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Book of Abstracts

Contents

Classical & Quantum Gravity / 8

Velocity dispersion of dark matter deficit ultra-diffuse galaxies: A case for modified gravity

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The line of sight velocity dispersion of the ultra-diffuse galaxies (UDGs) NGC1052-DF2 and NGC1052-DF4 have been reasonably explained only with the baryonic matter, without requiring any dark matter contribution.
The comparable ratio between the baryonic and halo mass also ascertain the above claim for the two dark matter deficit galaxies. This paves the way for analyzing alternative gravity theories such as the $f(R)$ gravity and the Renormalization Group correction to General Relativity (RGGR). The analysis of the line of sight velocity dispersion shows that the choice of $f(R)$ gravity models such as Taylor expanded $f(R)$ about $R = 0$ or a simple power law model of choice R^n is consistent with the observational data. Similar statistical analysis is done for the RGGR and is also found to be a viable explanation for the observed velocity dispersion. We perform a global fit of the model parameters together with both the UDGs. The coupling parameters of the theories are considered as the global ones, and local variables such as the scale parameters are considered to be dependent on the individual galaxy.

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Astrophysical Relativity / 10

The light bending phenomenon for a pulsar-black hole binary

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We devise a full general relativistic formalism to study the delays caused by the light bending effect in the signal of a radio pulsar in a binary. This delay is non negligible for neutron star - neutron star binaries and even stronger for neutron star - black hole binaries. We calculate bending delays for hypothetical neutron star - black hole binaries. The values of the bending delays obtained in our method match with the values obtained by an approximate method already known. However, the old method is valid only when the pulsar is at the superior conjunction and our method is valid for any configuration. Moreover, our formalism results in some additional features like a discontinuity in the delay curve near the superior conjunction, etc. We also show that the bending distorts the intensity distribution across the beam and as a result changes the shape of the pulse profile.

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Cosmology / 11

Extremely magnified stars in cluster lenses

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The first serendipitous detection of a highly magnified star in a spiral galaxy (z=1.49) lensed by a galaxy cluster, MACS1149 (z=0.54), has opened a new window to observe stars at cosmological distances. Since then, several other lensed stars have been detected in HST imaging of various galaxy clusters, and nearly all galaxy clusters observed by JWST revealed lensed stars candidates. Observing highly magnified stars at cosmological distances is a combined result of strong- and micro-lensing effects. The presence of point-like masses (such as stellar-mass objects) in the lens leads to the formation of micro-critical curves and micro-caustics in the lens and source planes, respectively. Whenever a star in a strongly lensed galaxy crosses a micro-caustic, it gets highly magnified, which might make it observable briefly as a transient source. In my presentation, I will discuss the basic idea behind detecting highly magnified stars in cluster lenses. I will also discuss our recent detection of lensed star candidates at z=4.8 in the MACS0647 galaxy cluster. The number of such lensed stars is expected to increase continuously, assisting us in probing the first stars and understanding the compact dark matter fraction in the intracluster medium.

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Cosmology / 12

Galaxy-dark matter connection of photometric galaxies from the HSC-SSP Survey using weak lensing

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In the paradigm of hierarchical structure formation, galaxies are thought to form and evolve inside a potential well environment of 'collisionless' and 'only gravitationally interacting' form of matter; the dark matter halos. These dark halos have formed at the peaks of initial density fluctuations due to gravitational instability and as observations have revealed, are the sites of most of the galaxy formation and evolution. Quantifying the presence of these dark structures of halos by using available galaxy surveys itself is an important and challenging task. This information can then be used to find out the connection between the galaxy and its host halo properties. Our current understanding of

the structure formation and evolution is driven by simulations. At large scales the full hydrodynamic simulations are not feasible due to computational cost. However using empirically derived galaxy-halo connections, semi-analytical models of structure formation can constrain the effectiveness of physical processes as a function of redshift and bypass the need of full simulation from scratch. In our work, we estimate the masses of dark matter halos which host the photometric galaxies from HSC survey (the lens galaxies) by using the 'weak gravitational lensing' phenomenon. Weak lensing being purely gravitational phenomena, directly and fully probes the total matter content responsible for lensing of the background source galaxies. We infer the 'halo mass - stellar mass' relation and its evolution as a function of redshift within 0.3-0.8 and stellar masses. This work also demonstrates the potential of wide photometric surveys like HSC survey, for putting observational constraints on galaxy-halo connection via statistical studies like weak lensing.

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Classical & Quantum Gravity / 13

Analytic three-dimensional hairy charged black holes and thermodynamics

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We present and discuss new families of hairy-charged black hole solutions in asymptotically anti{de Sitter space in three dimensions. The coupled Einstein-Maxwell-scalar gravity system, that carries the coupling $f(\phi)$ between the scalar and Maxwell fields are solved, and exact hairy black hole solutions are obtained analytically. The hairy solutions are obtained for three different profiles of the coupling function: (i) $f(\phi) = 1$, corresponding to no direct coupling between the scalar and Maxwell fields, (ii) $f(\phi) = e^{\phi}$, and (iii)$f(\phi) = e^{-\frac{\phi^2}{2}}$; corresponding to non-minimal coupling between them. For all these couplings the scalar field and curvature scalars are regular everywhere outside the horizon. We analyze the thermodynamics of the hairy black hole and find drastic changes in its thermodynamic structure due to the scalar field. For $f(\phi) = 1$, there exists a critical value of the hairy parameter above which the charged hairy black hole exhibits the Hawking/Page phase transition, whereas no such phase transition occurs below this critical value. Similarly, for $f(\phi) = e^{\phi}$ and $f(\phi) = e^{\frac{\phi^2}{2}}$, the hairy solution exhibits a small/large black hole phase transition for above critical values of the hairy parameter. Interestingly, for these couplings, the thermodynamic phase diagram of three-dimensional hairy charged black holes resembles that of a higher-dimensional RN-AdS black hole, albeit with two second-order critical points.

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Cosmology / 14

Primordial black hole dark matter abundance constraints using

lensing parallax of GRBs

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Primordial black holes, which could have formed during the early Universe through overdensities in primordial density fluctuations during inflation, are potential candidates for dark matter. We explore the use of lensing parallax of Gamma ray bursts, which results in different fluxes being observed from two different vantage points, in order to probe the abundance of primordial black holes in the unexplored window within the mass range $[10^{-15} - 10^{-11}]M_{\odot}$. We derive the optical depth for the detectability of lensing of GRBs with a distribution of source properties and realistic detector sensitivities. We comment on the ability of the proposed Indian twin satellite mission Daksha in its low earth orbit to conduct this experiment. If the two Daksha satellites observe 10000 GRBs simultaneously and the entirety of dark matter is made up of $[10^{-15} - 10^{-12}]M_{\odot}$ black holes, Daksha will detect non-zero lensing events with a probability ranging from [80, 50] per cent. Non-detections will not conclusively rule out primordial black holes as dark matter in this mass range. However, we show that meaningful constraints can be obtained in such a case if the two satellites are separated by at least the Earth-Moon distance.

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Classical & Quantum Gravity / 15

Testing f(R) Scalaron gravity near the Galactic Center black hole

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The presence of compact stellar orbits near the Galactic Center (GC) black hole presents a magnificent opportunity for testing modified theories of gravity as the gravitational potential (GM/c^2r) is equal to or more than 100 times the one encountered in the solar system. In this work, we study the effect of f(R) gravity near the GC black hole using both model dependent and independent approaches. In the model dependent approach, we choose a cosmologically motivated model, $f(R) \propto R^2$ and study the deviation in orbital pericentre shift from GR for both zero and non-zero spin of the black hole and with semi-major axis equal to or below a=1000 au (S0-2 like orbits). It is seen that f(R) gravity effects become prominent near compact orbits. In the model independent approach to f(R) gravity, the bounds on generic scalaron fields ($\psi = f'(R)$) and coupling constant (α) are extracted from the current bounds on Parametrised Post Newtonian (PPN) parameters (γ, β) near the GC black hole . Using the same bounds, the screening of f(R) gravity is further investigated. It has been observed that the lighter mass scalarons ($10^{-22}\ eV$) and intermediate mass scalarons ($10^{-19}\ eV$) remain unscreened near S0-2 like orbits (a \sim 1000 au) as well as near the orbit of newly detected short period star S4716 (a \approx 407 au). But the heavier mass scalarons ($10^{-16}\ eV$) tend to remain completely screened near these orbits. Testability of the f (R) gravity effects using astrometric capabilities of

current and upcoming Extremely Large Telescopes (ELTs) is also highlighted. A new rotating metric with scalaron is obtained using Newman Janis Algorithm from a previously proposed Schwarzschild metric with scalarons (Kalita 2018). The effective potential is developed for this scalaron Kerr metric. Prospects for testing gravity through pericentre shift in this model will also be highlighted.

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Cosmology / **16**

Using Big Bang Nucleosynthesis to constrain f(R) gravity scalarons and primordial black hole masses

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Big Bang Nucleosynthesis (BBN) is a strong probe for testing new physics of the early universe. Introducing modified gravity in the very early universe gives rise to some interesting effects. In this work, the effects of $f(R)$ gravity scalarons introduced in *Kalita (2018, 2020, 2021)* on the BBN era is investigated. Observed BBN constraints on the shift of freezeout temperature and elemental abundance of He^4 have been employed to give constraint on scalaron mass range and hence constraint on the primordial black hole (PBH) masses that is expected to contribute to non-baryonic dark matter. It has been found that for the range of PBH mass $(10^{-15} - 10^{6})\ M_{\odot}$, the observed BBN bound is satisfied. The associated scalaron mass range is $(10^{5} - 10^{-16})$ eV. The effects of $f(R)$ scalarons on neutron fraction and deuterium abundance has also been studied. It has been found that there is no appreciable change in neutron fraction value from the General Relativistic (GR) scenario and therefore the scalarons are found not to spoil the BBN era.

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Astrophysical Relativity / **17**

Indirect estimation of distance of a star from apparent magnitude.

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Space observatory Gaia has prepared a large catalog of 1 billion astronomical objects which consists primarily of stars but also planets, comets, asteroids and quasars among others whose parallaxes are measured instead of distances (r). Bailer-Jones (\citet{Bailer-Jones}) established that distance estimation from parallaxes is not trivial once the fractional parallax error is larger than about 20\%, which will be the case for about 80\% of stars in the Gaia catalog. In the present model the distance estimates are developed through a Bayesian model using apparent magnitudes which are distant dependent intrinsic properties of stars. The proposed model is based on apparent magnitude limited distribution (viz. $\phi(m)$) constructed with the combination of the probability density function (pdf) of an absolute magnitude limited distribution $\Phi(M)$ along with a prior. The former one is constructed from real data set of Gaia Catalogue of apparent magnitudes, corrected for extinction and parallaxes of a huge number of stars. The posterior distribution of the estimated distances thus found has variances and bias under control even for a lager fractional error (viz. more than 80 \% compared to the previous work) and hence for a larger distance.

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Astrophysical Relativity / **18**

Theoretical model of compact stars: Vanishing complexity approach

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Compact stars are unique laboratory for studying and testing extreme conditions in terms of density and gravity. In this paper under the framework of General Relativity we have developed a theoretical model representing compact stellar objects. For this we follow the Herrera's vanishing complexity condition in addition of assuming a particular geometry corresponding to g_rr component. All the conditions required for a physically acceptable compact sources have been tested. The developed model has been verified with the current estimated data from some observed pulsars.

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Cosmology / **19**

H_0 Tension in Torsion-based Modified Gravity

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The rising concern in the Hubble constant tension (H_0 tension) of the cosmological models motivates the scientific community to search for alternative cosmological scenarios that could resolve the H_0 tension. In this regard, we aim to work on a torsion-based modified theory of gravity which is an alternative description to the coherence model. We solve numerically for the Hubble parameter using two exponential Lagrangian functions of torsion T and a trace of energy-momentum tensor $\mathcal{T}$ for the dust case. Further, we constrain the cosmological and model parameters; to do that, we use Hubble, SNe Ia, Baryon Acoustic Oscillations, Cosmic Microwave Background samples, and Markov Chain Monte Carlo (MCMC) simulation through Bayesian statistics. We obtain the values of Hubble constant H_0 for our model, and the outputs align with the recent observational measurements of H_0. In addition, we check the deviation of our results from model-independent measurements of H_0 from Planck2018, SH_0ES, and H_0LiCOW experiments. In contrast, our finding partially solved the H_0 tension but gave a new possible direction to alleviate the H_0 tension.

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Cosmology / **20**

Emergence of cosmic space with Barrow entropy, a non-equilibrium thermodynamic description.

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Recently, a novel modification in the conventional area-entropy relation has been introduced by Barrow, as $S = (A/A_0)^{1+\Delta/2}$, by taking account of the quantum gravitational deformation effects on the black hole's surface. Recent literature has adopted this horizon entropy to the cosmological domain, leading to significant insights. In this line of thought, we formulated the law of emergence, which elucidates the dynamics of the universe having Barrow entropy for the horizon in the context of equilibrium thermodynamics. However, when considering Barrow entropy (a non-Bekenstein entropy), an additional entropy generation arises owing to the non-equilibrium thermodynamics. The corresponding field equation bears an effective coupling strength, which connects the geometry with an effective energy-momentum tensor. On accounting this, the law of emergence in non-equilibrium description has been formulated. In addition, the consistency of the derived laws has been checked in the context of entropy maximization. Interestingly, it is found that the non-equilibrium entropy generation rate decreases gradually, and the universe evolves to an equilibrium state of maximum entropy corresponding to the de Sitter epoch.

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Cosmology / **21**

Distinguishing cosmological models through quantum signatures of primordial perturbations

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In this talk, I discuss the evolution of various measures of quantumness of the curvature perturbation by integrating out the inaccessible entropic fluctuations in the multi-field models of inflation. In particular, I discuss the following measures of quantumness, namely purity, entanglement entropy and quantum discord. The models being considered in this talk are ones that produce large scale curvature power spectra similar to those produced by single-field models of inflation. More specifically, I consider different multi-field models which generate nearly scale invariant and oscillatory curvature power spectrum and compare their quantum signatures in the perturbations with the corresponding single-field models. I will show that, even though different models of inflation may produce the same observable power spectrum on large scales, they have distinct quantum signatures arising from the perturbation modes. This may allow for a way to distinguish between different models of inflation based on their quantum signatures.

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Gravitational Waves / 22

Gravitational waves from pulsars to understand generation mechanism of fast radio bursts

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This abstract is primarily based on my recent paper MNRAS 520 (2023) 3742. Since the discovery of fast radio bursts (FRBs), researchers have proposed several theories and models to explain their characteristics. One of the most recent models takes into account the Gertsenshtein-Zel'dovich (GZ) phenomenon, which suggests that a portion of gravitational radiation is converted into electromagnetic (EM) radiation when gravitational waves pass through a pulsar magnetosphere. This model can explain both repeating and non-repeating FRBs, and the pulsar's characteristics remain unchanged over time. My talk focuses on the gravitational radiation produced by the pulsar mechanism and how proposed gravitational wave detectors can detect these waves. If these detectors detect any continuous GW signal from the site of FRBs, it will provide significant support for the GZ theory and disprove the merger-like theories.

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Classical & Quantum Gravity / 23

Spontaneous Symmetry Breaking in Rindler frame and AdS space

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The phenomenon of spontaneous symmetry breaking (SSB) is one of the cornerstone paradigms of modern physics. In this work, we address fundamental questions related to the role of observers and curvature in phase transitions associated with SSB. Our study involves scalar field theory with $\lambda\phi^4$ interaction and the linear sigma model (LSM) at leading order in $1/N$. Employing these models, we explore two distinct scenarios with different symmetry groups and perturbation approaches. The scalar field theory with $\lambda\phi^4$ interactions involves a discrete Z_2 symmetry and perturbation in small λ. At the same time, the LSM features a continuous N-dimensional rotation group $O(N)$ and perturbation in $1/N$, which includes a more non-linear structure. By general covariance, it is clear that a set of inertial observers would perceive the mechanism of SSB as universal. However, the situation is not so straightforward when we consider this phenomenon from the perspective of a uniformly accelerating observer. We demonstrate that the spontaneously broken symmetries can be restored from the viewpoint of an accelerating observer but only above a certain critical value of acceleration, thereby establishing that SSB is indeed an observer-dependent phenomenon. In the analysis, we introduce proper renormalization methods for calculating the one-loop effective potential in the Rinlder frame in arbitrary dimensions. Also, our findings support the ontic nature of the Unruh effect.

To study the role of curvature, we focus on SSB in the Anti–de Sitter (AdS) space using LSM in the large N limit. We calculate a closed-form expression for the renormalized one-loop effective potential in various dimensions. In four-dimensional AdS space, the vacuum state of the theory is degenerate, and one needs to consider the global vacuum for studying SSB. We show that the $O(N)$ symmetry is spontaneously broken in three-dimensional AdS space, and there is no SSB in four-dimensional AdS space for LSM in large N limit. As we have a quantum gravity theory in AdS space (AdS/CFT correspondence), our results may help better understand SSB using AdS/CFT correspondence.

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Cosmology / 24

Cosmological events on the stochastic background of inflationary gravitational waves

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The effects of the cosmological phase transitions in the evolution of inflationary gravitational waves are reconsidered and normalized with the data from the late 2021 BICEP/Keck and Planck (BKP) joint data using a quite simple and easily executable method which can be easily modified to include the effects of cosmological events. The resulting energy density spectrum is obtained for the α-attractor models of inflation and the final spectrum is compared with the power-law integrated sensitivity curves of several upcoming detectors to test the potential detectability of the inflationary gravitational waves.

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Cosmology / 25

Non-Commutative to Commutative Geometry Transformation and Origin of Cosmic Scale Viscosity

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In this work we have discussed the origin of cosmic viscosity with the in of deformed cosmic phase space geometry. We have introduced the Non-Commutative(NC) deformed geometry and shown that the transformation from non-Riemannian geometry to Riemannian geometry (From Non-Commutative to Commutative(C) geometry) can provide the dissipation in cosmology. A single scalar field in deformed Non-Commutative cosmology can be dissociated into two scalar field models due to the transformation from NC-geometry to C-geometry. This dissociation mainly provides the radiation field with an interior viscosity-dependent interaction. Finally, we have provided the nature of phase space and their decomposition during the phase transition from single-field NC-geometry to Multi-field C-geometry.

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Cosmology / 28

Representations of New Phase Space and their Evolution in Different Inflationary Era

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We have proposed a new phase space coordinate system for scalar field theory that can provide a detailed analysis of the cosmological evolutionary phases in a more generalized manner. We have studied \textcolor{red}{(how many)} intermediate states of cosmic inflations. We have discussed fixed point analysis for these phases. The new phase space dynamics discussed here provide a new family of curves to discuss the cosmic phases as well as cosmic dynamics. We have analysed dynamical trajectories for our expanding universe model. This trajectories can help us to study the dynamics of entire universe phases. Finally, the Equation of state parameter (scalar field) and second law of thermodynamics with entropy based energy conditions have been discussed with these phase space coordinates.

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Classical & Quantum Gravity / 29

Boundary terms and Brown-York quasi-local parameters for scalar-tensor theory

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Boundary term and Brown-York (BY) formalism, which is based on the Hamilton-Jacobi principle, are complimentary of each other as the gravitational actions are not, usually, well-posed. In scalar-tensor theory, which is an important alternative to GR, it has been shown that this complementarity becomes even more crucial in establishing the equivalence of the BY quasi-local parameters in the two frames which are conformally connected. Furthermore, Brown-York tensor and the corresponding quasi-local parameters are important from two important yet different aspects of gravitational theories: black hole thermodynamics and fluid-gravity correspondence. The investigation suggests that while the two frames are equivalent from the thermodynamic viewpoints, they are not equivalent from the perspective of fluid-gravity analogy or the membrane paradigm. In addition, the null boundary term and null Brown-York formalism are the recent developments (so far obtained only for GR) which is non-trivial owing to the degeneracy of the null surface. In the present analysis these are extended for scalar-tensor theory. The present analysis also suggests that, regarding the equivalence (or inequivalence) of the two frame, the null formalism draws the same inferences as of the timelike case, which in turn establishes the consistency of the newly developed null Brown-York formalism.

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Classical & Quantum Gravity / 30

Collapsing scenarios in K-essence emergent generalized Vaidya spacetime through $f(\bar{R}, \bar{T})$ gravity

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The primary objective of this research is to examine the potential for collapse in the generalized emergent Vaidya spacetime, utilizing the theoretical framework of $f(\bar{R}, \bar{T})$ gravity, with a special emphasis on the K-essence theory. In this study, the non-standard Lagrangian of the Dirac-Born-Infeld type is employed to ascertain the emergent metric denoted as $\bar{G}_{\mu\nu}$. It is important to note that this metric does not exhibit conformal equivalence to the conventional gravitational metric. In this study, we utilize the function $f(\bar{R}, \bar{T})$ to denote the additive nature of the emergent Ricci scalar ($\bar{R}$) and trace of the emergent energy-momentum tensor ($\bar{T}$). Based on our study, it is possible to ascertain that specific choices of $f(\bar{R}, \bar{T})$ have the potential to give rise to the existence of a naked singularity as a consequence of gravitational collapse. Furthermore, different selections of the function $f(\bar{R}, \bar{T})$ have been found to result in an expanding cosmos that is predominantly influenced by dark energy. In addition, the investigation showed the presence of both positive and negative masses, which may be comprehended as a gravitational dipole. Additionally, it has been shown that the K-essence theory possesses the capacity to serve as a framework for dark energy as well as a straightforward gravitational theory, hence enabling the exploration of other cosmological phenomena.

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Cosmology / 32

Hubble tension in the light of eLISA/ET: A Three-Pronged Approach with Fisher, MCMC and ML

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Cosmology today, although precise, is perhaps not accurate. The so-called tensions in the standard ΛCDM model have been cited as a crisis in the field. With no clear evidence of systematical errors, nor a foolproof alternative theory as of now, the crisis is often attributed to the insufficiency of data at hand, that calls for future missions. In this presentation, I would investigate the prospects of the future space-based gravitational wave mission eLISA, set to probe the "intermediate" redshifts, in addressing the Hubble tension. I'll demonstrate a three-pronged approach - namely using Fisher matrices (the standard forecasting tool in cosmology), Markov chain Monte Carlo (MCMC) algorithms (the conventional parameter estimation scheme), and a machine learning algorithm like Gaussian processes (for non-parametric reconstruction), to help shed light on this disparity. By considering a few representative cosmological models as fiducials, some of which show promise at varied levels in alleviating the Hubble tension when confronted with current datasets (CMB+BAO+SNIa), we construct realistic mock-catalogs of bright standard siren events. Using these catalogs, I'll then demonstrate the inference of the Hubble constant independently from the three techniques. Finally, a comparative analysis among the methods, as well as the models, would be presented.

This would be based mostly on the work published in JCAP06(2023)038/arXiv:2301.12708.

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Classical & Quantum Gravity / 33

Unified Insights in Gravity Theories: Asymptotic Symmetries and Celestial Holography

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The Infrared (IR) triangle, famously portrayed by Strominger, highlights the unity between soft theorems, infinite-dimensional asymptotic symmetries, and Memory Effects within a single framework. In the realm of Gravity, this is known as BMS symmetry, with a corner relating to measurable classical Gravitational Memory Effects. The revolutionary detection of gravitational waves sets the stage for profound insights into Gravitational Wave Astronomy. Memory effect bridges classical observables with quantum phenomena, such as soft theorems and asymptotic symmetries, and is of particular importance.

The study engages quantum gravitational scattering to unveil the fundamental forces operating at lower energies. Employing Celestial Holography, this work explores scattering amplitudes and symmetries of asymptotically flat spacetimes, effectively translating intricate gravitational dynamics in higher dimensions into behaviors in lower dimensions at their boundaries. Here, the boundary in question is a null hypersurface that represents the celestial sphere of the gravitational system. This study delves into the exploration of asymptotic symmetries in gravity and supergravity theories, departing from conventional methods to embrace Celestial Holography. Recent developments have suggested the Operator Product Expansions (OPEs) of relevant celestial amplitudes to ascertain asymptotic symmetries in four-dimensional asymptotically flat pure gravity and $N = 1$ supergravity. Extending this approach, we apply it to four-dimensional Einstein-Yang-Mills and Einstein-Maxwell theories, revealing their asymptotic symmetry algebras 1. This method serves as a consistency validation for known algebras in the existing literature. Along with this, we explored the asymptotic symmetries in the case of maximally supersymmetric $N = 8$ supergravity theory [3], which is new in the literature. Moreover, these insights facilitate a deeper exploration of the Celestial Conformal Field Theory (CCFT) technique and its effective application in unraveling symmetries across diverse theories.

Further investigation employs the Double Copy (DC) formalism in the soft and collinear sectors of Gravitational Scattering amplitudes, yielding significant applications in modern gravitational physics. The DC technique, a multiplicative bilinear operation, finds application in diverse fields like string theory, particle physics, and gravitational physics. We focus on the soft and collinear sectors of both gravity and gauge theory, and the N=8 supergravity to $N = 4$ super Yang-Mills (SYM) duality is explored through the DC relation. Applying this formalism unveils the interplay between the two theories and facilitates calculations in the soft and collinear sectors of $N = 8$ supergravity via known results in $N = 4$ SYM 2.

As our understanding of gravitational wave physics advances, the expansion of our knowledge regarding soft limits, such as classical spins, highlights the remarkable potential of the field. By delving into scattering amplitudes in perturbative quantum gravity, classical interactions of massive objects within gravitational fields are effectively deciphered, guided by the newfound insights in Gravitational Wave Astronomy.

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Gravitational Waves / **34**

Precision Gravity: Gravitational waves using Feynman diagrams

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The observations of gravitational waves (GW) have proved to be a probe for the physics of celestial objects like black holes (BH) and neutron stars (NS). Such detections have the potential to unravel the mysteries of cosmic origins, equations of state of compact objects and will prove to be a test of the theory of general relativity. To successfully achieve these scientific goals, it is crucial to have waveform templates of high precision and accuracy. As the upgrades and the next generation of ground-based and space-based gravitational wave observatories become ever more sensitive, we need even more accurate waveform models to avoid systematics. My talk will focus on computing state-of-the-art effective two-body Hamiltonians for BHs and NSs using the techniques of quantum field theories and scattering amplitudes. These Hamiltonians are building blocks for waveform templates and they dictate the precision of the waveform model.

In the inspiral phase, the effective field theory techniques are used to obtain the post-Newtonian (PN) expansion i.e. expanding in orders of the small orbital velocity of binary constituents. Here nPN order is usually referred to as (v/c)ˆ(2n) order correction to the Newtonian interaction. The determination of the effective Hamiltonian at a given PN order is equivalent to the computation of corresponding scattering amplitudes. These amplitudes are then calculated using Feynman diagrams, where tree diagrams represent leading contributions and higher-order corrections come from multiple-loop diagrams. Here tree diagrams are rational functions of the kinematic variables and are easy to compute, whereas loop diagrams represent very challenging integrals that necessitate advanced techniques like integration-by-parts identities and differential equations.

In particular, I will focus on analyzing the effects of spin and tidal interaction on the dynamics of compact binary systems. Astrophysical compact objects usually have a non-zero angular momentum and the effects of this "spin" are studied in order of spin interactions. I will describe the computation of linear-in-spin Hamiltonian that describes the interaction between the orbital angular momentum of the binary and the spin of one of its constituents at 4.5PN order 1 and quadratic-in-spin Hamiltonian that describes the coupling between spins of the constituents of the binary at 5PN order 2. Furthermore, I will also describe oscillation modes of NS that arise due to tidal interactions, in particular, the fundamental-mode (f-mode) dynamical tides, which have been argued to be important in inferring the NS equation-of-state in upcoming observing runs of present GW detectors. I will talk about the computation of the effective Hamiltonians up to 3PN order [3,4] for dynamic f-mode tidal interactions. This is particularly interesting since it requires the introduction of counterterms to eliminate divergences, leading to a renormalization group flow of the post-adiabatic Love number.

In summary, my talk describes the computation of a two-body effective Hamiltonian that includes effects of spin and f-mode dynamic tides using effective field theories.

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Classical & Quantum Gravity / 35

Influence of tidal love number in pericenter shift of S-stars near Sgr A*.

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The Galactic Center (GC) hosting a supermassive black hole, Sgr A*is surrounded by a population of S-stars. The orbit of these S-stars is used as a probe for understanding the nature of gravity in such an extreme environment. In dynamic interaction between stars and a supermassive black hole, tidal interaction plays an important role in determining the fate of the interacting system. Thus in this work, we study in detail the tidal love number of polytopic S-stars near Sgr A.* We then used the tidal love number with a multipole expansion l = 2 & l = 3 and estimated their corresponding pericenter shift due to the tidal distortion effect up to a semi-major axis of 500au from the GC. The pericenter shift is estimated for low-mass stars ($0.18 \leq M/M_{\odot} \leq 1.5$) and high-mass stars ($1.6 \leq M/M_{\odot} \leq 30$) for polytopic index, n = 1, 1.5, 2, 2.5, 3, 4, 4.5 and 5. We found that the pericenter shift due to tidal distortion increases with an increase in stellar mass and a decreasing lower polytropic index. The results estimated are independent of general relativity and its alternative theories. However, the above-estimated pericenter shift will provide precise information on tests which use pericenter shift as a probe for testing gravitational theories near Sgr A*. Several factors that can strengthen the estimations for its application to alternative gravitational theories have also been emphasized.

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Cosmology / 36

Inflation in Minimlly Modified Gravity (MMG) theories

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Minimally Modified Gravity (MMG) theories are gravity theories that differ from Einstein's General Relativity (GR) but do not propagate any additional degree of freedom in the gravity sector. Such theories have given rise to a new direction to the study of modified gravity theories and their cosmological implications are being investigated enthusiastically. In my talk, I will briefly outline the results of applying two such MMG models to cosmic inflation. The first one is the so-called $f(\mathcal{H})$ theories, that are constructed by modifying the Hamiltonian, instead of the Lagrangian, of GR. The second one is another class of MMG theories built out of Spatially Covariant Gravity (SCG) lagrangians, which can be thought of as scalar-tensor theories of gravity written in the unitary gauge.

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Cosmology / **37**

Fast radio bursts as a probe to constrain primordial mass black holes made of dark matter

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This abstract is primarily based on our recent work arXiv:2308.16604. Fast Radio Bursts (FRBs) can be used as a tool to understand different cosmological phenomena because of their distinct features, such as short pulse width, relatively high dispersion measure, etc. On the other hand, over the past decades, researchers have proposed different modified gravity models. In my talk, considering a generic modified gravity theory, I will show how it affects the properties of gravitational lensing in FRBs. Thereby, using a set of FRBs from the recent CHIME dataset, I will discuss how it can constrain the fraction of dark matter made up of primordial black holes in such a theory. I will further show that modified gravity adds a screening effect on gravitational lensing similar to the case when there is plasma in the path of the light ray acting as a scattering screen.

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Cosmology / **38**

Signature flip in deceleration parameter: A thermodynamic phase transition?

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Under the assumption of thermal equilibrium between the horizon and the fluid inside, we conducted a thermodynamic stability analysis on a model designed to mimic the characteristics of the ΛCDM model, which is the prevailing framework for portraying the cosmic acceleration. The scale factor for this model is defined as $a \sim \sinh^{2/3}(t/t_0)$. The Hayward-Kodama temperature is opted for the evolving apparent horizon. The outcome of this analysis yielded a remarkable finding: the thermal capacity exhibited a negative value and a lack of thermodynamic stability within the cosmic matter enclosed by the horizon.

The significance of this study lies in the result indicating that the matter content experiences a phase transition precisely at the value of z where the Universe undergoes a transition from decelerated expansion to an accelerated one. Notably, this phase transition manifests characteristics akin to those of a second-order phase transition, as indicated by the discontinuity in heat capacity at constant volume (C_V). The deceleration parameter (q) serves as the order parameter and solidifies this correlation.

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Astrophysical Relativity / 39

White dwarfs in Gaia survey to constrain the fine-structure constant

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This abstract is primarily based on ApJ 949 (2023) 62. Understanding various physical mechanisms requires an understanding of fundamental constants, however, measurements of these constants are subject to error due to experimental constraints. Researchers have proposed several bounds on fundamental constants based on a variety of experiments and observations. These constraints are different primarily because of the energy scale of the systems used in the studies. We investigate the impact of system temperature and the effect of the underlying theory of gravity on these uncertainties using white dwarfs observed in the Gaia data survey. In my talk, using the structures of these white dwarfs, I will show that variations in temperature as well as the underlying theory of gravity can affect the accuracy of measurements for fundamental constants such as the fine-structure constant and the proton-to-electron mass ratio. This exploration emphasizes the importance of considering the energy of a system when putting bounds on fundamental parameters.

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Classical & Quantum Gravity / 41

A holographic study of the characteristics of chaos and correlation in the presence of backreaction

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We perform a holographic study to estimate the effect of backreaction on the correlation between two subsystems forming the thermofield double (TFD) state. Each of these subsystems is described as a strongly coupled large-Nc thermal field theory, and the backreaction imparted to it is sourced by the presence of a uniform distribution of heavy static quarks. The TFD state we consider here holographically corresponds to an entangled state of two AdS blackholes, each of which is deformed by a uniform distribution of static strings. In order to make a holographic estimation of correlation between two entangled boundary field theories in presence of backreaction we compute the holographic mutual information in the backreacted eternal blackhole. The late time exponential growth of an early perturbation is a signature of chaos in the boundary thermal field theory. Using the shock wave analysis in the dual bulk theory, we characterize this chaotic behaviour by computing the holographic butterfly velocity. We find that there is a reduction in the butterfly velocity due to a correction term that depends on the backreaction parameter. The late time exponential growth of an early perturbation destroys the two-sided correlation, whereas the backreaction always acts in favour of it. Finally we compute the entanglement velocity that essentially encodes the rate of disruption of correlation between two boundary theories.

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Astrophysical Relativity / 42

Accreting Millisecond X-ray Pulsars: Probing Strong Field Gravity

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X-ray binaries, the most luminous galactic objects, harbor the universe's fascinating Neutron Stars (NSs) and Black Holes (BHs). In particular, low-mass X-ray binaries (LMXBs), in which matter from a solar-like companion star falls towards the compact object via an accretion disc, represent excellent laboratories to investigate the motion of matter orbiting nearby these extreme objects. In some NSs, X-ray pulsations of the order of millisecond have been detected. They belong to peculiar X-ray

pulsars called accretion-powered millisecond X-ray pulsars (AMXPs). In this talk, I will present our recent results from the pilot survey of Accreting Millisecond X-ray pulsars (AMXPs) with AstroSat and the discovery of a new intermittent AMXP, XTE J1739-285, a valuable addition to this class of objects.

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Astrophysical Relativity / 43

Spectral and timing properties of GX 17+2 using AstroSat and NICER simultaneous view

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We report the analysis of the Z-track neutron star (NS) low-mass X-ray binary (LMXB) GX 17+2 using the simultaneous data from the AstroSat (LAXPC/SXT) and NICER mission data. On segmenting the hardness intensity diagram (HID) into three slices—horizontal branch (HB), hard apex (HA), and normal branch (NB)- we investigate the variability of the source and its spectral state evolution throughout the observation. We performed broadband X-ray spectroscopy in a wide energy range utilizing the soft X-ray observation of NICER & SXT/AstroSat and the hard X-ray observation of LAXPC/AstroSat. The source is found to be in a soft state with a photon index > 2 and tends to be in a softer state along the branches. We performed the timing analysis in all the branches separately to probe the presence of aperiodic variability. We determined the photon lag behavior, which is found to follow a hard lag trend. The fractional root mean square variability shows a decreasing variability trend along the branches from HB to NB via HA. We also represent the variation of the spectral parameters like the coronal temperature, photon index, blackbody temperature, and other obtained parameters along the track. Then, we compare the results of the two missions.

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Classical & Quantum Gravity / 44

Phases of scalar and fermionic field theories in thermal Anti-de Sitter Spaces

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Abstract: The primary ingredient for studying the phases of a quantum field theory is the effective action, which to the leading order involves computation of one-loop determinants. In this talk which is based on our papers 1 and 2, I will describe a method for computing one-loop partition functions for scalars and fermions on AdS_{d+1} for zero and finite temperature for arbitrary dimensions d that reproduces results known in the literature. The derivation is based on the method of images and uses the generalized eigenfunctions of the Laplacian and Dirac operators on Euclidean AdS which under thermal identification satisfy the desired periodicities. Employing these results, I will then discuss the phases of scalar and fermionic field theories in AdS spaces for $d = 1, 2, 3$ as regions in the corresponding parameter spaces. Along the way, I will also highlight the deviations from the flat space results. We will confirm, for the scalar field theories, that for a finite temperature theory in AdS there occurs a symmetry breaking phase in two dimensions in contrast to flat space where the Coleman-Mermin-Wagner theorem prohibits continuous symmetry breaking. We will also see that unlike flat space, there exists a region in AdS space where both the symmetry breaking and symmetry preserving phases coexist. We will next analyze the phases of the Yukawa theories. For Gross-Neveu models for $d = 1, 2$, in the large N limit we will see that, unlike flat space where the discrete chiral symmetry is restored beyond a certain temperature, the discrete chiral symmetry appearing in the zero fermionic mass limit remains broken at all temperatures in AdS space.

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Gravitational Waves / 45

Detecting astrophysical environment with extreme mass-ratio inspirals

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Aspects related to black holes surrounded by the astrophysical environment are underappreciated and require profound attention and effort. From an astrophysical viewpoint, we know that dark matter is asserted to be an undetected form of an elementary particle that is not visible, does not interact and contributes almost 27% to the matter-energy of the universe. The development of gravitational wave astronomy may fundamentally provide an understanding of the universe with such an invisible entity. Here, I would discuss the detection prospects of dark matter existence with an extreme mass ratio inspiral system where a stellar-mass object inspirals a supermassive black hole in the presence of an astrophysical environment. We estimate the gravitational wave fluxes, orbital

evolution and gravitational wave dephasing that exceptionally highlight the detection prospects of such an environment in gravitational wave observations with low-frequency detectors.

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46

Hunting for gravitational waves in the era of cosmic dawn

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Over the past decades, observations have established a sample of more than 200 bright Active galactic nuclei (AGN), powered by accretion onto massive black holes, in the first billion years of the Universe. The James Webb Space Telescope has significantly revised this sample by yielding a sample of unexpectedly numerous and large black holes (up to a 100 million solar masses) within the first 600 million years, posing an enormous challenge for black hole and galaxy formation models. Starting with possible pathways for creating such heavy black holes in the early Universe, I will show a census of the black holes and their properties expected through cosmic time. I will use these to highlight the gravitational wave event rates expected to be detected by LISA (the Laser Interferometer Space Antenna). Straddling the fields of cosmology, galaxy formation and black hole physics, I will show how theoretical models that couple the evolution of dark matter halos, their baryonic components and their black holes are crucially required to make predictions for facilities such as LISA.

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Classical & Quantum Gravity / 47

Strong deflection gravitational lensing by kazakov-solodukhin black hole

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We investigate the affine perturbation series of the deflection angle of a ray near the photon sphere of by kazakov-solodukhin black hole . The values of strong field parameters calculated and analyzed its variation with deformation parameter. With the help of lens equation the expression for angular position of innermost image, the angular separation of outermost image with the remaining images and the relative magnification derived. The numerical estimation of lensing observable for different super massive black holes are performed

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Gravitational Waves / 48

Probing globular clusters and other astrophysical environments with gravitational waves emitted by accelerated compact binary mergers

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The accelerated motion of binary black holes (BBHs) can be constrained by the corresponding gravitational waves (GWs) they emit. We investigate the prospects of detecting this acceleration in future third-generation and proposed space-based GW detectors. Since this acceleration could be indicative of the binary's formation channel, we also forecast accelerations of BBHs in dense stellar environments detectable in the DECIGO and LISA eras. We focus in particular on globular clusters (GCs). We use the output of the Cluster Monte Carlo (CMC) large-scale N-body simulations of GCs to study the effect of cluster properties –metallicity [illegible], virial and galactocentric radii [illegible], [illegible] –on the distribution of detectable accelerations. We find that Z and rv leave discernible imprints on the shape of the distributions of detectable accelerations and the corresponding BBH mass and redshift distributions. We thus demonstrate how future space-based detectors could provide novel probes of GCs.

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Astrophysical Relativity / 49

DEEP-TOV FOR CHARACTERIZING NEUTRON STARS

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The study of the interior regions of a neutron star is one of the active areas of research and gravitational wave astronomy is one of its critical tools. Currently, astronomers from across the spectrum are detecting different neutron star systems and it has become essential to consistently combine this information. We perform Bayesian inference to constrain the equation of state of the star by incorporating the distributions from NICER, radio as well as gravitational wave observations which, in turn, infers the mass-radius curve. As the number of observations increases, the dimensionality of the sampling for the inference also increases. Therefore, making the sampling process faster is essential. One way to do that is to speed up the Tolman-Oppenheimer-Volkoff (TOV) equation solver. In this work, we have
developed a physics-informed deep neural network model to solve the TOV equation.

