitational wave detection. Gravitational waves from the vast population of double white dwarfs overlap and interfere, producing an indistinguishable foreground component. This contamination complicates the search for other gravitational wave sources and reduces their signal-to-noise ratios. Since the foreground is essentially composed of numerous quasi-monochromatic signals, we exploit their stability by modeling the waveforms into three orthogonal basis-vector components. In the short term, multiple waveforms with similar frequencies can be coherently represented by these three orthogonal components, which can then be used to predict the subsequent waveform evolution. This approach provides an effective strategy for modeling and mitigating the Galactic foreground noise.

Primary author(s) : Dr GAO, Pin (University of Chinese Academy of Sciences)

Co-author(s) : Prof. HUANG, Da (The University of Chinese Academy of Sciences)

Presenter(s) : Dr GAO, Pin (University of Chinese Academy of Sciences)

Contribution ID : **10** Type : **not specified**

Ring formation from black hole superradiance through repeated particle production on bound orbits

Ultralight bosonic fields around a rotating black hole can extract energy and angular momentum through the superradiant instability and form a dense cloud. We investigate the particle ring formation mechanism induced by black hole superradiance. We examined the dynamics of axion-like particles ϕ and χ with a large mass hierarchy and a trilinear coupling around a rotating black hole. Against the background of a superradiant cloud formed by the ϕ field, χ particles are resonantly excited and accumulate in bound orbits to form ring-like structures. Combining analytical approximations and numerical evolution, we describe the resonance-triggered dynamics as well as the evolution of the superradiant cloud and particle rings, along with their final steady-state distribution characteristics. This study reveals a new mechanism for generating bound-state particles through resonance in superradiant clouds and highlights its potential significance for studying particle physics interactions in strong gravitational fields.

Primary author(s) : Mr LYU, Zhenhong; Prof. CAI, Rong-Gen; GUO, Zong-Kuan; Mr HE, Jian-Feng; Prof. LIU, Jing

Presenter(s) : Mr LYU, Zhenhong

Contribution ID : **11** Type : **not specified**

Sound waves from primordial black hole formations

We present a numerical investigation of primordial black hole (PBH) formation from super-horizon curvature perturbations and the subsequent generation and propagation of sound waves, which can serve as a new source of stochastic gravitational wave backgrounds (SGWBs) presented in a companion letter. Using the Misner-Sharp formalism with an excision technique, our simulations extend to significantly later times than previous work and indicate that the near-critical perturbations produce a distinct compression wave featuring both overdense and underdense shells, while significantly supercritical perturbations yield only an underdense shell. We also show that a softer equation of state suppresses the formation of compression waves. Furthermore, the comoving thickness of sound shells remains nearly constant during propagation and scales with the Hubble radius at horizon re-entry, thereby serving as a key link between the gravitational-wave peak frequency and PBH mass in the companion letter. These results offer new insights into the dynamics of PBH formation and suggest potential observational signatures of PBHs in the gravitational wave (GW) spectrum from associated sound waves.

Primary author(s) : NING, Zhuan (HIAS and ITP-CAS); ZENG, Xiang-Xi (ITP, CAS); YUWEN, Zi-Yan; WANG, Shao-Jiang (Institute of Theoretical Physics, Chinese Academy of Sciences); DENG, Heling; Prof. CAI, Rong-Gen

Presenter(s) : NING, Zhuan (HIAS and ITP-CAS)

Contribution ID : **12** Type : **not specified**

Machine Learning Techniques for Gravitational Wave data analysis

[illegible]

Primary author(s) : CAO, Zhoujian

Presenter(s) : CAO, Zhoujian

Contribution ID : **13** Type : **not specified**

Phase Transition Gravitational Waves as a Unique Discriminant for Warm Inflation

We investigate the properties of gravitational waves generated by heating-induced phase transitions in warm inflation. In this scenario, the heating phase of inflation followed by subsequent cosmological cooling can trigger two associated first-order phase transitions and generate characteristic gravitational waves. The correlated gravitational wave spectral features—amplitude, peak frequencies, and oscillatory behavior—originate from a unified model governing both phase transitions. These signatures allow discrimination between warm and cold inflation models, and give constraint on the key parameters including the dissipative coupling strength and the inflationary energy scale, collectively illuminating early-Universe dissipative dynamics. Future gravitational wave observatories such as BBO, Ultimate-DECIGO, μAres, resonant cavities, and Pulsar Timing Array experiments, will play a important role in testing these theoretical
predictions.

