
## Sunandan Gangopadhyay

Associate Professor

Theoretical Sciences

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## Guidance of Students/Post-Docs/Scientists

**a) Ph.D. Students**

1. Debabrata Ghorai; Holographic superconductors; Thesis Submitted; Biswajit Chakraborty (Co-supervisor)
2. Ankur Srivastav; Applications of gauge/gravity duality; Under progress
3. Sourav Karar; Holographic entanglement entropy and complexity; Under progress; Archan Majumdar (Co-supervisor)
4. Rituparna Mandal; Renormalization group approach to quantum gravity; Under progress
5. Neeraj Kumar; Black hole thermodynamics and phase transitions; Under progress
6. Anish Das; Black hole shadow; Under progress
7. Manjari Dutta; Noncommutative quantum mechanics; Under progress
8. Anirban Roy Chowdhury; Holographic investigation of quantum information theoretic quantities; Under progress

**b) Post-Docs**

1. Dharmesh Jain; String theory

## Teaching

1. Autumn semester; Advanced Quantum Mechanics and Applications (PHY303); Integrated PhD; 12 students; with 1 (Archan Majumdar) co-teacher
2. Autumn semester; Mathematical Methods (PHY 102); Integrated PhD; 5 students; with 1 (Rabin Banerjee) co-teacher
3. Spring semester; Advanced Quantum Field Theory (PHY 407); Integrated PhD; 9 students

## Publications

**a) In journals**


1. Neeraj Kumar and **Sunandan Gangopadhyay**, *Phase transitions in D-dimensional Gauss-Bonnet-Born-Infeld AdS black holes*, General Relativity and Gravitation, 53, 35, 2021
2. Anish Das, Ashis Saha and **Sunandan Gangopadhyay**, *Investigation of circular geodesics in a rotating charged black hole in the presence of perfect fluid dark matter*, Classical and Quantum Gravity, 38, 065015, 2021
3. Manjari Dutta, Shreemoyee Ganguly and **Sunandan Gangopadhyay**, *Exact Solutions of a Damped Harmonic Oscillator in a Time Dependent Noncommutative Space*, International Journal of Theoretical Physics, 59, 3852 – 3875, 2020
4. **Sunandan Gangopadhyay**, Dharmesh Jain, and Ashis Saha, *Universal pieces of holographic entanglement entropy and holographic subregion complexity*, Physical Review D, 102, 046002, 2020
5. Sukanta Bhattacharyya, **Sunandan Gangopadhyay** and Anirban Saha, *Generalized uncertainty*

*principle in resonant detectors of gravitational waves*, Classical and Quantum Gravity, 37, 195006, 2020

6. Ashis Saha, **Sunandan Gangopadhyay**, and Jyoti Prasad Saha, *Generalized entanglement temperature and entanglement Smarr relation*, Physical Review D, 102, 086010, 2020

7. Sourav Karar and **Sunandan Gangopadhyay**, *Holographic information theoretic quantities for Lifshitz black hole*, The European Physical Journal C, 80, 515, 2020

## Talks / Seminars Delivered in reputed conference / institutions

1. Talk delivered in Inter University Centre for Astronomy And Astrophysics (IUCAA), Pune on "Information theoretic quantities from gauge/gravity correspondence"; Jul 15, 2020; Online; 1 hour

2. Talk delivered in DAEHEP 2020, National Institute of Science Education and Research, Odisha; Dec 15, 2020; Online; 20 minutes

## Administrative duties

1. Member of various interview committees

## Scientific collaborations with other national / international institutions (based on joint publications)

1. Jyoti Prasad Saha, Physics department, Kalyani University; Sl. No. 6; International

2. Ashis Saha, Physics department, Kalyani University; Sl. No. 2, 4, 6; International

3. Anirban Saha, Physics department, West Bengal State University; Sl. No. 5; International

4. Sukanta Bhattacharyya, Physics department, West Bengal State University; Sl. No. 5; International

## Outreach program organized / participated

1. Talk given in University of Engineering and Management on Quantum Physics in 2020

## Areas of Research

Gauge/gravity duality, black hole shadow, renormalisation group approach to quantum gravity, quantum gravity phenomenology

I have been working with my Ph.D. students in research areas which include applications of gauge/gravity correspondence in quantum information and condensed matter physics, cosmology, minimal length theories such as non commutative quantum mechanics and the generalised uncertainty principle, black hole thermodynamics and quantum optics.

In the area of gauge/gravity duality and its connection with information theoretic quantities, I have observed that in the presence of excitation, a thermodynamic Smarr like relation corresponding to a generalized entanglement temperature can be holographically obtained for the entanglement entropy of a subsystem. We demonstrate this for three spacetime geometries, namely, a background with a nonconformal factor, a hyperscaling violating geometry background, and a charged black hole background which corresponds to a field theory with a finite chemical potential. This work got published in Phys.Rev.D 102 (2020) 8, 086010.

I have also investigated the holographic entanglement entropy for a linear subsystem in a 3 + 1-dimensional Lifshitz black hole. The entanglement entropy has been analysed in both the infra-red and ultra-violet limits, and has also been computed in the near horizon approximation. The notion of a generalized temperature in terms of the renormalized entanglement entropy has been introduced. This once again leads to a generalized thermodynamics like law $E = T_g S_{REE}$. We have then computed the holographic subregion complexity. Then the Fisher information metric and the fidelity susceptibility for the same linear subsystem have also been computed using the bulk dual prescriptions. It has been observed that the two metrics are not related to each other. This work got published in Eur.Phys.J.C 80 (2020) 515.