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Cosmology / **50**

Dynamical system analysis in teleparallel gravity with boundary term

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In this paper, we perform the dynamical system analysis of the cosmological models framed in the extended teleparallel gravity, the $f(T, B)$ gravity. We use the mapping, $f(T, B) = -T + f(T, B)$, and define the dynamical variables to form the autonomous dynamical system. The critical points are obtained in two well-motivated forms of $f(T, B)$, one that involves the logarithmic form of the boundary term B, and the other one is the non-linear form of the boundary term. The position of critical points is shown in the different evolutionary phases of the Universe such as radiation, matter, and de-Sitter phase. The stability condition of each of the critical points of both the models is derived and the behavior of each point has been obtained mathematically and through the phase portrait. The evolution of standard density parameters such as radiation (Ω_r), matter (Ω_m), and dark energy (Ω_{DE}) are also analyzed. Further to connect with the present cosmological scenario, the behavior of deceleration and equation of state parameter both in the dark energy phase (ω_{DE}) and total (ω_{tot}) are
shown from the initial condition of the dynamical variables. The accelerating behaviour has been obtained for both models.

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Cosmology / **51**

Early and Late time cosmology in Modified gravity with interacting fluids

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Abstract : We study evolution of the universe in modified theories of gravity. The dynamics of the universe is explored in the following theories (i) $f(R) = R + \gamma R^2 + \beta R^\delta$ where β, γ, δ are arbitrary constants, (ii) $f(R, GB) = R + f(GB)$, GB is the Gauss-Bonnet term : $GB = R^{\alpha\beta\gamma\delta}R_{\alpha\beta\gamma\delta} - 4R^{\alpha\beta}R_{\alpha\beta} + R^2$, where $R^{\alpha\beta\gamma\delta}$, $R^{\alpha\beta}$ and R are Riemann Tensor, Ricci tensor and Ricci scalar respectively. We investigate late time behaviour of the Universe in both the theories and estimate the model parameters. In the second case, GB term coupled with a free scalar field (ϕ) in the presence of interacting fluid we obtain a realistic cosmological model. The role of exponential interaction is explored to understand the transition of the decelerated universe to the present accelerated universe.

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Cosmology / **52**

The Scale Invariant Vacuum Paradigm: Main Results and the Current BBNS Progress

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The talk will present a summery of the main results within the Scale Invariant Vacuum (SIV) paradigm as related to the Weyl Integrable Geometry (WIG) as an extension to the standard Einstein General Relativity (EGR). After a short sketch of the mathematical framework, the main results until 2023 1 will be highlighted in relation to: the inflation within the SIV 2, the growth of the density fluctuations [3], the application of the SIV to scale-invariant dynamics of galaxies, MOND, dark matter, and the dwarf spheroidals [4], as well as MOND as a peculiar case of the SIV theory [5], along with the most recent results on the BBNS light-elements'abundances within the SIV [6].

Keywords: cosmology: theory, dark matter, dark energy, inflation, BBNS; galaxies: formation, rotation; Weyl integrable geometry; Dirac co-calculus.

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Classical & Quantum Gravity / 53

Singularity free Emergent Universe from Dynamical wormhole

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We present flat emergent universe with a dynamical wormhole with a modified matter described by nonlinear Equation of state (nEoS) in Einstein's gravity. The Emergent universe (EU) is free from initial singularity accommodating late accelerating universe satisfactorily. The basic assumption of the original EU model is that the present universe emerged out from an initial Einstein static universe in the infinite past. We have shown that such an Einstein Static universe corresponds to the throat of a dynamical wormhole. Considering a homogeneous Ricci scalar, a class of dynamical wormholes are identified with non-linear equation of state which permits an EU model. It is interesting and new to note that nEoS considered here is equivalent to three different types of cosmic fluids. In a higher dimension the space-time dimensions (D) determines the rate of change of a particular fluid with the scale factor of evolving universe for non-interacting fluids. A realistic scenario of EU is obtained considering interaction among the three fluids at a later epoch. In a four or higher dimensions it is found that near the throat null energy condition (NEC) is violated, but away from the throat NEC is found to obey admitting the observed universe accommodating dimensions four or more than the usual four dimensions. At a later epoch the EU model satisfactorily describes the observed universe with late accelerating behaviour. Thus a universe emerged from the wormhole throat that exists in the infinite past thereafter the evolved and pass through different phases encompassed the observed universe satisfactorily.

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Cosmology / 54

Background electric and magnetic fields in cosmological de Sitter spacetime and correlations

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We investigate analytically and numerically the aspects of entanglement for quantum field theoretic systems in the presence of constant-strength background electric and magnetic fields for the cosmological de Sitter spacetime. In particular, we wish to emphasize the role of the magnetic field in the presence of background electric or gravitational fields. Will it oppose the effect of an electric field? How does it affect the correlations between particles and antiparticles produced by the electric or gravitational fields?

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55

Binary Neutron Stars: from macroscopic collisions to microphysics

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I will argue that if black holes represent one the most fascinating implications of Einstein's theory of gravity, neutron stars in binary system are its richest laboratory, where gravity blends with astrophysics and particle physics. I will discuss the rapid recent progress made in modelling these systems and show how the gravitational signal can provide tight constraints on the equation of state and sound speed for matter at nuclear densities, as well as on one of the most important consequences of general relativity for compact stars: the existence of a maximum mass. Finally, I will discuss how the merger may lead to a phase transition from hadronic to quark matter. Such a process would lead to a signature in the post-merger gravitational-wave signal and open an observational window on the production of quark matter in the present Universe.

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Gravitational Waves / **56**

Unmasking noise transients mimicking intermediate-mass black hole binaries

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Intermediate-mass black holes (IMBHs) are considered to be seeds of supermassive black holes (SMBHs). Knowledge of the formation and the growth of IMBHs can lead to a better understanding of SMBH formation and galaxy evolution. In recent years, gravitational waves (GWs) have opened a new window to observe and study IMBHs. The advanced ground-based GW detectors, such as Advanced LIGO and Advanced Virgo, are sensitive to the lightest IMBH binaries (~100 to 800 solar masses). The first confident and highly significant IMBH binary event - GW190521 was observed in the third observation run of Advanced LIGO and Virgo detectors making the future of IMBH binary detection promising. However, there are several challenges in detecting and characterising them. One of them is the presence of noisy artefacts aka "glitches"in the detector data that mimic the morphology of IMBH binaries, leading to either increase in false alarms or misclassification of glitches having direct implication on IMBH population studies. In this talk, I will introduce a Jensen Shannon divergence based similarity metric that quantifies the consistency of astrophysical parameters across the detector network and helps to distinguish IMBH binaries from loud glitches that mimic IMBH binaries. I will demonstrate the method with events from the gravitational wave transient catalogues (GWTCs).

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Astrophysical Relativity / 57

Investigation of energy-dependent nature QPO of GRS 1716-249 during its "failed" outbursts.

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GRS 1716-249 is a transient galactic black hole that experienced nine months of outburst activity in 2016–17. During its outbursts, Astrosat observed it at three different epochs with a fair amount of exposure time. We investigate whether quasi-periodic oscillation (QPO) exists and how it has evolved throughout the three epochs. We also explore the energy-dependent nature of QPOs. We model the combined broadband LAXPC and SXT spectra. We study the energy-dependent properties, such as fractional root mean square variability and time-lag variations with energy, of the QPO and its harmonic. We use the spectral information from the broadband study to identify the radiative components responsible for the variabilities. Moreover, this work attempts to demonstrate a simple model with varying inner disc temperature, heating rate, and fractional scattering with a time delay to characterize the fractional root mean square (rms) and time-lag spectra. Eventually, it will aid in describing the energy-dependent characteristics and identifying the responsible spectral parameters for the source

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Astrophysical Relativity / 58

Can the inverse method unravel the matter at the neutron star interior?

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The quest to understand the properties of matter at high density has intrigued physicists for more than a few decades. The problem is complicated, as having a proper theory describing it is challenging. Also, earth-based experiments to probe them have yet to materialize. One of the naturally occurring laboratories where such matter exists is the cores of a neutron star. Recent precise mass and radius measurement of several pulsars, along with gravitational wave detection of binary mergers, has thrown some light towards constraining matter properties that can reside inside neutron stars. Usually, a neutron star problem is addressed as follows: assuming an EoS, we solve the tollman-oppenheimer-volkoff equation to obtain its mass and radius. Recently, physicists have been trying to address the problem inversely. Having some measurement or observation from a neutron star, one can invert the problem and deduce various parameters of the neutron star like the mass, radius, moment of Inertia and tidal deformability. It has been seen that few parameters of neutron stars are seen to be insensitive towards the microscopic description of matter and follow universal relations with each other. Therefore, one can expect to deduce some gross matter properties or constrain them effectively, thereby unravelling the properties of matter at the neutron star's core.

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Classical & Quantum Gravity / 59

Stochastic aspects for cosmic fluids

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I will present a new upcoming theme of research based on stochastic aspects of the cosmic fluids. The aim is to develop new foundations for a mesoscopic intermediate scale theory, which helps to probe nature and evolution of dense matter in compact stars and early universe cosmology around the era of decoherence of the inflaton field, at intermediate sub-hydro scales. Connections of generalized stochastic effects which suit an underlying spacetime structure with various phenomena like dissipation turbulences etc in the superfluid matter of dense compact matter will be discussed. Foundations for such a theory have just begun to take shape and open up new directions to explore and investigate in relativistic astrophysics for multi-scale phenomena which are suitable for simulations as well as observations in near future. The initial basic formalism with such a purpose that is taking shape is the classical Einstein-Langevin equation with its applications to relativistic astrophysics.

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Gravitational Waves / 60

Addressing issues in defining the Love numbers for black holes

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Among various properties of black holes studied so far, their response to an external tidal field remains an especially interesting topic. In our recent work [arXiv:2306.13627 \[gr-qc\]], we presented an analytic method for calculating the tidal response function of non-rotating and slowly rotating black holes from the Teukolsky equation in the small frequency and the near horizon limit. We pointed out that in the relativistic context, there can be two possible definitions of the tidal Love numbers and the dissipative part that arise from the tidal response function. Our results suggest that both of these definitions predict zero tidal Love numbers for a non-rotating black hole. On the other hand, for a slowly rotating black hole in a generic tidal environment, these two definitions of the tidal Love numbers do not coincide. While one procedure suggests zero tidal Love numbers, the other procedure gives purely imaginary tidal Love numbers. As expected, the dissipative terms differ as well. We emphasize that in our analysis we kept all the terms linear in the frequency, unlike previous works in the literature. Following this, we also discuss a procedure to calculate the tidal response function and hence the Love numbers for an arbitrarily rotating black hole presented in the aforementioned paper.

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Gravitational Waves / 61

Improved gravitational waveform surrogate modelling through lower error and model extension

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In the domain of gravitational wave exploration, the swift prediction of waveforms holds immense importance for real-time and computational scenarios. Our research revolves around the development of efficient surrogate models, encompassing a three-step process to engineer accurate representations of true waveforms. This endeavour brings about transformative enhancements in waveform

prediction, parameter estimation, and comprehensive studies 1.
Our primary focus is on refining surrogate models within gravitational wave astronomy. We achieve this by expanding a surrogate model built using Effective One Body (EOB) waveform training data, i.e. 1D_EOBNRv2, with the objective of addressing inherent errors. The scope of our work extends to pushing the mass ratio (q) to 100 and investigating the (2, 2) mode, drawing inspiration from 2. This exploration is facilitated using the BHPTNR-Sur1dq1e4 model. By embarking on this innovative expedition, we unveil the concealed harmonies within gravitational interactions, resonating throughout the cosmic expanse.
Our approach not only introduces efficiency in waveform prediction, enabling real-time applications and computational ease, but also significantly bolsters the precision of representing gravitational wave signals within predefined parameters. Consequently, our contributions advance the accuracy of parameter estimation and fortify the capabilities of future detectors. Our work stands out as a pioneering effort in refining surrogate models and expanding their potential in the field of gravitational wave astronomy.
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Cosmology / 62

The Role of Interaction parameter in Dark Energy and Structure Formations in Early Universe

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The dominance of dark energy in the universe has necessitated ways to introduce a repulsive gravity source to make q negative. The models for the dark energy range from Λ-CDM, K-essence, Chaplygin gas, etc. We look at the possibility where the interaction parameter Γ plays a vital role in various cosmological models, particularly those involving interactions between dark energy and other cosmic components, such as matter (including baryonic and dark matter) and radiation. It quantifies the strength of the interaction between dark energy and these components. In that case, understanding how Γ changes over time is crucial for precisely modeling the behavior of dark energy in the universe. In response to this paradigm, we propose an alternative framework for studying dark energy and its role in structure formation in the early universe. And assume that the interaction between dark energy and matter is a simple linear coupling with a varying equation of state. This allows us to track the rate of interaction, the entropy of dark energy and matter, and their densities over conformal time. To explore this framework, we investigate three different models: time-varying Λ, Generalized Chaplygin gas, and K-essence models. Each model has a different value of Γ. Our results suggest that while considering interactions between dark energy and matter, the Generalized Chaplygin gas model, when coupled with an interaction term, could provide a better fit to the observed power spectrum, particularly at $ell < 70$ when Γ falls within a specific range. This result is significant in two ways: 1) The standard Λ-CDM model doesn't fit well to explain the uncertainties arising in this specific range. 2) This behavior of Generalized Chaplygin gas is a new insight for constraining observational data or ruling out other models. For instance, if we measure a very small value of

Γ, it would rule out the K-essence model, as it is highly sensitive to the value of Γ. Conversely, if Γ is measured as non-zero, it would not rule out the K-essence model, as the Chaplygin gas model and the time-varying Λ model are also sensitive to the value of Γ. The corresponding calculations show that the K-essence model ($\Gamma = 0.1 \pm 1\%$) is more sensitive to the interaction between dark energy and matter due to its non-canonical kinetic term. On the other hand, the Chaplygin gas model ($\Gamma = 1.02 \pm 5\%$) and the time-varying Λ model ($\Gamma = 0.01 \pm 5\%$) are canonical scalar field models. As a result, these models are less sensitive to the interaction between dark energy and matter compared to the K-essence model. Furthermore, the interaction parameter also acts to suppress the power spectrum at low-ell values, where the Λ-CDM model typically falls short in predicting observations. However, it is important to note that further investigation is necessary to refine constraints on model parameters and distinguish between different dark energy models. Since observational data on Γ is currently weak, future observations are necessary to constrain its value and compare the predictions of the interacting dark energy model to observed data.

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Cosmology / 63

Loop contributions to the scalar power spectrum due to quartic order action in ultra slow roll inflation

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Recently, there have been efforts to examine the contributions to the scalar power spectrum due to the loops arising from the cubic order terms in the action describing the perturbations, specifically in inflationary scenarios that permit a brief epoch of ultra slow roll (USR). A phase of USR inflation leads to significant observational consequences, such as the copious production of primordial black holes and generation of gravitational waves of observable amplitudes. In this talk, I shall discuss the loop contributions to the scalar power spectrum in scenarios of USR inflation arising due to the quartic order terms in the action describing the scalar perturbations. I shall initially describe the computation of the loop contributions to the scalar power spectrum due to the dominant term in the action at the quartic order. Thereafter, I shall consider a scenario wherein a phase of USR is sandwiched between two stages of slow roll inflation and describe the behavior of the loop contributions in situations involving late, intermediate and early epochs of USR. In the inflationary scenario involving a late phase of USR, for reasonable choices of the parameters, I shall show that the loop corrections are negligible for the entire range of wave numbers. In the intermediate case, the contributions from the loops prove to be scale invariant over large scales, and we find that these contributions can amount to 30% of the power spectrum at the leading order. In the case wherein USR sets in early, we find that the loop contributions could be negative and can dominate the power spectrum at the leading order, which indicates a breakdown of the perturbative expansion. I shall conclude with a brief summary and outlook.

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Astrophysical Relativity / 64

High-soft to low-hard state transition in black hole X-ray binaries with GRMHD simulations

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To understand the decaying phase of outbursts in black hole (BH) X-ray binaries (BH-XRBs), we performed very long general relativistic magneto-hydrodynamic (GRMHD) simulations of a geometrically thin accretion disk around a Kerr BH with slowly rotating matter injected from outside. We thoroughly studied the flow properties, dynamical behavior of the accretion rate, magnetic flux rate, and jet properties during the temporal evolution. Due to the interaction between the thin disk and injected matter, the accretion flow near the BH goes through different phases. The sequence of phases is: soft state $\rightarrow$ soft-intermediate state $\rightarrow$ hard-intermediate state $\rightarrow$ hard state $\rightarrow$ quiescent state. The talk will discuss the process of transition in detail. Throughout the evolution, we also observed low-frequency QPOs ($\sim$ 10Hz) and high-frequency QPOs ($\sim$ 200Hz). The talk will also discuss the features of QPOs in detail.

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Cosmology / 65

A Bayesian Neural Network based ILC method to estimate accurate CMB polarization power spectrum over large angular scales

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Observations of the Cosmic Microwave Background (CMB) radiation have made significant contributions to our understanding of cosmology. While temperature observations of the CMB have greatly advanced our knowledge, the next frontier lies in detecting the elusive B-modes and obtaining precise reconstructions of the CMB's polarized signal in general. In anticipation of proposed and upcoming CMB polarization missions, this study introduces a novel method for accurately determining the angular power spectrum of CMB E-modes and B-modes. We have developed a Bayesian Neural Network (BNN)-based approach to enhance the performance of the Internal Linear Combination (ILC) technique. Our method is applied separately to the frequency channels of both the LiteBird and ECHO (also known as CMB-Bharat) missions and its performance is rigorously assessed for both missions. Our findings demonstrate the method's efficiency in achieving precise reconstructions of both CMB E-modes and CMB B-mode angular power spectra, with errors constrained primarily by cosmic variance.

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Cosmology / 66

Study of cosmological parameters from LRS-BI metric in f(Q) gravity theory

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Some observational deviations from the standard cosmological principles of isotropy and homogeneity lead to create more interest among the researchers on studying anisotropic characteristics of the Universe in recent times. In this context the locally rotationally symmetric Bianchi type I (LRS-BI) metric is appeared to be suitable and simplest candidate for studying anisotropic nature of the Universe. Further, the lack of observational evidence of dark matter and dark energy pushed the researchers to look for alternative gravity theories and $f(Q)$ is one of them. It is an extension of symmetric teleparallel theory equivalent to GR (STEGR), in which non metricity (Q) is the guiding force of gravity. In this study, we use the LRS-BI metric in $f(Q)$ gravity and derived various cosmological parameters like Hubble parameter (H), distance modulus (D_m), effective equation of state (ω_{eff}) etc. for $f(Q) = -\alpha Q^n$ model and tried to constraints various model parameters by using available observational data. Finally we have predicted the possible anisotropy at the early stage of the Universe and it's current effect.

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Cosmology / 67

Effect of diffusion on the propagation of UHECRs in the f(R) theory of gravity

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Although the sources of ultra-high energy cosmic rays (UHECRs) are unknown, the high-quality data acquired by the most modern CR observatories indicate that these CRs are of extragalactic origin. As the intergalactic media are predicted to be filled with turbulent magnetic fields (TMFs), these intergalactic magnetic fields may profoundly impact how UHECRs travel throughout the expanding Universe. Thus, incorporating these ideas into the theory is critical for comprehending the experimental findings on UHECRs. In this work, we investigate the effect of diffusion of ultra-high energy

(UHE) particles in the presence of TMFs using the f(R) theory of gravity. To this end, we consider one of the most studied f(R) gravity models, that is the Starobinsky model. For this model, we study the diffusive character of the propagation of UHECR protons in terms of their density enhancement. We compare the computed UHECR protons spectra for the considered f(R) gravity model to the data from the AKENO, HiRes, and AUGER experiments. We can see that the Starobinsky f(R) gravity model produces the energy spectra of UHECRs with all experimentally observed features, which are substantially within the range of combined data from all experiments across the whole energy range of interest. These results suggest that the f(R) theory of gravity is a promising framework for understanding the propagation of UHECRs.

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Classical & Quantum Gravity / 68

New regular black holes: geometry, matter sources and shadow profiles

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A new two-parameter, static and spherically symmetric regular geometry is proposed, which, for specific parameter choices, represents a geodesically complete, regular black hole. However, unlike most regular black holes which have Schwarzschild spacetime as their singular limit, our spacetime reduces to a singular, mutated Reissner–Nordström geometry, for a particular choice of parameters. The required matter (within the framework of General Relativity (GR)) violates the energy conditions, but not in the entire domain of the radial coordinate. Despite energy condition violation, we are able to construct a viable source for our geometry, which involves a nonlinear magnetic monopole in a chosen version of nonlinear electrodynamics. An alternative source in braneworld gravity is also suggested. Further, we obtain the shadow profile for our geometry and try to estimate the metric parameters using recent observational results from the EHT collaboration.

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Classical & Quantum Gravity / 69

End-state of gravitational collapse of scalar and vector fields: Strong naked singularities

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We study here the unhindered gravitational collapse of spatially homogeneous (SH) scalar fields ϕ with a potential $V_s(\phi)$, as well as vector fields $\tilde{A}$ with a potential $V_v(B)$ where $B = g(\tilde{A}, \tilde{A})$ and g is the metric tensor. If the past end-point of a causal geodesic is a singularity, then this singularity is said to be naked. Such a singularity is strong if the volume of an object vanishes when it approaches the singularity. We show that for both scalar and vector fields, classes of potentials exist that give rise to black holes or naked singularities. There are classes of potentials, as well, for which the resultant singularities are strong. There is a non-zero subset of such potentials where the resultant singularities are both naked and strong.
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Classical & Quantum Gravity / 70

Gravitational collapse with torsion and nonsingular Universe in a black hole

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We consider gravitational collapse of a fluid sphere with torsion generated by spin, which forms a black hole.
We use the Tolman metric and the Einstein-Cartan field equations with a relativistic spin fluid as a source.
We show that gravitational repulsion of torsion prevents a singularity, replacing it with a nonsingular bounce.
Quantum particle creation during contraction prevents shear from overcoming torsion.
Particle creation during expansion can generate a finite period of inflation and produce large amounts of matter.
The resulting closed universe on the other side of the event horizon may have several bounces.
Such a universe is oscillatory, with each cycle larger than the preceding cycle, until it reaches a size at which dark energy dominates and expands indefinitely.
Our universe might have therefore originated from a black hole existing in another universe.

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Cosmology / 71

Synchrotron radiation from cosmic string wakes.

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Magnetic fields can be generated in cosmic string wakes due to the Biermann mechanism in the presence of neutrino inhomogeneities. As the cosmic string moves through the plasma, the small magnetic field is amplified by the turbulence in the plasma. Relativistic charged particles that cross the magnetized wake of a cosmic string will therefore emit synchrotron radiation. The opening angle of the cosmic string is very small, so the wake appears like a relativistic jet. Assuming a homogeneous magnetic field in the wake of the string, we obtain the synchrotron emission from non-thermal relativistic electrons in the wake of the string. The emitted radiation has a broad peak and is over a wide range of frequencies. We show that the spectrum can be mapped to some of the unknown sources in different regions of the current available sky catalogs.

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Astrophysical Relativity / 72

Massive, magnetized compact stars: Theory and Simulation

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Over the last few years, there has been considerable interest in massive compact stars, specifically neutron stars (NSs) and white dwarfs (WDs). Peculiar over-luminous type Ia supernovae (such as SNLS-03D3bb) and gravitational wave observations (such as GW190814) lend observational support to this idea. These massive compact stars are also prime candidates to fill in the observational mass gap that currently exists between the heaviest NSs and the lightest black holes. It is found that the magnetic field greatly contributes to the existence of these massive stars, both through classical and quantum effects. In this work, we explore both massive WDs and NSs formed as a result of the classical effects of the star's magnetic field. For WDs, this results in masses greater than the conventional Chandrasekhar limit, leading to super-Chandrasekhar WDs and new mass limit(s), depending on the magnetic field geometry. We explore the full evolution and stability of these objects from the main sequence stage through the one-dimensional stellar evolution codes STARS and MESA. There is however no consensus on a Chandrasekhar type maximum mass for a NS due to the high-density nuclear matter equation of state (EOS) still being unknown. As a result, the study of massive NSs ends up simultaneously becoming an exploration of strong interactions in highly dense, magnetized environments. Pulsar observations (PSR J1614-2230, PSR J0348+0432, PSR J0740+6620, PSR J0952–0607) indicate that NS's limiting mass, if there is any, could be well over $2M_{\odot}$. We do a semi-analytic exploration of massive NSs by employing various relativistic mean field EOSs along with magnetic field and a model anisotropy. We also explore additional implications like that of tidal deformability and universal relations. On the whole, our exploration shows that magnetic field can lead to significant increase in the masses of both NSs and WDs, violating their conventional limits.

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Cosmology / 73

Constraints on Compact Dark Matter from Gravitational Wave Microlensing

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If a significant fraction of dark matter is in the form of compact objects, they will cause microlensing effects in the gravitational wave signals observable by LIGO and Virgo. From the non-observation of microlensing signatures in the binary black hole events from the first two observing runs and the first half of the third observing run, we constrain the fraction of compact dark matter in the mass range 10^2–$10^5\mathrm{M}_{\odot}$ to be less than 50%-80% (details depend on the assumed source population properties and the Bayesian priors). These modest constraints will be significantly improved in the next few years with the expected detection of thousands of binary black hole events, providing a new avenue to probe the nature of dark matter.

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Cosmology / 74

Probing the HI distribution during post-reionization using the redshifted 21-cm marked power spectrum

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Observations of the neutral hydrogen (HI) 21-cm signal have the potential to map out the large-scale structures (LSS) of our Universe during the post-reionization era (z ⊠ 6). Several present and future experiments are planned to give their efforts to probe the signatures of the LSS inherent in the expected signal over a large redshift range. A correct prediction of the expected signal demands a detailed modeling of the HI distribution, and more so for a correct interpretation of the signal once detected. In this work, we have carried out semi-numerical simulations to model the HI distribution and study its power spectrum and marked power spectrum during post-reionization. The so-called marked power spectrum studied in this work is a way to use power spectra that give more weight to low and intermediate HI densities and show a clear time evolution of the HI distribution. On the contrary, the standard power spectrum, which is only affected by the high-density regions, shows a weaker time evolution of the HI distribution when compared to the evolution of the dark matter distribution. However, a crucial assumption that the HI distribution on a large scale follows the underlying dark matter distribution, suggests the HI distribution evolves significantly during the the post-reionization. In this work for the first time, we show that the marked power spectrum can provide a better insight into the HI distribution and its time evolution together with its environment and, thus, might be able to put a better constraint on the cosmological parameters.

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Cosmology / 75

Singular Bounce in Generalised Brans-Dicke Theory

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In this work, we present singular bounce scenario
in the framework of the generalised Brans-Dicke (GBD)theory where an evolving BD parameter along with a self-interacting potential is considered. The GBD field equations are derived for an anisotropic space time to provide a more general approach to the cosmic expansion. The evolutionary behaviour of the Brans-Dicke scalar field, dynamical Brans-Dicke parameter and the self interacting potential are studied.
Observational bounds on our model favours the Phantom dark energy phase.

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Cosmology / 76

Starobinsky inflation and its spin-offs in the light of exact solutions

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In this paper, we discuss a general method to obtain exact cosmological solutions in modified gravity, to demonstrate the method it is employed to obtain exact cosmological solutions in f(R,phi) gravity. Here, we show that, given a particular evolution of the Universe, we could obtain different models of gravity that give that evolution, using the same construction. Further, we obtain an exact inflationary solution for Starobinsky action with a negligible cosmological constant. This analysis helps us to have a better understanding of Starobinsky inflation. With our analysis, we could refine the parameter values and predictions of Starobinsky inflation. Also, we make an observation that there exists a no-go theorem for a bounce from Starobinsky action in the absence of scalar fields or a cosmological constant.

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Classical & Quantum Gravity / 77

Galactic wormholes: Geometry, stability, and echoes

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In this work, we present the environmental effects on wormhole geometries residing in a galaxy through a fully relativistic analysis. In particular, we consider two wormhole spacetimes classes: the Damour-Solodukhin wormhole and the braneworld wormhole. While there is no classical matter model for the Damour-Solodukhin wormhole, the braneworld wormhole, on the other hand, is supported by a scalar-tensor theory on the four-dimensional brane. Intriguingly, it turns out that the presence of a dark matter halo surrounding these wormholes can tame the violations of energy conditions present in generic wormhole spacetimes. Our results also demonstrate that the galactic Damour-Solodukhin wormhole is more stable than its isolated counterpart, whereas we obtain the opposite behavior for the braneworld wormhole. The perturbation of these wormholes leads to echoes in the ringdown waveform, which are sensitive to the properties of the dark matter halo. To be precise, the time delay between two echoes is affected by the galactic matter environment, and it appears to be a generic effect present for any exotic compact object living in a galaxy. This allows us to identify the galactic parameters, independently from the gravitational wave measurements, if echoes are observed in future generations of gravitational wave detectors. For completeness, we

have also analyzed the impact of the galactic environment on the photon sphere, the innermost stable circular orbits, and the shadow radius. It turns out that the dark matter halo indeed affects these locations, with implications for shadow and accretion physics.

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Gravitational Waves / 78

A novel test of strong field gravity using binary black hole ringdowns

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Binary black hole mergers produce a remnant black-hole in a perturbed state. This then relaxes to form a stable Kerr black hole by emitting gravitational waves, which we call as the ringdown. Ringdowns contain imprints of both strong field linear and non-linear dynamics predicted by the general theory of relativity. Traditionally, we have been using ringdown to test strong-field linear dynamics. In this talk, I will introduce a novel idea to test the consistency of the strong-field non-linear gravity dynamics observationally using binary black hole ringdowns. It uses amplitudes and phases of excitation of ringdown and is thus called the amplitude-phase consistency test (APC test). Specifically, I will present a simpler proof-of-concept implementation of this test and summarise effort towards generalising it.

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Classical & Quantum Gravity / 79

Unveiling the elusive traces of extra dimensions through the dimming of the photon ring of black holes via axion-photon conversion mechanism

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Axions are hypothetical pseudoscalar, originally proposed as a resolution to the strong CP problem in quantum chromodynamics. These particles are considered to be potential candidate for dark matter. Hence probing axions and determining its mass is of great interest, especially near supermassive black holes like M87∗. We have examined the phenomenon of photon axion conversion occuring in the spacetime surrounding a black hole. Specifically, we focus on the potential existence of a magnetic field around the supermassive black hole M87∗, which could facilitate the conversion of photons into axions in close proximity to the photon sphere. As photons travel across curved spacetime due to gravity, they spend time near the photon sphere, where they are further converted into axions. As a result, the intensity of the photon ring around the black hole decreases. We suggest monitoring the photon sphere with better resolution telescopes to investigate the possibility of discovering these hypothetical axion particles. This allows us to obtain vital insights into the conversion mechanism that occurs within a generic spherically symmetric black hole. Furthermore, we study how photon ring luminosities are affected if the black hole is considered in presence of extra-dimension.It is vital to note that the conversion mechanism's success is dependent on the axion-photon coupling and mass. As a result, studying the modified luminosity of the black hole's photon ring provides a useful way of restricting the axion's mass and coupling parameters within a given range. We predicted frequency range upon which the luminosity of the photon sphere may be effected due photon-axion conversion phenomenon. We find that the dimming rate of photon sphere changes not only with frequency of photons but also with the change in extra-dimensional parameter. This study helps to understand the dimming phenomena of photon sphere due to axion-photon coversion in presence of extra dimension.

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Astrophysical Relativity / 80

Shadow of regular black hole in scalar-tensor-vector gravity theory

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The existence of black holes is one of the most astonishing predictions of general theory of relativity. The Event Horizon Telescope (EHT) collaboration's latest observations, as well as the discovery of gravitational wave signals by the Laser-Interferometer Gravitational Wave-Observatory (LIGO) and Virgo corroborate the existence of these celestial objects. Despite the success, there are unresolved issues like existence of singularity in the theory and no observational evidence of dark matter. These two issues can be overcome by considering the regular black hole solution in scalar-tensor vector theory of gravity or MOG theory of gravity.

As a result of lensing, the black hole scatters photons with greater angular momentum from the source, delivering them to the distant observer, while photons with lower angular momentum fall into the black hole, creating a shadow zone and maybe a light ring. The black hole shadow that forms adjacent to the event horizon provides us with a rough idea of the underlying geometrical structure of horizons. Recent observation of black hole shadow of M87∗ and SAG A∗ by EHT collaboration has opened the new window to test alternative gravity theories. We have studied the details of the regular black hole in MOG theory and analysed the shadow structure for the same. These kind of black hole differs from Schwarzschild-Kerr black hole by a parameter β. A critical value of the parameter β is found to be $\beta_{\text{crit}} = 0.4026$. The shadow for the horizonless dark compact object has been analysed for the static, spherically symmetric case and compared with M87*and Sgr A* data.

Shadow observables have been determined in the context of the regular black hole and used for obtaining the energy emission rate. The peak of the energy emission rate shifts to lower frequency for the increasing value of the parameter β.

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Astrophysical Relativity / 81

Modified Gravity Approach to Compact Star Study in $f(R,T)$ Model

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We study the equilibrium configurations and the radial stability of spherically symmetric relativistic Neutron Stars(NS) with a polytropic equation of state (EoS) in a modified $f(R,T)$ gravity framework by introducing a quadratic term in T (where T is the trace of the conserved energy-momentum tensor $T_{\mu\nu}$ of the matter-energy) for the functional form of $f(R,T)$ with $f(R,T) = R + h(T)$ where $h(T)$ is an arbitrary function of T, R is the Ricci scalar and $h(T) = 2\lambda T + \xi T^2$. Here λ and ξ are the modified gravity parameters. In this work, we have studied the neutron star properties such as mass, radius, pressure and energy density, and their dependence on the modified gravity parameters λ and ξ. For $\xi = 0$ and $= -1, -3, -5$ we find that for the radius of neutron star $R < 8R_{\odot}$ ($R_{\odot}$, the Solar radius), its mass M increases, whereas for $R > 8R_{\odot}$, M decreases with the increase in R. The equilibrium configurations of the neutron star predict a maximum mass limit for neutron stars of $M = 2.44M_{\odot}$ corresponding to $\lambda = -5$ and $\xi = 0$. This higher value of NS mass can be compared with gravitational wave data(GW170817) which is $2.33M_{\odot}$.

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Classical & Quantum Gravity / 82

The breaking point of general relativity through f(R) scalaron gravity and higher dimensional Kaluza-Klein gravity near Sgr A*

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The Galactic Center supermassive black hole, Sgr A* provides an ideal laboratory for testing general relativity (GR) and constraining its alternatives. In this work, we search for GR breaking points by estimating the pericenter shift of stellar orbits having a semimajor axis in the range of (45 - 1000)au. We work with theoretical scalaron field amplitude and coupling. The scalaron mass is taken in the range (10ˆ{−22}–10ˆ{−17}) eV. The breaking point of GR arises only for higher scalaron coupling resulting from the Hees et al. 2017 observations within a few tens of au to a = 1000 au. We also estimate the pericenter shift with a power-law potential V(r) ~ 1/r2 arising in five-dimensional gravity and obtain allowed ranges of the five-dimensional Planck mass through existing bounds on the parameterized post-Newtonian parameters coming from the orbits of S-2, S-38, and S-55. The breaking point for GR arises from a five-dimensional Planck mass of about 104 GeV. Constraint on this parameter, expected from the astrometric capabilities of existing and upcoming large telescopes, is also presented.

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Astrophysical Relativity / 83

Oscillating shocks in the transonic, viscous, variable Γ accretion flows around black holes

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We investigate the time evolution of the transonic-viscous accretion flow around a non-rotating black hole. The input parameters used for the simulation are obtained from semi-analytical solutions. This code is based on the TVD routine and correctly handles the angular momentum transport due to viscosity. The thermodynamic properties of the flow are described by an equation of state with a variable adiabatic index. We regenerate the inviscid and viscous steady-state solutions including shocks, using the simulation code and compare them with the semi analytical solutions. Then we investigate accretion in the limit of viscosity where the solution becomes time-dependent. Particularly interesting is how shocks behave in the presence of viscosity. As the viscosity parameter (α) crosses a critical value, the previously steady shock becomes time-dependent, eventually leading to oscillations. The value of this critical viscosity depends on the injection angular momentum (λ_{ou}) and the specific energy (ϵ). We estimated the posteriori bremsstrahlung and synchrotron cooling and the net radiative output also oscillates with the frequency of the shock. We also study the variation of frequency, amplitude, and mean position of oscillation with α. Considering a black hole with a mass of $10M_{\odot}$, we observed that the power spectrum exhibits a prominent peak at the fundamental frequency of a few to about tens of Hz, accompanied by multiple harmonics. This characteristic is frequently observed in numerous accreting black hole candidates.

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Classical & Quantum Gravity / 85

Quantum Bottleneck in Chaotic Inflation and in the subsequent Reheating

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It has been long since chaotic inflation has explained the inflationary epoch of the early Universe. Although it has explained the particle creation mechanism via parametric resonance in the reheating region, it has not been employed to study the backreaction of particle creation in the inflationary phase.

In the present work, we take the minimal model of chaotic inflation and show that the backreaction of particle creation works against the phenomenon of inflation itself as it does not allow for any possibility of having the right initial conditions to meet the slow roll conditions with the prescribed sixty number of e-foldings.

To circumvent this situation, we bring in quantum mechanical restriction owing to Heisenberg's uncertainty principle in the process of distributing particles in the configuration space. This creates a bottleneck effect that inhibits the energy flow from the inflaton field restricting creation of particles.

Our numerical simulation shows that this bottleneck effect operates not only in the inflationary epoch but also in most part of the subsequent reheating phase. We find sufficient reheating and the energy density of the created particles attains a peak value of $\rho_r = 1.13 \times 10^{55}$ GeV^4, which corresponds to a reheating temperature of $T_r = 2.38 \times 10^{13}$ GeV. The inflationary era lasts for 8.15×10^{-37} sec whereas the subsequent reheating period spans over a time of 3.10×10^{-34} sec.

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Gravitational Waves / 86

A new approach to study the high redshift binary black hole population using gravitational waves.

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The astrophysical Stochastic Gravitational Wave Background (SGWB) is the superposition of all the compact binary merger events that go undetected as individual events along with other sources such as supernovae, magnetars, etc. The individual gravitational wave (GW) signals from these events vary over time, depending on the source parameters. The timescale of the individual events along with the timescale of the interval between two events gives rise to the correlation between different frequency modes in the signal covariance matrix of the SGWB. The structure of the covariance matrix can be shown be depend on the population parameters. This structure in the covariance matrix provides extra information about the source population on top of the power spectrum. In this work, we demonstrate that utilizing this additional information significantly improves the Figure of Merit when compared to the case with only power spectrum for the LIGO-Virgo-KAGRA (LVK) network of detectors with the design sensitivity noise with two years of observation. Incorporating this spectral correlation in SGWB in the analysis of the SGWB signal will prove advantageous for detecting the SGWB signal within the LVK frequency bands as well as even at lower frequencies.

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Cosmology / 87

Formation of massive black holes with M = (10^3-10^8) M_Θ through accretion of self-interacting dark matter onto a stellar mass seed black hole

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The distant luminous quasars host supermassive black holes of mass 109 MΘ thus questioning the presence and formation of the later in the early universe. The formation of massive black holes is studied by the process of Hoyle-Lyttleton-Bondi accretion of self-interacting dark matter (SIDM) onto a 20 M seed black hole moving with velocity 100 km/s in the SIDM halo. We consider observationally constrained range of the specific SIDM cross section (σ/mdm) taken as (0.1 −5) cm^2g^{-1}. The formation time of these massive black holes of mass M = $(10^3 - 10^8)$ M is calculated for the universal NFW profile of accreted dark matter, Singular Isothermal Sphere (SIS), power law profiles with cusp index 2.19≤γ≤2.5 of accreted dark matter and core-modified isothermal profiles. The ambient sound speed is taken as Cs= (10-100) km/s. Within all the considered profiles $(10^3 - 10^8)M$ black holes are found to grow within few tens to hundred Myrs at redshifts z= (5-30), well before the quasar epoch.

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Cosmology / 88

Self-interactions of ULDM to the rescue?

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Recently Ultra Light Dark Matter (ULDM), where DM is described by a scalar field with $m \sim 10^{-22}$ eV has emerged as a promising alternative to the standard Cold Dark Matter (CDM) model. However, viability of models with no self-interactions (also called Fuzzy Dark Matter), is under question as relevant masses are increasingly constrained using various astrophysical and cosmological observations. It is then interesting to consider the effects of self-interactions on such constraints. We look at two observables that can potentially constrain self-interactions: (1) amount of mass contained within some region around the galactic centre, (2) galactic rotation curves of dwarf galaxies. We find that for the former, using an example of the M87 halo, attractive self-interactions are more constrained than repulsive self-interactions. For the latter, we find that ULDM with repulsive self-interactions of strength $\sim \mathcal{O}(10^{-90})$ are allowed by the rotation curve data of Low Surface Brightness dwarf galaxies (from the SPARC catalogue) while simultaneously satisfying an empirical Soliton-Halo relation.

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Cosmology / 89

The possibility of Q-balls as cosmological and galactic dark matter

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The Cold Dark Matter (CDM) hypothesis accurately predicts structure formation on cosmological scales and fits the temperature fluctuations of the Cosmic microwave background (CMB) and large-scale structure. However, observations that probe the innermost regions of dark matter halos and the properties of dwarf galaxy satellites have persistently challenged CDM. In contrast, the Modified Newtonian Dynamics (MOND) hypothesis can explain a broad range of galactic events. However, MOND can not explain the complex shape of the CMB and matter power spectra. It appears that CDM and MOND are effective in almost mutually exclusive regimes. This leads to the question: Is there a physical mechanism where CDM and MOND share a common origin? This talk discusses that non-topological solitons —the Q-balls —formed in the early Universe can mimic CDM at the cosmological scales. In contrast, they mimic MOND at galactic scales in the late Universe. Specifically, we discuss that Q-balls can form in the radiation-dominated epoch naturally. We also put an upper bound on the number density of Q-balls, which depends on the charge of the Q-ball and the primeval small charge asymmetry. We then discuss the possibility of forming Bose-Einstein condensate and superfluid phases of matter by the Q-balls in the present Universe.