Primary author(s) : SUI, Xiao-Bin; LIU, Jing; CAI, Rong-Gen

Presenter(s) : SUI, Xiao-Bin

Contribution ID : **14**   Type : **not specified**

Measuring the cosmic dipole with golden dark sirens in the era of next-generation ground-based gravitational wave detectors

The tensions between cosmological parameter measurements from the early-universe and the late-universe datasets offer an exciting opportunity to explore new physics, if not accounted for unknown systematics. Apart from the well-known Hubble tension, a tension up to ~ 4.9σ in the cosmic dipole has also been reported. While the cosmic dipole is mainly induced by the observer's kinetic motion, an intrinsic dipole arising from the anisotropy of the universe could also play an import role. Such an intrinsic anisotropy can be a dark energy mimicker that causes the observed accelerating expansion of the universe. As a new and powerful tool, gravitational waves can serve as an independent probe to the cosmic dipole. A useful type of events to achieve this is the “golden dark sirens”, which are near-by well-localized compact binary coalescences whose host galaxies can be identified directly due to precise localization. By forecasting golden dark sirens obtained from 10-year observations using different possible detector networks in the future, we find that the standard LIGO-Virgo-KAGRA detectors are not able to detect a meaningful amount of golden dark sirens, and hence next-generation ground-based detectors are essential to obtain a strong constraint on the cosmic dipole. In particular, we find that a three-detector network consisting of more than one next-generation detectors can yield a constraint on the cosmic dipole at an order of 10^{-3} when jointly measured with H_0. Moreover, a constraint on the cosmic dipole at an order of 10^{-4} can be achieved when fixing H_0.

Primary author(s) : CHEN, An (International Center for Theoretical Physics (Asia-Pacific), University of Chinese Academy of Sciences)

Presenter(s) : CHEN, An (International Center for Theoretical Physics (Asia-Pacific), University of Chinese Academy of Sciences)

Contribution ID : **15** Type : **not specified**

Simulating scalar-induced gravitational waves

Scalar-induced gravitational waves (SIGWs) are ubiquitous in many early-Universe processes accompanied by non-Gaussianity; hence, precise calculations of SIGWs involve a full understanding of non-Gaussianity. Therefore, we propose to use the lattice simulations to directly calculate the energy density spectra of SIGWs with non-Gaussianity up to all orders. Our proposal has been first verified to match the existing semi-analytical results with non-Gaussianity, and then applied to more general cases, including high-order primordial non-Gaussianities, the logarithmic dependence in curvature perturbations, the curvaton model, and the ultra slow-roll model. We find that even a modest non-Gaussianity can significantly alter ultraviolet behaviors in SIGW spectra, necessitating
special cautions in future detections as well as mutual constraints on/from primordial black holes.

Primary author(s) : ZENG, Xiang-Xi (ITP, CAS)

Co-author(s) : NING, Zhuan (HIAS and ITP-CAS); WANG, Shao-Jiang (Institute of Theoretical Physics, Chinese Academy of Sciences); CAI, Rong-Gen

Presenter(s) : ZENG, Xiang-Xi (ITP, CAS)

Contribution ID : **16** Type : **not specified**

Enhancement of first-order phase transitions through a mass-acquiring scalar field

Phase transitions in the early Universe give rise to effective masses for massless fields in the symmetry-broken phase. We use the lattice simulations to investigate the impact of a spectator scalar field with mass generation on the dynamics of first-order phase transitions and the generation of gravitational waves. In addition to the well-known friction effects, we identify a novel effect that significantly enhances the strength of first-order phase transitions. The amplitude of the mass-acquiring field is highly suppressed in the true vacuum bubbles, resulting in additional release of vacuum energy that concentrate on the bubble walls. We also establish an analytical method to explain our numerical results.

Primary author(s) : Mr LI, Yuanjie (University of Chinese Academy of Science); LIU, Jing; GUO, Zong-Kuan

Presenter(s) : Mr LI, Yuanjie (University of Chinese Academy of Science)

Contribution ID : **17** Type : **not specified**

AI-Driven Modeling and Inference in Gravitational Wave Astronomy

The growing capabilities of ground- and space-based GW detectors demand advanced tools for signal detection, waveform modeling, and parameter estimation. AI, particularly deep learning, offers powerful solutions. Physics-Informed Neural Networks (PINNs) embed physical laws into neural networks for consistent waveform generation and inverse modeling without large datasets. Normalizing Flows enable fast, flexible Bayesian inference of complex posteriors. This report highlights recent progress in applying these methods to GW science, emphasizing their role in real-time modeling and inference—paving the way for AI-driven, multi-messenger astrophysics.

Primary author(s) : [illegible], [illegible] ([illegible])

Presenter(s) : [illegible], [illegible] ([illegible])