I have then proposed that the definition of holographic subregion complexity (HSC) needs a slight modification for supergravity solutions with warped anti-de Sitter (AdS) factors. Such warp factors can arise due to the nontrivial dilaton profile, for example, in $AdS_6$ solutions of type IIA supergravity. This modified definition ensures that the universal piece of the HSC is proportional to that of the holographic entanglement entropy, as is the case for supergravity solutions without warp factors. This also means that the leading behaviour at large N is the same for both these quantities, as we show for some well-known supergravity solutions (with and without warp factors) in various dimensions. We also show that this relation between the universal pieces suggests "universal" relations between field theoretical analogue of HSC and the sphere partition function or Weyl a-anomaly in odd or even dimensions, respectively.

I have obtained a charged black hole solution in the presence of perfect fluid dark matter (PFDM) and discuss its energy conditions. The metric corresponding to the rotating avatar of this black hole solution is obtained by incorporating the Newman-Janis algorithm. We then compute two types of circular geodesics, namely, the null geodesics and time-like geodesics for this rotating space time geometry. For the case of time-like geodesics, we consider both neutral as well as charged massive particles. The effective potentials of the corresponding circular geodesics has also been studied. We then present our results by graphically representing the collective effects of the black hole parameters, namely, the charge of the black hole (Q), spin parameter (a) and the PFDM parameter ( ) on the energy (E), angular momentum (L) and effective potential ($V_{eff}$) of the concerned particle. Finally, we discuss the Penrose process in order to study the negative energy particles having possible existence within the ergosphere, and which in turn leads to the energy gain of the emitted particle. This work got published in Classical and Quantum Gravity 38 (2021) 065015.

I have then studied FLRW cosmology, taking into account quantum gravitational corrections in the formalism of the exact renormalization group flow of the effective action for gravity. We calculate the quantum corrected scale factor, energy density, and entropy production at late times, taking different cut-off functions. Our approach differs from previous ones in the way energy-momentum conservation is imposed - we include the running Newton constant G(k) in the definition of energy-momentum tensor, keeping in mind the covariant conservation identity of the Einstein tensor. The quantum corrections obtained in this approach are different from what are found by letting the conservation equation remain the same as for a scale-independent Newton constant. We also find that for a specific choice of the cut-off scale, the quantum corrected behaviour of the Newton constant and the cosmological constant lead to a bouncing emergent universe solution. This work is under communication.

In the area of black hole thermodynamics, I have investigated the phase transition in black holes when Gauss-Bonnet corrections to the spacetime curvature and Born-Infeld extension in stress-energy tensor of electromagnetic field are considered in a negative cosmological constant background. It is evident that the black hole undergoes a phase transition as the specific heat capacity at constant potential shows discontinuities. Further, the computation of the free energy of the black hole, the Ehrenfest scheme and the Ruppeiner state space geometry analysis are carried out to establish the second order nature of this phase transition. The effect of non-linearity arising from Born-Infeld electrodynamics is also evident from our analysis. Our investigations are done in general D-spacetime dimensions with $D > 4$, and specific computations have been carried out in $D = 5, 6, 7$ space time dimensions. This work got published in General Relativity and Gravitation 53 (2021) 35.

In the area of non commutative quantum mechanics, I have obtained the exact eigenstates of a two dimensional damped harmonic oscillator in time dependent noncommutative space. It has been observed that for some specific choices of the damping factor and the time dependent frequency of the oscillator, there exists interesting solutions of the time dependent noncommutative parameters following from the solutions of the Ermakov-Pinney equation. Further, these solutions enable us to get exact analytic forms for the phase which relates the eigenstates of the Hamiltonian with the eigenstates of the Lewis invariant. We then obtain expressions for the matrix elements of the coordinate operators raised to a finite arbitrary power. From these general results we then compute the expectation value of the Hamiltonian. The expectation values of the energy are found to vary with time for different solutions of the Ermakov-Pinney equation corresponding to different choices of the damping factor and the time dependent frequency of the oscillator. This work got published in International Journal of Theoretical Physics 59 (2020) 3852.

With the direct detection of gravitational waves by advanced LIGO detector, a new "window" to quantum gravity phenomenology has been opened. At present, these detectors achieve the sensitivity to detect the length variation ( L), O $10^{-17} - 10^{-21}$ meter. Recently a more stringent upperbound on the dimensionless parameter $_0$, bearing the effect of generalized uncertainty principle has been given which corresponds to the intermediate length scale $\ell_{im} = {}_0\ell_{pl} \sim 10^{-23}$m. Hence the flavour of the generalized uncertainty principle can be realised by observing the response of the vibrations of phonon modes in such resonant detectors in the near future. In this paper, therefore, we calculate the resonant frequencies and transition rates induced by the incoming gravitational waves on these detectors in the generalized uncertainty principle framework. It is observed that the effects of the generalized uncertainty principle bears its signature in both the time independent and dependent part of the gravitational wave-harmonic oscillator Hamiltonian. We also make an upper bound estimate of the GUP parameter. This work got published in Classical and Quantum Gravity 37 (2020) 195006.

## Plan of Future Work Including Project

1. The work that I plan to carry out in the future would be focussed in the following directions: I would like to investigate various information theoretic quantities from gauge/gravity correspondence. In particular I would like to calculate the entanglement entropy and complexity of field theoretical systems and try to see whether they agree with the holographic dual computations. I would also like to investigate the standard model of cosmology using the renormalisation group approach to quantum gravity. I also intend to find out a connection between time dependent harmonic oscillators and geometric phases in quantum mechanics.

## Any other Relevant Information including social impact of research

1. The societal impact of the research carried out by me would be to train Ph.D. students in Theoretical Physics. This would help in forming a solid foundation of our country's think tank who would be prepared to develop innovative ideas that would help in the development of science and technology. Fundamental research is always important since it is the only way by which future technology can be invented and implemented for the betterment of mankind. I feel the kind of research that I pursue would definitely make way for modern technology in future.