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Classical & Quantum Gravity / 90

A detection mechanism for black hole memory effect

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The gravitational memory effect manifests the permanent relative separation between two test masses, initially held at relative rest, upon interaction with the gravitational waves. It is also shown, that this memory effect is related to the BMS symmetries that emerge at the asymptotic region of spacetimes where the test masses are placed. A similar effect can be obtained near the horizon of black holes and termed the black hole memory effect. We outline a model for the detection of such near-horizon memory and show an observable effect can be obtained in the upcoming gravitational wave detectors.

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Cosmology / 91

Thermodynamic behaviour of GUP-corrected black holes in bumblebee gravity

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Bumblebee gravity theory is a class of vector-tensor theory of gravity with growing interest in literature. We explore a Schwarzschild-type metric corrected by Generalized Uncertainty Principle (GUP) and possessing topological defects within the framework of Bumblebee Gravity. We investigate the thermodynamic quantities associated with the black hole metric, like temperature, entropy and heat capacity. The effects of the Lorentz Symmetry Breaking parameter (LSB) inherited in bumblebee gravity framework and also the global monopole parameter on the various properties of the black hole are studied. It was found that these parameters of the theory have significant impact on the temperature, entropy as well as on heat capacity, and causes significant variation from ideal Schwarzschild behaviour.

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Classical & Quantum Gravity / 92

Raychaudhuri Equation in f(T) gravity: Classical and Quantum aspects

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The present work deals with the classical and quantum aspects of the Raychaudhuri equation in the framework of $f(T)$-gravity theory. In the background of homogeneous and isotropic Friedmann–Lemaitre–Robertson-Walker space-time, the Raychaudhuri equation has been formulated and used to examine the focusing theorem and convergence condition for different choices of $f(T)$. Finally in quantum cosmology, the wave function of the universe has been shown to be the energy eigen function of the time-independent Schrödinger equation of a particle. Also probability measure on the minisuperspace has been examined at zero volume for singularity analysis in the quantum regime. Lastly, the Bohemian trajectory for the present quantum system has been explicitly determined for some particular choices. These trajectories unlike classical geodesics are shown to obliterate the classical singularity in the presence of quantum potential.

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Cosmology / 93

Noether Symmetry Analysis in Scalar Tensor Cosmology : A Study of Classical and Quantum Cosmology

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The present work deals with a complex scalar field in scalar tensor gravity theory in the background of spatially flat Friedmann-Lemaî$\hat{\imath}$tre-Robertson-Walker (FLRW) geometry. Noether symmetry analysis has been used to determine the classical cosmological solution of a scalar field in scalar-tensor theory with the scalar field as a nonminimally coupled complex field. Noether symmetry analysis is not only used to find a symmetry vector and potential but also it helps in finding an appropriate transformation $(a,\ \phi,\ \theta) \rightarrow (u,\ v,\ \theta)$ in the augmented space so that one of the new variables becomes cyclic. In quantum cosmology, the Wheeler-DeWitt (WD) equation has been formed in the minisuperspace and its solution i.e. the wave function of the universe has been evaluated by using the operator version of the conserved (Noether) charge. Finally, the nature of the classical solution has been discussed from the observational point of view and the cosmological singularity has been examined both classically and quantum mechanically.

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Classical & Quantum Gravity / 95

Raychaudhuri Equation in the Context of a Collapsing Fermionic Distribution Incorporating Effective Four-Fermi Interaction

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The intrinsic angular momentum of fermions can generate torsion in spacetime. This gives rise to an effective four-fermi interaction that fermions experience within a fermionic distribution. This interaction is expected to become significant when densities start to grow. In this contribution, I will discuss some findings from our ongoing exploration regarding the role of this interaction in a gravitationally collapsing fermionic distribution. Our specific aim is to explore if this interaction can provide a repulsive contribution and prevent the formation of the final singularity. We consider a collapsing distribution of electrons which incorporates both chiralities. We use the Raychaudhuri equation and the focusing condition for congruences to carry out our investigation. Using simplified yet reasonable assumptions, we establish that a repulsive contribution arises depending on how torsion couples with different chiralities. Also, the effect of the interaction starts to dominate as the collapse proceeds, providing a means to avoid the final singularity formation.

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Classical & Quantum Gravity / 96

Radiative processes of single and entangled detectors on circular trajectories in (2+1) dimensional Minkowski spacetime

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We investigate the radiative processes involving two entangled Unruh-DeWitt detectors that are moving on circular trajectories in (2+1)-dimensional Minkowski spacetime. We assume that the detectors are coupled to a massless, quantum scalar field, and calculate the transition probability rates of the detectors in the Minkowski vacuum as well as in a thermal bath. We also evaluate the transition probability rates of the detectors when they are switched on for a finite time interval with the aid of a Gaussian switching function. We begin by examining the response of a single detector before we go on to consider the case of two entangled detectors. As we shall see, working in (2+1) spacetime dimensions makes the computations of the transition probability rates of the detectors relatively simpler. We find that the cross transition probability rates of the two entangled detectors can be comparable to the auto transition probability rates of the individual detectors. We discuss specific characteristics of the response of the entangled detectors for different values of the parameters involved and highlight the effects of the thermal bath as well as switching on the detector for a finite time interval.

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Gravitational Waves / 97

Multi-band Extension of the Wideband Timing Technique

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The wideband timing technique enables the high-precision simultaneous estimation of Times of Arrival (ToAs) and Dispersion Measures (DMs) while effectively modeling frequency-dependent profile evolution. We present two novel independent methods that extend the standard wideband technique to handle simultaneous multi-band pulsar data incorporating profile evolution over a larger frequency span to estimate DMs and ToAs with enhanced precision. We implement the wideband likelihood using the libstempo python interface to perform wideband timing in the tempo2 framework. We present the application of these techniques to the dataset of fourteen millisecond pulsars observed simultaneously in Band 3 (300 - 500 MHz) and Band 5 (1260 - 1460 MHz) of the upgraded Giant Metrewave Radio Telescope (uGMRT) as a part of the Indian Pulsar Timing Array (InPTA) campaign. We achieve increased ToA and DM precision and sub-microsecond root mean square post-fit timing residuals by combining simultaneous multi-band pulsar observations done in non-contiguous bands for the first time using our novel techniques.

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Classical & Quantum Gravity / 98

Rindler trajectories and Rindler horizons in the Schwarzschild spacetime

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We investigate the generalised radial Rindler trajectories and their corresponding Rindler horizons in the background of the Schwarzschild spacetime. In a curved spacetime, a covariant definition for Rindler trajectories is provided in terms of the generalised Letaw-Frenet equations. A generalized Rindler trajectory remains linearly uniformly accelerated throughout its motion with constant scalar curvature and vanishing torsion and hypertorsion. Interestingly, we arrive at a bound on the magnitude of acceleration for Rindler trajectories such that, for acceleration greater than the bound value, the Rindler trajectory always falls into the black hole and the distance of closest approach for the trajectory to turn away from the black hole is always greater than the Schwarzschild radius for all finite boundary data. We further investigate the past and future Rindler horizons using the analytical solutions for the trajectories and discuss their features.

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Classical & Quantum Gravity / 99

Extra dimension(s) of vanishing proper length: A non-Einsteinian phase in gravity and the implications

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A dynamical theory of gravity based on an extra dimension of vanishing
proper length is introduced and explored. Unlike the Kaluza-Klein framework, this formulation is free of an infinite tower of higher eigenmodes, and the fifth dimension cannot be detected in principle. The associated theory emerging from this new extra dimensional formulation in vacuum has a number of implications. We discuss these, in particular in the context of dark matter problem, non-Einsteinian black hole
solutions and cosmology. We also show that this formulation leads to a unique theory of quadratic curvature gravity (effective 4d Einstein-Gauss-Bonnet theory) which does not involve any singular limit such as D->4. [Based on: S. Sengupta, JCAP 02, 2022, 020 (2022),
S. Sengupta, PRD 101, 104040 (2020)]

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Classical & Quantum Gravity / 100

Role of the Unruh effect in Bremsstrahlung

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We demonstrate an equivalence between the Minkowski photon emission rate in the inertial frame for an accelerating charge moving on a Rindler trajectory with additional transverse drift motion and the combined Rindler photon emission and absorption rate of the same charge in the Rindler frame in the presence of the Davies-Unruh thermal bath. We further show that the equivalence can be extended for the Bremsstrahlung emitted by the same charge as calculated using the machinery of classical electrodynamics. We then generalise the equivalence for the case of accelerating charges moving on a Rindler trajectory with additional arbitrary transverse motion. We discuss the related issues and experimental implications.

Reference :

K. Paithankar and S. Kolekar, Phys. Rev. D 101, 065012 (2020).

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Classical & Quantum Gravity / 101

Energetics of a self-gravitating quantum system of charged particles

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The General Theory of Relativity(GTR), Quantum Field Theory(QFT) and Newtonian Quantum Gravity(NQG) are three alternative approaches to study Full Quantum Gravity(FQG). We investigate a system of self-gravtitating fermionic particles with small but significant charges using the NQG model. We derive the equation for ground state energy by adding the energy resulting from charges to the total energy and using uncertainty relation. Then incorporating special relativistic effects, we derive the radius of a non-singular charged compact object. We show an intriguing comparison

between our result and the Reissner-Nordstorm black hole obtained from GTR. We also explore the additional results like Hawking temperature and Buchdahl limit.

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Astrophysical Relativity / 102

Spectral energy distributions for transonic accretion flow in non-Kerr spacetime

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The study of accretion flow for astrophysical sources like active galactic nuclei (AGNs), black hole X-ray binaries (BHXRBs), etc., is essential to understand their spectral features. Nowadays, theorists hugely focused on the alternative gravity theory to explain some distinctive observational results from the usual Kerr BH. One such emerging non-Kerr spacetime is the Johannsen-Psaltis (JP) metric, which is described by a deformation parameter in addition to the mass and spin of BH. Also, based on spacetime parameters in JP metric, the central object can become a BH or naked singularity (NS). However, isolating BH and NS objects by the accretion disc theory is very challenging. The disparity between the disc properties around these objects has been reported in the literature. But, no one considers the transonic accretion flows, which are yet to be explored. Motivated by this, we explore the spectral properties of accretion disc around BH and NS objects by studying the transonic accretion flow in the JP non-Kerr background. To do this, we numerically solve the energy and momentum equations under the framework of general relativistic hydrodynamics. We find all classes of accretion solutions in the parameter space of the flow energy and angular momentum. Then, we calculate corresponding disc luminosity (L) and spectral energy distributions (SEDs) by considering thermal bremsstrahlung emission. It is observed that I-type solutions generate high L and SEDs compared to the remaining solutions for both BH and NS models. Moreover, for BH model, SEDs for O and A-type solutions significantly differ from W and I-type solutions, especially for low energy accretion flow. On the other hand, for NS model, SEDs for different accretion solutions are identical in the whole parameter space. Most importantly, from a comparative study between the SEDs at a given flow parameters, we find that a NS object can produce a higher luminous power spectrum than a BH. These results open a window to find the nature of central singularities through the spectral analysis of accretion disc.

Based on the works: 1. arXiv:2308.12839; 2. Phys. Dark Univ. 37 (2022) 101120

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Classical & Quantum Gravity / 103

Soft Graviton Theorem and Gravitational Memory Effect at Finite Temperatures

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We study the finite temperature effects on the soft graviton theorem and the gravitational memory effect using the thermofield dynamics formalism. The soft factor depends on the nature of the scatterers at finite temperatures. Thus, the universal behaviour of the soft factor is lost. However, the universality in the scattering cross-section of the soft processes is observed at low temperatures. Further, we obtain the gravitational memory operator and its action on the asymptotic out-state using the soft graviton theorem. We observed that the memory effect depends on the nature of the particles responsible for the gravitational radiation at finite temperatures. The soft graviton theorem and the gravitational memory effect at finite temperatures are consistent with their zero-temperature counterparts.

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Astrophysical Relativity / 104

Effects of modified gravity on stability and age of white dwarfs

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This abstract is based on our recent papers PRD 105 (2022) 024028 and PRD 107 (2023) 044072. Recent observations of several peculiar over- and under-luminous type Ia supernovae infer indirect evidences for the violation of the Chandrasekhar mass-limit by suggesting the existence of super- and sub-Chandrasekhar limiting mass white dwarfs (WDs). In an attempt to explain these phenomena in the context of general relativistic extensions, we study them in $f(R)$ gravity. We obtain the super- and sub-Chandrasekhar limiting masses as well as the dynamical instability criteria for WDs in the given gravitational theory. In my presentation, I'll show that the conventional stability condition $\partial M/\partial \rho_c > 0$ with M being the WD's mass and ρ_c central density, is also valid in modified

gravity. Moreover, I'll discuss that the underlying gravity model plays a crucial role in determining the internal properties, such as specific heats, Debye temperature, etc. Thereby, I'll demonstrate that a modified gravity inspired WD can have much lesser cooling age than a conventional WD.

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Gravitational Waves / 105

Tidal heating as a direct probe of Strange matter inside Neutron stars

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The cores of neutron stars (NS) reach densities several times the nuclear saturation density and could contain strangeness containing exotic particles such as hyperons. During the binary inspiral, viscous processes inside the NS matter can damp out the tidal energy induced by the companion and convert this to thermal energy to heat up the star. In this work, we demonstrate that the bulk viscosity originating from the non-leptonic weak interactions involving hyperons is several orders of magnitude higher than the standard neutron matter shear viscosity in the relevant temperature range of $10^6 - 10^9$K and for heavier mass NSs ($M \geq 1.6 M_\odot$) that contain a significant fraction of hyperons in their core, the bulk viscosity can heat up the stars upto $0.1 - 1$ MeV before the final merger. We also show that this "tidal heating" process introduces a net phase shift in the order of $0.1 - 0.5$ rad in the gravitational wave (GW) signal that can potentially be detected using current and future generation GW detectors. Such a detection would be the first direct confirmation of the presence of hyperons inside the NS core, having a great significance for the study of dense matter under extreme condition.

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Gravitational Waves / 107

Gear-up for the Action Replay: Leveraging Lensing for Enhanced Gravitational-Wave Early-Warning

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Pre-merger gravitational-wave (GW) sky-localisation of binary neutron star (BNS) and neutron star black hole (NSBH) coalescence events, would enable telescopes to capture precursors and electromagnetic (EM) emissions around the time of the merger. We propose an astrophysical scenario that could provide early-warning times of hours to days before coalescence with sub-arcsecond localisation, provided that these events are gravitationally lensed. The key idea is that if the BNS/NSBH is lensed, then so must the host galaxy identified via the EM counterpart. From the angular separation of the lensed host galaxy images, as well as its redshift and the (foreground) lens redshift, we demonstrate that, \response{for galaxy-scale lenses}, we can predict the {\bf time delays/arrival time differences} assuming a standard lens model. We further assess the feasibility and benefits {\bf of lensing as a tool for early-warning} in various GW observing runs of the LIGO-Virgo-Kagra network, including Voyager, and the third generation network. To that end, we study the effect of limited angular resolution of the telescopes on our ability to predict the time delays. We find that with an angular resolution of $0.05''$, we can predict time delays of > 1 day with 1σ error-bar of $\mathcal{O}$(hours) at best. We also construct realistic time delay distributions of detectable lensed BNSs/NSBHs to forecast the early-warning times we might expect in the observing scenarios we consider.

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Classical & Quantum Gravity / 108

Evolution of Universe in κ-deformed Non-commutative space-time

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Quantum gravity has been studied using various approaches and all of these approaches introduce a fundamental length scale in the theory. Non-commutative space-time is an approach which incorporates this fundamental minimum length scale naturally and provides a testing ground to build quantum gravity models. Thus, it is of paramount interest to study how non-commutative space-time will affect the cosmological models.

In this work, we investigate the evolution of the universe in κ-deformed space-time, a non-commutative space-time which is the underlying space-time associated with doubly special relativity as well as that of certain quantum gravity models.
This is done by adapting the Newtonian cosmological framework to κ-space-time. We obtain the modified Friedmann equations, valid up to the first order in the deformation parameter, using generalized energy conservation equation and generalized first law of thermodynamics to κ-deformed space-time. We find the temporal evolution of the scale factor in the cases of radiation-dominated, matter-dominated, and vacuum (energy) dominated worlds by analyzing these deformed equations. We illustrate that the non-commutativity of space-time modifies the rate of change of the scale factor in each of the three cases and that this rate depends on the sign of the deformation parameter. We

take out this research for two distinct realizations of
non-commutative space-time. We also argue in both cases for the presence of bounce in the evolution of the universe.

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Cosmology / 110

Ultra-low mass primordial black holes in the early universe can explain the PTA signal

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Ultra-low mass primordial black holes (PBHs), which evaporate far before Big Bang Nucleosynthesis (BBN), are unconstrained to dominate the energy density of our universe for a short duration. We analyze the stochastic gravitational wave background (SGWB) signals from the domination of ultra-low mass PBHs to explain this recent discovery of SGWB from Pulsar Timing Array collaborations at nanohertz frequencies. This scenario requires a relatively broad peak in the power spectrum of scalar perturbations from inflation with a spectral index in a narrow range of 1.45 to 1.6. The resulting PBH population would have mass around 10^8g, and the initial abundance β_f lies between 10^{-10} and 10^{-9}. We find strong Bayesian evidence that for NANOGrav 15-year data and IPTA data release-2, this explanation is preferred by the data over the generic model where supermassive black hole binaries (SMBHBs) are considered as the source. Though these very light PBHs would decay before BBN, upcoming third-generation terrestrial laser interferometers like the Einstein Telescope (ET) can test the model by observing the GW spectrum produced during the formation of the PBHs. Also, the scalar power spectra associated with our scenario will be within the reach of PIXIE probing CMB spectral distortions.

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Gravitational Waves / 111

Testing of general relativity at the fourth post-Newtonian order

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Gravitational-wave observations are unique means to test general relativity (GR) in the strong-field regime. Parametrized tests of post-Newtonian theory have been very efficient in testing GR in the inspiral phase of compact binary dynamics. In this test, one introduces deformation coefficients at each post-Newtonian order in the inspiral phase of the gravitational wave which by definition are zero in GR. Gravitational wave data is used to obtain posterior distribution on these phase deformation coefficients and consistency of them with zero is assessed.
Recently, the post-Newtonian expansion of the non-spinning inspiral phase of a binary has been extended to 4 PN and 4.5 PN order. These higher PN terms carry information about new physical effects like the tail-of-memory, spin-quadrupolar tails and quartic-tail effects. They help probe the non-linear nature of gravity and take the PN expansion phase ever closer to the high-frequency regime. In our work, we propose extending the parameterized test to include these newly computed PN orders, introducing four additional deformation coefficients. We compute the bounds on these new parameters through the Fisher matrix on these deformation coefficients using a modified IMRPhenomD waveform for the noise sensitivity of AdvLIGO and CE. We conclude that there is the possibility of measuring these deformation coefficients with good precision through GW observations with the present and next-generation GW detectors.

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Cosmology / 112

Short Gamma Ray flares from cosmic string wakes.

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There are several observed Gamma Ray flares which are of short duration which cannot be explained by the conventional models of black holes, active galactic nuclei and neutron stars. Some of these also correspond to high redshift values. The nature of the bursts indicate an extremely compact emission region typically associated with magnetic reconnections. We conjecture that these magnetic reconnections could have occurred in the magnetized wakes of cosmic strings. We show that the narrow width of the cosmic string wake would result in fast reconnection of the misaligned fields produced due to the Biermann mechanism. Such fast reconnections would give rise to short Gamma ray flares in the cosmic string wakes.

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Classical & Quantum Gravity / 113

Charged Scalar Hair on Reissner-Nordström Black Holes

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The Israel-Carter theorem (famously known as "no-hair theorem") puts a restriction on the existence of parameters other than mass, electric charge, and angular momentum of a black hole. On the other hand, Bekenstein showed the possibility of existence of scalar hair by considering a massless conformal scalar field non-minimally coupled to gravity. The Einstein-Maxwell-scalar solution for a static spherically symmetric metric was found to be unbounded at the horizon. Bekenstein's study established scalar charges, like other parameters allowed by the no-hair theorem, to be also admissible in black hole solutions. There also exists a new family of Einstein-Maxwell-scalar field models where the scalar field is non-minimally coupled with the Maxwell field.

In the present work, we consider a novel Einstein-Maxwell-scalar model where an electrically charged scalar field is gauge-coupled with the Maxwell field, generating interaction of the charge e with the electromagnetic field, described by the action

S=$\int d^4x\sqrt{-g}\left[\frac{R}{16\pi G}-(D_\mu\phi)^*D^\mu\phi-\mu^2\phi^*\phi-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}\right]where\mathrm{D}_\mu=\partial_\mu+ieA_\mu$ is the covariant derivative, μ is the mass of the scalar field, and $F_{\mu\nu}=\partial_\mu A_\nu-\partial_\nu A_\mu$, with A_μ the vector potential.

Detailed solution of this Einstein-Maxwell-scalar model in the background of a static spherically symmetric Reissner-Nordstr\"om spacetime yields a charged hairy black hole solution. A stability analysis shows that this charged hair is stable against time-dependent perturbations.

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Classical & Quantum Gravity / 114

Maximal volume of a black hole in 2+1 dimensions

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While the area of a black hole is a well defined quantity given by the killing vectors, the enclosed volume depends on the choice of slicing the coordinate system. In this talk we will present the idea of the maximal volume for a family of black holes in 2+1 dimensions. We will demonstrate that the primary contribution to the maximal volume comes from what we call the steady state radius, which depends on the black hole parameters and the AdS length scale. We will further compute the entropy for a field living on this maximal hypersurface in the near extremal limit and show that it is proportional to the horizon entropy.

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Classical & Quantum Gravity / 115

A master equation for gravitational wave memory

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A permanent offset caused by the passage of gravitational waves, known as the memory effect, is under active research in both theoretical and observational aspects of gravitational physics. Due to its relation to asymptotic symmetries and soft theorems, the memory effect has received considerable attention for asymptotically flat spacetimes in general relativity (GR). As a result, the memory effect can only be effectively achieved for a limited class of geometries. We use the covariant approach of splitting the GR field equations into 1+1+2 form to generalize this for a larger class of spacetimes. We show that the covariant approach allows us to obtain a master equation that describes gravitational wave memory in a more general class of spacetimes. A brief overview of the covariant 1+1+2 formalism, the ensuing calculations, and some examples of spacetime geometries in which this approach has been applied will be presented in this talk.

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Cosmology / 116

Inflationary Cosmology with a scalar-curvature mixing term $\xi R\phi^2$

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We use the PLANCK 2018 and the WMAP data to constraint inflation models driven by a scalar field ϕ in the presence of the non-minimal scalar-curvature mixing term $\frac{1}{2}\xi R\phi^2$. We consider four distinct scalar field potentials $\phi^p e^{-\lambda\phi},\ (1-\phi^p)e^{-\lambda\phi},\ (1-\lambda\phi)^p$ and $\frac{\alpha\phi^2}{1+\alpha\phi^2}$ to study inflation in the non-minimal gravity theory. We calculate the potential slow-roll parameters and predict the scalar spectral index n_s, the tensor-to-scalar ratio r {\bf and the non-Gauissianity parameter f_{NL}} in the parameters (λ, p, α) space of the potentials. We have compared our results with the ones existing in the literature, and this indicates the present status of the non-minimal inflation after the release of the PLANCK 2018 data.

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Classical & Quantum Gravity / 117

Some observational aspects of black holes in degenerate Einstein Gauss-Bonnet gravity

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In this study, we analyse the quasinormal modes of black holes occurring within the framework of degenerate gravity. We investigate the properties of the asymptotically flat spacetimes introduced recently in [JCAP 02(2022)02] which are solutions to the degenerate Einstein Gauss-Bonnet(dEGB) action and belong to a much larger class of solutions which include cosmological constant. These solutions can be classified into two distinct branches akin to Einstein Gauss-Bonnet(EBG) gravity. However, unlike the EBG solutions, both the branches of dEGB are well-defined asymptotically. The negative branches from both theories can be identified for the asymptotically flat case. We observe black holes for specific ranges of the Gauss-Bonnet coupling parameter and perform a stability analysis by calculating the quasinormal modes (QNMs) under scalar wave propagation. Finally, the ringdown spectrums of our black holes are compared with their GR counterparts.

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Classical & Quantum Gravity / 118

The effect of massive gravitons on wormhole formation in ghost-free gravity

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In my talk, I will explore the intriguing aspects of ghost-free dRGT massive gravity, which introduces two additional characteristics scales, γ and Λ, representing non-zero graviton masses. I will delve into how these parameters influence wormhole solutions, ultimately leading to a loss of asymptotic flatness near the throat region. This inconsistency arises from the induced repulsive effects of gravity within massive gravitons, exerting a significant influence on spacetime geometry and disrupting curvature. Furthermore, the discussion will encompass the potential for wormhole models featuring ordinary matter at the throat, satisfying all energy conditions, while the massive gravitons serve as a source for negative energy density. This investigation sheds light on the nature of gravity and complex interplay between graviton masses and wormhole dynamics.

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Cosmology / **119**

Cosmological perturbation in Einstein frame and Jordan frame for two-field model

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In this work, we try to compare the cosmological perturbation in the Einstein frame and the Jordan frame for the two-field model. Here we match the metric potentials in both frames to find the equivalence. Further, we evolve the perturbations numerically for selected models.

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Cosmology / **120**

Consistency of loop quantum cosmology with the cosmic microwave background bispectrum

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Primordial non-Gaussianity has set strong constraints on models of the early universe. Studies have shown that Loop Quantum Cosmology (LQC), which is an attempt to extend inflationary scenario to planck scales, leads to a strongly scale dependent and oscillatory non-Gaussianity. In particular, the non-Gaussianity function $f_{\rm NL}(k_1,\, k_2,\, k_3)$ generated in LQC, though similar to that generated during slow roll inflation at small scales, is highly scale dependent and oscillatory at long wavelengths. In this work, we investigate the imprints of such a primordial bispectrum in the bispectrum of Cosmic Microwave Background (CMB). Inspired by earlier works, we propose an analytical template for the primordial bispectrum in LQC. We write the template as a sum of strongly scale dependent and oscillatory part, which captures the contribution due to the bounce, and a part which captures the scale invariant behaviour similar to that of slow roll. We then compute the reduced bispectra of temperature and electric polarisation and their three-point cross-correlations corresponding to these two parts. We show that the contribution from the bounce to the reduced bispectrum is negligible compared to that from the scale independent part. Thus, we conclude that the CMB bispectra generated in LQC will be similar to that generated in slow roll inflation. We conclude with a discussion of our results and its implications to LQC.

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Gravitational Waves / 121

Gravitational Waves from Magnetized Neutron Stars in Eccentric Orbits

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We investigate the influence of tidal deformability and strong magnetic fields on the generation of gravitational waves during the inspiral of binary neutron stars in eccentric orbits. Although the current number of identified neutron stars exhibiting strong magnetic fields (10^{14-15} G) remains limited, the maximum allowed magnetic fields in these stars is 10^{18} G. Neutron star binaries formed via dynamical capture could possess strong magnetic fields and sizable eccentricity at the late inspiral stage. It is thus imperative to undertake investigations on these systems and the dominant physical processes at play in them. Strong magnetic fields can govern the orbital dynamics by inducing additional tidal deformation in their companion (corrections to tidal love number), radiating some orbital energy (magnetic dipole in motion), and inducing effects of attraction/repulsion based on the relative orientation of the magnetic axes. Prior studies have investigated the individual influence of these factors on gravitational waves. However, our research takes into account the combined effects of magnetic fields, tidal deformability, and orbital eccentricity. In order to quantify these impacts, we conduct an analysis of the accumulated cycles observed in gravitational waves while also evaluating the rates at which energy is lost as a result of electromagnetic and gravitational radiation.

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Cosmology / 122

Non-thermal moduli production during preheating in α-attractor inflation models

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Abstract: Production of gravitationally coupled light moduli fields must be suppressed in the early universe, so that its decay products do not alter Big Bang Nucleosynthesis (BBN) predictions for light elements. On the other hand, the moduli quanta can be copiously produced non-thermally during preheating after the end of inflation. In this work, we study the production of moduli in the α-attractor inflationary model through parametric resonances. For our case, where the inflationary potential at its minimum is quartic, the inflaton field self-resonates, and subsequently induces large production of moduli particles. We find that this production is suppressed for small values of α. Combining semi-analytical estimation and numerical lattice simulations, we infer the parametric dependence on α and learn that α needs to be less than 10^{-8} m_{pl} to be consistent with BBN. This in turn predicts an upper bound on the energy scale of inflation and on the reheating temperature. Further, it implies an extremely small tensor-to-scalar ratio that quantifies the amplitude of primordial gravitational waves over large scales.

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Classical & Quantum Gravity / 123

Naked singularity in 4D Einstein-Gauss-Bonnet novel gravity: Echoes and instability

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The stability of an asymptotically flat, static, spherically symmetric naked singularity spacetime in the novel four-dimensional Einstein-Gauss-Bonnet (EGB) gravity has been studied. Such a naked singularity is obtained from the four-dimensional EGB black
hole for large enough values of the coupling parameter. The stability and
the response of the spacetime are studied against the perturbations by test scalar, electromagnetic and Dirac

fields, and the time evolution of these perturbations was observed numerically. Distinct echoes were seen in the time-domain profiles for $l = 1$ modes of scalar,
electromagnetic perturbation, and $l = 0, 1$ modes of Dirac perturbation. However, as the coupling constant increases, the echoes align, and the quasinormal
mode structure of the 4D-EGB naked singularity-spacetime becomes prominent. For higher values of the
multipole number, the spacetime becomes unstable, thereby restricting the parameter space for the coupling
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Astrophysical Relativity / 124

Superradiant driven evoulution of Active Galactic Nuclei

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Superradiance in spinning black holes is an intriguing phenomenon through which the black hole loses its energy and angular momentum over time. In this work, we explore the transient effect of the superradiance process in active galactic nuclei (AGN). We aim to see the spin-down effect on the accretion disk using an analytic model named Shakura Sunayev. Considering this model, we show how the accretion disk characteristics such as the total flux, temperature, density, pressure, height, and optical depth evolve with time. We then obtain the evolution of the AGN spectrum with time due to superradiance.

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Classical & Quantum Gravity / 125

Dyonic Kerr-Sen black holes revisited: shadow profiles and consequences

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Black holes with dyonic charges in Einstein-Maxwell-dilaton-axion supergravity theory are revisited in the context of black hole shadows. We consider static as well as rotating (dyonic Kerr-Sen) black holes. The matter stress-energy tensor components, sourced by the Maxwell, axion and dilaton fields satisfy the standard energy conditions. The analytical expressions for the horizon and the shadow radius of the static
spacetimes demonstrate their dependence on $P^2 + Q^2$ (P, Q the magnetic and electric charges, respectively) and the mass parameter M.
The shadow radius lies in the range $2M < R_{shadow} < 3\sqrt{3}M$ ($G = 1,\, c = 1$) and there is no stable photon orbit outside the horizon. Further, shadows cast by the rotating dyonic Kerr-Sen black holes are studied and compared graphically with their Kerr-Newman and Kerr-Sen counterparts. Deviation of the shadow boundary is prominent with the variation of the magnetic charge, for the relatively slowly rotating dyonic Kerr-Sen spacetimes. We test any possible presence of a magnetic monopole charge in the backdrop of recent EHT observations for the supermassive black holes M87* and Sgr A*. Deviation from circularity of the shadow boundary (ΔC) and deviation of the average shadow radius from the Schwarzschild shadow radius (quantified as the fractional deviation parameter δ) are the two observables used. The observational bound on ΔC (available only for M87*) is satisfied for all theoretically allowed regions of the parameter space and thus cannot constrain the parameters. The observational bound on δ available for Sgr A* translates into an upper limit on any possible magnetic monopole charge linked to Sgr A* and is given as P
$lesssim 0.873M$.
Constraints on P obtained from other astrophysical effects, such as the observed temperature of clouds of warm ionized medium (WIM) in the Milky Way and the Parker bound on the flux of magnetic monopoles, are however expected to be far more stringent though rigorous analyses along these lines is lacking. Future refined imaging (shadow) observations
will surely help in improving the bound on P arrived at here.

Reference: S. Jana and S. Kar, Phys. Rev. D **108**, 044008 (2023).

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Cosmology / **126**

Loop-level contributions of primordial non-Gaussianities and their observational consequences

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Abstract :
Primordial non-Gaussianity arising from inflationary models is a unique probe of non-trivial dynamics of the inflaton field and its possible interactions with other fields. However, direct observational constraints on the magnitude of non-Gaussianities are relatively weaker compared to those on scalar and tensor power spectra. In my talk, I shall discuss the indirect constraints one can obtain for non-Gaussianities through their loop-level contributions to the power spectra, using two

specific approaches. The first is a quantum field theoretic approach, through which I shall present the impact of loop-level contribution due to the quartic-order action on scalar power in models of inflation involving a brief epoch of ultra slow roll 1. These models are widely debated in the literature in the context of primordial black hole formation and our result addresses certain crucial issues regarding perturbativity of the model. The second is a classical approach, by which I shall illustrate the imprints of contributions arising from cubic-order action on observables namely, the cosmic microwave background and the scalar-induced secondary gravitational waves [2,3]. Through these results using different approaches and on different observables, I shall try to convince that the non-Gaussian contributions of various orders can seriously affect the structure and amplitude of the power spectra and hence they warrant revising of existing fits of models against data.

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Classical & Quantum Gravity / 127

Analyzing quantum gravity spillover in the semiclassical regime

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The uneasiness associated with the notion of a quantum state of a universe presents challenges not only on the interpretational front but on the phenomenological front as well. A reductionist approach that somewhat circumvents this issue is to consider sharply peaked states on the classical trajectory and introducing a quantum-corrected spacetime arising from a quantum gravity model. This procedure assumes that the expectation value of the metric variable for these states effectively captures the relevant quantum gravity subtleties in the semiclassical regime. We investigate the viability of this assumption and look for the signatures of ordering ambiguity in the case of a flat-FLRW universe with perfect fluid. A generalized ordering scheme for the Hamiltonian is considered, and the implication of different ordering choices on the observables is investigated. We first check the consistency of this quantum-corrected geometry by comparing the geometric quantities calculated for this metric with their expectation values. In the limit of sharply peaked states, the expectation value of the geometric quantities matches their semiclassical counterparts. Furthermore, we check the dependence of the expectation value of the observables on the ordering of the Hamiltonian. We demonstrate that the operator ordering ambiguity leaves no imprint on the states sharply peaked on the classical trajectory, leading to a consistent semiclassical picture for a quantum-corrected spacetime. Therefore, a reductionist viewpoint on the quantum nature of the universe leads to an ambiguity-free quantum theory.

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Cosmology / 128

An effective field theory approach to understand the primordial magnetogenesis

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At all Universe scales, there is a detectable amount of magnetic field. This observed magnetic field has several probable origins, including the possibility that it was produced during the early Universe. There are several models for primordial magnetogenesis, and if the inflationary background is taken into account, breaking conformal symmetry is required to generate a sufficient amount of magnetic field. The conformal symmetry breaking is introduced either by new couplings between the electromagnetic field and the inflaton field or by adding higher derivative terms to the theory. To unify these different approaches in the literature, we propose an Effective Field Theory (EFT) approach, in which EFT parameters describe the magnetogenesis in the early Universe, and different choices of parameters correspond to different models. The approach also shows that conformal breaking alone is not a sufficient criterion for generating primordial magnetic fields.

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Astrophysical Relativity / 129

Mass loss from relativistic magnetized accretion disc around rotating black holes

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We investigate the ejection mechanism in a relativistic, magnetized, viscous, advective accretion flow around a rotating
black hole (BH) in presence of radiative cooling. Considering the accretion flow to be threaded by toroidal magnetic fields, we self-consistently solve the coupled governing equations that describe the accretion-ejection scenario in terms of the dissipation parameters, namely viscosity (α), accretion rate ($\dot{m}$) and plasmaβ. With this, we compute the outflow rate ($R_{\dot{m}}$) defined as the ratio of outflow to inflow mass flux and find that $R_{\dot{m}}$ increases as the magnetic activity inside the disk is

increased. Further, we observe that nearly 30% (24%) accreted matter is ejected from a magnetized disc (inner edge plasma-$\beta \sim 30$) around a rapidly (weakly) rotating black hole of spin $a_{\rm k} = 0.99$ (0.0). Finally, we discuss the astrophysical implications of this formalism in explaining the jet kinetic power commonly observed in black holes systems.

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Classical & Quantum Gravity / 130

Compactified Hyperboloidal Evolution in Numerical Relativity

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One of the challenges in numerical relativity is to include future null infinity in the computational domain with a well-posed formulation. Success will not only enable us to evolve any system of astrophysical interest, e.g. binary black holes and extracting the gravitational wave signal at future null infinity, with any desired accuracy, but also help in studying various phenomena of fundamental interest. One proposal is to use hyperboloidal slices. In this talk, I shall give an alternative approach to numerical relativity that uses hyperboloidal slices, present our ongoing efforts for obtaining a well-posed formulation of the Einstein Field Equations on these slices, and finally propose numerical schemes that assure stability and convergence for linear hyperbolic systems on these slices for long times. A natural extension will be to generalize these numerical methods to full Einstein Field Equations with suitable initial data.

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Astrophysical Relativity / 131

Investigation of Black Holes in Analogous and Astrophyscial Regimes

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We explore the behaviour of barotropic and irrotational fluids with a small viscosity under the effect of first-order acoustic perturbations. We discuss, following the extant literature, the difficulties in

gleaning an acoustic geometry in the presence of viscosity. In order to obviate various technical encumbrances, when viscosity is present, for an extraction of a possible acoustic geometry, we adopt a method of double perturbations, whereby dynamical quantities such as the velocity field and underlying potential undergo a perturbation both in viscosity and in an external acoustic stimulus. The resulting perturbation equations yield a solution which can be interpreted in terms of a generalised acoustic geometry, over and above the one known for inviscid fluids. Once the black hole's physics is understood in a laboratory-like setting, we embark on understanding the phenomenology of black holes in a astrophysical setting. We explore various properties of astrophysical black holes and their associated accretion disks. Using numerical and simulation techniques, we evaluate the luminosity of radiation coming from accretion disks and the corresponding spectra for black holes with different parameters like plasma-β of the accretion disk, mass and spin of the black hole. These results are used to interpret the dependence of spectra and luminosity on the aforementioned parameters and also to explain the behaviour and constituent details of anomalous X-ray sources like ultraluminous X-ray sources etc.

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Cosmology / **132**

Effects of Z3 symmetric dark matter models on global 21-cm signal

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$\mathbb{Z}_3$ symmetric dark matter models have demonstrated remarkable potential in addressing various (astro-)particle physics challenges. In this presentation, I will discuss the diverse ways in which this model can successfully explain the different cosmological observations. We have considered two such promising models: semi-annihilating dark matter (SADM) and Co-SIMP $2 \to 3$ interaction, and investigated their effects on the global 21-cm signal. We found that SADM model has a lesser impact on explaining the EDGES dip, while the Co-SIMP model can successfully explain the absorption dip measured by EDGES experiment by virtue of it's intrinsic cooling effect. Additionally, given the ongoing debate between EDGES and SARAS 3 experiments regarding the global 21-cm signal, we demonstrate that our chosen models can still remain viable in this context, even if the EDGES data requires reassessment in future. Furthermore, we have explored the impacts of these models during the Dark Ages and conducted a consistency check with CMB and BAO observations using the Planck 2018(+BAO) datasets.

This talk is based on our recent work: arXiv:2308.04955 .

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Astrophysical Relativity / 133

Impact of the net vertical magnetic field on thick accreting torus around black holes

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We study a global, two-dimensional (2D) general relativistic magnetohydrodynamics (GRMHD) simulation of an accreting torus around a non-rotating black hole. Our initial configuration is threaded with a net-vertical magnetic flux. This study investigates the effects of initial field strength onto the disk dynamics. We find that the initial net vertical magnetic field significantly enhances its amplification over a few dynamical time scales. The behavior of MRI turbulence is regulated by the initial plasma-β (i.e., ratio of gas-to-magnetic pressure) at the inner edge of the torus. Therefore, we perform simulations with different β spanning from weakly-to-strongly magnetized cases, $\beta^{\rm in}_{\rm edge} = 2800, 700, 350$, respectively. The shear flow amplifies a strong toroidal magnetic field within the torus via the dynamo process. Consequently, the magnetic fields are sufficient to provide magnetic pressure support for the elevated accretion, $z/R \sim 0.2$. Furthermore, we identify two more regions, (1) gas-pressure dominated dense mid-plane, and (2) moderately magnetized low dense polar region. Finally, over the duration of our simulations, we find an evidence that the net-flux attains a quasi-steady state and can stably maintain an inner disk with surface accretion.

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Cosmology / 134

A semi-analytical treatment of coupled CDM-massive neutrino perturbations in diverse cosmological backgrounds

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Massive neutrinos are well-known to cause a characteristic suppression in the growth of structures at scales below the neutrino free-streaming length. A detailed understanding of this suppression is essential in the era of precision cosmology we are entering into, enabling us to better constrain the total neutrino mass and possibly probe LCDM cosmological model(s) and beyond. In this talk, I will give a semi-analytical treatment to obtain and interpret solutions at the linear scales of the two-fluid system (CDM+ massive neutrino) coupled via gravity treating neutrino mass fraction as a perturbative parameter with redshift dependent-neutrino free-streaming length. I will also discuss the effects of different cosmological backgrounds in the fluid model and their implications on observations.

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Astrophysical Relativity / 135

Probing the Accretion/Ejection Geometry of X-ray Binaries Using Spectro-Polarimetry Study

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It is widely postulated that the high-energy radiation in X-ray binary systems arises from the upscattering of photons originating from the accretion disk, likely due to interactions with an electron cloud or a corona. Nevertheless, our understanding of the exact geometry and orientation of these coronal structures remains limited. In recent times, spectro-polarimetry studies have emerged as a powerful tool for unraveling the intricate geometry of material flows within these systems. In this overview, we delve into recent advancements that aim to elucidate critical parameters such as inclination angles and the presence and alignment of scattering regions within X-ray binary systems. These findings carry significant implications for our comprehension of various phenomena, including accretion disk dynamics, the formation of jets, and the interplay between the compact object and its surrounding environment.
Our spectro-polarimetric observations have unveiled intriguing energy-dependent polarization signatures and variations in the degree of polarization corresponding to different spectral states exhibited by X-ray binaries.

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Cosmology / 136

Non-linear joint density-velocity evolution in f(R) theories of modified gravity

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Recent observations have indicated that all is not well with the standard Lambda-Cold-Dark-Matter (LCDM) model of the Universe. Clues that help constrain the modifications to LCDM are hidden in the large scale structure of the Universe. The fractional density and peculiar velocity are the two main variables that are used to characterize this structure. When the perturbations are small, linear theory works well and the density and velocity divergence are proportional. The proportionality

constant, is the 'linear growth factor'which is a sensitive probe of the underlying cosmology and indeed many upcoming observational missions aim to constrain it. However, this linear relation breaks down when the perturbations are of order unity i.e., in the non-linear regime.

The work to be presented, investigates the extension of this relation in the non-linear regime. We will use the spherical top-hat model and examine the evolution of perturbations in the joint density-velocity divergence 'phase-space'. In particular, we will consider the f(R) model of modified gravity with the Hu-Sawicki form as a working example. The equations of motion in f(R) theories are significantly more complicated than the LCDM case and even the simple top-hat model needs to be evolved using a hybrid Lagrangian-Eulerian approach. We find that the results depend sensitively on the ratio of two length scales: the Compton wavelength of the associated scalar field and the width of the top-hat.

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Gravitational Waves / 137

Testing General Relativity in presence of binary eccentricity

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The parametrized post-Newtonian (PN) test of general relativity (GR) currently assumes binary black holes (BBHs) in quasi-circular orbits. However, population simulations predict that a subpopulation of BBHs retain residual eccentricity in the frequency-band of ground-based detectors. To perform robust parametrized tests of GR with eccentric binaries, corrections due to orbital eccentricity need to be taken into account in the waveform. Here, we develop two different waveform parametrizations that capture GR deviations for BBHs in eccentric orbits. In the first parametrization, we introduce deviations in both the circular and eccentric parts of the gravitational-wave phase in a theory agnostic way. The second parametrization is motivated by the periastron advance, a physical effect that is only present in eccentric binaries. BBHs in eccentric orbits have two dynamical frequencies, radial and azimuthal, related via a periastron advance parameter (alpha). GR deviations are parametrized in terms of alpha, with GR recovered In the limit when alpha goes to one. Using these parametrizations, we obtain bounds on deviation parameters in both the ground-based (aLIGO/CE) and space-based (LISA/DECIGO) GW detectors. We find that the best constraint on alpha is obtained with an accuracy of ˜10ˆ-5 in the DECIGO band, complementary to the bound (˜1.5 x 10ˆ-5) obtained via double-pulsar observations. Both parametrizations provide initial steps towards testing GR with eccentric BBHs.

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Classical & Quantum Gravity / 138

Love for an Expanding universe and SdS black holes

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Love numbers of compact objects are a valuable tool in probing gravity at its strong field regime and testing for horizons using Gravitational waves. In this talk, we will discuss the definition of Love numbers for compact objects which are asymptotically deSitter. First, we shall discuss a way of defining Love numbers if the spacetime is not asymptotically flat and an appropriate definition for asymptotically deSitter compact objects. Following this, we will discuss the Love numbers for SdS black holes and obtain their values for the dominant mode of scalar perturbations on a small SdS black hole background up to $\mathcal{O}(H^2M^2)$.

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Classical & Quantum Gravity / 139

Gravitational Red-shift of emitted photons and frame dragging from Bardeen black hole in presence of clouds of string

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An investigation has been done on the gravitational red-shift and blue-shift of photons emitted by time-like geodesics orbiting in the regular Bardeen black hole in the presence of clouds of strings. As the particles/gas are orbiting in a black hole in space-time, they emit light that travels along null geodesics towards the point of detection (observer). In terms of killing vector formalism and first integrals of motion (E and L), the expressions of the redshift and frame dragging have been obtained. The black hole parameters for the redshift of photons ejected from massive particles orbiting in the vicinity of regular black holes are subject to observational constraints. The mass and charge parameters have been calculated in terms of the gravitational red/blue shifts and compared with observational data.
Keywords: Bardeen black hole, Time-like geodesics, Gravitational Red-shift, Frame dragging

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Astrophysical Relativity / 141

Testing the equivalence principle with Blackhole image observations

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Observation of Blackhole shadows by the VLBI Telescopes provides an excellent opportunity to test General Relativity in the strong field regime. One can use these observations to test the fundamental foundations of GR, such as Einstein's equivalence principle. In simple terms, Einstein's equivalence principle refers to simply changing the partial to covariant derivatives of the matter fields. However, this assumes that matter fields (like electromagnetic fields) are minimally coupled to gravity. Thus, any detection of a non-minimal coupling of the electromagnetic field to gravity will imply a violation of the equivalence principle. In this talk, we discuss using the Blackhole image observations to constrain the non-minimal coupling via the Riemann tensor, which is also the leading-order quantum correction to gravity. First, we look at the photon trajectory in Schwarzchild space-time in the presence of the non-minimal coupling. We show that the non-minimal coupling can lead to unstable circular photon orbits, which can be used to constrain the coupling strength from the observed image of the black hole. We will also briefly discuss the effect of the coupling on the photon trajectory in the Kerr space-time, which is more relevant to the upcoming observations of the supermassive black holes by the next-generation VLBI observations.

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Classical & Quantum Gravity / 142

Topology of thermodynamics in R-charged black holes

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Topology of thermodynamics in R-charged black holes
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Abstract
In this presentation, our investigation focuses on the topological aspects of thermodynamics in R-charged black holes across four, five, and seven dimensions. Specifically, the 4D R-charged black hole features four charges, while the 5D and 7D counterparts possess three and two charges, respectively. Within our study, we explore how the charge configuration of these R-charged black holes influences the topological characteristics of their thermodynamics. Within each of these black holes, we systematically examine various charge configurations, calculating the corresponding topological charges associated with critical points. These critical points are subsequently classified as either conventional or novel, guided by the values of their respective topological charges. It's noteworthy that the number and nature of these critical points are contingent upon the charge configuration of the R-charged black holes, regardless of the dimensionality involved. Remarkably, our analysis reveals a consistent total topological charge across all charge configurations in the 4D, 5D, and 7D scenarios, maintaining a constant value of Q=-1. This finding strongly suggests that R-charged black holes in these dimensions share the same thermodynamic topological class. In conclusion, our research underscores that variations in charge configurations do not exert any discernible impact on the topological classification of thermodynamics for R-charged black holes in 4D, 5D, and 7D dimensions.

(This talk is based on a recent work that is published in Physical Review D.)

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Cosmology / 143

Constraints on Dark Matter-Neutrino Interaction from 21-cm Cosmology

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We have done a thorough investigation of the possible effects of interaction between dark matter (DM) and neutrinos during both the reionization and post-reionization epoch. We have constrained the interaction strength using 21 cm Cosmology and found possible deviations from standard, non-interacting ΛCDM scenario. Comparing the results with the existing constraints from present cosmological observations reveals that 21 cm observations are more competent to constrain the interaction strength by a few orders of magnitude. We have also searched for prospects of detecting any such interaction during the reionization epoch using the upcoming 21 cm mission SKA1-Low by doing a forecast analysis and error estimation. In the post-reionization era, we have conducted both Fisher matrix forecast analysis and Markov Chain Monte-Carlo (MCMC) simulations to investigate the constraints on the upcoming 21 cm missions SKA1 and SKA2, as well as galaxy surveys like Euclid. Furthermore, to improve the constraints, we have performed a joint analysis by combining future CMB missions with Large Scale Structure (LSS) experiments. Our analysis reveals that both

SKA2 and the combination of CMB-S4, Euclid, and SKA1 IM2 will impose tighter constraints on the interaction parameters.

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Classical & Quantum Gravity / 144

Gravastar model in Cylindrically Symmetric Space-time and its possible mass limit

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A class of new Gravastar solution is presented here following the Mazur and Mottola model in gravitational Bose-Einstein condensate (GBEC) star in the cylindrically symmetric space-time. A stable gravastar with three distinct regions namely, (i) interior de-Sitter space, (ii) intermediate thin shell with a slice of finite length and (iii) exterior vacuum region. The interior region is characterised by positive energy density and negative pressure ($p = -\rho$), which exerts a repulsive outward force on the thin shell. The thin shell separating the interior and exterior is supposed to be consisting of ultra-relativistic stiff fluid having equation of state $p = \rho$, which satisfies the Zel'dovich's criteria (Y. B. Zel'dovich, Sov. Phys. JETP 14, 1143 (1962) & Y. B. Zel'dovich, Mon. Not. R. Astron. Soc. 160, 1P (1972)). This thin shell, which is considered as the critical surface for the quantum phase transition, replaces both the classical de-Sitter and Schwarzschild event horizons. Flat exterior space-time is achieved though the computation of Kretschmann scalar. The new solution is free from any singularities. The energy density, total energy, proper length, mass and entropy of the shell region are explored in this model. From the consideration of gravitational surface redshift, we have obtained a constraint on the possible numerical value of mass limit (2.714 $M_\odot$ - 3.316 $M_\odot$) for gravastars with different characteristic radii (9.009 Km-11.009 Km). Thus, we have noted singularity free physically viable gravastar solution.

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Classical & Quantum Gravity / 145

Mass limit of strange star in colour flavour locked equation of state and density dependent B parameter

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In this article we have analyzed a class of strange star described in terms of CFL phase equation of state. The results obtained by considering CFL equation of state is then compared with those obtained from MIT bag model equation of state. It is noted that if we consider the CFL phase equation of state in which the quarks are assumed to form cooper pair, the maximum mass of strange star takes value as high as 3.61 $M_{\odot}$ which is higher than the value 2.03 $M_{\odot}$ obtained by considering MIT bag model equation of state for non-interacting quarks. This higher mass limit of strange star in CFL equation of state admits wider range of compact objects such as 4U 1820-30, PSR J1614-2230, PSR J0030+0451, PSR J1903+0327, PSR J0740+6620, PSR J0952-0607 and mass of the companion star in gravitational wave events GW170817 and GW190814. Prediction of radius of few compact objects shows that CFL equation of state admits smaller radius of compact objects than MIT bag equation of state.

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Gravitational Waves / 146

A Bayesian investigation of the neutron star equation-of-state vs. gravity degeneracy

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Despite its elegance, the theory of General Relativity is subject to experimental, observational, and theoretical scrutiny to arrive at tighter constraints or an alternative, more preferred theory. In alternative gravity theories, the macroscopic properties of neutron stars, such as mass, radius, tidal deformability, etc. are modified. This creates a degeneracy between the uncertainties in the equation of state (EoS) and gravity since assuming a different EoS can be mimicked by changing to a different theory of gravity. We formulate a hierarchical Bayesian framework to simultaneously infer the EoS and gravity parameters by combining multiple astrophysical observations. We test this framework for a particular 4D Horndeski scalar-tensor theory originating from higher-dimensional Einstein-Gauss-Bonnet gravity and a set of 20 realistic EoS and place improved constraints on the coupling constant of the theory with current observations. Assuming a large number of observations with upgraded or third-generation detectors, we find that the A+ upgrade could place interesting bounds on the coupling constant of the theory, whereas with the LIGO Voyager upgrade or the third-generation detectors (Einstein Telescope and Cosmic Explorer), the degeneracy between EoS and gravity could be resolved with high confidence, even for small deviations from GR.

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Classical & Quantum Gravity / 147

Perturbing the perturbed: Quasi-normal mode instability in asymptotically de Sitter black holes

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In this talk, we aim to address the question of whether the quasi-normal modes, which represent the characteristic frequencies associated with perturbed black hole spacetimes and are central to the stability of these black holes, are themselves stable. We begin by presenting a general method for transforming to a hyperboloidal coordinate system in both asymptotically flat and asymptotically de Sitter spacetimes. We shall discuss how such a coordinate system effectively captures the dissipative boundary conditions, resulting in a non-self-adjoint differential operator. To fully understand the behaviour of a non-self-adjoint operator, we must study both the spectrum and the *pseudo-spectrum* of such an operator. We shall therefore introduce and explain the relevance of the notion of pseudo-spectrum in black hole physics. We then study the spectrum and the pseudo-spectrum of asymptotically de Sitter black holes numerically using spectral methods. Our analysis demonstrates how external perturbations to the scattering potential cause the quasi-normal modes to deviate from their unperturbed values. Additionally, we also highlight the implications of the instability observed in the fundamental quasi-normal mode on issues like the validity of the strong cosmic censorship conjecture.

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Classical & Quantum Gravity / 149

Thermodynamics of multi-horizon spacetimes

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There exist several well-established procedures for computing thermodynamics for a single horizon spacetime. However, for a spacetime with multi-horizon, the thermodynamics is not very clear. It is not fully understood whether there exists a global temperature for the multi-horizon spacetime or not. Here we show that a global temperature can exist for Schwarzschild-de Sitter spacetime, Reissner-Nordstrom-de Sitter spacetime, and rotating BTZ black hole. This temperature does not coincide with the conventional Hawking temperature related to the outer horizon.

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Gravitational Waves / 150

Direct mapping of tidal deformability to the iso-scalar and iso-vector nuclear matter parameters

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Matter inside a neutron star is composed of nucleons in β-equilibrium up to 2-3 times saturation density(ρ0). The equation of state(EOS) of such matter can be expressed using iso-scalar and iso-vector nuclear matter parameters (NMPs) which characterize the symmetric nuclear matter (SNM) and density-dependent symmetry energy, respectively. The tidal deformation of a neutron star in a binary system has an imprint on the gravitational wave signal and the amount of tidal deformation depends on the equation of state which is described by the tidal deformability parameter(Λ). In this presentation, I will discuss which of the NMPs are most important to describe the tidal deformation of neutron stars for a range of gravitational masses (1.2M0 - 1.8M0). We also have developed an empirical relation for quick estimation of reliable values of tidal deformability, in terms of the NMPs, across a wide range of NS mass for a given EoS model. We will also show that the tidal deformability value which is determined from our empirical relation agrees within 5-10% of its true value obtained by solving TOV equation.

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Gravitational Waves / 151

Estimate on maximum characteristics strain of Continuous Gravitational Wave from systematic study on galactic pulsar population in context of various observational scenarios.

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We have investigated the detection probability of continuous Gravitational Wave (CW) signals from the spinning neutron stars in our galaxy across a wide range of their spin frequency. For this purpose, we use observed neutron stars' spin frequencies and spin-down rates, observed with radio telescopes as provided in the Australia Telescope National Facility (ATNF) pulsar catalog. We model the CW strain as a function of source properties including spin frequency, spin-down, moment of inertia, ellipticity, and source-distance with varying degrees of realistic calculations and assumptions. Along with considering a fiducial value of the moment of inertia of the neutron stars, we have estimated the Newtonian and post-Newtonian (empirical approximation) values by computing it from the Nuclear Equation of State with the observed mass distribution of the neutron star population. We then apply observational constraints from NICER, XMM-Newton, and LIGO-Virgo Collaboration

on the neutron star equation of State and select the valid ones. The estimations for all these source properties are combined to predict different observational scenarios for well-known search methods, fully coherent and semi-coherent, to detect CW signals with present and future-generation GW detectors.

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Cosmology / 153

Dark energy, D-branes, and Pulsar Timing Arrays

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Recently, several pulsar timing array collaborations announced the first detection of a Stochastic Gravitational Wave Background (SGWB). In this talk, I shall discuss a post-inflationary mechanism, driven by an early scalar-tensor dominated epoch, which is capable of enhancing the size of inflationary tensor fluctuations at frequencies detectable by pulsar timing arrays. The resultant gravitational wave signal has a broken power-law profile, and constitutes a possible contribution towards the explanation of the recent detection of the SGWB. Moreover, the model allows us to obtain a realization of an Early Dark Energy (EDE) phase, followed by a Late Dark Energy (LDE) era. While EDE has drawn attention as a possible means to address the Hubble tension, the LDE epoch can explain the current acceleration of the universe without requiring a cosmological constant.

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Cosmology / 154

Ultra-light primordial black holes from first-order phase transition with unique gravitational wave spectrum

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We study ultra-light Primordial Black hole (PBH) formation from first-order phase transition (FOPT) by considering bubble collisions and false vacuum collapse as the leading mechanisms. While FOPT leads to the generation of gravitational wave (GW) spectrum with typical blue and red-tilted spectrum around a peak frequency, the ultra-light PBH, if dominates the universe for a finite epoch, can act as a separate source of GW having a blue-tilted spectrum. These two sources of GW lead to a unique GW spectrum which can be probed at future GW experiments like LISA, DECIGO, ET etc. Such a signature can not only probe a PBH dominated phase in the early universe, but also their formation mechanism.

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Cosmology / 155

Cosmology in $f(Q)$ Gravity through Unified Dynamical System Analysis.

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Motivated by the effectiveness of $f(Q)$ gravity models in fitting observational data at both background and perturbation levels, our study employs a comprehensive dynamical system analysis to independently validate these findings. We focus on two well-studied $f(Q)$ models, specifically the power-law and exponential variants. Our analysis reveals a matter-dominated saddle point in both cases, accurately exhibiting the expected matter perturbation growth rate. Subsequently, we observe a stable dark-energy-dominated accelerated universe, maintaining constant matter perturbations. Additionally, an examination of $f\sigma_8$ behavior demonstrates successful alignment with observational data, resembling the ΛCDM scenario, although the exponential model lacks this as a specific limit. This independent dynamical systems approach corroborates previous observational results, solidifying the potential of $f(Q)$ gravity as a promising alternative to the ΛCDM concordance model.

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Classical & Quantum Gravity / 157

Maximal hypersurface in a D-dimensional dynamical spacetime

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In this article, we set up a variational problem to arrive at the equation of a maximal hypersurface inside a spherically symmetric evolving trapped region. In the first part of the article, we present the Lagrangian and the corresponding Euler-Lagrange equations that maximize the interior volume of a trapped region that is formed dynamically due to infalling matter in D-dimensions, with and without the cosmological constant. In the second part, we explore the properties of special radii, which we call Reinhart radii, that play a crucial role in approximating the maximal interior volume of a black hole. We derive a formula to locate these Reinhart radii in terms of coordinate invariants like area radius, principle values of the energy-momentum tensor, Misner Sharp mass, and cosmological constant. Based on this formula, we estimate the location of Reinhart radii in various scenarios:(a) the case of static BTZ black holes in 2+1 dimensions and for the Schwarzschild, Schwarzschild-deSitter, and Schwarzschild-Anti deSitter black holes in D-dimensions. We plot the location of the Reinhart radii in relation to the event horizon and cosmological horizon in a static D-dimensional scenario, (b) cosmological case: we prove that these Reinhart radii do not exist for homogeneous evolving dust for the zero and negative cosmological constant but exist in the presence of positive cosmological constant when the scale factor is greater than a critical value. We also show the relation between these Reinhart radii and Kodama vector.

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Classical & Quantum Gravity / 158

Some classical aspects of Ellis-Bronnikov wormholes embedded in a warped background.

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Recently we have shown that Ellis-Bronnikov wormholes embedded in warped background do satisfy energy conditions. We present analysis of particle trajectories, geodesic congruences in such wormhole spacetimes and their quasinormal modes. We emphasize on distingushing signatures of the wormhole geometry and the warped extra dimension.

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Gravitational Waves / 159

Gravitational analog of Gertsenshtein-Zeldovich effect.

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Correspondence between gravity and other fields in gauge theories is yet to be well understood and experimentally verified. The linearity of other gauge theories(such as Maxwell's theory) and the nonlinearity of general relativity make exploring this realm of gravity quite strenuous. The Gertsenshtein-Zeldovich (GZ) effect belongs to this realm, where electromagnetic (EM) waves passing through a region with very high magnetic fields produce gravitational waves (GW). This work aims to look for the generation of GW from the interaction of a test EM pulse with the curvature of a static and spherically symmetric massive object. We name it a gravitational analog to the GZ effect. In this gravitational analog, the spacetime curvature acts as a catalyst. In this talk, using covariant $1+1+2$ formalism, we explicitly show a test EM pulse in a static and spherically symmetric spacetime, resulting in a flux of GW. We quantify this using the Regge Wheeler tensor, which mimics the generated GW sourced by the EM energy and flux. We also discuss the implications for EM and GW memory.

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Cosmology / 160

Impact of sources of Epoch of Reionization (EoR) on the 21-cm bispectrum

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The fluctuations in the 21-cm radiation emitted by the neutral hydrogen(HI) in the Intergalactic medium(IGM) during different stages of the Epoch of reionization (EoR) is expected to be highly non-Gaussian. The degree of non-Gaussianity varies with the nature of the ionizing sources, state of the IGM and the underlying physical processes within the IGM. One of the crucial observable statistic

that can be estimated from the radio interferometric observations of the EoR that can quantify non-Gaussianity present in the signal is the 21-cm bispectrum. In this work, we considered different reionization scenarios, which differ by how the number of ionizing photons is related to the host halo mass and the distribution of the rest frame energy of the photons. These variations are expected to result in a significant difference in the IGM 21-cm topology. We analyze the impact of these different reionization scenarios in the 21-cm bispectrum for all the unique k-triangles. Our findings reveal that the shape, sign, and magnitude of the 21-cm bispectrum combinedly outperforms the power spectrum in distinguishing the different reionization scenarios. Additionally, we found that the sign changes in the squeezed-limit bispectrum are unique tracers of the HI distribution and capture two important topological transitions during reionization. These results highlight the potential of using the 21-cm bispectrum for constraining different reionization models.

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Astrophysical Relativity / 161

Revisiting the Black hole binary XTE J1859+226 to understand the disk-jet coupling.

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We revisit the black hole X-ray binary source XTE J1859+226 during its outburst phase in 1999-2000 and carry out the spectral and timing analyses using RXTE observations. Over the course of outburst, type-B QPO is observed multiple occasions and the combined spectro-temporal results reveal enhanced hard X-ray contributions as $\mathrm{QPO}_{\mathrm{rms}}\% \sim 1-3$, covering fraction $\sim 0.4-0.6$ and Comptonized flux ratio $\sim 0.45-0.5$. Further, type-B QPO shows a hard lag suggesting possible alteration in coronal geometry. Using continuum fitting, we estimate the spin (a_{k}) of the source and find $a_{\mathrm{k}} \sim 0.12$–0.38. In addition, we attempt to connect the observed X-ray properties with the observed radio flux in the context of disk-jet coupling and estimate the jet velocity as $\sim 0.94-0.98$ c, c being the speed of light.

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Cosmology / 162

HI stacking predictions for upcoming surveys with SKA precursors

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We present our Monte-Carlo simulation of galaxy properties: optical and HI. We use this simulation to study the expected number of direct detections in upcoming surveys (MIGHTEE with MeerKAT and WALLABY with ASKAP). We also study the expected detections in redshifted 21cm line emission with HI stacking. We propose that with these surveys HI stacking can be done in bins with a given range of optical luminosity and color, enabling studies of galaxy evolution in the upcoming surveys. We also discuss the sensitivity of these surveys towards the HI mass function and its evolution with redshift. The stacking of optically selected galaxies provides a statistical estimate of HI properties. We will also investigate the evolution of diverse scaling relations in both optical and HI.

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Cosmology / 163

Cosmology from Cross-Correlation of ACT-DR4 CMB Lensing and DES-Y3 Cosmic Shear

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Cross-correlation between weak lensing of the Cosmic Microwave Background (CMB) and weak lensing of galaxies offers a way to place robust constraints on cosmological and astrophysical parameters with reduced sensitivity to certain systematic effects affecting individual surveys. We measure the angular cross-power spectrum between the Atacama Cosmology Telescope (ACT) DR4 CMB lensing and the galaxy weak lensing measured by the Dark Energy Survey (DES) Y3 data. Our baseline analysis uses the CMB convergence map derived from ACT-DR4 and Planck data, where most of the contamination due to the thermal Sunyaev Zel'dovich effect is removed, thus avoiding important systematics in the cross-correlation. In our modelling, we consider the nuisance parameters of the photometric uncertainty, multiplicative shear bias and intrinsic alignment of galaxies. The resulting cross-power spectrum has a signal-to-noise ratio =7.1 and passes a set of null tests. We use it to infer the amplitude of the fluctuations in the matter distribution ($S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5} = 0.782 \pm 0.059$) with informative but well-motivated priors on the nuisance parameters. We also investigate the validity of these priors by significantly relaxing them and checking the consistency of the resulting posteriors, finding them consistent, albeit only with relatively weak constraints.

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Gravitational Waves / 164

Probing black hole hair with gravitational micro-lensing of gravitational waves

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Gravitational lensing of gravitational waves (GW) opens up the exciting possibility of studying the properties of the lens. If the wavelength of GW is comparable to the Einstein radius of the lens, diffraction effects modulate the GW waveform. Previous work has shown that if the lens is a stellar mass Schwarzschild black hole (BH), and the GWs have wavelengths detectable by the LIGO-Virgo-Kagra network, then the resulting waveform modulations (with respect to unlensed GWs) enable constraints on the mass of the BH (M), as well as the impact parameter (y). In this work, we determine the additional modulations incurred due to a non-zero hair Q, which could be interpreted as the electromagnetic charge in Reissner-Nordstrom black holes or the torsion parameter in $\mathcal{F}(T)$ gravity. We investigate the prospects of exploiting these modulations to constrain Q.

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Cosmology / 166

Constraints on modified form of quadratic chaotic inflation through reheating

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The era of Reheating is an interesting phase of inflationary Universe and it can be parameterized by various parameters like reheating temperature T_{re}, reheating duration N_{re} and average equation of state parameter $\overline{\omega}_{\mathrm{re}}$, which can be constrained by observationally viable values of scalar power spectral amplitude A_{s} and spectral index n_{s}. In our work, we have done the reheating study of a slightly modified form of quadratic chaotic potential in order to put some limits on parameter space of model. By investigating the reheating epoch using Planck's 2018 data, we show that even a slight modification in the quadratic chaotic model can make it consistent with latest cosmological

observations. We also find that the study of reheating era helps to put much tighter constraints on model and effectively improves accuracy of model.

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Gravitational Waves / 167

Surrogate models for eccentric binary black hole coalescences

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Orbital eccentricity of coalescing compact binaries produces a strong imprint in the gravitational waves (GWs) emitted by these systems. Its presence indicates at dynamically assembled binaries in dense stellar environments like globular clusters, nuclear star clusters, etc. Hence, detecting an eccentric merger will significantly enhance our knowledge about the formation channels of these binaries. Furthermore, neglecting eccentricity will also lead us to infer the other source parameters of the binary incorrectly. However, GW detectors are yet to unambiguously detect eccentric binaries and therefore such sources are often ignored in the current GW data analyses. But the prospects will improve in the near future as current detectors reach their design sensitivities and the proposed highly-sensitive third-generation detectors join the global GW detector network. Their broader sensitive frequency band will help in not only detecting more GW events but also in observing much longer inspirals, thereby substantially improving the range and precision of eccentricity measurements.

Theoretical GW waveform models in the near future will require improvements not only in their physics content and accuracy but also in their evaluation speeds so that accurate analyses of GW events can be arrived at in pace with the increasing amounts of incoming data. Surrogate models/ reduced order models are fast and accurate approximations of waveform models created using data-driven techniques like reduced bases and empirical interpolation. However, eccentric binary black hole waveforms have much more features than their quasi-circular counterparts and hence are trickier to model efficiently. In this talk, I will discuss some strategies for building their efficient and accurate surrogate/ reduced-order models.

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Classical & Quantum Gravity / 168

Membrane paradigm for slowly spinning compact objects

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Searches for exotic compact objects (ECOs) from gravitational wave data require a thorough understanding of their signatures during the inspiral and the ringdown. ECOs are motivated by quantum gravity extensions of general relativity and are characterized by the absence of a horizon and partial reflectivity. In the ringdown, which can serve as a fingerprint of an ECO, it is essential to incorporate the effect of spin in post-merger remnants.
The membrane paradigm is a useful framework to model generic compact objects and study the relationship between different observables, such as the reflectivity and the quasi-normal modes (QNMs). The membrane paradigm was used to model black holes and non-spinning ECOs. In this talk, I will describe our extension of the membrane paradigm to slowly spinning compact objects and the derivation of their reflectivity and characteristic QNMs. Finally, I will discuss the implications of these results regarding the stability of spinning horizonless objects.

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Classical & Quantum Gravity / 169

Quantum-to-classical transition of leading-order background fluctuations

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Understanding the emergence of classical behavior from a quantum theory is vital towards establishing the quantum origin for the temperature fluctuations observed in the Cosmic Microwave Background (CMB). This talk presents how a real-space approach can comprehensively address this problem even in the leading order of curvature perturbations. Spatial bipartitions of quantum fluctuations are tested for three different indicators of classical behavior: i) decoherence, ii) peaking of the Wigner function about classical trajectories, and iii) relative suppression of non-commutativity in observables. These signatures are obtained from the covariance matrix of a multi-mode Gaussian state and addressed primarily in terms of entanglement entropy and log-classicality. Through a phase-space stability analysis of such states, we ascertain that the underlying cause for the dominance of classicality signatures is the occurrence of gapped inverted mode instabilities. We demonstrate that the absence of decoherence preempts a quantum-to-classical transition of scalar fluctuations in an expanding background in (1+1)-dimensions using two examples: i) a Tanh-like expansion and ii) a de-Sitter expansion. We then extend the analysis to leading order fluctuations in (3+1)–dimensions to show that a quantum-to-classical transition occurs in the de-Sitter expansion and discuss the relevance of our study in distinguishing cosmological models.

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Classical & Quantum Gravity / 170

An analytical approach to compute conductivity of p-wave holographic superconductors

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In this work we have analytically deduced the frequency dependent expression of conductivity and the band gap energy in AdS4 Schwarzschild background for p-wave holographic superconductors considering Einstein-Yang-Mills theory. We also used the self consistent approach to obtain the expressions of conductivity for different frequency ranges at low temperature. We then compared the imaginary part of conductivity at low frequency region. The band gap energy obtained from these two methods seem to agree very well.

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Astrophysical Relativity / 171

Equation of states in the curved spacetime of compact stars and their effects on tidal deformability

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In the study of degenerate compact stars such as neutron stars, general relativistic effects are incorporated by using Tolman-Oppenheimer-Volkoff equations to describe their interior spacetime. However, the equation of states employed in such studies are often computed in flat spacetime. Here, we discuss about the equation of states that are computed in the curved spacetime of these stars. In particular, we discuss about the effects of gravitational time dilation on the mass-radius relation as well as on the tidal deformability of these stars.

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Astrophysical Relativity / 172

Neutrino dominated accretion flow around rotating black hole

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Abstract: We study the properties of the neutrino-dominated accretion flow (NDAF) around the rotating black holes. The accretion flow of this kind involves hyper-accretion rate ($\dot{m} \sim 0.001 - 10$ $M_\odot$ s^{-1}) and because of this, the disk becomes geometrically as well as optically thick that makes it difficult for photons to escape. On the contrary, neutrinos easily move out the disk resulting the cooling of the flow via radiative emissions and annihilation processes. Considering all these, we self-consistently solve the governing equations to obtain the global transonic shocked accretion solutions and compute the maximum neutrino luminosity, $L_\nu^{\max}$ and neutrino annihilation luminosity, $L_{\nu\bar{\nu}}^{\max}$ for shocked accretion solutions for black holes of different spin value (a_k). Furthermore, we compare $L_{\nu\bar{\nu}}$ with the observed output power $\dot{E}$ of Gamma-Ray Burst (GRB) sources for a wide range of mass accretion rate and spin of BH and find good agreement. With this, we perceive that the neutrino-dominated shocked accretion solutions seem potentially viable to account for the energy budget of the central engine of GRBs.

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Astrophysical Relativity / 173

Modelling Einstein cluster using Einasto profile

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We demonstrate a general relativistic approach to model dark matter halos using the Einstein cluster, with the matter stress-energy comprising collisionless particles moving on circular geodesics in all possible
angular directions and orbital radii. Such matter, as is known, allows an anisotropic pressure profile with non-zero tangential but zero radial pressure. We use the Einasto density profile for the Einstein cluster. Analytical studies on its properties (metric functions) and stability issues are investigated. Further, to establish this model (with the Einasto profile) as one for a dark matter halo,
we use the SPARC galactic rotation curve data and estimate the best-fit
values for the model parameters. General relativistic features (beyond the
Keplerian velocities) such as the tangential pressure profile are quantitatively explored. Thus, Einstein clusters with the Einasto profile may provide a viable model
for dark matter halos which tally well with observations.

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Classical & Quantum Gravity / 174

Properties of relativistic star in 5-D Einstein-Gauss-Bonnet gravity

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In recent years, there has been a growing interest in understanding the General Theory of Relativity (GTR) in several ways for the construction of stellar modeling. One of such modification is the inclusion of higher order curvature terms in the Lagrangian. By introducing a quadratic form of the Riemann tensor to the standard Einstein-Hilbert action Lovelock extended GTR in higher dimensions, which is known as the Einstein-Gauss-Bonnet (EGB) gravity. Even though the universe we live in is 4-dimensions, investigations on the impacts of higher dimensional effects on space-time geometry and matter remains a fascinating field of research, in this paper, for a relativistic star in static equilibrium, we invoke the 5 dimensional Einstein-Gauss-Bonnet gravity. The configuration is assumed to be filled with an anisotropic matter distribution that admits a linear equation of state (EOS). We make the EGB field equations tractable by introducing a particular coordinate transformation and closing the system with a single generating function. By specifying the generating function Z(x), we solve the system. We show that the solution is well-behaved and stable and the energy conditions are fulfilled. We fix the model parameters a and B of the solution by matching the interior solution to the exterior Boulware-Deser metric, which facilitates its physical analysis. A numerical study of the developed model helps us understand EGB gravity's effects on the
geometry of localized objects and gross physical features of the matter variables. In particular, our investigation brings to attention the role of the Gauss-Bonnet coupling parameter α in fine-tuning the values of the matter variables.

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Astrophysical Relativity / 175

Long term Wideband X-ray properties of outbursting black hole sources GX 339-4 and H1743-322: AstroSat and NuSTAR results

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We present the comprehensive analyses of the wide band spectral and timing variabilities of the two BH sources, namely GX 339−4 and H 1743−322, using AstroSat and NuSTAR observations during 2016 − 2022. We observe that both GX 339−4 and H 1743−322 experienced successful as well as failed outbursts during 2016 − 2022. Using long-term MAXI and BAT light curves, we examine the outburst profiles of both sources when they underwent failed and successful outbursts. GX 339−4 transits from quiescence to outburst and the broad-band spectral modelling indicates that the source traces through the several spectral states, namely hard ($kT_{\rm bb} = 0.29 - 0.53$ keV, $\Gamma = 1.46 - 1.65$ and $L_{\rm bol} = 0.25 - 8.37$\% $L_{\rm Edd}$), intermediate ($kT_{\rm bb} = 0.17 - 0.71$ keV, $\Gamma = 1.71 - 2.49$, $L_{\rm bol} = 6.46 - 9.11\%\, L_{\rm Edd}$) and soft states ($kT_{\rm in} = 0.51 - 0.93$ keV, $\Gamma = 1.67 - 3.74$, $L_{\rm bol} = 1.48 - 12.66\%\, L_{\rm Edd}$), respectively. On the contrary, H 1743−322 transits from quiescent state to hard state ($\Gamma = 1.57 - 1.71$, $L_{\rm bol} = 3.07 - 5.81\%\, L_{\rm Edd}$) only. We detect both type-B and type-C Quasi-periodic Oscillations (QPOs) in GX 339−4 of frequencies varying between $0.1 - 5.37$ Hz along with harmonics. For H 1743−322, prominent type-C QPO is found with frequencies in the range $0.22 - 1.03$ Hz along with distinct harmonics. The energy-dependent power density spectrum reveals that the fundamental QPO and harmonics disappear beyond 20 keV in GX 339−4, whereas the fundamental QPO is present in the $3-40$ keV energy band, and the harmonic disappears beyond $\sim$ 20 keV. Finally, we discuss the implications of our observational findings in the context of accretion dynamics around the black hole binaries.

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Cosmology / 176

Expansion-collapse duality between Einstein and Jordan frames: Implications at quantum level

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The Jordan and Einstein frame representations of scalar-tensor theories of gravity are mathematically equivalent; however, the cosmological evolutions therein can be drastically different. An interesting example is an expansion-collapse duality – a continually expanding Einstein frame universe can have a dual Jordan frame description that is always contracting. The scenario eventually runs into an apparent paradox. When a collapsing universe approaches singularity, the classical description of the spacetime becomes inadequate. The contracting Jordan frame universe is expected to develop quantum characteristics when its scale factor becomes sufficiently small. However, at the same time, the corresponding Einstein frame universe is expected to behave classically due to the arbitrarily large size it has grown to. In this case, the conformal map appears to be providing a duality between a quantum effect-dominated universe and a universe behaving classically. We investigate the status of the conformal map at the quantum level in such a scenario, focusing on addressing this paradox. The Einstein and Jordan frame universes are quantized individually using the Wheeler-DeWitt prescription. We show that the classical conformal map holds at the quantum level when

compared through the expectation values of the scale factor operators in the two frames. The relative quantum fluctuation in the scale factor is found to be conformally invariant, and it increases in both the past and future directions according to the internal clock. Expectedly, the quantum fluctuations in the collapsing Jordan frame keep on increasing as it shrinks towards singularity. More surprisingly, the quantum fluctuations in the expanding Einstein frame keep on increasing as well, even as its classical scale factor becomes larger. Despite having drastically different cosmological evolutions, the rise in quantum characteristics in a collapsing frame implies the same in its expanding counterpart, thereby resolving the apparent paradox.
Based on "Einstein and Jordan frame correspondence in quantum cosmology:
expansion-collapse duality", Mukherjee and Sahota. Eur.Phys.J.C 83 (2023) 9, 803 (https://doi.org/10.1140/epjc/s10052-023-11934-9)

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Classical & Quantum Gravity / 177

Local first law of black hole

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The first law of black hole mechanics is not physically well-defined because some quantities, such as mass and angular momentum, are defined at infinity, while others, like surface gravity and angular velocity, are defined at the event horizon. Establishing the full law requires traveling back and forth between the horizon and infinity, as well as the knowledge of the entire spacetime, which poses challenges for real measurements. We are currently working on establishing a local form of the first law, and intriguingly, we have found that it is independent of charge and angular momentum in a meaningful way. This result holds particular significance and applicability for astrophysical black holes.
Reference: e-Print: 2307.10986 [gr-qc].

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Classical & Quantum Gravity / 178

Cosmology of Bianchi type-I metric using renormalization group approach for quantum gravity

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In this work, we have studied the anisotropic Bianchi type-I cosmological model at late times, taking into account quantum gravitational corrections in the formalism of the exact renormalization group flow of the effective average action for gravity.
The cosmological evolution equations are derived by including the scale
dependence of Newton's constant G and cosmological constant Λ. We have
considered the solutions of the flow equations for G and Λ at next to leading order in the infrared cutoff scale. Using these scale dependent G and Λ in Einstein equations for the Bianchi-I model, we have obtained the scale factors in different directions. It is shown that the scale factors eventually evolve into FLRW universe for known matter like radiation. However, for dust and stiff matter we find that the universe need not evolve to the FLRW cosmology in general, but can also show Kasner type behaviour.

Reference : Rituparna Mandal, Sunandan Gangopadhyay, Amitabha Lahiri, "Cosmology of Bianchi type-I metric using renormalization group approach for quantum gravity", Classical and Quantum Gravity, 37, 065012 (2020).

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Classical & Quantum Gravity / 179

Foamy Interior Geometry of Schwarzschild Black Holes in Quantum Gravity

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The Hawking-Wheeler conjecture that the spacetime has a foamy structure at Planckian scales is an attractive feature to be captured in any theory of Quantum Gravity. While Loop Quantum Gravity predicts a discrete geometry at such fundamental scales, String Theory begins with the assumption of stringy nature of all fundamental particles. Both these fundamental theories of Quantum Gravity have been applied to study the quantum nature of the black hole spacetime.

In this work, we study the quantum nature of Schwarzschild black hole spacetimes in yet another well-formulated theory of Quantum Gravity, namely, the Wheeler-DeWitt quantization scheme. We solve the Wheeler-DeWitt equation $\hat{H}\Psi = 0$ in the minisuperspace approximation with the spherically symmetric metric $ds^2 = -N^2dt^2 + u^2dr^2 + v^2(d\theta^2 + \sin^2\theta\, d\phi^2)$, the metric coefficients being treated as functions of both r and t.

The corresponding eigen value problem reduces to Bessel's equation. The black hole interior (exterior) solution is Bessel (modified Bessel) function of imaginary order with real argument, both being determined by the metric coefficients. Applying restriction on the wave function coming from boundary conditions, we obtain legitimate forms of the metric coefficients that encode the foamy interior geometry of the black hole. Our results are in close resemblance with those obtained via Loop Quantum Gravity.

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Cosmology / 180

Probing the signatures of astrophysical scatter in the EoR 21cm signal using auto-bispectrum

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The high-redshift observations of galaxies with instruments like the JWST can be complemented with the upcoming SKA, which will map the early IGM via intensity mapping of the redshifted 21cm signal with improved sensitivity over the current generation of radio interferometers. These star-forming galaxies are expected to emit most of the bulk of ionizing photons during the Epoch of Reionization (EoR) and reionize the surrounding IGM while star-formation continues inside these galaxies. However, since the star-formation rates of these galaxies have an intrinsic scatter with the host halo mass, the ionizing photon flux is not perfectly correlated to it. It might affect the observable summary statistics of the 21cm signal as compared to the usual models of cosmic reionization where the ionizing photon flux is perfectly correlated with the halo mass. Using semi-numerical simulations, we find that unlike the 21cm power spectrum, where the impact of this astrophysical scatter is primarily limited to only 5 percent and up to 10-15 percent, the 21cm auto-bispectrum captures the small-scale ($k \sim 2.55$ Mpc^{-1}) non-Gaussinaties induced by the astrophysical scatter in the highly non-Gaussian 21cm signal with high-statistical significance ($> 5\sigma$ at $\overline{x}_{\rm H\,I} > 0.81$), while the impact ranges from 20 to 100 percent. However, the detectability of the bispectrum at these scales is beyond our reach considering SKA1-Low observations. Therefore, the large-scale 21cm auto-bispectrum is primarily unaffected by the astrophysical scatter and requires no additional modeling; however, any future generation of radio interferometers might aid in unveiling the information at the smaller length scales.

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Classical & Quantum Gravity / 181

causal description of marginally trapped regions in D dimensions

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In this paper, we analyze the causal aspects of evolving marginally trapped surfaces in a D dimensional
spherically symmetric spacetime, sourced by perfect fluid with a cosmological constant. The norm of the
normal to the marginally trapped tube is shown to be the product of lie derivatives of the expansion parameter of future outgoing null rays along the incoming and outgoing null directions. We obtain a closed
form expression for this norm in terms of principal density, pressure, areal radius and cosmological constant. For the case of a homogeneous fluid distribution, we obtain a simple formula for determining the
causal nature of the evolving horizons. We obtain the causal phase portraits and highlight the critical radius.
We identify many solutions where the causal signature of the marginally trapped tube or marginally antitrapped tube is always null despite having an evolving area. These solutions do not comply with the
standard inner and outer horizon classification for degenerate horizons. We propose an alternate prescription for this classification of these degenerate horizons

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Cosmology / 182

Revisiting Dipole Dark Matter at Proposed International Linear Collider

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If the dark matter is a Dirac fermion(χ) and it has an electric and magnetic dipole moment, it can couple with the Standard Model photon through a dimension five effective operators, suppressed by a New Physics(NP) scale Λ. We probe the parameter space in terms of Dark Matter mass (m_χ) and the New Physics scale Λ via a mono-photon signal at the upcoming International Linear Collider(ILC). With the beam polarization taken into account, and with the beam configurations of the ILC with $\sqrt{s} = 500$ GeV and 4 ab^{-1} integrated luminosity, we show that it can probe DM up to a Λ value of 3.8 TeV.

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Cosmology / 184

Reheating by Parametric Resonance in the ϕ^4 Model of Chaotic Inflation

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Kofman, Linde and Starobinsky had showed that preheating can occur due to a huge amount of particle creation by parametric resonance after the inflationary era of the Universe. In the ϕ^2 model, they confirmed the existence of narrow and broad resonances as well as stochastic resonance in the presence of an expanding background, by means of exact numerical computation of the corresponding Mathieu equation. On the other hand, they obtained a Lam\'e-type equation for the ϕ^4 model in an approximate scheme, which showed resonance bands quite different in nature from their previous study.

In the present work, we reconsider the ϕ^4 model of inflation and study the parametric resonance patterns in the preheating stage after the inflationary era. Hence we construct the dynamical equation for the mode functions of the created particles coupled with the oscillatory dynamics of the inflaton field in the reheating regime. We solve these coupled equations exactly by numerical integration.

We find resonance patterns quite different from those of ϕ^2 model obtained earlier by Kofman et al. The mode functions gain in amplitude only in the initial stage of decay of the inflaton field and thereafter their amplitude remains almost constant for a long time. This shows that the resonance in the ϕ^4 model is maintained for a longer time than in the ϕ^2 model. We have verified this feature by numerical computation for a time-span of five times higher than in the existing literature.

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Gravitational Waves / 186

Constraining the abundance of Galactic compact objects with continuous gravitational waves

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Galactic spinning compact objects (COs) with non-zero ellipticity are expected to be sources of continuous gravitational waves (CGWs). Certain classes of hypothetical compact objects, such as neutron stars with quark cores (hybrid stars), and quark stars, are thought to have large ellipticities from theoretical considerations. These should enable such COs to produce CGWs detectable by the current LIGO-Virgo-Kagra GW detector network. Since no detections for CGWs, from searches in LIGO-Virgo data, have so far been reported, for the first time, we place constraints on the abundance of such exotic compact objects (eCOs) in our Galaxy. We formulate a Bayesian framework to place

upper limits on the total number count (N_{tot}) of Galactic eCOs. We divide our constraints into two classes: an "agnostic"set of upper limits on N_{tot} evaluated on a CO spin-frequency and ellipticity grid that depend only on the choice of spatial distribution of COs; and a model-dependent set that additionally assumes prior information on the distribution of ellipticities and frequencies. Assuming a spin-frequency distribution for eCO's, we revisit the constraints on N_{tot} and we place upper limits on the ellipticities of eCO's which we find to be ϵ
$lesssim 2 \times 10^{-7}$ for the most optimistic case.

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Classical & Quantum Gravity / 187

Emergent Spin in Quantum Cosmology of Bianchi Type-I Universe

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Although the universe presently looks homogenous and isotropic at cosmological scales, there exist small-scale inhomogeneities and anisotropies. In fact, Bianchi had proposed a few anisotropic classical models of the universe which are important in the context of quantum cosmology. In particular, anisotropy is expected to be prominent during the early phase of the universe when it was dominated by quantum mechanical fluctuations.

In this work, we consider the Bianchi type I model of the universe in the Wheeler-DeWitt quantization scheme with the matter field represented by a scalar field ϕ. Consequently, the quantum mechanical equation of the universe is obtained in the minisuperspace consisting of the Misner variables $(\alpha, \beta_+, \beta_-)$ and the scalar field ϕ. In order to obtain a self-adjoint Hamiltonian via Dirac decomposition, we choose the Misner variable α to play the role of time in the quantum universe. The Schrodinger-type equation so obtained involves Pauli matrices and the wavefunction of the universe becomes a two-component spinor for both expanding and contracting solutions.

We further find that the minisuperspace angular momentum operator does not commute with the Hamiltonian. Consequently, we obtain the missing part of the angular momentum so that the total angular momentum commutes with the Hamiltonian. This missing part of the angular momentum acts on the spinor space and we identify it as the spin of the quantum universe. We further note that the emergence of three-component spin vector is owing to the presence of anisotropy in the universe which is absent in any quantized isotropic models of the universe.

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Astrophysical Relativity / 188

Properties of relativistic advective accretion flow in a Kerr-like wormhole

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We study the relativistic, inviscid, advective accretion flow in a stationary axisymmetric Kerr-like wormhole spacetime characterized by the spin parameter ($a_{\rm k}$) and the dimensionless parameter (β). While doing this, we solve the governing equations that describe the relativistic accretion flow in a Kerr-like wormhole and calculate all types of accretion solutions, including transonic as well as subsonic ones. Further, we examine how the behavior of the accretion solutions alters due to the variation of the model parameters, namely energy (E), angular momentum (λ), $a_{\rm k}$, and β. We identify the effective region of the parameter space in $\lambda - E$ plane for multiple critical points and observe the effect of $a_{\rm k}$ and β in obtaining the parameter space. Moreover, we also retrace the parameter space in $a_{\rm k} - \beta$ plane for multiple critical points in terms of energy (E) and angular momentum (λ). We calculate the disc luminosity (L) considering free-free emissions for transonic accretion solutions and examine the profile of maximum disc luminosity ($L_{\rm max}$) with $a_{\rm k}$ and β. Finally, we discuss the implication of this model formalism in the context of the astrophysical applications.

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Astrophysical Relativity / 189

Search for spatial correlation between IceCube Neutrinos and Radio pulsars

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The study aimed to examine the connection between radio pulsars and ultra-high energy neutrinos using the IceCube catalog of point source neutrino events. For this purpose we use the *unbinned maximum likelihood* method to search for a statistically significant excess from each of the pulsars in the ATNF catalog.
Next, we performed a *Stacked search* to further *enhance signal to noise ratio* for a better validation of correlation between Neutrinos and Radio Pulsars.

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Gravitational Waves / 190

Novel probes of dark matter with continuous gravitational waves

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The third observing run of advanced LIGO, Virgo and KAGRA brought unprecedented sensitivity towards a variety of quasi-monochromatic, persistent gravitational-wave signals. Continuous waves allow us to probe not just the canonical asymmetrically rotating neutron stars, but also different forms of dark matter, thus showing the wide-ranging astrophysical implications of using a relatively simple signal model. In this talk, I will summarize recent results from searches for dark matter in the form of asteroid-mass primordial black holes, dark matter clouds that could form around rotating black holes, and even dark matter that could interact with the detectors themselves.

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Cosmology / 191

Primordial black hole reheating and its possible signatures

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We compare the dark matter(DM) production processes and its parameters space in the background of reheating obtained from two chief systems in the early Universe: the inflaton ϕ and the primordial black holes (PBHs). We concentrated on the mechanism where DMs are universally produced only from the PBH decay and the generation of the standard model plasma from both inflton and PBHs. Whereas the distribution of Primordial Black Holes behaves like dust, the inflaton phenomenology depends strongly on its equation of state after the inflationary phase, which in turn is conditioned by the nature of the potential $V(\phi)$. Depending upon the initial mass and population of PBHs, a large range of DM mass is shown to be viable if reheating is controlled by PBHs itself. Inflaton-dominated reheating is observed to further widen such possibilities depending on the initial population of black holes and its mass as well as the coupling of the inflaton to the standard model sector.
References: Arxiv: 2305.10518 (Accepted in PRD), 2309.06505

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Classical & Quantum Gravity / 192

Exploring Dynamic Wormholes with Modified Chaplygin Gas in the Emergent Universe.

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In this talk, I will explore a dynamic wormhole solution featuring the Modified Chaplygin Gas (MCG) as the matter at the throat, characterized by an equation of state (EOS): p = Aρ - B/ρˆα.Its global properties, its traversability and the necessary energy conditions to maintain it within the framework of the standard Big Bang cosmological model will be explored.

Further, I will investigate this dynamic wormhole model within the context of the Emergent Universe (EU) cosmological model, analyzing its properties to ensure both existence and traversability. Our findings reveal that the dynamic wormhole solution with MCG EOS satisfies all essential properties proposed by Morris and Thorne, and the embedding diagram indicates its geometry's dependence on the scale factor.

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Classical & Quantum Gravity / 193

Fate of an infalling Passenger at the Cauchy Horizon of a Reissner-Nordström Black Hole

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Ever since Penrose & Simpson contradicted Novikov's prediction that an infalling passenger would emerge into an asymptotically flat universe, there have been a continued interest in predicting the fate of an infalling passenger near the Cauchy horizon (CH) of a Reissner-Nordström (RN) black hole. Poisson & Israel observed that the CH singularity becomes stronger upon considering the backscattered particles in addition to highly blueshifted infalling massless particles. However, their analysis did not reveal if the singularity is strong enough to destroy the infalling passenger. On the other hand, Ori showed that the tidal forces are not strong enough and the particle separation

remain finite leading to the possibility of extension of spacetime beyond the CH. This unresolved issue has maintained the motivation of researchers until recent times.

In this work, we consider a massive scalar field in the RN geometry to mimic the dynamics of the infalling passenger. This results in two coupled differential equations, namely, the Einstein field equation and the Klein-Gordon equation in this background. To study the behavior of the mass function and the scalar field near the CH, we develop a perturbative method to solve the coupled dynamical equations.

Our detailed analysis shows that the otherwise well-behaved mass function exhibits a very rapid and unbounded growth, behaving with the advanced time as $v^{-\alpha}$ with α ranging from 0.09 to 0.13, upon approaching the CH. In addition, we find that even though the scalar field is well behaved outside the CH, it exhibits abrupt and rapid fluctuations with infinite jumps near the CH, and it completely vanishes beyond the CH. This indicates complete destruction of an infalling passenger as well as no possibility of extension of spacetime beyond the CH, confirming Penrose's prediction. Consequently, our findings do not agree with theories predicting weak singularity at the CH.

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Classical & Quantum Gravity / 194

Aspects of transitivity in quantum field theory and its possible consequences

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Testing transitivity in quantum field theory is a fundamental aspect of understanding the consistency of the theory and its predictions. In our paper, we considered a vacuum state of the massless scalar field in Minkowski spacetime and two Rindler wedges, Rindler-1 and Rindler-2, separated by a distance. From a set-theoretic view, this setup assumes the picture where the Minkowski spacetime with the scalar field defined on it is a universal quantum field set, and Rindler-1 and Rindler-2 are subsets or subsystems. Note here that Rindler-2 is also a subset of Rindler-1.

To investigate the transitivity, we have calculated the reduced state of the field in Rindler-2 in two independent ways. The first approach is straightforward: We took the vacuum state in Minkowski and found the reduced state in Rindler-2 by tracing-out the degrees of freedom of the left wedge, giving a Planckian spectrum. Similarly, in the second case, we first evaluated the reduced state in Rindler-1 from the vacuum of Minkowski, which yielded a thermal density matrix, and then the reduced density matrix in Rindler-2 from Rindler-1. We found that these independent paths of calculations do not yield the same reduced state in Rindler-2.

This variation in reduced state calculations indicates that there are quantum field theoretic systems in which the reduced quantum state of a subsystem can be path-dependent and, hence, not unique. Therefore, transitivity is violated, but it is still unclear whether this is a desirable property for a quantum field theory or a flaw in our current formulation of the quantum field theory.

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Cosmology / 195

MCF studies on High redshif galaxies

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The galaxy Marked Correlation Function (MCF), where the two point correlation function is measured by weighing galaxies with a mark depending on their intrinsic properties, is a powerful statistical tool for probing the environmental dependence of galaxy clustering. We measure and model the MCF of Lyman Break Galaxies from the Subaru HSC-SSP survey1 in the redshift range 3 to 5 for galaxy samples selected by their derived stellar masses. The measured MCF is found to deviating strongly from unity for $\theta \le 100$ arcsec, a scale bigger than the size of a typical galaxy, indicating strong environmental dependence of clustering as a function of stellar mass. Further, the MCF signal is found to be higher for for galaxy samples with higher stellar masses and also at higher redshifts. We also present a model based on the halo model that reasonably explains the measured MCF.

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Cosmology / 196

Baryogenesis by Heavy Scalar Field in the Inflationary Universe

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The observed Universe made up of only baryonic matter indicates that the standard
model of particle physics should be modified to break symmetry between particles and antiparticles. This symmetry breaking is expected to generate unequal number of leptons and antileptons in the reheating era after the inflationary epoch generating the required baryon asymmetry.

To model this scenario in the inflationary Universe, we include in the Lagrangian a complex massive scalar field with mass in the order of the Hubble rate. The phase of this complex scalar field is capable of generating CP-violation. The dynamics of this complex scalar field is coupled with the dynamics of the inflaton field. In additon, we include leptonic symmetry breaking terms in the Lagrangian capable of generating baryon
asymmetry at a later stage. An analysis of this model shows the possibility of the generation of leptonic asymmetry in the reheating regime after the inflationary epoch and barynoic asymmetry at a later stage. The baryon-to-photon ratio appears to approach a very small number, less than 10^{-9}, which requires tuning of several model paramerters.

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Classical & Quantum Gravity / 198

Plasma-photon interaction around Exotic Compact Objects

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Astrophysical Compact objects are surrounded by accretion disks. The photons emitted by the accreting compact object interacts with the plasma in the interstellar medium. In this work, we investigate the dynamics of electromagnetic field propagating in the background of Exotic Compact Objects. We discuss whether or not bound states can form in the case of exotic compact object and how the frequencies of the bound states, if formed depend on the plasma profile and the background geometry.

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Gravitational Waves / 199

Effects of Phase Transition in Gravitational Wave Signals From Binary Neutron Star Mergers

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Quantum chromodynamics predicts that at high enough temperature/density, hadronic matter (HM) deconfines to quark-gluon matter. it is conjectured that the deconfinement transition from HM to quark matter (QM) takes place at an intermediate density range (a few times nuclear matter density). However, there is no ab-initio calculation, nor are there any earth-based experiments. The only naturally present laboratories to probe matter at such densities are the neutron stars (NSs).
We performed the full-3D GRMHD simulations of binary NS merger systems and studied the effects of the onset of phase transition (PT) by probing the stellar properties and gravitational wave spectra. We used the hybrid equation of state (EoS), which has the hadronic degrees of freedom at low density, the mixed-phase region at intermediate density, and pure QM at very high density. We constructed different hybrid EoSs by varying the onset point where quark matter first appears and performed various BNSMs (equal and unequal mass binaries).
A significant difference is observed in the post-merger properties if QM appears at low densities. If the matter properties with hadronic and quark degrees differ significantly, it is reflected in the stability of the final merger product. Hadronic EoS can give a stable post-merger remnant, whereas in hybrid EoS cases, the possibility of a core-collapse scenario increases. However, when unequal mass binaries (the mass difference is significant) merge, the difference in the observational signals depending on the EoS is evident from the point of first contact between the stars.

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Gravitational Waves / 200

Memory Effect of Gravitational Wave Pulses in PP-Wave Spacetimes

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In this paper we study the memory effect produced in pp-wave spacetimes due to the passage of gravitational wave pulses. We assume the pulse profile in the form of a ramp (which may be considered as an appropriate representation of burst gravitational waves), and analyse its effects on the evolution of nearby geodesics. For a ramp profile, we are able to determine analytical solutions of the geodesic equations in the Brinkmann coordinates. We have plotted the solutions to examine the changes in the separation between a pair of geodesics and their velocity profiles. We find that in the presence of the pulse, the separation (along x or y-direction) increases monotonically from an initial constant value, whereas the relative velocity grows from zero and settles to a final non-zero constant value. These resulting changes are retained as memory after the pulse dies out. The nature of this memory is found to be similar to that obtained by other workers using Gaussian, square and other pulse profiles, thereby validating the universality of gravitational wave memory.

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Astrophysical Relativity / **201**

Microlensing Black Hole Shadows

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A detailed analysis is presented of the gravitational microlensing by intervening compact objects of the black hole shadows imaged by the Event Horizon Telescope (EHT). We show how the center, size, and shape of the shadow depend on the Einstein angle relative to the true/unlensed shadow size, and how the location of the lens affects the shift, size, and asymmetry of the black hole shadow due to microlensing. Assuming a supermassive black hole (SMBH) casts a circular-shaped true shadow, microlensing can create an asymmetry of up to approximately 8\%, which is twice the asymmetry caused by the SMBH's spin and its tilt relative to us. Furthermore, the size can be enhanced by $\sim$50\% of the true shadow. Currently, the terrestrial baselines of EHT lack the resolution to detect microlensing signatures in the shadows. However, future expansions of EHT including space-based baselines at the Moon and L_2, could potentially enable the detection of microlensing events. For Sgr˜A*, an event rate of 0.0014 per year makes the microlensing phenomena difficult to observe even with space-based baselines for the stellar population in the stellar bulge and stellar disk for lens mass $\sim M_\odot$. However, continuously monitoring the shadow of Sgr˜A* could offer novel insights into the compact object population surrounding the galactic center.

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Gravitational Waves / **202**

"ENIGMA"- An aligned-spin eccentric IMR waveform model for compact binary mergers

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The network of LIGO-Virgo detectors has detected nearly 100 compact binary mergers in their three observing runs, among which most of the merger events are from quasicircular orbits. Though binaries tend to circularize when they enter the LIGO band, binaries formed via dynamical interactions in dense stellar clusters or through Kozai-Lidov processes can have large residual eccentricities. As the

effect of eccentricity is substantial in waveform, neglecting it results in a low signal-to-noise (SNR) ratio while detecting a likely eccentric candidate. Also, orbital eccentricity is the cleanest feature to know about binary formation channels. On the other hand, spins of individual compact objects are one of the most important physical effects that significantly modify the shape of the waveform. As the sensitivities of current ground-based detectors are upgraded, there is an urgent need for an eccentric spinning waveform model. In this talk, we present ENIGMA, an eccentric, aligned-spin, time-domain, inspiral-merger-ringdown (IMR) waveform model for compact binary mergers that include higher gravitational-wave harmonics. ENIGMA incorporates the latest spinning eccentric information available in the literature to date. This model can help us understand the astrophysical origins of spinning eccentric binaries by inferring the orbital parameters of detected events in the upcoming observing runs of gravitational wave detectors.

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Cosmology / 204

Modified Power Law Cosmology with higher order curvature terms and observational constraints

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This research paper examines the Ricci scalar R and the Gauss-Bonnet invariant G to characterize a cosmological model in flat space-time via $f(R, G)$ gravity. Our model assumes that $f(R, G)$ is an exponential function of G combined with a linear combination of R. We scrutinize the observational limitations under a power law cosmology that relies on two parameters - H_0, the Hubble constant, and q, the deceleration parameter, utilizing the 57-point H(z) data, 8-point BAO data, 1048-point Pantheon data, joint data of H(z) + Pantheon, and joint data of H(z) + BAO + Pantheon. The outcomes for H0 and q are $H_0 = 68.008^{+0.087}_{-0.079}$ km s^{-1} Mpc^{-1}, $q = -0.105^{+0.009}_{-0.011}$, $H_0 = 67.989^{+0.096}_{-0.102}$ km s^{-1} Mpc^{-1}, $q = -0.107^{+0.010}_{-0.010}$, $H_0 = 68.020^{+0.098}_{-0.108}$ km s^{-1} Mpc^{-1}, $q = -0.110^{+0.009}_{-0.010}$, $H_0 = 68.016^{+0.097}_{-0.096}$ km s^{-1} Mpc^{-1}, $q = -0.109^{+0.010}_{-0.011}$, $H_0 = 68.010^{+0.094}_{-0.100}$ km s^{-1} Mpc^{-1}, $q = -0.108^{+0.010}_{-0.010}$ respectively. We also address Energy Conditions, $Om(z)$ analysis, and cosmographical parameters like Jerk, Lerk, and Snap. Our estimation of H_0 is remarkably consistent with various recent Planck Collaboration studies that utilize the ΛCDM model. According to our research, the power law cosmology within the context of $f(R, G)$ gravity provides the most comprehensive explanation for the important aspects of cosmic evolution.

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Cosmology / 205

Power Law solution for FRW Universe with Observational Constraints

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In this study, The power-law solution for an isotropic and homogeneous universe under $f(R,T)$ gravity is examined by taking into account its functional form, $f(R,T) = R + \xi RT$, where ξ is a positive constant. We have constructed the field equation in f(R, T) gravity for homogeneous and isotropic space-time. The solution of the constructed model is given by the $a = \alpha t^{\beta}$. We used the redshift in the $0 \leq z \leq 1.965$ range and obtained the model parameters α, β, H_0 using the Markov Chain Monte Carlo method (MCMC). The constrained value of model parameter $H_0 = 65.777^{+2.043}_{-2.171}$ km s^{-1} Mpc^{-1}, $H_0 = 66.685^{+2.098}_{-1.765}$ km s^{-1} Mpc^{-1}, $H_0 = 67.226^{+1.197}_{-1.172}$ km s^{-1} Mpc^{-1}, $H_0 = 66.965^{+2.201}_{-2.020}$ km s^{-1} Mpc^{-1}, by bounding the model with H(z) (Hubble parameter) dataset, BAO (Baryon Acoustic Oscillations) dataset, joint H(z) + Pantheon dataset and joint H(z) + BAO + Pantheon dataset respectively. These observational values of derived H_o nicely correspond with the results from the Plank collaboration values. The model is analysed and discussed by studying the behaviour of energy conditions on our achieved solution. We have examined the validity of our model by jerk parameter, Om diagnostic, and statefinder diagnostic tools. Our findings reveal that the present study is consistent with these observations.

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Astrophysical Relativity / 206

Dependence of maximum mass on finite strange quark mass of anisotropic strange quark star in Finch-Skea geometry

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A class of relativistic compact objects is analysed in modified Finch-Skea geometry described by modified MIT bag model equation of state of the interior matter. The bag constant B plays an important role in determining the physical features of strange star. In this work we have considered the effect of finite strange quark (m_s 0) on the stability of quark matter inside a star. We have noted that inclusion of strange quark mass affects the gross properties of stellar configuration such as maximum mass, compactness, surface red-shift, radius of strange quark stars. We have considered three compact objects which are supposed to be strange stars namely (i) 4U 1820-30 (ii) VELA X-1 and (iii) PSR J 1903+327 for physical application. It is noted that the range of B is restricted from 57.55 to $B_{max}(MeV/fm^3)$ for which strange matter might be stable relative to iron (^{56}Fe). However, we have also observed that the metastable and unstable strange matter depends on B and m_s . All energy conditions held well in this approach. Stability in terms of TOV equation, Herrera cracking condition, adiabatic index and Lagrangian perturbation of radial pressure are studied in this paper.

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Classical & Quantum Gravity / 207

Gyroscopic Precession in the Vicinity of a Black Hole's Event Horizon and Naked Singularity for Static and Stationary Spacetime

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In this work, we employ the Frenet-Serret formalism of gyroscopic precession to compute the precession frequency close to the event horizon and naked singularity (NS) for spherically symmetric and axisymmetric spacetime. We aim to determine the possibility of using the gyroscopic precession to distinguish a black hole event horizon from a naked singularity. We show that it is possible to have a timelike trajectory crossing the black hole along which the precession frequency remains finite at the horizon. We demonstrate these using spherically symmetric static solutions as well as axisymmetric stationary Kerr solutions. We will also discuss how the gyroscopic precession frequency helps us to distinguish a black hole's event horizon from a naked singularity for these above kinds of spacetime by using both spinning extended and non-spinning point mass test gyroscopes.

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Gravitational Waves / 208

Detection possibility of continuous gravitational waves from isolated rotating magnetized compact objects

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In the past decades, several neutron stars (NSs), particularly pulsars, with mass $M > 2M_\odot$ have been observed. Hence, there is a generic question of the origin of massive compact objects. Here we explore the existence of massive, magnetized, rotating NSs with various equation of states (EoSs) using XNS code, which solves axisymmetric stationary stellar equilibria in general relativistic magnetohydrodynamics (GRMHD). We visualise the deformation of NS due to magnetic field (Toroidal and/or Poloidal) and rotaion (Uniform or Differential), by solving the Einstein equation (describes space-time metric) and Magneto-Hydrostatic Equilibrium (provides distribution of matter/energy) simultaneously. Such rotating NSs with magnetic field and rotation axes misaligned, hence (triaxial system) having non-zero obliquity angle, can emit continuous gravitational waves (GW), which can be detected by upcoming detectors, e.g., Einstein Telescope, etc. We discuss the decays of magnetic field, angular velocity and obliquity angle with time, due to Hall, Ohmic, ambipolar diffusion and angular momentum extraction by GW and dipole radiation, which determine the timescales related to the GW emission. Further, in the Alfvén timescale, a differentially rotating, massive proto-NS rapidly loses angular momentum to settle into a uniformly rotating, less massive NS due to magnetic braking and viscous drag. These explorations suggest that detecting massive NSs is challenging and sets a timescale for detection. We calculate the signal-to-noise ratio of GW emission, which confirms that any detector cannot detect them immediately, but detectable by Einstein Telescope, Cosmic Explorer over months of integration time, leading to direct detection of NSs.

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Classical & Quantum Gravity / 209

Effective quantum states for trapped surfaces

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Trapped surfaces are the basic building blocks of a black hole region. Marginally trapped surfaces, which are trapped surfaces with vanishing value of the outward null expansion scalar, foliate the null horizon of a black hole in equilibrium. Using the intrinsic geometry of trapped surfaces, it shall be argued that the algebra of classical charges follow a simple algebra. The representation of this algebra leads to an effective description of quantum states residing of the horizon.

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Gravitational Waves / 210

Noise analysis of the Indian Pulsar Timing Array data release I

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The Indian Pulsar Timing Array (InPTA) collaboration has recently made its first official data release (DR1) for a sample of 14 pulsars using 3.5 years of uGMRT observations. We present the results

of single-pulsar noise analysis for each of these 14 pulsars using the InPTA DR1. For this purpose, we consider white noise, achromatic red noise, dispersion measure (DM) variations, and scattering variations in our analysis. We apply Bayesian model selection to obtain the preferred noise models among these for each pulsar. Properties vary dramatically among pulsars. For example, for PSR J1600−3053, we find no evidence of DM and scattering variations, while for PSR J1909−3744, we find no significant scattering variations. We find a strong chromatic noise with chromatic index ~ 2.9 for PSR J1939+2134, indicating the possibility of a scattering index that does not agree with that expected for a Kolmogorov scattering medium consistent with similar results for millisecond pulsars in past studies. Despite the relatively short time baseline, the noise models broadly agree with the other PTAs and provide, at the same time, well-constrained DM and scattering variations.

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Classical & Quantum Gravity / 211

Is the no-hair theorem a feature of gravity or General Relativity?

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A pivotal question in black hole physics is whether the No-hair theorem is a property of gravity or General Relativity. Associated questions are: Do modified gravity theories allow rotating black hole solutions besides Kerr? If so, what type of modified gravity theories support it, and how are they distinct from the Kerr solution in general relativity? We address some of these questions by explicitly constructing multiple slow-rotating black hole solutions in $f(R)$ gravity up to the second order in the rotational parameter. In this presentation, we demonstrate analytically that a number of vacuum solutions satisfy the field equations up to the second order in the rotational parameter. Consequently, our findings imply that the no-hair theorem for modified gravity theories must be expanded to incorporate the coupling constants from the higher-derivative terms. Our results are unique since they are obtained without conformal transformation.

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Cosmology / 212

A Local Perspective on Hubble Tension from Cosmological N-body Simulations

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We use cosmological N-body simulations to study a local Hubble constant measurement and study the uncertainty introduced by our lack of peculiar velocities. We consider observers to be located in dark matter halos and target galaxies to be distributed amongst dark matter halos. We average over all observers. Our findings show a trend where local measurements have a significant dispersion but these progressively converge toward the global value as we extend our measurements to the local volumes at greater distances. The statistical errors attributed to the influence of the large-scale structure diminish as we move farther away, ultimately reaching a level of comparability with the errors found in Planck and SH0ES measurements at approximately 100 Mpc. Measurements at smaller scales are susceptible to errors arising from peculiar motions and this error can propagate to measurements at larger scales in the distance ladder. Notably, we observe a negative correlation between the local overdensity around an observer and the deviation of the local Hubble constant from the global value. We show that deviations larger than 5% of the global values can be encountered frequently at scales of up to 40 Mpc.

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Astrophysical Relativity / 213

Investigating the existence of gravitomagnetic monopole in M87*

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When the fuel of a very massive star is spent, it collapses due to its own gravitational pull and eventually becomes a very small region of arbitrarily high matter density, that is a 'Singularity', where the usual laws of physics may break down. If this singularity is hidden within an event horizon, which is an invisible closed surface from which nothing, not even light, can escape, then we call this object a black hole (BH). But if the event horizon does not form, we are left with the tantalizing option of observing a naked singularity (NS). In 2018, we reported the first observational indication of the gravitomagnetic monopole (gravitational analogue of Dirac's magnetic monopole) using the X-ray data from a star GRO J1655-40, which collapsed into the most extreme object in the universe, a Singularity. However, in 2019, the Event Horizon Telescope (EHT) mapped the compact radio source (M87*) of the elliptical galaxy M87 and showed that it is consistent with a Kerr black hole, yet alternatives to this are not ruled out. We examine the possibility for the existence of a gravitomagnetic monopole (n) in M87* by using the results obtained from its first EHT image. Using the EHT observational results, we obtain the allowed parameter space of a Kerr-Taub-NUT metric description for M87*. We have found that the observational constraints on the size and circularity of the M87* shadow do not exclude the possibility that M87* can be a naked singularity and contain the gravitomagnetic monopole. Essentially, accurate measurements of both the shadow size and asymmetry could put strong constraints on the Kerr parameter a and n and break the degeneracies between the different metrics (including those between the BHs and NSs).

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Cosmology / 214

Alleviating H0 Tension with New Gravitational Scalar Tensor Theories

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We investigate the cosmological applications of new gravitational scalar-tensor theories and we analyze them in the light of H0 tension. In these theories the Lagrangian contains the Ricci scalar and its first and second derivatives in a specific combination that makes them free of ghosts, thus corresponding to healthy bi-scalar extensions of general relativity. We examine two specific models, and for particular choices of the model parameters we find that the effect of the additional terms is negligible at high redshifts, obtaining a coincidence with ΛCDM cosmology, however as time passes the deviation increases and thus at low redshifts the Hubble parameter acquires increased values ($H0 \approx 74$km/s/M pc) in a controlled way. The mechanism behind this behavior is the fact that the effective dark-energy equation-of-state parameter exhibits phantom behavior, which implies faster expansion, which is one of the sufficient conditions that are capable of alleviating the H0 tension. Lastly, we confront the models with Cosmic Chronometer (CC) data showing full agreement within 1σ confidence level.

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Classical & Quantum Gravity / 215

High-energy corrections to CGHS model: a systematic procedure

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The knowledge of what entered them is completely lost as black holes evaporate. This contradicts the unitarity principle of quantum mechanics and is referred to as the information loss paradox. Understanding the end stages of black hole evaporation is key to resolving this paradox. As a first step, we need to have exact models that can mimic 4-D black holes in General relativity in classical limit and have a systematic way to include high-energy corrections. While there are various models in the literature, there is no systematic procedure by which one can study high-energy corrections. In this talk, we obtain Callan, Giddings, Harvey, and Strominger (CGHS) — a (1+1)-D — model from 4-D scalar-tensor theory action. We then show that 4-D Horndeski action — the most general scalar-tensor theory that does not lead to Ostrogradsky ghosts — can systematically provide a route to include terms relevant at the end stages of black hole evaporation. We discuss some of the interesting features of the corrected CGHS model and obtain Hawking flux. We compare our results with other works.

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Classical & Quantum Gravity / 216

Harmonic coordinates in binary black hole mergers

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Harmonic coordinates are often used in analytical calculations of the general relativistic binary problem, since they simplify Einstein's equations to a set of quasilinear wave equations. However, numerical relativity simulations of merging binary black holes are commonly performed in different gauges. In this article, we develop a technique to construct harmonic coordinates for binary black hole spacetimes in numerical simulations. We investigate the existence of harmonic coordinates in highly dynamical spacetimes of merging black holes, with the aim of capturing binary kinematics from numerical relativity in this coordinate gauge that holds special utility in analytical relativity. We find that harmonic coordinates exist throughout the inspiral and plunge of merging binary black holes. However, in a time-window lasting several BH light-crossing times around merger, we find that (a) harmonic coordinates may become singular, and (b) harmonic time slices become timelike. After merger, harmonic coordinates are well behaved everywhere in our computational domain, and can thus represent the evolution of the perturbed merged black hole into a stationary Kerr black hole.

Using our new techniques to construct harmonic coordinates, we investigate the inspiral trajectories of the black holes in harmonic coordinates. We compare these harmonic trajectories to post-Newtonian results in the same gauge and find good agreement. *This enables gauge-dependent comparisons of two-body kinematics between numerical relativity and post-Newtonian theory results, allowing for better understanding of general relativistic models for binary black hole dynamics.*

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Gravitational Waves / 217

Superradiant Scattering Of Electromagnetic Field And Scalar Field By The Ringing Black Holes

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Within the framework of static-charged and rotating black hole spacetime, an extensive amount of work suggests that the bosonic fields exhibit superradiant scattering. In this work, we have investigated the scattering of scalar waves and electromagnetic (EM) waves for Schwarzschild black hole in the ring down phase (we refer to this black hole as the "ringing black hole"), which is the last phase of the black hole merging process. Using the minimal coupling prescription, we have found the superradiant enhancement for both scalar and electromagnetic waves by numerically evaluating the absorption cross-section of the ringing black hole. Moreover, treating the scattered scalar field as an axion, we further computed its observable effects on the rotation of the plane of polarization of the photon. On the other hand, we have also put forward the prospect of direct detection of the superradiant enhancement for EM wave by the ringing black hole of primordial origin. Our current findings suggest an intriguing opportunity to investigate the black hole merging phenomena through other fundamental fields.

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Cosmology / 218

Dynamical systems approach in cosmology

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The present work deals with a dynamical systems study of quintessence potentials leading to the present accelerated expansion of the universe. The principal interest is to check for late time attractors which give an accelerated expansion for the universe. Two examples are worked out, namely the exponential and the power-law potential. Furthur we can encountered with the other type of potential where linear stability analysis fails and we prefer to other approaches like Centre Manifold theorem and Lyaponuv functions to check the stability of the system.

Key words; Quintessence,Linear stability theorem, Centre Manifold Theorem and Lyapunov Functions.

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Gravitational Waves / 219

Quasinormal Modes of Slowly Rotating Black Holes in Dynamical Chern-Simons Gravity up to Second Order in Spin

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One of the key aims of next-generation gravitational wave detectors is to test General Relativity (GR) in the strong gravity regime. It is expected that gravity is modified in the strong gravity regime. Hence, it is imperative to obtain rotating black hole solutions in modified theories of gravity, look at their quasinormal mode (QNM) signatures, and obtain the difference between the new solutions and the GR solutions. However, it is hard to find exact black hole solutions in modified theories of gravity. We consider dynamical Chern-Simons (DCS) gravity, one of the simplest parity-violating models, in which a scalar field is non-minimally coupled to the Pontryagin density and whose rotating solution is non-Kerr. Slowly rotating blackhole solutions for DCS gravity exist in the literature up to the fifth order in the spin parameter a and quadratic order in the CS coupling parameter (α). In this work, we obtain the linear perturbation equations of these slowly rotating non-Kerr solutions and their QNM frequencies accurate up to $O(a^2, \alpha^2)$. To our knowledge, these have not been obtained. We discuss the implications for Cosmic Explorer and Einstein Telescope.

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Astrophysical Relativity / 220

A deeper insight into the accretion scenario of BH-ULXs with XMM-Newton

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We present the results of a comprehensive long-term spectro-temporal analysis of eight ultra-luminous X-ray sources (ULXs) with the central object being a black hole, using XMM-Newton monitoring of about a decade. Temporal studies reveal the existence of short-term variability in each sources with fractional variance varying in the range of $1.42 - 27.28$ per cent. Five sources of the sample are found to exhibit Quasi-periodic Oscillations (QPOs) with frequency $\sim 8 - 667$ mHz. The thermal Comptonization component along with a disc component is found to be the best description of the energy spectra in $0.3 - 10$ keV energy range over other models. Some of the sources are found to exhibit a negative correlation between luminosity and disc temperature ($L_{\rm disc} \propto T_{\rm in}^{-\alpha}$), whereas rest of the sources show clear positive correlation ($L_{\rm disc} \propto T_{\rm in}^{+\alpha}$). A detailed spectro-temporal correlation study indicates significant contribution of Comptonized flux ($50-90\%$) in the total spectral flux as compared to disc contribution ($\sim 50\%$) in presence of QPO features in selected sources. Overall findings based on spectro-temporal correlation studies indicate that possibly Comptonization plays a viable role in the generation of QPOs. In addition, significant long-term spectral evolution is seen in each of the sources, indicating several spectral state transition. Finally, we employ a model formalism based on the relativistic, viscous, optically thin, advective accretion flow around black hole to infer the mass of the central black hole using the observed QPO frequency and luminosity of the selected ULXs.

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Classical & Quantum Gravity / 221

Traversable wormholes in bi-metric gravity

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The ghost-free bi-metric gravity theory is a viable theory of gravity that explores the interaction between a massless and a massive graviton and can be described in terms of two dynamical metrics. In this paper, we present an exact static, spherically symmetric vacuum solution within this theory. The solution is spatially Schwarzschild-de Sitter, with the value of the cosmological constant determined by the graviton mass and the interaction parameters of the theory. Notably, for specific parameter ranges, the solution represents a traversable Lorentzian wormhole that violates the weak energy condition near its throat. Furthermore, we have investigated the evolution of scalar and electromagnetic fields in this wormhole spacetime and observed the presence of arbitrarily long-lived quasi-resonant modes in the quasinormal spectrum.

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Gravitational Waves / 222

Bayesian framework to infer the Hubble constant from cross-correlation of individual gravitational wave events with galaxies

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Gravitational waves (GW) from the inspiral of binary compact objects offer a one-step measurement of the luminosity distance to the event, which is essential for estimating the Hubble constant, H_0, that characterizes the expansion rate of the Universe. However, unlike binary neutron stars, the inspiral of binary black holes is not expected to be accompanied by electromagnetic radiation and, thus, a subsequent determination of its redshift using the traditional host identification method is not possible. Consequently, independent redshift measurements of such GW events are necessary to measure H_0. In this study, we present a novel Bayesian approach to infer H_0 from the cross-correlation between galaxies with known redshifts and individual binary black hole merger events. We demonstrate the efficacy of our method with 250 simulated GW events distributed within 1 Gpc in colored Gaussian noise of Advanced LIGO and Advanced Virgo detectors operating at O4 sensitivity. We show that such measurements can constrain the Hubble constant with a precision of $lesssim 10\%$ (90% highest density interval). We highlight the potential improvements that are required before the method can be applied to real data.

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Classical & Quantum Gravity / 223

Gravitational radiation from binary systems in f (R) gravity: A semi-classical approach

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The rate of energy loss and orbital period decay of quasi- stable compact binary systems is a useful tool to constrain theories of gravity. In this talk, we present exact expressions for energy loss and orbital period decay are in three $f(R)$ theories derived using the method of a single vertex graviton emission process from a classical source. After linearising the f (R) action written in an equivalent scalar-tensor format in the Einstein frame, we identify the appropriate interaction terms between the massless spin-2 tensor mode, massive scalar mode, and the energy momentum tensor. Using the interaction vertex we compute the rate of energy loss due to spin-2 quadrupole radiation, which comes out to be the same as the Peter-Mathews formula with a multiplication factor, and also the energy loss due to the scalar dipole radiation. The total energy loss is the sum of these two contributions. Our derivation is most general as it is applicable for both arbitrary eccentricity of the binary orbits and arbitrary mass of the scalar field. Using the derived theoretical formula for the period decay of the binary systems, we compare the predictions of $f(R)$ gravity and general relativity for the observations of four binary systems, i.e. Hulse-Taylor Binary, PSR J1141-6545, PSR J1738+0333, and PSR J0348+0432. Thus we put bound on three well-known $f(R)$ dark energy models, namely the Hu-Sawicki, the Starobinsky, and the Tsujikawa model. We get the best constraint on $f'(R_0)-1$ (where R0 is the scalar curvature of the Universe at the present epoch) from the Tsujikawa model, i.e $|f'(R_0)-1| < 2.09 \times 10^{-4}$. This bound is stronger than those from most of the astrophysical observations and even some cosmological observations.

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Classical & Quantum Gravity / 224

Gravitational wave memory for various black hole and wormhole geometries

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Gravitational wave (GW) memory is studied in the context of a certain class of braneworld wormholes. Unlike other wormhole geometries, this novel class of wormholes do not require any exotic matter fields for its traversability. First, we study geodesics in this wormhole spacetime, in the presence of a GW pulse. The resulting evolution of the geodesic separation shows the presence of displacement and velocity memory effects. Motivated by the same, we study the memory effects at null infinity using the Bondi-Sachs formalism, adapted for braneworld wormhole. Our analysis provides a non-trivial change of the Bondi mass after the passage of a burst of gravitational radiation and hence manifests the memory effect at null infinity. In both of these exercises, the presence of extra dimension and the wormhole nature of the spacetime geometry gets imprinted in the memory effect. Since future GW detectors will be able to probe the memory effect, the present work provides another avenue to search for compact objects other than black holes. In fact GW memory effect can be used to differentiate between black holes and various exotic compact objects (ECOs). Keeping this in mind we have studied memory effect for various spherically symmetric spacetimes of GR and theories beyond GR.

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Cosmology / 225

Measuring secondary halo bias using nearest neighbor distributions

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Dark matter haloes in a given mass range are expected to cluster differently based on secondary halo properties such as concentration or spin, a behaviour known as secondary halo bias. While secondary halo bias has been quantified in simulations, observational uncertainties in halo properties make it difficult to measure the signal in data using only two-point clustering. The k-Nearest Neighbour Cumulative Distribution Functions (kNN-CDFs) are sensitive to all N-point correlation functions of the underlying field and are more potent as summary statistics to study clustering. In this talk, I present my work on measuring the secondary bias due to concentration in *cluster-sized* haloes taken from the Quijote simulations. I quantify the clustering of the *cluster-sized* haloes using their *auto-correlation* as well as their *cross-correlation* with *galaxy-sized* haloes and demonstrate that the kNN-CDFs provide a much larger signal-to-noise than the 2PCF in each case. The kNN-CDFs can detect a statistically significant secondary bias signal even in the cluster auto-correlation, where the 2PCF does not see any signal. I discuss the effect of introducing numerical scatter in the halo concentration to mimic observational uncertainties and demonstrate that the kNN-CDFs are more robust to noise, giving a statistically significant signal even at large scatter values.

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Cosmology / 226

On the independence of predictions of LQC on the inflationary potential

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In Loop Quantum Cosmology (LQC), a quantum bounce precedes inflationary epoch. The presence of a quantum bounce leads to a departure from scale invariance of the spectra of primordial perturbations. Studies conducted mostly at the level of the primordial power spectrum show that this departure from scale invariance is a remnant of the bounce and is largely independent of the form of the inflationary potential. In this talk, we present our detailed investigation of the (in)dependence of the predictions of LQC on the form of the potential at the level of the primordial bispectrum.

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Classical & Quantum Gravity / 227

Gravitational Waves in F(R) Gravity

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We explore the formulation of Gravitational Waves(GWs) in the modified f(R) gravity model given by f(R)=\frac{R^{1+\delta}}{R^\delta_c}. We introduce the weak field approximation and study polarization of GWs. The Gravitational Waves carry an extra mode of polarization beyond the TT mode for the weak field approximation. We discuss the dependence of the polarization of these waves on the scalaron mass and effective potential.

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Astrophysical Relativity / 228

Astrophysical significance of tidal interaction between white dwarfs and intermediate-mass black holes

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Tidal disruption of white dwarfs (WD) is an astrophysical transient phenomenon capable of revealing significant information on the presence of intermediate-mass black holes (IMBH). Using hydrodynamical simulations, we explore the observable properties of these astrophysical events. We accurately calculate the fallback rate of the tidal debris during its accretion onto an IMBH. We find the remnant core's mass fraction, tidal kick velocity, its trajectory deviation, as well as their dependence on binary mass ratio and orbital eccentricity in partial tidal disruption events. For an IMBH-WD system, we also simulate the burst-like gravitational wave (GW) emission, expected to be detected by LISA. After disruption, the tidal debris is not compact enough to produce the GW signal. Thus, using both the electromagnetic and GW signals, we identify the observable signatures to decipher binary parameters, including the mass of the black hole, the interior structure of the WD, and orbital specifications. We implement this method to investigate a class of modified gravity theories that leaves its footprint inside the WD by altering its mass-radius relation and tidal radius even in the Newtonian limit.

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Classical & Quantum Gravity / 229

Exploring Quasinormal Modes and Strong Cosmic Censorship in 2D Black Hole Models

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We study linear scalar perturbations of black holes in two-dimensional (2D) gravity models with a particular emphasis on Jackiw-Teitelboim (JT) gravity. We obtain an exact expression of the quasinormal mode frequencies for single horizon black holes in JT gravity and then verify it numerically using the Horowitz-Hubeny method. We shall also consider the dimensionally reduced Bañados-Teitelboim-Zanelli (BTZ) black hole and obtain the exterior and interior quasinormal modes. The dynamics of a scalar field near the Cauchy horizon mimics the behavior of the same for the usual BTZ black hole, indicating a possible violation of the strong cosmic censorship conjecture in the near-extreme limit. However, quantum effects seem to rescue strong cosmic censorship.

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Gravitational Waves / 230

How does Carter flux may affect the resonance crossing in an EMRI inspiral ?

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In this talk, I will discuss the resonance crossing in an Extreme Mass Ratio Inspiral (EMRI). By assuming a charged particle moving in an external homogeneous magnetic field under the electromagnetic self force (ESF), we discuss how it encounters the resonances. In a past work, we compare the resonance timescale between ESF and its adiabatic counterpart, and obtain a qualitative similarity. Here, we will discuss how the inclusion of Carter's flux would affect this timescale. Given that the system is non-integrable, it holds useful similarities with more realistic EMRI models, such as with secondary' s spin. Not to mention that environmental effects may also be non-integrable in general, and our work may be useful to address long-lived resonances in those systems.

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Classical & Quantum Gravity / 231

A study on the maximum mass and stability of strange stars affected by the mass of strange quarks (m_s≠0).

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In this article, we analyze a class of compact object in spheroidal geometry described by Vaidya–Tikekar model and MIT bag equation of state considering the finite value of strange quark mass (m_s). The maximum mass and radius is evaluated by maximizing the radial sound velocity (v_r^2) at the centre of the star. For monotonically decreasing nature of the sound velocity, it is noted that an upper limit of the spheroidal parameter (λ) exists. Therefore, to calculate maximum mass, arbitrary choice of (λ) is not allowed. The effect of strange quark mass on the maximum mass is found to satisfy previously obtained result (Li et al 2021 Eur. Phys. J. C 81 921). We consider the compact stars 4U 1608-52 and 4U 1820-30 to study the relevant properties in this approach. The stability of strange quark matter inside these compact objects is explored by taking different values of the bag constant B. It is found that 4U 1608-52 may be categorized as strange star with wider stability window for three-flavor (u, d, s) quark matter whereas 4U 1820-30 only shows metastability. The model is found to be stable against small radial perturbation.

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Cosmology / 232

Qualitative Stability Analysis of Cosmological models in $f(T, \phi)$ Gravity

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Using the dynamical system approach, we investigated the stability condition of two considered models in $f(T, \phi)$ gravity where T is the torsion scalar of teleparallel gravity and ϕ is a canonical scalar field. In this context, we are concerned with the phenomenology of the class of models with non-linear coupling to gravity and exponential potential. We assume the forms of G(T) as (i) $G(T)$ = $\alpha T + \frac{\beta}{T}$ and (ii) $G(T)$ = ζT ln(ψT), where α, β, ζ and ψ be the free parameters and $G(T)$ is the function of T. We evaluated the equilibrium points for these models and examine the stability behaviors. For Model I, we found four stable critical points while for Model II, we found three stable critical points. The stable critical points represent the attractors with accelerated expansion. The phase plots for these systems are examined and discussed the physical interpretation. We illustrate all the cosmological parameters such as Ω_m, Ω_ϕ, q and ω_{Tot} at each fixed points and compare the parameters with observational values. In both Model I and Model II, we found $\Omega_{de} = 1$ which represents the dark energy dominant Universe. Further, we assume hybrid scale factor to develop our model and this model produces a transition phase from deceleration to the acceleration. We transform all the parameters in redshift and examine the behavior of these parameters. From the Figures, it is observed that $q = -1$ represents the accelerating stage of the Universe and EoS parameter $\omega = -1$ represents the ΛCDM model. For Model I, we get $\omega_0 = -0.992$ and for Model II, we get $\omega_0 = -0.883$ which is comparable to the observational data. The energy conditions are examined in terms of redshift while strong energy condition is violated for both models which shows the accelerated expansion evolution of present universe. We also find the statefinder parameters $\{r, s\}$ in terms of z and discuss the nature of $r - s$ and $r - q$ plane. For both models, $r = 1, s = 0$ and $r = 1, q = -1$ represent the ΛCDM model. We observed that our $f(T, \phi)$ models are stable and it is in accordance with the observational data.

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Cosmology / 233

Detectable signatures of non-Bunch-Davies 3-point correlation from primordial magnetic fields: CMB μT spectrum

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We investigate the non-Gaussian three-point cross-correlation function between the primordial curvature perturbation and the primordial magnetic field generated via direct gauge-inflaton coupling, for generic non-standard initial vacua. Among the possible triangular configurations of the resulting cross-bispectrum, we find that the squeezed limit leads to a product form decomposition in terms of the scalar and magnetic power spectra, which is a general result independent of any specific choice of the non-Bunch-Davies initial states. We subsequently explore the prospects of such a primordial cross-correlator in sourcing a detectable CMB correlation between μ-type spectral distortions and temperature anisotropies prior to recombination. Our forecast analysis for various next-generation CMB missions reveals that compared to the standard Bunch-Davies case, the signal-to-noise ratio (SNR) of the μT cross-power spectrum can be enhanced significantly for specific combinations of the Bogolyubov coefficients, which correspond to particular choices of initial vacua.

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Gravitational Waves / 234

The Role of r-Modes in Pulsar Spindown, Pulsar Timing and Gravitational Waves

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Pulsars are fast spinning neutron stars that lose their rotational energy via various processes such as gravitational and magnetic radiation, particle acceleration and mass loss processes. This dissipation can be quantified by a spin-down equation that measures the rate of change of the frequency as a function of the rotational frequency itself. We explore the pulsar spin-down and consider the spin-down equation upto the seventh order in frequency. This seventh order term accounts for energy loss due to the gravitational radiation caused by a current type quadrupole in the pulsar due to r-modes. We derive the rotational frequency due to the r-modes and find a solution in terms of the Lambert function. We also present an analytic exact solution for the period from the spindown equation and numerically verify this for the Crab pulsar. This analysis will be relevant for the detection of continuous gravitational waves by 3G ground based and space based gravitational wave detectors.

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Cosmology / 235

Thermalised dark radiation in the presence of PBH: Neff and gravitational waves complementarity

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We study the possibility of detecting dark radiation (DR) produced by a combination of interactions with the thermal bath and ultra-light primordial black hole (PBH) evaporation in the early universe. We show that the detection prospects via cosmic microwave background (CMB) measurements of the effective relativistic degrees of freedom $\mathrm{N_{eff}}$ get enhanced in some part of the parameter space compared to the purely non-thermal case where DR is produced solely from PBH. On the other hand, for certain part of the parameter space, DR which initially decouples from the bath followed by its production from PBH evaporation, can re-enter the thermal bath leading to much tighter constraints on the PBH parameter space. We also discuss the complementary detection prospects via observation of stochastic gravitational wave (GW) sourced by PBH density perturbations. The complementary probes offered by CMB and GW observations keep the detection prospects of such light degrees of freedom very promising in spite of limited discovery prospects at particle physics experiments.

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Cosmology / 236

Revisiting Cosmic Microwave Background (CMB) Spectrum using COBE/FIRAS dataset: Blackbody Radiation Inversion problem

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A plethora of knowledge about the universe's chronology may be found in the spectral properties of the CMB energy spectrum. The spectral aberrations of the CMB complement all other cosmological investigations. According to the astonishing measurement of the CMB spectrum by COBE/FIRAS, the CMB spectrum resembles a blackbody with a temperature of TCMB = 2.72548 ± 0.00057 K. This paper aims to present a new Blackbody Radiation Inversion (BRI) Method which could reconstruct the CMB monopole as well as dipole spectrum. The BRI technique uses the observed radiated power spectrum to estimate the probability distribution of temperature. This study uses a gaussian function to obtain a blackbody radiation inversion and calculate the probability distribution of temperature. This inversion method estimates the temperature distribution of the producing medium from the blackbody radiation field of the CMB, the universe's first light. Investigating this distribution's key characteristics leads to a prediction that the cosmic microwave background spectrum has distortion. The temperature of the CMB spectrum, its fluctuation and distortions are calculated with the new proposed BRI method.
Keywords: CMB, Blackbody Radiation Inversion, dipole

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Classical & Quantum Gravity / 237

Lorentzian Wormhole in the framework of Loop Quantum Cosmology

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In this paper, we construct a traversable static Lorentzian wormhole in the effective scenario of Loop Quantum Cosmology (LQC), where the field equations are modified due to the ultraviolet (UV) corrections introduced at large space-time curvatures. A stable wormhole can be constructed in the effective scenario without the violation of Null energy condition (NEC) by physical matter at the throat. The NEC is effectively violated due to the corrections in the field equations from LQC, resolving the Weyl curvature singularity at the throat. However, the physical matter does violate the Strong energy condition (SEC), suggesting the interesting possibility that dark energy can be harnessed into a wormhole. A possible explanation for this is the presence of inherent pressure isotropy in the UV-corrected field equations (discussed and compared to braneworld wormholes in the discussion). No additional exotic ingredient (violating NEC) is required, avoiding quantum instabilities. The tidal forces at the throat do not diverge and also the throat is found to be stable. The wormhole features an attractive geometry. LQC can resolve both types of curvature singularities appearing at the black hole centre and wormhole throat, without exotic matter.

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Gravitational Waves / 239

Rapid Identification and Classification of Eccentric BBH mergers using Machine Learning

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The future of Gravitational Wave (GW) detectors [LVK] have made remarkable progress, with an expanding sensitivity band and the promise of exponential increase in detection rates for upcoming observing runs [O4 and beyond]. Among the diverse sources of GW signals, eccentric Binary mergers present an intriguing and computationally challenging aspect. We address the imperative need for efficient detection and classification of eccentric Binary mergers using Machine Learning (ML) techniques. Traditional Bayesian Parameter estimation methods, while accurate, can be prohibitively time-consuming and computationally expensive. To overcome this challenge, we leverage the capabilities of ML to expedite the identification and classification of eccentric GW events. I will present our approach that employs Separable Convolutional Neural Networks (SCNN) to discriminate between non-eccentric and eccentric Binary mergers and further classifying the latter into categories of low, moderate, and high eccentricity mergers.

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Gravitational Waves / 240

Inferring additional physics through model-agnostic signal reconstructions

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Post-detection analyses targeting inferences of source properties are often time-consuming and computationally expensive. Assumptions concerning source properties, such as the circularity of binary orbits or the absence of precessing component spins, are routinely made to reduce analysis costs. We shall present a method that may be used to infer the presence (or the lack thereof) of physical effects NOT captured by signal waveforms commonly employed in analysing observed GW signals with a latency similar to real-time analysis pipelines and thus help perform targeted follow-up analyses.

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Classical & Quantum Gravity / 241

Influence of gravity on the quantum speed limit in neutrino oscillations

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The quantum speed limit (QSL) specifies the shortest amount of time required for a quantum system to evolve from an initial to a final state. In this work, we look into QSL for the unitary evolution of neutrinos and antineutrinos in the presence of a gravitational field. Since the transition probabilities between neutrino and antineutrino in the framework of one and two flavors depend on the strength of the gravitational field, the QSL time behavior indicates fast flavor neutrino-antineutrino transitions as the gravitational field strength increases. Subsequently, we observe quick suppression of entanglement by exploring the speed limit for entanglement entropy of neutrino-antineutrino oscillations in the early universe and surrounding black holes.

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Cosmology / 242

Axion dark matter and helical electromagnetic fields

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Primordial electromagnetic fields can strongly affect the cosmic evolution of axions and vice versa. We show that if helical electromagnetic fields are coherently produced in the early universe, their remnants source a field velocity to the coupled axions and enhance the relic abundance of axion dark matter. We discuss the implications for the QCD axion and axion-like particles that are coupled to the SM or hidden gauge groups. For a QCD axion coupled to hidden photons, we find that the conventional window for the axion decay constant 10^8 GeV
$lesssim f$
$lesssim 10^{12}$ GeV can be completely closed due to overproduction of axion dark matter by helical electromagnetic fields as little as $\alpha\,\Delta N_{\rm eff}$
$gtrsim 10^{-12}$, where α is the gauge coupling and $\Delta N_{\rm eff}$ is the effective extra relativistic degrees of freedom of the hidden photons.

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Classical & Quantum Gravity / 243

Unruh effect via radiative energy level shift

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The Unruh effect states that the transition rates of a uniformly accelerated atom in the inertial vacuum has a thermal character at a temperature proportional to the atom's acceleration. Numerous proposals, studying different system properties under varied settings, to detect the Unruh effect still await fruition as the signal of interest is very weak. Here, we make case for a suitably modified density of field states to be complemented by a judicious selection of the system property to be monitored. We study the radiative energy level shift in a uniformly accelerated atom coupled to a massless quantum scalar field inside a long cylindrical cavity. The interest in the shifts in atomic energy levels as an observable for the detection of the Unruh effect stems from an experimental precision that the atomic spectroscopy has achieved so far. We show that the noninertial contribution to the energy shift can be isolated and enhanced relative to the inertial contribution by suitably modifying the density of field modes. Further, we show that monitoring the radiative energy shift, as compared to transition rates, allows us to reap even stronger purely-noninertial signal.

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Gravitational Waves / 244

Measuring Earth's Motion Using a Population of Gravitational-Wave Sources

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Measurements of the Cosmic Microwave Background Radiation indicate the presence of a dipole anisotropy in the sky distribution of temperature fluctuations of the CMB photons. It is believed that the CMB dipole arises because of the earth's motion with respect to the cosmic rest-frame; hence, the strength of the dipole provides an estimate of the earth's speed. Similar measurements

recently performed using the sky distribution of distant quasars yield a value for the earth's speed in tension with that inferred from the CMB. An equivalent dipole is expected in the sky and mass distribution of gravitational-wave sources. In this talk, I present a hierarchical Bayesian inference framework that utilises Doppler shifting of features present in the distribution of chirp masses of merging Binary Neutron Stars (BNSs) to extract information about the earth's peculiar velocity. I create realistic, dipole-distributed mock BNS catalogs using forecasts for third-generation detector sensitivities, and recover the injected speed and direction of earth's motion using Markov Chain Monte Carlo sampling. I discuss how well the model constrains the earth's motion as a function of the number of simulated mergers. This provides an estimate for the minimum number of detections needed to get an independent estimate of the earth's speed using gravitational-wave astronomy and potentially help mitigate the statistical tension between the dipoles measured from the CMB and quasars.

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Cosmology / **245**

Towards a possible solution to the Hubble tension with Horndeski gravity

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The Hubble tension refers to the discrepancy in the value of the Hubble constant H_0 inferred from the cosmic microwave background observations, assuming the ΛCDM model of the universe, and that from the distance ladder and other direct measurements. In order to alleviate this tension, we construct a plausible dark energy scenario, within the framework of Horndeski gravity which is one of the most general scalar-tensor theories yielding second-order equations. In our set-up, we include the self-interactions and nonminimal coupling of the dynamical dark energy scalar field which enable very interesting dynamics leading to a phantom behaviour at low redshifts along with negative dark energy densities at high redshifts. These two features together make this model a promising scenario to alleviate the Hubble tension for appropriate choices of the model parameters. Finally, as a consistency check, we show that this set-up is also free of the gradient and ghost instabilities.

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Cosmology / **246**

Non-linear regression with errors on both axes and its implications on Hubble tension.

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While fitting a non-linear model to data, it is common to consider errors only in the dependent variable and treat other variables as perfectly measured. A more flexible model fitting considering errors in independent variables is expected to better estimate the parameters of the model from the same data. We employ a Bayesian method to consider redshift errors in the Pantheon sample of Type-Ia supernovae, and find that it improves the ΛCDM fit to the data. We are investigating the implications of this method on cosmological tension in the value of Hubble constant H_0 with presently available data and with simulated data of larger volume and better quality expected to be available in the future.

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Cosmology / **247**

Evolution of global 21 cm temperature in scalar field models

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The study investigates the evolution of the global 21 cm temperature, a pivotal cosmological probe for understanding the early Universe, employing a novel approach rooted in scalar field dynamics.In this research, we use scalar field models to understand its impact on 21 cm cosmology, aiming to uncover the unexplored nuances in the temperature fluctuations. Furthermore, we try to understand the scalar field's role in modulating the thermal history of the intergalactic medium and other aspects of cosmology.

This study not only presents a novel perspective on the global 21 cm temperature evolution but also highlights the broader applicability of scalar field dynamics in cosmological investigations. The results offer a valuable foundation for future research endeavors, paving the way for a deeper understanding of the intricate interplay between scalar fields and the cosmic microwave background radiation. Additionally, these insights hold significant implications for refining our comprehension of early Universe cosmology and the nature of dark energy.

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Classical & Quantum Gravity / 249

An Effective Theory model for Black Hole Membranes from Constraints of Symmetry

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Einstein equations projected on Black Hole horizons give rise to the equations of motion of a viscous fluid. This suggests a way to understand the microscopic degrees of freedom on the Black Hole horizon by focusing on the physics of this fluid. In this talk, we shall approach this problem by building a crude model for the Horizon-fluid(HF) corresponding to asymptotically flat Black Holes in 3+1 dimensions. The symmetry requirement for our model is that it should incorporate the S1 diffeo-symmetry on the BH horizon. The second constraint comes from the demand that the correct value of the Coefficient of the Bulk Viscosity of the HF can be deduced from the model in the hydrodynamic limit. Both these requirements can be satisfied by an adoption of the eight vertex Baxter model on a S2 surface. We discuss how this model can also be viewed as an effective theory at comparatively lower energies. The adiabatic entropy quantisation proposed by Bekenstein also follows from this theory. Finally, we argue the results obtained so far suggest that a perturbed Black Hole can be described by a CFT perturbed by relevant operators and discuss the usefulness of the theory in understanding the thermalisation and escape of information at late times.

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Gravitational Waves / 250

Effect of spins on the orbital dynamics of a binary system

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So far, the post-Newtonian technique has generated spin-less gravitational waveforms of binaries in quasi-circular orbits to a very high degree of precision, or to a high post-Newtonian order. Including spins and eccentricity in the system brings challenges that have not been fully tackled to a high degree of accuracy. The inclusion of spins leads to characteristic effects on the orbital dynamics of the binary and in turn, on the gravitational wave waveform. Advanced earth-based or space-borne detectors can detect such effects on the gravitational wave signals due to spins. Hence it becomes important to model gravitational waves with the presence of spin. In this work, we calculate the effects of spins on the evolution of orbital elements under the parametrized Quasi-Keplerian scheme.

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Gravitational Waves / 251

Testing general relativity via direct measurement of black hole kicks

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Asymmetric emission of gravitational waves during a compact binary coalescence results in the loss of linear momentum and a corresponding 'kick' or recoil on the binary's center of mass. This leads to a direction-dependent Doppler shift of the ringdown gravitational waveform. We quantify the measurability of the kick imparted to the remnant black hole in a binary black hole merger. Future ground- and space-based gravitational wave detectors will measure this effect to within $\sim 2\%$ to $\sim 30\%$ for a subset of their expected observed sources. Certain binary configurations in the LISA band may allow a sub-percent-level measurement of this effect. This direct measurement of black hole kicks can also facilitate a novel test of general relativity based on linear momentum balance. We formulate this kick consistency test via measurement of a null variable that quantifies the difference between the inferred kick (using numerical relativity) and that observed via the Doppler-shifted ringdown signal. This null variable can be constrained (at 90% confidence) to $\sim 10\%$ to 30% with Cosmic Explorer and to $\sim 3\%$ to 12% with LISA.

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Cosmology / 252

Dark energy in light of the early JWST observations

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Early data from the James Webb Space Telescope (JWST) has uncovered the existence of a surprisingly abundant population of very massive galaxies at extremely high redshift, which are hard to accommodate within the standard ΛCDM cosmology. We explore whether the JWST observations may be pointing towards more complex dynamics in the dark energy (DE) sector. Motivated by the ubiquity of anti-de Sitter vacua in string theory, we consider a string-inspired scenario where the DE sector consists of a negative cosmological constant (nCC) and a evolving component with positive energy density on top, whose equation of state is allowed to cross the phantom divide. We show that such a scenario can drastically alter the growth of structure compared to ΛCDM, and accommodate the otherwise puzzling JWST observations if the dynamical component evolves from the quintessence-like regime in the past to the phantom regime today: in particular, we demonstrate that the presence of a nCC (which requires a higher density for the evolving component) plays a crucial role in enhancing the predicted cumulative comoving stellar mass density. Our work reinforces the enormous potential held by observations of the abundance of high-z galaxies in probing cosmological models and new fundamental physics, including string-inspired ingredients.

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Gravitational Waves / **253**

Population Inference of Merging Compact Binaries in the Presence of Lensing

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Lensing due to intervening matter such as clusters or galaxies can (de)magnify a gravitational-wave (GW) event, leading to a biased measurement of the source mass and redshift. Hierarchical inference on the detected GW events can be performed to estimate the population properties of binary black holes, such as their mass and redshift distributions. Currently, it is assumed that the current events are not significantly magnified due to their low lensing probability. When the lensing probability is higher (as expected for future detectors), this can bias our estimation of the population hyperparameters. In this work, we develop a Bayesian hierarchical inference formalism estimate of the true population hyperparameters of the GW sources as well as lenses.

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Gravitational Waves / **254**

Unraveling the Connection: Eccentric Binary Black Holes and Microlensed Signals

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Microlensing and eccentricity are two distinct physical effects that have not yet been observed in real gravitational wave events. While the rate of microlensed signals remains uncertain, the impact of non-zero eccentricity becomes increasingly significant as we explore the early stages of binary evolution or improve the sensitivity of detectors. Therefore, it is crucial to investigate whether microlensing modulations can mimic the effects of eccentricity, potentially affecting microlensing searches. In this study, we examine the degeneracy between eccentricity and microlensing by analyzing both eccentric numerical relativity (NR) data and TEOBResumS injections. Our findings indicate that the preference for the microlensing hypothesis over the usual unlensed hypothesis strengthens with: (i) higher eccentricities, (ii) longer waveforms, and (iii) high signal-to-noise ratios (SNRs). Population studies demonstrate that microlensing templates are consistently favored over unlensed templates when eccentricities exceed approximately 0.2. Based on these results, our study strongly suggests that any identified microlensed signal should also be confirmed using an eccentric waveform model to resolve the degeneracy. We further demonstrate this by recovering signals with eccentric templates and comparing them with the microlensed ones.

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Classical & Quantum Gravity / 255

Pole-skipping in holography with scalar-Gauss-Bonnet coupling

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Pole-skipping is a phenomenon when lines of poles and zeroes of retarded Green's function intersect-which means a would-be pole gets skipped in a complex $\omega - k$ plane. People have claimed these points are connected to the Lyapunov exponent and butterfly velocity of a chaotic system. In this talk, I will show the effect of scalar-Gauss-Bonnet coupling (higher curvature term coupled to the scalar field) on these Pole-skipping points in shear and sound mode analysis. The connection to chaos will also be discussed.

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Gravitational Waves / 256

Localizing binary neutron star sources with LIGO-Aundha

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LIGO-Aundha is expected to join the network of terrestrial broadband gravitational wave (GW) detectors and begin operations in the early 2030s. We study the impact of this additional detector on the accuracy of determining the direction of incoming transient signals from coalescing binary neutron star sources. Our study involves performing a full Bayesian parameter estimation (PE) over a heterogeneous detector network from a lower seismic cut-off frequency $f_{\rm low} = 10$ Hz, using the recently developed meshfree approximation aided fast Bayesian inference pipeline, providing a more robust approach than the `BAYESTAR` algorithm. With the improvements in network sensitivities, the future observing runs shall require performing estimation of source parameters from $f_{\rm low} = 10$ Hz in second generation ground based detectors, hence increasing the computational cost drastically. Our analysis takes this scenario into account. This distincts our work from previous related studies involving multi-detector sky localization of GW sources. We find that even in a 'worst-case scenario' , where a typical BNS source is sub-threshold in the LIGO-Aundha detector (a significant possibility in the early commissioning stages), it could play an essential role in improving the localization of the source and thus contribute to the exciting science from multi-messenger astronomy. The analysis involves taking into account the varying detector sensitivities and duty cycles representing different stages of improvements in the operational phases over the course of years. Once the detector reaches design sensitivity, further improvements in source localization are seen, as expected. We also present its impact on reconstructing other parameters of these compact binary sources.

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Cosmology / 257

A geometrical interpretation of foreground filters for HI intensity

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We give a new geometrical interpretation of HI intensity mapping foreground filters in harmonic space, for both single-dish and interferometer mode surveys. We derive the foreground-filtered HI auto power spectrum and then extend this to the cross-power spectrum of HI with CMB lensing. Foreground filtering leads to a loss of isotropy in Fourier space, resulting in harmonic space non-diagonal correlations, which we show are small compared to the diagonal ones. On large scales, foreground filters lead to a major loss of power in the HI $\times$ CMB lensing correlations.

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Gravitational Waves / 258

Resolving the eccentricity of stellar mass binary black holes with next generation gravitational wave detectors

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Next generation gravitational wave (GW) detectors are expected to detect 10^4–10^5 binary black holes (BBHs) per year. Understanding the formation pathways of these binaries is an open question. Orbital eccentricity can be used to distinguish between the formation channels of compact binaries as different formation channels are expected to yield distinct eccentricity distributions. Due to the rapid decay of eccentricity caused by the emission of GWs, measuring smaller values of eccentricity poses a challenge for current GW detectors due to their limited sensitivity. In this study, we explore the potential of next generation GW detectors such as Voyager, Cosmic Explorer (CE), and Einstein Telescope (ET) to resolve the eccentricity of BBH systems. Considering a GWTC-3 like population of BBHs and assuming some fiducial eccentricity distributions as well as an astrophysically motivated eccentricity distribution (Zevin et $al.$ (2021)), we calculate the fraction of binaries that can be confidently distinguished as eccentric. We find that for Zevin eccentricity distribution, Voyager, CE, and ET can confidently measure the non-zero eccentricity for $\sim 3\%$, 9%, and 13% of the detected BBHs, respectively. In addition to the fraction of resolvable eccentric binaries, our findings indicate that Voyager, CE, and ET require minimum eccentricities
$gtrsim0.02$, 5×10^{-3}, and 10^{-3} at a GW frequency of 10 Hz, respectively, to identify a BBH system as eccentric. The better low-frequency sensitivity of ET significantly enhances its capacity to accurately measure eccentricity.

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Gravitational Waves / 259

Examining the Evidence for Gravitational Wave Lensing in LIGO-Virgo Observations

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Gravitational waves (GWs) emitted from astrophysical sources can get lensed on their way to Earth, similar to electromagnetic waves. There are claims that detections made by LIGO and Virgo in earlier observational runs show evidence of lensing. Lensing has been invoked to explain the discovered high mass events, the bimodal mass function distribution of black holes, and for the objects in the mass-gap region. In this work, we critically examine these arguments and see if they are consistent with a variety of observational data (e.g., the inferred mass and redshift distributions of compact binaries and the non-observation of multiple images and stochastic GW background).

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Astrophysical Relativity / 260

Universe at extreme energies through GZK neutrinos and photons

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Ultra-high energy cosmic rays (UHECRs) beyond the Greisen-Zatsepin-Kuzmin (GZK) cut-off provide us with a unique opportunity to understand the universe at extreme energies. Secondary GZK photons and GZK neutrinos associated with the same interaction are indeed interconnected and render access to multi-messenger analysis of UHECRs. The GZK photon flux is heavily attenuated due to the interaction with Cosmic Microwave Background (CMB) and the Extra-galactic Radio Background (ERB). The present estimate of the ERB comprising of several model uncertainties together with the ARCADE2 radio excess results in large propagation uncertainties in the GZK photon flux. On the other hand, the weakly interacting GZK neutrino flux is unaffected by these propagation effects. In this work, we make an updated estimate of the GZK photon and GZK neutrino fluxes considering a wide variation of both the production and propagation properties of the UHECR like, the spectral index, the cut-off energy of the primary spectrum, the distribution of sources and the uncertainties in the ERB estimation. We explore the detection prospects of the GZK fluxes with various present and upcoming UHECR and UHE neutrino detectors such as Auger, TA, GRAND, ANITA, ARA, IceCube and IceCube-Gen2. The predicted fluxes are found to be beyond the reach of the current detectors. In future, proposed IceCube-Gen2, AUGER upgrade and GRAND experiments will have the sensitivity to the predicted GZK photon and GZK neutrino fluxes. Such detection can put constraints on the UHECR source properties and the propagation effects due to the ERB. We also propose an indirect lower limit on the GZK photon flux using the neutrino-photon connection for any future detection of GZK neutrinos by the IceCube-Gen2 detector. We find this limit to be consistent with our GZK flux predictions.

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Gravitational Waves / 262

Accelerated parameter estimation of massive black hole binaries in LISA using meshfree approximation

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LISA (Laser Interferometer Space Antenna) a planned space-based gravitational wave observatory to be launched in 2034 will be capable of detecting gravitational waves in the milli-Hertz band. Among various sources, LISA will detect the coalescence of massive black hole binaries (MBHBs) with total mass in range $[10^4 - 10^8]\mathrm{M}_\odot$ up to redshift ~ 10. As such cataclysmic coalescence will take place in gas rich environments, they will be accompanied by electromagnetic (EM) radiation that can be triggered during the inspiral, merger and post-merger phase of the binary evolution. The joint observation of gravitational waves and associated EM counterpart will lead to unveil the astrophysical environment around merging binaries and constrain the cosmological parameters. As these sources will be observed at a very high redshift, the associated EM counterpart will be characterized by faint EM emission. Therefore, in order to promptly locate them in the sky using EM facilities, accurate sky localization using gravitational wave observation is crucial well ahead of merger. Although the GW signal from such sources lasts for several months (or days) in the detector's bandwidth, the signal-to-noise ratio surpass the detection threshold only few days (or hours) before merger, challenging the accurate inference of source parameters including sky localization. We extend the recently developed Bayesian inference pipeline assisted by meshfree approximation of the likelihood function for MBHBs to be seen in LISA and estimate source parameters as a function of time left before coalescence.

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Gravitational Waves / 263

Inferring the quantum black hole signatures from gravitational-wave observations

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We propose a novel test for the quantum nature of astrophysical black holes using gravitational-wave measurements.
It is known that the black hole absorption and emission spectra will be quantised if the black hole area is quantised. Focusing on the black hole absorption spectra for binary black holes in the pre-merger signal, we quantify the measurability of black hole area quantisation parameter from the recent gravitational-wave detections through the LIGO-Virgo detectors. Furthermore, considering different

binaries we study the possibility of putting stringent bounds on the area quantisation parameter from future gravitational-wave detector such as DECIGO.

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Cosmology / **264**

Primordial Connection of CMB Anomalies

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Analysis of Planck data has revealed to us the presence of several anomalies in the Cosmic Microwave Background (CMB). Many investigations have revealed to us the interconnection between several such anomalies. In this talk, we highlight the primordial connection of some of these anomalies. In particular, we analyse certain templates of the primordial power spectrum and explain how features in the primordial power spectrum can alleviate tensions in the CMB such as power suppression, lensing anomaly and preference for odd parity.

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Classical & Quantum Gravity / **265**

Particle creation in a dynamical gravitational wave background

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We attempt a computation of the spectrum of scalar particles produced in the background of a spherical gravitational wave. The idea was adopted form the great work by Parker in 1976 where he showed the phenomenon of particle creation in the background of an early expanding universe, the spectrum of which was found to be thermal. In fact, any dynamical spacetime, which is a spacetime having no time like isometries, should result in a non-zero early time vacuum expectation value of the late time number operator in the language of quantum field theory. The dynamical nature of the fabric of spacetime results in the aforementioned particle creation. The exact mathematical treatment in our case of particle creation at the LIGO observatory requires the consideration of gravitational wave pulses, but for the sake of simplification and also to make the physics more suited to the problem, we have worked with spherical gravitational waves, the dynamical nature of which is solely carried by the gauge invariant degrees of freedom of the incoming wave. Using the methodology of perturbation theory, we indeed get a non-zero value for the amplitude of the created particles.

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Classical & Quantum Gravity / 266

Testing the Weyl proposal of gravitational entropy in gravitational collapse & other gravitational systems

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We investigate the status of the gravitational arrow in the case of spherical collapse of a fluid which conducts heat and radiates energy. In particular, we examine the results obtained by W. B. Bonnor in his 1985 paper, where he found that the gravitational arrow was opposite to the thermodynamic arrow. The measure of gravitational epoch function used by Bonnor was given by the ratio of the Weyl square to the Ricci square. In this investigation, we have assumed the measure of gravitational entropy to be given by the ratio of the Weyl scalar to the Kretschmann scalar. Our analysis indicates that Bonnor's result seems to be validated, i.e., the gravitational arrow and the thermodynamic arrow of time point in opposite directions. This strengthens the opinion that the Weyl proposal of gravitational entropy is applicable only to the universe as a whole (provided that we exclude the white wholes). Following our previous works on gravitational entropy, we are also investigating different astrophysical and cosmological models and testing whether the gravitational entropy is giving us a correct sense of time or not.

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Cosmology / 267

Interfacing Theory with Data: An Interactive Tool for Cosmological Analysis

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This presentation introduces a software tool for cosmologists interested in cosmic inflation. Through a user-friendly interface, users input potential functions and visualize how theoretical models of inflation align with observational datasets. Real-time symbolic differentiation calculates key parameters like the scalar spectral index ns and the tensor-to-scalar ratio r, which are superimposed on contour plots of BICEP, PLANCK, and various other observational datasets. This integration offers an effective means for swift cosmological analysis.

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Cosmology / 268

Higher Order Quantum Gravity Corrections on Inflationary Dynamics

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We investigate the higher-order quantum gravity effect on inflationary dynamics within the framework of effective field theory. Our analysis encompasses a broad range of inflationary potentials without specific constraints on their form. We examine the tensor-to-scalar ratio and the running of the spectral indices by considering the generalized inflationary parameters with higher-order quantum gravity corrections. These parameters provide insights into gravitational wave generation and primordial density fluctuations. Our findings have implications for experimental tests of quantum gravity and single-field inflationary models, contributing to a deeper understanding of the early universe. This work offers a comprehensive analysis of higher-order quantum gravity effects on inflation, facilitating future cosmological experiments and shedding light on gravity's fundamental nature.

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Gravitational Waves / 269

Modelling eccentricity in Not-So-Equal mass binary black hole inspirals

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Most of the gravitational wave (GW) signals detected so far by LIGO and Virgo detectors consist of comparable mass binary black holes (BBHs). Another interesting source of GWs is highly eccentric intermediate mass ratio inspirals (IMRIs). GW signals from IMRI sources are expected to be highly eccentric when they enter the detection band of the space based detectors such as LISA and DECIGO. Eccentricity is a feature which can be used as a discriminator for BBH's formation pathways. Data analysis studies of GW signals from such asymmetric sources using a higher mode IMRI waveform will help us measure the source parameters more precisely and accurately. In this work, we combined the post-Newtonian and black hole perturbation results to model IMRIs in highly relativistic eccentric orbits with higher modes. We have also explored the possibility of the detection of such eccentric high mass ratio sources in the context of DECIGO band.

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Classical & Quantum Gravity / 271

Unruh-de Witt detectors in curved spacetime

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The two-level particle detector models, such as Unruh-DeWitt detectors(UDD), play a significant role in understanding quantum effects in different frames of reference such as the Unruh effect. These two-level quantum probes are used to study quantum field theory for different observers in flat spacetime as well as in curved spacetime. In recent years, there has been an interest in relativistic quantum information processes using these quantum probes.
In the presence of gravity, for a detector in stationary motion, it can happen that the acceleration and the tidal acceleration due to curvature can intertwine and affect the response of a detector. We have uncovered such a result in a previous work1. We extend these studies2 for rotational motion in de Sitter and anti-de Sitter spacetimes and arrive at specific conditions in anti-de Sitter spacetime for periodicity in geodesic distance in Euclidean time. We found specific mappings for stationary motion in dS/AdS spacetime to stationary motion in Minkowski spacetime.
We also explore an indirect yet universal role of spacetime curvature in creating entanglement between two quantum probes coupled to a scalar field in a suitable vacuum state. These quantum probes are initially not entangled and are placed at two causally disconnected points. The entanglement between the detectors is affected by the curvature of spacetime and can be elucidated by

the deformation of the causal structure and deviation of detector trajectories due to the presence of curvature.

1 Hari K and Dawood Kothawala, Phys. Rev. D 104, 064032 (2021).
2 Hari K and Dawood Kothawala, arXiv:2307.16413
[3] Hari K, Subhajit Barman and Dawood Kothawala, in progress

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Gravitational Waves / **272**

Improved eccentric models for binary black hole mergers with gauge-invariant definitions of orbital elements.

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In general relativity, eccentricity is not defined uniquely. Different waveform models rely on gauge-dependent definitions of eccentricity and other orbital elements, which leads to incompatibility between different models. We employ a recently proposed gauge invariant eccentricity definition to eliminate this ambiguity in our PN-NR comparisons. We also present an eccentric GW model by suitably joining an eccentric inspiral model, evolved assuming this new gauge-independent definition for orbital eccentricity, with a quasi-circular template. The model is calibrated against a set of long Inspiral-Merger-Ringdown (IMR) waveforms constructed by comparing spherical harmonic modes of PN and NR waveforms.

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Astrophysical Relativity / **273**

Misaligned circum-single disks embedded in an AGN disk

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The LIGO/Virgo detections showed unexpected progenitor black hole masses (~66 solar mass). Such black holes with their mass falling in the pair instability mass-gap region seek a new formation channel. We focus on the so-called AGN channel to understand such a puzzling progenitor mass. In this study, we numerically model 3D global MHD accretion flows of embedded black holes within a turbulent AGN disk. The turbulent AGN disk material starts to accrete into newly borned stellar mass black holes and forms randomly aligned accretion disk structures (circum-single disks). In this talk, I will show preliminary results of what causes such a misalignment and how this could affect the evolution of the accretion disk and eventually the spin parameter of the black hole.

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Cosmology / 274

Reconstructing the universe with machine learning

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I shall discuss the prospects of machine learning algorithms, namely Gaussian processes and neural networks, to reconstruct the evolutionary history of the Universe with present available observational data independent of any cosmological model. Through this reconstruction, one can constrain different cosmological parameters, which can serve as a promising tool in addressing the rising tensions in cosmology. Finally, I will focus on two future surveys, viz., the upcoming gravitational wave missions like the evolved Laser Interferometer Space Antenna and the Einstein Telescope. I will discuss their possible role in reconstructing the Hubble parameter, and hence H_0, within the observational window of the specific missions under consideration.

Based on: arXiv: 2202.07886, 2305.15499, 2303.05169

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Gravitational Waves / 275

A Machine learning approach to detect IMBH signals

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Intermediate mass black holes (IMBH) with mass ranges between $100M_\odot$ to $10^5M_\odot$ provide a missing link between stellar mass and supermassive black holes. Understanding them provides an insight into galaxy formation as they are considered to be the precursors of supermassive black holes. The high mass of IMBH binaries leads to a short gravitational wave signal duration and bandwidth in current generation GW detectors. Instrumental transients or glitches mimic these signals and can thus raise false alarms. These issues can be circumvented by using stricter signal-glitch discriminators as was done by the PyCBC-IMBH pipeline. Machine learning (ML) algorithms provide an alternate approach to this problem since they can be trained to distinguish between signals and glitches. In this talk, I will present a new method that takes advantage of CNNs'(Convolutional Neural Networks') feature extraction ability to distinguish between spectrograms of signals and glitches. The improved separation between noise and signal will allow the detection of weaker signals previously buried in noise, increasing the search sensitivity. This search, which is based on the pre-existing THAMES algorithm, is trained on various classes of glitches, quasi-circular quadrupole and multipole signals. This enables it to probe complex signal morphologies and in certain cases, THAMES performs better than the PyCBC-HM search which includes higher order modes. Our work thus aims to make ML based searches a staple in future observing runs.

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Cosmology / 276

Testing statistical isotropy and Gaussianity of CMB lensing data from the Atacama Cosmology Telescope.

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In this project we focus on testing statistical isotropy and Gaussianity of CMB lensing convergence maps using recently released data of the cosmic microwave background (CMB) radiation from the Atacama Cosmology Telescope
(ACT). The CMB photons are lensed by gravitational potential wells of the
large-scale matter distribution. This CMB temperature data is converted to convergence map by applying the method of quadratic estimator using the pipelines provided by the ACT collaboration. We use the methodology of Minkowski functionals to test Gaussianity and the alpha statistic, which is constructed from the contour Minkowski tensor, to test for statistical isotropy. From our analysis, we find that the convergence map is non-Gaussian, and the nature of non-Gaussianity is of kurtosis type. This finding indicates the effect of gravitational clustering of matter at the resolution of the ACT data. Statistical isotropy is tested by taking small patches of sky regions and comparing with simulated mock data of the convergence map that include instrumental effects. This work is still ongoing.

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Gravitational Waves / 277

Microlensing meets TGR

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GR tests used by the LIGO-Virgo-KAGRA collaboration probes various parts of the gravitational-wave signal. However, a comprehensive understanding of the tests requires accounting for potential biases introduced by unmodeled physical effects like eccentricity, spin precession, or lensing. In this talk, we delve into the intricate influence of microlensing and millilensing on the IMR consistency test and TIGER analysis. By employing Bayesian inference tools, we demonstrate that microlensed signals can potentially lead to deviations from GR. By unraveling the impact of lensing effects in these tests, we shed light on the subtle complexities of lensing effects in gravitational wave astronomy and highlight the significance of considering lensing templates for robust mitigation of biases in GR tests.

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Gravitational Waves / 278

Exploring the Efficacy of Curriculum Learning in Training Neural Networks for Gravitational Wave Detection and Parameter Estimation in Near-Realistic Conditions

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The detection and parameter estimation of compact binary coalescences (CBC) through the analysis of gravitational wave signals have been revolutionized by the advent of deep learning neural networks. Conventionally, curriculum learning, a method that progressively exposes a neural network to more challenging examples during training, has emerged as the de facto procedure for training these networks in the context of gravitational wave analysis. This approach capitalizes on the unique advantage of generating waveform data with desired signal-to-noise ratios (SNR) using well-established modules such as PyCBC.

This study diverges from the established paradigm by investigating the effectiveness of multiple deep learning neural networks, such as CNNs, RNNs, Autoencoders and Transformers, for gravitational wave detection and parameter estimation when curriculum training is not employed, and the noise conditions deviate from the typical Gaussian and stationary assumptions. In astrophysical scenarios, gravitational wave signals often encounter non-ideal conditions, including non-Gaussian noise and non-stationary backgrounds. Understanding and quantifying how neural networks perform under these realistic conditions is crucial for advancing the field of multi-messenger astronomy.

We present the results of comprehensive experiments that involve training deep learning models on datasets containing non-Gaussian and non-stationary noise profiles. We evaluate the networks' ability to accurately detect gravitational wave events and estimate their parameters in these challenging

scenarios. Our findings shed light on the adaptability and robustness of neural networks in the face of real-world noise challenges and evaluate the resilience and fragility of deep learning algorithms for gravitational wave analysis.

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Astrophysical Relativity / 279

Black hole mimickers in light of the recently observed shadows of Sagittarius A* and M87*

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The recent observations of the shadows and images of the supermassive compact objects Sgr A*and M87* at the hearts of Our Galaxy and the nearby galaxy M87, respectively, by The Event Horizon Telescope (EHT) collaboration have opened up a new window in observational astronomy to probe and test gravity and fundamental physics in the strong-field regime. It is commonly believed that the gravitational field around astrophysical compact objects is described by the Kerr black hole geometry. The EHT data, therefore, can be used to test this hypothesis and put constraints on spacetime geometries which deviates from the Kerr. In this talk, I will talk about shadows cast by some Kerr black hole mimickers and discuss whether and to what extent these mimickers can be constrained using the EHT results.

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Gravitational Waves / 280

Probing the nature of dark matter using gravitational-wave strong lensing

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Third generation gravitational wave (GW) detectors are expected to detect millions of binary black hole (BBH) mergers during their operation period. A small fraction of them (~1%) will be strongly lensed by intervening galaxies and clusters, producing multiple observable copies of the GW signals. The expected number of lensed events and the distribution of the time delay between lensed images strongly depend on the mass distribution of dark matter halos. Warm dark matter (WDM) or fuzzy dark matter (FDM) models predict lower abundances of small mass halos as compared to the standard cold dark matter. This will result in a reduction in the number of strongly lensed GW events, especially at small time delays. Using the total number of lensed events and the time delay distribution, we can put a lower bound on the mass of the WDM/FDM particle from a catalog of lensed GW events. The expected bounds from GW strong lensing from third-generation GW detectors are better than the existing constraints.

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Gravitational Waves / **281**

Prospects of detection of strongly lensed gravitational waves using LGWA

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The lensing of gravitational waves occurs when it passes near massive objects like galaxies and clusters that bends its path. The detection of the first lensed gravitational wave is expected within the next few years. Decihertz detectors such as Lunar Gravitational Wave Antenna (LGWA) are expected to detect gravitational waves from intermediate mass blackhole mergers and white dwarf binaries. A small fraction of these signals would be lensed, potentially enabling interesting probes of astrophysics and cosmology. We calculate the expected detection rates of strongly lensed gravitational waves by LGWA and discuss its implications.

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282

AstroSat - Indian Space-based multi-wavelength Observatory

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AstroSat, India's first multi-wavelength space observatory is an unique platform to observe cosmic X-ray sources, especially to probe the strong gravity aspects of 'compact' objects. I will discuss the capabilities of AstroSat and present some interesting results to decipher the environment around the 'compact' objects.

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Classical & Quantum Gravity / 283

Electromagnetic extension of Buchdahl bound in $f(R, T)$ gravity

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We develop a static charged stellar model in $f(R, T)$ gravity where the modification is assumed to be linear in T which is the trace of the energy momentum tensor. The exterior spacetime of the charged object is described by the Reissner-Nordstr\"om metric. The interior solution is obtained by invoking the Buchdahl-Vaidya-Tikekar ansatz, for the metric potential g_{rr}, which has a clear geometric interpretation. A detailed physical analysis of the model clearly shows distinct physical features of the resulting stellar configuration under such a modification. We find the maximum compactness bound for such a class of compact stars which is a generalization of the Buchdahl bound for a charged sphere described in $f(R, T)$ gravity. Our result shows physical behaviour that is distinct from general relativity. In particular, our study shows that the compactness can be increased by considering a modification in Einstein's gravity which is further enhanced by the inclusion of charge.

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Cosmology / 284

Morphological Characterization of Galactic Foreground Emissions

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Accurate component separation of full-sky maps in the radio and microwave frequencies, such as the cosmic microwave background (CMB), relies on a thorough understanding of the statistical properties of the Galactic foreground emissions. These Galactic emissions include Galactic synchrotron, free-free, thermal dust emissions, Anomalous Microwave Emission (AME), etc. Extracting the morphological features of these emissions is crucial from the cosmological perspective as well as from the perspective of understanding the physical processes in our Galaxy. With this objective, we have studied the statistical properties, namely the nature of non-Gaussianity and statistical isotropy, of the 408 MHz Haslam synchrotron map using morphological statistics, such as Minkowski functionals (MFs) and tensors (MTs). Through a careful analysis of this map at different sky regions and angular scales, we have quantified the amplitude and nature of the non-Gaussianity of the synchrotron emission. Our study shows that the synchrotron non-Gaussianity is kurtosis-type towards small angular scales. Next, we extend this formalism to other synchrotron maps, mainly the ones given by Planck and WMAP. Here, our motivation is twofold –to understand the frequency dependence of the morphological features of synchrotron emission and to see how well the synchrotron maps given by the component separation pipelines in Planck and WMAP reproduce the Haslam results we got previously. By comparing different synchrotron maps, we also look into the efficiency of different component separation methods employed in CMB experiments. Next, we study the statistical properties of other Galactic emissions, namely free-free, AME and thermal dust. Here, we investigate whether the observed kurtosis nature of non-Gaussianity in synchrotron maps is a generic feature of foreground emissions or any random field with positively skewed probability distribution. In this talk, I will summarise the major findings of our analyses and discuss the new avenues the morphological characterization of Galactic emissions opens up in improving the component separation methods in CMB experiments.

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Classical & Quantum Gravity / 285

Probing Extra Dimensions through Scalar Perturbations in Rotating Black Hole Spacetimes

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The general theory of relativity (GR) states that black holes can possess three hairs, namely mass, charge, and angular momentum. Nevertheless, modifications to GR have the potential to alter the spacetime geometry by introducing additional hairs. In light of a potential solution to the so-called hierarchy problem in the standard model of particle physics, GR may be modified through the addition of an extra warped spatial dimension in the theory. Such a modified theory of gravity s yield intriguing consequences for various aspects of black holes. Therefore, we have conducted an investigation into massive scalar perturbations of four-dimensional Kerr-like black holes, incorporating an additional property, the tidal charge, within the Randall-Sundrum braneworld framework. The tidal charge of the black hole contains information pertaining to the extra spatial dimension in the braneworld model. These black hole spacetimes are also noteworthy because they permit the black hole's rotation parameter to exceed unity, a circumstance forbidden by the general theory of relativity. Consequently, they offer valuable insights into exploring the repercussions of modifications to Einstein's theory through future observations. Our approach involves the numerical solution of the perturbed field equations using the continued fractions method to ascertain the quasi-normal mode spectra of the braneworld black hole. We also investigate the existence of quasibound states and, consequently, the superradiant stability of the spacetime when perturbed by a massive scalar field. In comparison to four-dimensional black holes, we have detected distinctive signatures of the tidal charge and the rotation parameter, which manifest as signals of the extra dimension in both the quasinormal modes and the quasibound states. Furthermore, we will engage in a discussion regarding the physical implications of our findings.

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Cosmology / **286**

Alleviating the Hubble tension with curvaton scenario

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The mismatch in the present value of Hubble parameter estimated by Supernova based local measurements and CMB based observations is known as Hubble tension. We attempt to resolve the Hubble tension by considering the curvaton scenario. We show that curvaton influences the Hubble parameter if it gains mass after the inflation and can therefore alleviate the Hubble tension.

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Gravitational Waves / **287**

A phenomenological gravitational waveform model of binary black holes incorporating horizon fluxes

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Being subject to the tidal field of its companion, each component of a coalescing binary suffers a slow change in its mass (tidal heating) and spin (tidal torquing) during the inspiral and merger. For black holes, these changes are associated with the energy and angular momentum fluxes down their horizons. This effect modifies the inspiral rate of the binary, and consequently, the phase and amplitude of its gravitational waveform. Numerical relativity waveforms contain these effects inherently, whereas analytical approximants for the early inspiral phase have to include them manually in the energy balance equation. In this work, we construct a frequency-domain gravitational waveform model which incorporates the effects of tidal heating of black holes, by recalibrating the inspiral phase of the waveform model IMRPhenomD to accommodate the phase corrections for tidal heating. We also include corrections to the amplitude, but add them directly to the inspiral amplitude model of IMRPhenomD. We show that the model is faithful, with better than 1% mismatches against a set of hybrid waveforms, except for one outlier that barely breaches this limit. The recalibrated model shows mismatches of up to $\sim 16\%$ with IMRPhenomD for high mass ratios and spins. Amplitude corrections become less significant for higher mass ratios, whereas phase corrections leave more impact - suggesting that the former is practically irrelevant for gravitational wave data analysis. Comparing with a set of numerical relativity waveforms, we find that the median of mismatches decreases by $\sim 4\%$ in Advanced LIGO, and by $\sim 2\%$ with a flat noise curve. This implies a modest but notable improvement in waveform systematics.

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Cosmology / 288

Bayesian analysis of the DAMA/LIBRA data

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The DAMA/LIBRA experiment has been claiming evidence for annual modulation for over 20 years, which they argue is evidence for dark matter WIMP interactions in the detector. However, this result has not been confirmed by any other experiment. We carry out a Bayesian analysis of a search for annual modulation in the DAMA/LIBRA data, which is complementary to the frequentist tests done by the collaboration. We also search for a time-dependence of the best-fit DAMA amplitude and higher harmonics in the. We do not find any evidence for higher harmonics in the data or time-dependence of best-fit amplitude. These analyses can easily be extended to the analysis of data from other underground dark matter experiments which are looking for such an annual modulation.

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Cosmology / 289

Magnetogenesis from anisotropic universe

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Magnetic fields are observed throughout the universe on different length scales having different strengths. Galaxies and galaxy clusters have a magnetic field strength of $\sim 10^{-9}\ G$ coherent over a 1KPc scale. We find magnetic fields at $\sim 1MPc$ scale having a strength of $\sim 10^{-16}\ G$ in the intergalactic medium (IGM). Inflationary magnetogenesis is the most profound theory of large-scale magnetic field generation. Here, we propose that a spatial anisotropy in spacetime during the inflationary era can induce a large-scale magnetic field. The spatial anisotropy generically breaks the conformal invariance of the Maxwellian gauge field and produces an electromagnetic (EM) field with a present-day strength of $\sim 10^{-20}\ G$. This formalism does not suffer from the strong coupling problem, as it does not include explicit coupling with the inflaton field.
Furthermore, we show that the produced electromagnetic field does not affect the inflationary background or the anisotropy. In addition, assuming very low conductivity during the reheating era, we can further observe the evolution of the EM field. Moreover, with the data from PLANCK and other observables of the magnetic field, we can put strong bounds on the effective equation of state ω_{eff}.

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Cosmology / 290

The abundance of core–collapsed subhalos in SIDM: insights from structure formation in ΛCDM

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Dark matter halos can enter a phase of gravothermal core–collapse in the presence of self-interactions. This phase that follows a core–expansion phase is thought to be subdominant due to the long timescales involved. However, it has been shown that the collapse can be accelerated in tidal environments particularly for halos that are centrally concentrated. Cosmological simulations in ΛCDM give us the full distribution of satellite orbits and halo profiles in the universe. We use properties of the orbits and profiles of subhalos from simulations to estimate the fraction of the subhalos in different host halo environments, ranging from the Large Magellanic cloud(LMC)–like hosts to clusters, that are in the core–collapse phase. We use fluid simulations of self–interacting dark matter (SIDM) to evolve subhalos in their hosts including the effect of tidal truncation at the time of their pericenter crossing. We find that for parameters that allow the interaction cross-section to be high

at dwarf scales, at least 10 % of all subhalos are expected to have intrinsically collapsed within Hubble time up to the group mass host scales. This fraction increases significantly, becoming at least 20% when tidal interactions are considered. To identify these objects we find that we either need to measure their densities at very small radial scales, where the subhalos show a bimodal distribution of densities, or alternatively we need to measure the slopes of their inner density profiles near the scale radius, which are much steeper than NFW slopes expected in cold dark matter halos. Current measurements of central slopes of classical dwarfs do not show a preference for collapsed objects, however this is consistent with an SIDM scenario where the classical dwarfs are expected to be in a cored phase.

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Classical & Quantum Gravity / 291

Traversable Lorentzian wormhole on the Shtanov-Sahni braneworld with matter obeying the energy conditions

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In this paper we have explored the possibility of constructing a traversable wormhole on the Shtanov-Sahni braneworld with a timelike extra dimension. We find that the Weyl curvature singularity at the throat of the wormhole can be removed with physical matter satisfying the NEC $\rho + p \geq 0$, even in the absence of any effective Λ-term or any type of charge source on the brane. (The NEC is however violated by the effective matter description on the brane arising due to effects of higher dimensional gravity.) Besides satisfying NEC the matter constituting the wormhole also satisfies the Strong Energy Condition (SEC), $\rho + 3p \geq 0$, leading to the interesting possibility that normal matter on the brane may be harnessed into a wormhole. Incidentally, these conditions also need to be satisfied to realize a non-singular bounce and cyclic cosmology on the brane, where both past and future singularities can be averted. Thus, such a cyclic universe on the brane, constituted of normal matter can naturally contain wormholes. The wormhole shape function on the brane with a timelike extra dimension represents the tubular structure of the wormhole spreading out at large radial distances much better than in wormholes constructed in a braneworld with a spacelike extra dimension and have considerably lower mass resulting in minimization of the amount of matter required to construct a wormhole. Wormholes in the Shtanov-Sahni (SS) braneworld also have sufficiently low tidal forces, facilitating traversability. Additionally they are found to be stable and exhibit a repulsive geometry. We are left with the intriguing possibility that both types of curvature singularity can be resolved with the SS model, which we discuss at the end of the concluding section.

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Classical & Quantum Gravity / 292

On the propagation of gravitational waves in matter-filled Bianchi I universe

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In this paper we apply the Regge-Wheeler formalism to study the propagation of axial and polar gravitational waves in matter-filled Bianchi I universe. Assuming that the expansion scalar Θ, of the background space-time is proportional to the shear scalar σ, we solve the background field equations in the presence of matter (found to
behave like a stiff fluid). We then derive the linearised perturbation equations for both the axial and polar modes. The analytical solutions in vacuum spacetime could be determined in an earlier paper 1 in a relatively straightforward manner. However, here we find that in the presence of matter, they require more assumptions for their solution,
and bear more involved forms. As compared to the axial modes, the polar perturbation equations contain far more complicated couplings among the perturbing terms. Thus we have to apply suitable assumptions to derive the analytical solutions for some of the cases of polar perturbations. In both the axial and polar cases, the radial and temporal solutions for the perturbations separate out as products. We find that the axial waves are damped owing to the background anisotropy, and can deform only the azimuthal velocity of the fluid. In contrast, the polar waves must trigger perturbations in the energy density, the pressure as well as in the non-azimuthal components of the fluid velocity. Similar behaviour is exhibited by axial and polar gravitational waves propagating in the Kantowski-Sachs universe 2. Our work is in contrast to the work done in 3, where the authors analysed anisotropic universes modelled by Kasner spacetime and Rindler wedges using the method of gauge-invariant perturbations in the RW gauge.

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Gravitational Waves / 293

Black holes immersed in environment

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From electromagnetic observations, we know that the supermassive black holes at galactic centers are surrounded by dark and baryonic matter. With the advent of gravitational wave (GW) astronomy, we are poised to probe the details of geometry from where GW gets generated. GWs from binaries containing at least one supermassive black hole will be observed with space-based detector LISA. In such a backdrop it is necessary to know the effect of the environment around such binaries on the geometry and as a consequence on the emitted GW. For this purpose metrics in the presence of the environment must be known. I will discuss how the existence of matter affects the geometry and will unveil the subtleties regarding sound speed which puts restrictions on the matter profile. These corrections may affect GW generation and propagation and may be characterized by future observatories. I will discuss the numerical results for different families of dark matter profiles, namely the Hernquist, the Navarro-Frenk White, and the Einasto models, and the potential prospects of such results. The talk will based on a paper which is currently in preparation.

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Astrophysical Relativity / 294

Numerical simulations of relativistic radiatively driven jets

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We present the axisymmetric numerical simulations of the relativistic transonic jets around black holes driven by the radiation field of the accretion disk. We show that starting from a very low velocity at the base, jets can be accelerated to relativistic terminal speeds. Our results show the morphology of the jets during their different evolutionary stages. In addition to acceleration, the radiation also acts as a collimating agent. The radiation pressure acts as the primary collimating agent, which suppresses the lateral expansion of the. The radiation field can also remove angular momentum from the jet and make the jet stable against the centrifugal force.

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Gravitational Waves / 295

Tidal deformation of dynamical horizons in binary black hole mergers and its imprint in their gravitational radiation

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It is widely believed that in the post-Newtonian approach, the asymptotic gravitational fields of non-spinning black holes do not deform under the influence of its companion. Would their horizons deform? In this talk, we present an alternate approach to the problem of tidal deformations of black holes in binary mergers using the source multipole moments of their dynamical horizons and numerical relativity. We probe their deformations in the strong field regime without any limitations, all the way up to merger. We point out that several interesting features of the binary black hole dynamics are encoded in these deformations. Finally, we discuss the existence of strong correlations between the deformations and the dynamics at future null infinity.

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Gravitational Waves / **296**

Tests of binary black hole nature of observed compact binary mergers employing double-spin precessing waveforms

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We investigate the prospect of performing binary black hole (BBH) nature tests using spin-induced multipole moment (SIQM) measurements when the binary is fully precessing. As SIQM is strongly degenerate with spin parameters, we are interested in the degeneracies the SIQM parameter has with spin precession. We extend the previous SIQM-based BBH nature tests by incorporating two-parameter spin-precession effects, studying the effects beyond the leading harmonic in the gravitational waveform for binaries with various mass and spin combinations. We also report the posterior distributions on the SIQM parameter on the observed gravitational wave events through the first three observing runs of the ground-based detectors employing IMRPhenomXP and IMRPhenomX-PHM.

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Cosmology / **297**

Statistical Approaches to Study statistical Isotropy in CMB Sky maps

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Observations of the cosmic microwave background (CMB) anisotropies have played a key role in developing modern cosmology. Detailed and accurate measurements of the CMB anisotropies tell us a lot about the global properties, the constituents, and the history of the universe. Standard cosmological model assumes Statistical Isotropy and Gaussianity of the CMB anisotropy in FRW cosmology. There have been detections of the breakdown of SI in WMAP and Planck. In this talk, I will discuss statistical measures to study deviations from SI. We will discuss the Bipolar Spherical Harmonic (BipoSH) representation of the general covariance structure on the sphere and reduction of the basis to a new irreducible representation leading to new measure called mBipoSH functions, depicting real space angular correlation functions for SI violation features of the CMB sky.

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Gravitational Waves / 298

Exploring binary dynamics and radiations from binaries in deformed Kerr geometries

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In this talk we will explore the late inspiral and then the transition regime to the plunge phase of a secondary, less massive compact object into a more massive deformed Kerr black hole. We will show how one can find fluxes such as the energy and the angular momentum and henceforth use them to infer about their detectibility from a GW standpoint. We also explore how the different deviation parameters play an important role in binary dynamics for such a particular scenario.

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Astrophysical Relativity / 300

Slow Rotating Bose-Einstein Condensate stars

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We obtain the global properties of static and slowly rotating self-gravitating Bose-Einstein condensate (BEC) stars and study the effect of temperature on the stellar structural properties. For this we consider a recently developed temperature dependent equation of state of BEC stars formed due to Cooper pairing of nucleons. We use the Hartle-Thorne slow rotation approximation equations to obtain the stellar profiles. The mass-radius values are found to be decreasing with increasing temperatures for both the static and rotating cases. We find that the inclusion of temperature has only a negligible effect on the maximum mass but a considerable effect on the rotating stellar profiles. Our analysis was extended to studying the effect of various EoS parameters like the boson mass and the interaction strength on the static and rotating stellar structures of temperature dependent BEC stars.

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Cosmology / 301

Precision Weak Lensing Analysis In CMB Observations For Upcoming Missions

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The Cosmic Microwave Background continues to be a cornerstone of precision cosmology. It has provided the most accurate parameter constraints for the widely used Λ cosmological constant and Cold Dark Matter (ΛCDM) model, via missions like COBE, WMAP, and Planck. In precision regimes, accounting for the weak lensing of the CMB photons by the large structure gravitational potential, is a critical challenge. Lensing of the CMB is both a source of information as well a contamination to resolve, in light of unbiased and precise parameter estimation. Therefore in light of upcoming high precision CMB cosmology missions (Simons Observatory, CMB-S4), updated estimators that include higher order lensing corrections at higher precision, are necessary. We discuss the standard minimum variance quadratic estimators used in lensing reconstruction, and promising approaches that improve estimator variance and accuracy with respect to parameter inference and primordial B-mode hunting. We also discuss lensing effects in the context of model independent inflationary power spectra reconstruction and the role delensing plays in improving accuracy for novel estimators.

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Classical & Quantum Gravity / 303

Particle dynamics and new horizon structure around Kerr-Newman singularity

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In this talk, the particle motion around the naked singularity and black hole of Kerr-Newman spacetime will be discussed with a special attention on the closed timelike orbits. For KN black hole, the Cauchy surface is always located inside the inner horizon where particles with positive angular momentum that co-rotate with the spacetime can only pass through. It is found that in both the naked singularity and black hole, the singularity is covered by causality violating regions and only particles with positive angular momentum can traverse within the closed timelike curves. In both the cases, test particles are confined at a distance significantly far from the singular point such that there always exists an empty region surrounding the singularity which prevents particles from interacting with it. The radius of the empty surface that depends on the source parameters and the particle characteristics, is investigated with a precise expression. This study provides a thorough insight on the intricate dynamics of particles near singularities in Kerr-Newman geometry.

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Classical & Quantum Gravity / 304

QBHs in the Sky

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Einstein's General Relativity (GR) is perfectly utilitarian but is considered not yet complete, mainly because of the presence of singularities and its general incompatibility with a quantum description. This had historically motivated a lot of attempts at quantising gravity. The (adiabatic invariant) area quantisation hypothesis by Beckenstein and Mukhanov in 1974 was the first step towards a hueristic description of quantum gravity. Beyond-GR theories received renewed interest since the first GW detection and the periodic upgrades in detector sensitivity have allowed us to constrain these models to better and better accuracies. In that spirit, the beyond-GR GW signatures from the model of QBHs have been investigated recently in the literature, (most notably by Agullo et.al. in 2020), which forms the basis for our work.

In our most recent work we demonstrate that the QBH models thus considered suffer from an ergoregion instability, which limits their probability of occurrence. Considering some of the aspects of BBH formation history, we demonstrate that most of the space of progenitors to BBHs are actually off limits to stable QBHs. We also show that progenitor physics predict that stable binary QBHs are bounded from above in both total mass (m) and mass ratio (q)

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Cosmology / 305

Post-reionization HI 21cm signal: A probe of negative cosmological constant

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In this study, we investigate a cosmological model involving a negative cosmological constant (AdS vacua in the dark energy sector). We consider a quintessence field on top of a negative cosmological constant and study its impact on cosmological evolution and structure formation. We use the power spectrum of the redshifted HI 21 cm brightness temperature maps from the post-reionization epoch as a cosmological probe. The signature of baryon acoustic oscillations (BAO) on the multipoles of the power spectrum is used to extract measurements of the angular diameter distance $D_A(z)$ and the Hubble parameter $H(z)$. The projected errors on these are then subsequently employed to forecast the constraints on the model parameters $(\Omega_\Lambda, w_0, w_a)$ using Markov Chain Monte Carlo techniques. We find that a negative cosmological constant with a phantom dark energy equation of state (EoS) and a higher value of H_0 is viable from BAO distance measurements data derived from galaxy samples. We also find that BAO imprints on the 21cm power spectrum obtained from a futuristic SKA-mid like experiment yield a $1-\sigma$ error on a negative cosmological constant and the quintessence dark energy EoS parameters to be $\Omega_\Lambda = -0.883^{0.978}_{-2.987}$ and $w_0 = -1.030^{0.023}_{-0.082}$, $w_a = -0.088^{0.162}_{-0.343}$ respectively, which is competitive with other probes reported in the literature.

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Cosmology / 306

Exploring Cosmic Anisotropy in the Bianchi-I Cosmological Model

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We delve into the intricacies of the Bianchi-I cosmological model, driven by the intriguing backdrop of anisotropic cosmic microwave background (CMB) observations. In our pursuit to understand the

underlying anisotropy of this model, we introduce anisotropic sources into the framework, augmenting the isotropic matter with dust-like dark matter and dark energy in the form of a cosmological constant (Λ). Our investigation centers on the constraint of critical parameters, including the Hubble parameter, density fractions associated with anisotropic matter, cold dark matter (CDM), and dark energy (Λ), within the context of the Bianchi-I metric, notable for its planar symmetry and global ellipsoidal geometry. Our primary objective is to detect signs of a cosmic preferred axis within this cosmological paradigm.

Our analysis yields intriguing results, providing weak evidence for the existence of a cosmic anisotropy axis. Remarkably, this preferred axis is found to align, at the very least, with the same quadrant as several other cosmic axes previously examined in the scientific literature. Additionally, our investigation uncovers indications of non-trivial shear and eccentricity, adding a layer of complexity to the cosmic landscape. Our study relies on Pantheon Type Ia supernova (SNIa) data, offering substantial constraints on fundamental cosmological parameters. However, to refine our understanding of the anisotropy axis, we anticipate that future observations, such as those from the James Webb Space Telescope (JWST) and other forthcoming surveys, will provide the necessary SNIa host galaxy data required for more precise constraints on distance measurements and absolute magnitude calibration. These forthcoming data sources hold the promise of unveiling deeper insights into the cosmic mysteries that continue to captivate our curiosity.

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Astrophysical Relativity / 307

Imprints of spin on the solution and emission spectrum of accretion flows around black holes

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We investigate accretion flows around rotating black holes (BHs) and obtain self-consistent transonic solutions in full general relativistic prescription. The flow is assumed to be viscous and radiative. Viscosity helps in the removal of angular momentum outwards, allowing matter to get accreted inwards. In addition, viscous heat dissipated makes the matter hotter. On the other hand, radiation mechanisms like bremsstrahlung, synchrotron, and their inverse-Comptonisations cools down the matter. Thus, the solution depends highly on the interplay between heating and cooling processes. In our work we investigate the entire energy–angular momentum parameter space and obtain both shocked and shock-free accretion solutions. Because of the spin in Kerr black holes, the event horizon is dragged to a region <2GM/c^2, increasing the efficiency of accretion process. Ample of works showed a rotating BH to yield high temperature solutions compared to a Schwarzschild BH. This suggests higher emission. Interestingly we have found a distinct annihilation line present only in extremely rotating BHs arising from regions very close to the central object. We have investigated further the other effects of spin on the spectrum obtained from accretion flows around BHs. We find efficiencies reaching >30% for maximally rotating BHs.

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Classical & Quantum Gravity / 308

Using Lyapunov Exponents to portray Black Hole Phase Transitions

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We investigate the conjectured relationship between Lyapunov exponents and black hole phase transitions. Our study involves the computation of Lyapunov exponents for both massless and massive particles as a function of temperature. We observe that a first-order phase transition occurs at specific parameter values, where the Lyapunov exponents exhibit a discontinuity, serving as the order parameter. Furthermore, we note a consistent minimum saturation value of Lyapunov exponents at a constant length scale, which remains uniform across all black holes in our analysis.

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Cosmology / 309

Review of The Measurements and Results of the Coma Cluster Dark Mass

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We have examined data from 852 Coma cluster galaxies from three different catalogs and grouped them according to their velocity and magnitude in two fields to survey the core (Coma1) and the periphery (i.e. southwest of the core and centered on NGC4839; Coma3). We have identified a group of these galaxies that appear to be a dense cluster (main cluster) of 545 galaxies (430 in Coma1 and 115 in Coma3) at a distance of 104 Mpc. Furthermore, we have calculated their kinetic energy ((〖10〗 ˆ54J) and potential energy ((〖10〗 ˆ54J) using observational data. Then we calculated the total mass (〖10〗 ˆ45 kg) using luminosity and from the virial theorem, we obtained the virial mass (〖10〗 ˆ47 kg), that the virial mass was greater than the total mass of the galaxies in the cluster. These galaxies cover the range of 12.7 < R < 22.7, which corresponds to, −22.5 < MR < −12.5 (H = 67.4 ± 0.5 km s−1 Mpc−1) and the velocity of this set is in this range (1000 km s−1 < v < 10000 km s−1). Our sample is 95% complete in redshift up to a magnitude b26.5 = 18.0 mag.

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Classical & Quantum Gravity / 310

Hawking radiation at finite temperature

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One of the most revolutionary outcomes of Einstein's general theory of relativity is the Black Hole (BH). In 1974 Stephen Hawking showed that BHs can also emit particles called Hawking radiation. The spectrum of the emitted particles is a black body spectrum. Till now we have considered the BH an isolated one and the particle emission spectrum is a Planckian. But we are interested if the BHs are immersed in a thermal bath, will the emission spectrum going to change? By applying thermal Quantum Field Theory we have shown that if the BHs are immersed in a thermal bath the emission spectrum is not a Planckian anymore and the particle production rate from the BH is now different.

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Cosmology / 311

Model-independent reconstruction of the evolution of dark energy using Gaussian process regression

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We study the evolution of the dark energy density parameter and the equation of the state parameter. We also study other relevant background quantities related to the late time cosmic acceleration such as deceleration parameter and effective equation of state of dark energy. This study is mainly based on the Hubble parameter data from the cosmic chronometer observations. Other cosmological datasets like cosmic microwave background and the measurement of the present value of the Hubble parameter are used. We use the Gaussian process regression analysis to find the derivative of the Hubble parameter data w.r.t redshift. From the combinations of the Hubble parameter data and its derivative, we study the dynamic evolution of the dark energy. This study is independent of any cosmological model. We find evidence for a dynamical dark energy behavior. We also find that at lower redshifts (z

$lesssim 1$), the ΛCDM model is around 1σ away from the obtained mean of a relevant quantity.

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Cosmology / 312

Ruling out Strongly Interacting Dark Matter–Dark Radiation Models from Joint Observations of Cosmic Microwave Background and Quasar Absorption Spectra

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The cold dark matter (CDM) paradigm provides a remarkably good description of the Universe's large-scale structure. However, some discrepancies exist between its predictions and observations at very small sub-galactic scales. To address these issues, the consideration of a strong interaction between dark matter particles and dark radiation emerges as an intriguing alternative. In this talk, we explore the constraints on those models using joint observations of Cosmic Microwave Background (CMB) and Quasars absorption spectra with our previously built parameter estimation package CosmoReionMC. At 2-□ confidence limits, our analysis rules out all strongly interacting Dark Matter - Dark Radiation models proposed to date, representing the most stringent constraint on those models to the best of our knowledge.

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Cosmology / 313

A Novel Count-In-Cells Model for Galaxies

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The count-in-cells (CIC) is a one point spatial statistic that is used to describe the spatial distribution of galaxies in the Universe. Besides the computational simplicity, it can be modelled theoretically to allow estimation of the parameters describing the large-scale structure of the Universe, such as the σ_8 and bias. In this work, we measure the galaxy CIC distribution at high redshift. The measured CIC is also modelled in the framework of the halo occupation distribution, which connects the number of galaxies in a dark-matter halo to its mass. This also requires a description of the underlying matter density distribution, such as the lognormal or generalized extreme value distribution.

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Cosmology / **314**

Gravitational Waves Background from Quintessential Inflation and NANOGrav data

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In this talk ,I will discuss about the process of induced gravity waves due to large scalar fluctuations in the paradigm of quintessential inflation. Numerically solved the Mukhanov-Sasaki equation for different sets of parameters are used to obtain the power spectra. It is been demonstrated that the induced gravity wave signal generated in this framework can falls within the region of the NANOGrav data for the chosen values of model parameters. There is an allowed region of parameter space where the effect shifts to high frequency regime relevant to LISA and other available sensitivities.

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Gravitational Waves / **315**

Can LIGO Detect Non-Annihilating Dark Matter?

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Dark Matter (DM) is ubiquitous and thus has been proposed to be probed by several terrestrial and celestial detectors. DM particles from the galactic halo can accumulate in Neutron Stars (NS) and transmute them into sub-2.5 solar mass black holes (BH) if the DM particles are heavy, stable, and have feeble but sufficient interactions with nucleons. These BHs are named Transmuted Black Holes (TBHs). Null detection of these TBH-TBH mergers from LIGO's low mass BH search can exclude an interesting parameter space in the DM particle mass (m_{\chi}) vs. interaction strength with nucleons (\sigma_{\chi n}) plane. These exclusion limits depend on the priors chosen on DM parameters and the currently uncertain Binary Neutron Star (BNS) merger rate density, precisely on the merger rate density of the low mass compact object binaries. The prospect of using Gravitational Wave (GW) detectors as a non-annihilating DM detector is found to be very positive given continued null detection and with increased sensitivity (50 times the current sensitivity) over the next decade.

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Classical & Quantum Gravity / 316

The Conspiracy of dS Space in String Theory (?)

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In this talk, I will discuss various string-loop, warping, and curvature corrections, which are expected to appear in type IIB moduli stabilization scenarios. It has recently been a topic of active debate whether these corrections can be consistently as well as simultaneously ignored for concrete de Sitter constructions. We study this question in the presence of a new weakly-warped LVS de Sitter vacua, which represents a distinctive branch in the parameter space, featuring small conifold fluxes. We have found that the warping corrections are less problematic and few corrections help us to land in this regime of parameter space. I will end my talk with a detailed description of how to avoid these corrections, if at all possible, in order to not destroy the consistency of the weakly-warped LVS de Sitter solution.

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Cosmology / 317

A new method to simultaneously determine the reionization history and power spectrum

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The light-cone (LC) effect arises from the cosmological evolution of the redshifted 21-cm signal along an observer's line of sight (LoS), which is the frequency axis. It is particularly pronounced during the Epoch of Reionization (EoR) when the mean neutral hydrogen fraction (x_HI) and statistical properties change rapidly. The 3D power spectrum only quantifies the ergodic part of the signal and fails to capture the variation of the x_HI. The multifrequency angular power spectrum (MAPS), on the other hand, quantifies the entire second-order statistics of the signal in the presence of the LC effect, including the homogeneous and isotropic statistical fluctuations along the angular directions and systematic variation along the LoS direction due to cosmological evolution. We propose a new method to observationally determine the reionization history along with the power spectrum by assuming a model where the systematic frequency dependence along the LoS direction arises entirely due to the evolution of the mean neutral hydrogen fraction. We validate our method by calculating MAPS from a simulated LC EoR 21-cm dataset and using Markov Chain Monte Carlo (MCMC).

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Cosmology / 318

Halo Occupation Distribution of Quasars : Redshift Evolution

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The Halo Occupation Distribution (HOD) has been used as a powerful tool in interpreting quasar clustering and the quasar-halo connection. The HOD formalism provides a complete knowledge of the host halo mass distributions of quasars over a range of redshifts. While extracting host halo distributions of quasar and Active Galactic Nuclei(AGN) from clustering studies, the HOD is assumed to be weakly dependent on redshift. Without any theoretical study of redshift evolution of the HOD, this assumption poses a challenge for studies with quasar clustering and studies of stacked signals from quasars.

We use SIMBA and IllustrisTNG suite of cosmological simulations to probe the HOD of the high end of the AGN luminosity function and characterise their redshift evolution. We find that owing to different models of subgrid AGN-physics, TNG and SIMBA produce different HOD of quasars. In both simulations, we find that the highest luminosity quasars have a significant redshift evolution in both simulations. SIMBA produces a stronger redshift evolution for lower luminosity AGNs as compared to TNG.

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Cosmology / 319

Light dark matter around 100 GeV from the inert doublet model

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We made global fits of the inert Higgs doublet model (IDM) in the light of collider and dark matter search limits and the requirement for a strongly first-order electroweak phase transition (EWPT). These show that there are still IDM parameter spaces compatible with the observational constraints considered. In particular, the data and theoretical requirements imposed favour the hypothesis for the existence of a scalar dark matter candidate around 100 GeV. This is mostly due to the pull towards lower masses by the EWPT constraint. The impact of electroweak precision measurements, the dark matter direct detection limits, and the condition for obtaining a strongly enough first-order EWPT, all have strong dependence, sometimes in opposing directions, on the mass splittings between the IDM scalars.

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Classical & Quantum Gravity / 322

Shadow of Rotating Bardeen Blackhole in Asymptotically Safe Gravity

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In this paper, We have studied the Shadow cast by a rotating Bardeen black hole in the background of asymptotically safe gravity. Using Hamilton-Jacobi variable separation method we have derived the null geodesics and the shadow observables. We have found that the size of the shadow decreases with an increase in ASG parameter (ω) and gets more distorted with an increase in spin parameter (a). The shadow characteristics depend on the blackhole's monopole charge (g). We have used the shadow observables to calculate the Energy emission rate of the blackhole for changing ASG parameters.

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Astrophysical Relativity / 323

Inclination distributions in tidal disruption events by spinning supermassive black holes

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Most galaxies host a supermassive black hole (SMBH) at their centers, yet a large fraction of SMBHs are quiescent and only observable through their transient interactions with stellar objects. As a star approaches an SMBH, the tidal gravitational forces can overwhelm the star's self-gravity, resulting in a tidal disruption event (TDE). The disrupted debris accretes onto the black hole, potentially powering an electromagnetic flare that can last for years. The stellar orbital distribution for disrupted stars is expected to be isotropic in inclinations, where the inclination is the angle of orbital angular momentum relative to the SMBH spin. This distribution will have notable observational consequences, such as inclination-dependent relativistic precession, energy reservoir at the innermost stable circular orbits for the accretion disk, or observable quasi-periodic oscillations. Our research highlights the importance of the orbital inclinations and evaluates their distribution which are a result of an interplay between tidal gravitational forces, direct capture by the event horizon, and two-body scattering that dictates the loss cone refilling. Finally, we integrate the inclination distributions to get total TDE rates for SMBHs with different masses and spins. Our results have significant implications for the observable properties of TDEs, which are to be explored as a part of future work.

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Classical & Quantum Gravity / 324

Testing Bell's inequality for Black holes

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A remote observer in black hole spacetime sees the creation of a pair of particles. Now, one can use Bell's operator to test whether the two spacelike-separated particles (one outside the horizon and one inside the horizon) are quantum mechanically entangled or not. Also, we describe a prescription

to check entanglement of particles created outside the horizon and inside the horizon using non-vacuum states such as excited states and coherent states.

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Cosmology / 325

Critical analysis of modulus stabilization in a higher dimensional F(R) gravity

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An exact solution for the bulk five-dimensional geometry is derived for F(R) gravity with nonflat de Sitter 3-branes located at the M4 × Z2 orbifold boundaries. The corresponding form of F(R) that leads to
such an exact solution of the bulk metric is derived, which turns out to have all positive integer powers of R.
In such a scenario, the stability issue of the modulus (radion field) is analyzed critically for different curvature epochs in both Einstein and Jordan frames. The radion in the effective 4D theory exhibits a phantom epoch, making this model viable for a nonsingular bounce. Simultaneous resolution of the
gauge-hierarchy problem is exhibited through the resulting stable value of the radion field in the effective
3 + 1-dimensional theory.

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Cosmology / 326

The origin of supermassive black holes at high redshift

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Almost every galaxy hosts a supermassive black hole at its center, and the mass of the black hole is correlated with the velocity dispersion of the galaxy, pointing to a co-evolution that has been a focus of research. Interestingly, supermassive black holes are detected even at redshifts greater than 6 when the Universe was very young and it is a mystery how a black hole could have grown to that high a mass in the short amount of time after the formation of galaxies began. We investigate the formation of SMBH considering an accretion flow into a dark matter halo and find that the flow is not possible without the presence of a seed black hole. We calculate the mass accretion rate for the trans-sonic flow and find that it is proportional to the square of the halo mass for a cold isothermal flow. The calculated Eddington ratio is also mildly supersonic for a brief period of time, that too when the black hole mass is not sufficient to drive outflows and stop accretion. Our findings explain the existence of SMBH at redshift above 6 recently detected by JWST and also detected in earlier quasar surveys with SDSS.

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Cosmology / **327**

The co-evolution of supermassive black holes and their host haloes

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Masses of supermassive black holes (SMBH) are known to correlate with the spheroidal component of their host galaxies according to the so-called M-sigma (Magorrian) relation. A further proposal of a correlation between the SMBH mass and halo mass is a focus of research. In this talk, we propose a mechanism for the co-evolution of black holes and their host dark matter haloes based on the hydrodynamics of accretion flow. We find that the massive haloes above a transition halo mass will be able to grow black holes to achieve a constant ratio between the hole and halo mass that agrees with the proposed black-hole and halo mass relation. Haloes below the transition halo mass would host black holes smaller than expected from the black-hole mass halo mass relation. We also compare our results with observations and find a good agreement.

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Cosmology / **328**

Tensor non-gaussianities in Loop Quantum Cosmology

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In Loop Quantum Cosmology
(LQC), inflation is preceded by a bounce. The scalar and tensor power
spectra and scalar bispectrum have been investigated in LQC. These
studies show that the presence of the bounce sets a new scale in the
problem. The spectra of perturbations with wavelengths comparable to or
larger than this scale departs from the nearly-scale invariant behaviour
predicted in slow-roll inflation. In this work, we investigate the
evolution of tensor perturbations in LQC. In particular, we review the
tensor perturbations at the level of power spectrum and present our
investigations at the level of bispectrum and non-gaussianities. We compare our results with
the scalar bispectrum generated in LQC.

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Cosmology / 329

Cosmological Perturbations and Complexity in Bianchi I Spacetime

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The study of cosmological perturbations and quantization during inflation has predominantly focused on the Friedmann-Lemaitre-Robertson-Walker (FLRW) spacetime. Still, there are very few non-FLRW spacetime cosmological perturbation studies. Among these, the Bianchi I model is one of the simplest anisotropic spacetime models, featuring varying scale factors (a(t)) in orthogonal directions. This characteristic renders Bianchi I a more encompassing representation of spacetime than the FLRW model. Recent studies have discussed cosmological perturbations and quantization in Bianchi I spacetime and have shown shear coupling between scalar-vector-tensor perturbation, which is absent in the FLRW case. The primordial universe has shown signs of chaos, and studying this can help in understanding the anisotropic nature of the universe. The evolution of out-of-time-ordered correlators (OTOC) has emerged as a valuable tool for quantifying quantum chaos. In recent years, the study of OTOCs and quantum chaos has gained interest in various fields, including condensed matter and cosmology. OTOCs were initially devised to calculate vertex correction of current in superconductors but have evolved into a method of measuring quantum chaos and growth of complexity in quantum information theory. OTOC calculations have been used to measure complexity in the squeezed state of cosmological perturbations of FLRW metric and have shown that quantum chaos manifests during the inflationary epoch but gradually diminishes during the radiation-dominated era. Here, we use the OTOC calculation to study the same in anisotropic spacetime models, namely the Bianchi I model, and compare it with FLRW and show the intricate interplay between quantum effects and the evolving structure of the universe, particularly during the critical epochs of cosmic inflation and radiation domination.

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Gravitational Waves / 330

Analysing the sensitivity of nuclear equation of state parameters with stellar observables using f-modes oscillations in Neutron Stars

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Gravitational wave(GW) astronomy has been maturing rapidly since the first detection of gravitational waves. Already, the current GW detectors have the sensitivity to detect gravitational waves emitted from neutron stars. Next-generation detectors will improve on this, resulting in a golden age of GW astronomy for Neutron Stars(NS). The observed mass of NS is limited to around two times that of the Sun. Recently, NICER provided a mass and radius measurement of an isolated neutron star through soft X-ray timing, while LIGO/Virgo measured the tidal deformability of neutron stars through gravitational waves. The goal is to use these observations to explore the interior composition of NS. To date, there is no consensus about the core constituents. Hundreds of equation of state (EoS) models for the NS core exist in the literature that can successfully connect to the global properties. One approach is constructing a spectral fit of these large collections of realistic neutron-star EoSs using few parameters. These representations can be used to extract EoS information from data obtained by X-ray and gravitational-wave observations of neutron stars. In particular, we perform a fully general relativistic study of the f-mode oscillations of NS, choosing a large set of EoS consistent with the latest astrophysical observations from NICER and LIGO. The fundamental f-modes are within the sensitivity range of the current generation of GW detectors and are correlated with the tidal deformability during the inspiral phase of binary neutron star mergers. They also carry information about the interior composition and viscous forces that bring the perturbed star back to equilibrium. The empirical relations among quasinormal oscillation mode frequencies and the compactness and tidal deformability of the NS can help us constrain the allowed EoS for the NS core. We systematically look at the correlations of mode frequencies and estimate the correlations for our spectral set of EoS. We also find out the EoS parameters that are sensitive to stellar observables, like the radius and f-mode frequencies.

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Gravitational Waves / 331

Constraining Reheating Dynamics with Gravitational Waves

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In the standard Big Bang model, Reheating follows inflation but precedes Big Bang Nucleosynthesis (BBN), marking the transition from the inflationary epoch to the hot Big Bang. During inflation, the universe expands exponentially due to the inflation field's energy. After inflation, as the field oscillates, it transfers energy to other particles, forming a hot, dense plasma. This phase depends on parameters like inflaton mass, self-coupling, and radiation field coupling, represented by the equation of state (EoS) and the reheating temperature Tre. Our understanding of this process remains incomplete despite advances in cosmological observations.

The past decade has witnessed the rise of gravitational waves (GWs) in observational cosmology, starting with LIGO-Virgo's 2015 detection of GWs from distant binary black hole mergers. This era includes the recent discovery of a stochastic GW background in the nano-Hertz range using Pulsar Timing Arrays, posing challenges in identifying sources beyond known astrophysical binaries but promising insights into early universe mysteries.

Cosmologists have long studied stochastic gravitational waves, especially primordial stochastic gravitational waves (PSGWs). PSGWs, believed to originate from quantum vacuum fluctuations amplified during inflation, confirm the inflationary paradigm and offer insights into high-energy physics.

Secondary gravitational waves (SGWs) can arise from a time-varying anisotropic stress-energy tensor in the early universe, carrying valuable information about cosmic dynamics and source characteristics. Our research specifically investigates SGWs generated by electromagnetic fields, with a primary focus on their role in inflationary magnetogenesis during Reheating. This study aims to demonstrate how SGWs can effectively constrain both inflationary and reheating dynamics, in addition to refining inflationary magnetogenesis models.

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Classical & Quantum Gravity / 332

Are multiple reflecting boundaries capable of enhancing entanglement harvesting?

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Quantum entanglement harvesting in the relativistic setup attracted a lot of attention in recent times. Acquiring more entanglement within two qubits may be very desirable to establish fruitful communication between them. On the other hand use of reflecting boundaries in a spacetime has close resemblance to the cavity quantum optomechanical systems. Here, in presence of two reflecting boundaries, we study the generation of entanglement between two uniformly accelerated Unruh-DeWitt detectors which are interacting with the background scalar fields. Like no boundary and single boundary situations, entanglement harvesting is possible for their motions in opposite Rindler wedges. We observe that the reflecting boundaries can play double roles. In some parameter space it

causes suppression, while in other parameter space we can have enhancement of entanglement compared to no boundary and single boundary cases. Thus increase of boundaries has significant impact in this phenomena and a suitable choices of parameters provides diresable increment of it.

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Cosmology / 333

Squeezing, Chaos and Thermalization in Periodically Driven Quantum Systems: The Case of Bosonic Preheating

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The phenomena of Squeezing and chaos have recently been studied in the context of inflation. We apply this formalism in the post-inflationary preheating phase. During this phase, inflaton field undergoes quasi-periodic oscillation, which acts as a driving force for the resonant growth of quantum fluctuation or particle production. Furthermore, the quantum state of the fluctuations is known to have evolved into a squeezed state. In this submission, we explore the underlying connection between the resonant growth, squeezing, and chaos by computing the Out of Time Order Correlator (OTOC) of phase space variables and establishing a relation among the Lyapunov, Floquet exponents, and squeezing parameters. For our study, we consider observationally favored α-attractor E-model of inflaton which is coupled with the bosonic field. After the production, the system of produced bosonic fluctuations/particles from the inflaton is supposed to thermalize, and that is believed to have an intriguing connection to the nature of chaos of the system under perturbation.
We conjecture a relation between the thermalization temperature $(\bar{T}_{\rm SS})$ of the system and quantum squeezing, which is further shown to be consistent with the well-known Rayleigh-Jeans formula for the temperature symbolized as $\bar{T}_{\rm RJ}$, and that is $\bar{T}_{\rm SS} \simeq \bar{T}_{\rm RJ}$. Finally, we show that the system temperature is in accord with the well-known lower bound on the temperature of a chaotic system proposed by Maldacena-Shenker-Stanford (MSS).

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Plenary / 334

Binary Neutron Stars: from macroscopic collisions to microphysics

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I will argue that if black holes represent one the most fascinating implications of Einstein's theory of gravity, neutron stars in binary system are its richest laboratory, where gravity blends with astrophysics and particle physics. I will discuss the rapid recent progress made in modelling these systems and show how the gravitational signal can provide tight constraints on the equation of state and sound speed for matter at nuclear densities, as well as on one of the most important consequences of general relativity for compact stars: the existence of a maximum mass. Finally, I will discuss how the merger may lead to a phase transition from hadronic to quark matter. Such a process would lead to a signature in the post-merger gravitational-wave signal and open an observational window on the production of quark matter in the present Universe.

Plenary / 335

Free-falling in Quantum Spacetime

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Gravity is usually regarded classically, obeying Newton's law or Einstein's equations. Here I will show that, when the gravitational field is treated quantum-mechanically, the classical trajectories of freely falling objects are subject to random fluctuations, or "noise". Intuitively, the fluctuations can be viewed as arising due to the bombardment of the falling object by gravitons. This fundamental noise might even be observable at gravitational wave detectors and, if detected, would provide experimental evidence for the quantization of gravity. I will also show that, when these results are extended to congruences of geodesics, the quantum fluctuations of spacetime give rise to an additional term in the Raychaudhuri equation.

Plenary / 336

LIGO observations and future with LIGO India

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We are in the era of gravitational-wave and multi-messenger astronomy. The latest catalog of transient events from LIGO-Virgo-KAGRA contains 90 high-confidence detections from the first three observing runs. The ongoing fourth observing run is yielding a steady stream of events, with public alerts being issued at a rate of approximately 2-3 per week. All observations are believed to originate from merging neutron stars and/ or black holes, and are providing new insights into the properties and origins of compact objects and binaries. In this talk, I will provide a summary of the key observations to date, highlighting what we can learn about the astrophysics of compact objects. I will also discuss what these observations mean for the future when LIGO India comes online, expanding the global detector network and ushering in an even brighter era of gravitational-wave astronomy.

Inauguration / 337

Inauguration

Workshop on Classical & Quantum Gravity / 338

Regular spacetimes: black holes, wormholes and bubbles (Invited talk)

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In this talk, I will provide a brief overview of regular spacetimes in theories of gravity. In particular, I will primarily review some of the well–known regular black holes and also discuss wormholes and bubble spacetimes. Some recent results, as well as physical effects in such spacetimes will be mentioned. We will end with
general comments and open questions.

Workshop on Classical & Quantum Gravity / 339

Contributed talks

Special Sessions / 340

Biographical overview

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Special Sessions / 341

Quantum Gravity (ħ=1)

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Special Sessions / 342

Induced Gravity (ħ=1 to ħ=0)

Plenary / 343

Ultra-long wavelength gravitational waves with pulsar timing array

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A rapidly emerging messenger in astrophysics is gravitational waves (GWs). A new window in the GW spectrum was recently opened when emerging evidence for ultra-long wavelength or nanoHertz frequency GWs was reported by four major pulsar timing array experiments (PTAs). These experiments use a collection of widely separated pulsars in the sky to look for a characteristic spectrum and spatial correlation due to an isotropic stochastic gravitational wave background (SGWB) believed to

originate by the superposition of continuous gravitational waves emitted by an ensemble of gravitational radiation dominated in-spiralling super-massive black hole binary systems. A review of these experiments in the context of SGWB will be presented in this talk followed by a discussion of results of joint analysis by Indo-Japanese pulsar timing array (InPTA) and European pulsar timing array (EPTA) collaboration. These results will be examined in the context of similar results from Parkes pulsar timing array (PPTA), North American nanoHertz Observatory for gravitational waves (NANOgrav) and Chinese pulsar timing array (CPTA). Results from a recent comparison of these results jointly by International pulsar timing array (IPTA) will be presented, which suggests a higher significance detection after combining data from all the experiments. Recent efforts in improving the noise models with low frequency data and challenges in IPTA data combination will be described. Finally, the talk concludes with a brief look at possible new astrophysics, where the PTA data as well as multi-messenger astronomy is likely to contribute significantly in developing the field of gravitation and cosmology.

Plenary / **344**

Theoretical developments in modeling cosmological structure formation

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The evolution and growth of the skeleton of the Cosmic Web goes hand-in-hand with the evolution of gas and galaxies in the Universe and intertwines primordial physics (the details of inflation, dark matter and dark energy) with astrophysics (reionization, star formation and the growth of black holes). Untangling this correlated evolution in order to use the Cosmic Web as a cosmological probe requires a judicial use of theoretical techniques ranging from perturbation theory and non-linear analytical approximations to semi-numerical models to full-fledged numerical simulations of dark matter, gas and galaxies. Such techniques are critical in understanding the degeneracies between cosmology and astrophysics that are imprinted on any given astrophysical probe of cosmology. I will discuss some of the progress in this field over the last several years, highlighting a few different themes from the literature. At low redshifts, I will discuss the emerging importance of uncertain physical effects such as galaxy assembly bias and the role played by novel statistical probes of non-linear structure. At high redshifts, I will briefly describe the development of accurate and fast tools for capturing the physics of reionization. Finally, I will showcase our recent efforts at distinguishing the 'standard' Lambda-CDM model from alternative theories.

Plenary / **345**

Gravitational Wave Detectors (India): Present status & future plans

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Gravitational Waves are the periodic stretching and contracting of space-time produced by rotating astrophysical objects possessing a finite quadrupole moment such as binary stars, binary neutron stars, neutron star-black hole binary or black-hole-black-hole binary, etc. A passing gravitational wave will modulate the distance between two inertial test masses albeit by a very miniscule amount. Gravitational waves can be detected by measuring these minuscule changes using techniques such as resonant bars, resonant spheres, interferometric measurement, etc. Of these the interferometer detector is most promising due to it broadband sensitivity and scalability in size. The Michelson interferometer is a 39;natural39; detector of gravitational waves because of the differential changes in its two orthogonal arms induced by the quadruple field of the gravitational waves. As the displacement of two mirrors separated by a distance L, scales with the distance interferometer detector with

arm length of kms is required to be able to detect Gravitational waves. Two such km class detectors are the Laser Interferometer Gravitational-wave Observatory (LIGO) detectors in the US, located in Livingston, Louisiana, and Hanford, Washington, separated by about three thousand kilometers. The third detector labeled LIGO-India is being setup in India under a joint collaboration between NSF and DAE-DST. The talk will provide a brief overview of the LIGO-India Project, it's current status and plans for it's upgrades to "arrive"in the global network of Gravitational Wave Detectors with an optical configuration similar to the other two LIGO detectors. The various activities on the Indian side for the LIGO-India Project will be presented in detail. The activities and plans for contributing to the next generation Gravitational Wave detector and a possible deci-Hz Gravitational Wave detector in space will also be discussed briefly.

Plenary / 346

Hunting for gravitational waves in the era of cosmic dawn

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Over the past decades, observations have established a sample of more than 200 bright Active galactic nuclei (AGN), powered by accretion onto massive black holes, in the first billion years of the Universe. The James Webb Space Telescope has significantly revised this sample by yielding a sample of unexpectedly numerous and large black holes (up to a 100 million solar masses) within the first 600 million years, posing an enormous challenge for black hole and galaxy formation models. Starting with possible pathways for creating such heavy black holes in the early Universe, I will show a census of the black holes and their properties expected through cosmic time. I will use these to highlight the gravitational wave event rates expected to be detected by LISA (the Laser Interferometer Space Antenna). Straddling the fields of cosmology, galaxy formation and black hole physics, I will show how theoretical models that couple the evolution of dark matter halos, their baryonic components and their black holes are crucially required to make predictions for facilities such as LISA.

Workshop on Classical & Quantum Gravity / 347

Spontaneous Symmetry Breaking in Rindler frame and AdS space (Session 1)

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Special Sessions / 348

Raychaudhuri and the singularity theorems

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Plenary / 349

Gravitational Wave Paleontology: a new frontier to probe massive stars through cosmic history

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In this talk I will discuss the challenges and prospects of Gravitational-wave Paleontology: studying massive stars from their 'remnants'as compact object coalescences, with the goal to answer the key questions in gravitational-wave astronomy today: What can we learn from these gravitational-wave sources about the formation, lives, and explosive deaths of massive stars across cosmic time? How do we unravel the gravitational-wave formation channels? I will discuss open challenges in gravitational waves including the "Uncertainty Challenge"and give an overview of current efforts in the field to overcome this.

Special Sessions / 350

Introducing Working Group on Gender

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Special Sessions / 351

Women of Gravity

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Plenary / 352

Black hole thermodynamics in higher derivative theories of gravity

Einstein's equations are a set of classical differential equations for gravity with maximum two space-time derivatives. Black holes are some singular solutions to Einstein's equations. They behave like large thermodynamic objects, indicating that they are actually an ensemble of the quantum states of gravity. Now any consistent quantum completion of Einstein's theory typically generates several higher derivative corrections. Therefore we expect that black holes will continue to satisfy the laws of thermodynamics even after adding the quantum gravity induced corrections to Einstein's equation. In this talk, we would like to see to what extent we could prove this expectation.

Public Lecture / 353

The Gravitational-Wave Revolution: Observing Some Of The Most Cataclysmic Events In The Universe With The Most Precise Detectors Ever Constructed

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Plenary / 354

Do the Fundamental Constants change with Time?

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Temporal evolution in low-energy fundamental constants such as the fine structure constant and the proton-electron mass ratio is a generic prediction of theories that attempt to unify the Standard Model of particle physics and general relativity. The exciting possibility of low-energy tests of such unification theories has inspired a number of methods to probe fundamental constant evolution on a range of timescales, from years to billions of years. Astrophysical studies of redshifted spectral lines provide a powerful probe of such putative changes in the low-energy fundamental constants across a large fraction of the age of the Universe. After reviewing the current state of the field, I will describe new high-sensitivity results on changes in the proton-electron mass ratio over the last 8 Gyr using methanol radio spectral transitions. Finally, if time permits, I will discuss present limitations of such studies and the improvements that are likely to be possible with the advent of new experimental and observational facilities over the next decade.

Plenary / 355

Cosmography with gravitational waves: from current detections to future observatories

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Compact binaries observed in gravitational waves (GWs) are standard distance indicators or standard sirens. This has opened up a novel path to measuring cosmological parameters such as the Hubble constant. In this talk we give a brief overview of the current results in this context from the LIGO-Virgo-KAGRA detector network, some of the near-future prospects, and finally move over to the unique opportunities offered by future GW observatories.

Workshop on Classical & Quantum Gravity / 356

TBC

Workshop on Classical & Quantum Gravity / 357

Influence of gravity on the quantum speed limit in neutrino oscillations (Session 1)

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Workshop on Classical & Quantum Gravity / 358

New regular black holes: geometry, matter sources and shadow profiles (Session 1)

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Workshop on Classical & Quantum Gravity / 359

Gravitational radiation from binary systems in f (R) gravity: A semi-classical approach (Session 1)

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Workshop on Classical & Quantum Gravity / 360

Phases of scalar and fermionic field theories in thermal Anti-de Sitter Spaces (Session 1)

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Workshop on Classical & Quantum Gravity / 361

Effective quantum states for trapped surfaces (Session 1)

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Workshop on Classical & Quantum Gravity / 362

Particle dynamics and new horizon structure around Kerr-Newman singularity (Session 1)

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Workshop on Classical & Quantum Gravity / 363

Energetics of a self-gravitating quantum system of charged particles (Session 1)

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Workshop on Classical & Quantum Gravity / 364

Pole-skipping in holography with scalar-Gauss-Bonnet coupling (Session 2)

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Workshop on Classical & Quantum Gravity / 365

Singularity free Emergent Universe from Dynamical wormhole (Session 2)

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Workshop on Classical & Quantum Gravity / 366

Thermodynamics of multi-horizon spacetimes (Session 2)

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Workshop on Classical & Quantum Gravity / 367

The Conspiracy of dS Space in String Theory (?) (Session 2)

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Workshop on Classical & Quantum Gravity / 368

An analytical approach to compute conductivity of p-wave holographic superconductors (Session 2)

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Workshop on Classical & Quantum Gravity / 369

Are multiple reflecting boundaries capable of enhancing entanglement harvesting? (Session 2)

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Workshop on Classical & Quantum Gravity / 370

Unruh-de Witt detectors in curved spacetime (Session 2)

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Workshop on Gravitational Waves / 371

Probing fundamental physics with gravitational wave observations (Invited Talk)

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Workshop on Gravitational Waves / 372

Quasinormal Modes of Slowly Rotating Black Holes in Dynamical Chern-Simons Gravity up to Second Order in Spin

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Workshop on Gravitational Waves / 373

Noise analysis of the Indian Pulsar Timing Array data release I

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Workshop on Gravitational Waves / 374

Novel probes of dark matter with continuous gravitational waves

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Workshop on Gravitational Waves / 375

Multi-band Extension of the Wideband Timing Technique

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Workshop on Gravitational Waves / 376

Probing globular clusters and other astrophysical environments with gravitational waves emitted by accelerated compact binary mergers

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Workshop on Gravitational Waves / 377

A Bayesian investigation of the neutron star equation-of-state vs. gravity degeneracy

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Workshop on Gravitational Waves / 378

Analysing the sensitivity of nuclear equation of state parameters with stellar observables using f-modes oscillations in Neutron Stars

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Workshop on Astrophysical Relativity / 379

AstroSat - Indian Space-based Multi-wavelength Observatory (Invited Talk)

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AstroSat, India's first multi-wavelength space observatory is an unique platform to observe cosmic X-ray sources, especially to probe the strong gravity of 'compact' objects. I will discuss the capabilities of AstroSat and present some interesting results to decipher the environment around the 'compact' objects.

Workshop on Astrophysical Relativity / 380

Accreting Millisecond X-ray Pulsars: Probing Strong Field Gravity

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Workshop on Astrophysical Relativity / 381

Misaligned circum-single disks embedded in an AGN disk

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Workshop on Astrophysical Relativity / 382

Mass loss from relativistic magnetized accretion disc around rotating black holes

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Workshop on Astrophysical Relativity / 383

Investigating the existence of gravitomagnetic monopole in M87*

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Workshop on Astrophysical Relativity / 384

Equation of states in the curved spacetime of compact stars and their effects on tidal deformability

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Workshop on Astrophysical Relativity / 385

Microlensing Black Hole Shadows

Workshop on Astrophysical Relativity / 386

High-soft to low-hard state transition in black hole X-ray binaries with GRMHD simulations

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Workshop on Cosmology / 387

Mapping the baryonic Universe: a new window into the cosmos (Invited Talk)

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Mapping the baryonic content of the Universe, especially after the epoch of Cosmic Dawn – the birth of the first stars and galaxies — promises rich insights into both astrophysics and cosmology. The technique of intensity mapping (IM) has emerged as a powerful tool to explore this phase of the Universe by measuring the integrated emission from sources over a broad range of frequencies. A particular advantage of IM is that it provides a tomographic, or three-dimensional picture of the Universe, unlocking significantly more information than we presently have from galaxy surveys. Astrophysical uncertainties, however, constitute an important systematic in our attempts to constrain cosmology with IM. I describe an innovative approach which allows us to fully utilize our current knowledge of astrophysics in order to develop cosmological forecasts from IM. Analytically driven extensions to this framework allow us to interpret the latest auto-correlation IM results from

the MeerKAT facility, as well as its counterparts in the microwave and sub-millimetre regimes. The framework can be used to exploit synergies with other complementary surveys, thereby opening up the fascinating possibility of constraining physics beyond Lambda CDM from future IM observations.

Workshop on Cosmology / 388

Using Big Bang Nucleosynthesis to constrain f(R) gravity scalarons and primordial black hole masses (Session 1)

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Workshop on Cosmology / 389

Exploring Cosmic Anisotropy in the Bianchi-I Cosmological Model (Session 1)

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Workshop on Cosmology / 390

Detectable signatures of non-Bunch-Davies 3-point correlation from primordial magnetic fields: CMB μT spectrum (Session 1)

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Workshop on Cosmology / 391

Extremely magnified stars in cluster lenses (Session 1)

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Workshop on Cosmology / 392

An effective field theory approach to understand the primordial magnetogenesis (Session 1)

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Workshop on Cosmology / 393

Ruling out Strongly Interacting Dark Matter–Dark Radiation Models from Joint Observations of Cosmic Microwave Background and Quasar Absorption Spectra (Session 1)

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Workshop on Cosmology / 394

Squeezing, Chaos and Thermalization in Periodically Driven Quantum Systems: The Case of Bosonic Preheating (Session 1)

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Workshop on Cosmology / 395

Self-interactions of ULDM to the rescue? (Session 2)

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Workshop on Cosmology / 396

Model-independent reconstruction of the evolution of dark energy using Gaussian process regression (Session 2)

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Workshop on Cosmology / 397

Probing the signatures of astrophysical scatter in the EoR 21cm signal using auto-bispectrum (Session 2)

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Workshop on Cosmology / 398

Effects of Z3 symmetric dark matter models on global 21-cm signal (Session 2)

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Workshop on Cosmology / 399

Dark energy, D-branes, and Pulsar Timing Arrays (Session 2)

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Workshop on Cosmology / 400

Statistical Approaches to Study statistical Isotropy in CMB Sky maps (Session 2)

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Workshop on Cosmology / 401

Expansion-collapse duality between Einstein and Jordan frames: Implications at quantum level (Session 2)

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Workshop on Classical & Quantum Gravity / 402

Analyzing quantum gravity spillover in the semiclassical regime (Session 1)

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Workshop on Classical & Quantum Gravity / 403

A master equation for gravitational wave memory (Session 1)

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Workshop on Classical & Quantum Gravity / 404

Unruh effect via radiative energy level shift (Session 1)

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Workshop on Classical & Quantum Gravity / 405

QBHs in the Sky (Session 1)

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Workshop on Classical & Quantum Gravity / 406

Rindler trajectories and Rindler horizons in the Schwarzschild spacetime (Session 1)

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Workshop on Classical & Quantum Gravity / 407

End-state of gravitational collapse of scalar and vector fields: Strong naked singularities (Session 2)

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Workshop on Classical & Quantum Gravity / 408

Boundary terms and Brown-York quasi-local parameters for scalar-tensor theory (Session 2)

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Workshop on Classical & Quantum Gravity / 409

Membrane paradigm for slowly spinning compact objects (Session 2)

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Workshop on Classical & Quantum Gravity / 410

Charged Scalar Hair on Reissner-Nordström Black Holes (Session 2)

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Workshop on Classical & Quantum Gravity / 411

Fate of an infalling Passenger at the Cauchy Horizon of a Reissner-Nordström Black Hole (Session 2)

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Workshop on Classical & Quantum Gravity / 412

Gravitational collapse with torsion and nonsingular Universe in a black hole (Session 2)

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Workshop on Gravitational Waves / 413

"ENIGMA"- An aligned-spin eccentric IMR waveform model for compact binary mergers

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Workshop on Gravitational Waves / 414

Inferring the quantum black hole signatures from gravitational-wave observations

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Workshop on Gravitational Waves / 415

Testing general relativity via direct measurement of black hole kicks

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Workshop on Gravitational Waves / 416

Testing of general relativity at the fourth post-Newtonian order

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Workshop on Gravitational Waves / 417

Precision Gravity: Gravitational waves using Feynman diagrams

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Workshop on Gravitational Waves / 418

Addressing issues in defining the Love numbers for black holes

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Workshop on Astrophysical Relativity / 419

Testing the equivalence principle with Blackhole image observations

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Workshop on Astrophysical Relativity / 420

The light bending phenomenon for a pulsar-black hole binary

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Workshop on Astrophysical Relativity / 421

Universe at extreme energies through GZK neutrinos and photons

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Workshop on Astrophysical Relativity / 422

DEEP-TOV FOR CHARACTERIZING NEUTRON STARS

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Workshop on Astrophysical Relativity / 423

Superradiant driven evoulution of Active Galactic Nuclei

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Workshop on Astrophysical Relativity / 424

Black hole mimickers in light of the recently observed shadows of Sagittarius A* and M87*

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Workshop on Cosmology / 425

Morphological Characterization of Galactic Foreground Emissions (Session 1)

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Workshop on Cosmology / 426

Ultra-light primordial black holes from first-order phase transition with unique gravitational wave spectrum (Session 1)

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Workshop on Cosmology / 427

Measuring secondary halo bias using nearest neighbor distributions (Session 1)

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Workshop on Cosmology / 428

Impact of sources of Epoch of Reionization (EoR) on the 21-cm bispectrum (Session 1)

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Workshop on Cosmology / 429

The co-evolution of supermassive black holes and their host haloes (Session 1)

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Workshop on Cosmology / 430

Primordial black hole reheating and its possible signatures (Session 1)

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Workshop on Cosmology / 431

Probing the HI distribution during post-reionization using the redshifted 21-cm marked power spectrum (Session 2)

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Workshop on Cosmology / 432

Cosmological events on the stochastic background of inflationary gravitational waves (Session 2)

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Workshop on Cosmology / 433

Emergence of cosmic space with Barrow entropy, a non-equilibrium thermodynamic description (Session 2)

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Workshop on Cosmology / 434

Galaxy-dark matter connection of photometric galaxies from the HSC-SSP Survey using weak lensing (Session 2)

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Workshop on Cosmology / 435

The abundance of core–collapsed subhalos in SIDM: insights from structure formation in ΛCDM (Session 2)

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Workshop on Cosmology / 436

Ultra-low mass primordial black holes in the early universe can explain the PTA signal (Session 2)

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Workshop on Classical & Quantum Gravity / 437

Even a tiniest positive cosmological constant has a long tail (Invited Talk)

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The physics of gravitational waves is well understood for asymptotically flat space-times. Asymptotic flatness presumes a vanishing cosmological constant. However, cosmological observations over the decades have indicated that our universe is undergoing an accelerated expansion, which is most simply modelled by a de Sitter universe or equivalently by a positive cosmological constant. Even a tiniest value of positive cosmological constant profoundly alters the asymptotic structure of space-times, forcing a re-look at the theory of gravitational radiation. We will present an overview of the study of gravitational radiation in the de Sitter universe. We will discuss the progress and state-of-the-art of the subject.

Workshop on Classical & Quantum Gravity / 438

The breaking point of general relativity through f(R) scalaron gravity and higher dimensional Kaluza-Klein gravity near Sgr A* (Session 1)

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Workshop on Classical & Quantum Gravity / 439

Gyroscopic Precession in the Vicinity of a Black Hole's Event Horizon and Naked Singularity for Static and Stationary Spacetime (Session 1)

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Workshop on Classical & Quantum Gravity / 440

Harmonic coordinates in binary black hole mergers (Session 1)

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Workshop on Classical & Quantum Gravity / 441

Maximal volume of a black hole in 2+1 dimensions (Session 1)

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Workshop on Classical & Quantum Gravity / 442

Cosmology of Bianchi type-I metric using renormalization group approach for quantum gravity (Session 1)

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Workshop on Classical & Quantum Gravity / 443

Extra dimension(s) of vanishing proper length: A non-Einsteinian phase in gravity and the implications (Session 1)

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Workshop on Classical & Quantum Gravity / 444

Causal description of marginally trapped regions in D dimensions (Session 2)

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Workshop on Classical & Quantum Gravity / 445

Stochastic aspects for cosmic fluids (Session 2)

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Workshop on Classical & Quantum Gravity / 446

Is the no-hair theorem a feature of gravity or General Relativity? (Session 2)

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Workshop on Classical & Quantum Gravity / 447

Compactified Hyperboloidal Evolution in Numerical Relativity (Session 2)

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Workshop on Classical & Quantum Gravity / 448

Galactic wormholes: Geometry, stability, and echoes (Session 2)

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Workshop on Classical & Quantum Gravity / 449

Raychaudhuri Equation in the Context of a Collapsing Fermionic Distribution Incorporating Effective Four-Fermi Interaction (Session 2)

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Workshop on Classical & Quantum Gravity / 450

Dyonic Kerr-Sen black holes revisited: shadow profiles and consequences (Session 2)

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Workshop on Gravitational Waves / 451

New black hole mergers in LVK data from a gravitational wave search including higher-order harmonics (Invited Talk)

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Nearly all of the previous gravitational wave (GW) searches in the LIGO-Virgo-Kagra (LVK) data include GW waveforms with only the dominant quadrupole mode, i.e., omitting higher-order harmonics such as the octupole which are predicted by general relativity. We improved our search pipeline by introducing higher harmonics in the GW templates, and downweighting noise transients ("glitches") to improve the search sensitivity to high-mass binary black hole (BBH) mergers. We searched over the public LVK data from the third observing run (O3) and used the detection threshold as the astrophysical probability being over 0.5 (following the approach of the LVK catalogs). This led to the detection of 13 new BBH merger events. Some of the new events have interesting astrophysical properties such as populating the pair instability mass gap in the black hole (BH) mass distribution and high redshift. While our new events individually have modest false alarm rates

(>˜ 1/yr), combining all the 13 events with their respective pastro values could have an impact on population analysis studies (e.g., probing the evolution of mass and spin distribution of BHs with redshift).

Workshop on Gravitational Waves / **452**

Exploring the Efficacy of Curriculum Learning in Training Neural Networks for Gravitational Wave Detection and Parameter Estimation in Near-Realistic Conditions

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Workshop on Gravitational Waves / **453**

Black holes immersed in environment

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Workshop on Gravitational Waves / **454**

Unmasking noise transients mimicking intermediate-mass black hole binaries

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Workshop on Gravitational Waves / **455**

Effect of spins on the orbital dynamics of a binary system

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Workshop on Gravitational Waves / **456**

Gear-up for the Action Replay: Leveraging Lensing for Enhanced Gravitational-Wave Early-Warning

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Workshop on Gravitational Waves / **457**

Probing the nature of dark matter using gravitational-wave strong lensing

Workshop on Astrophysical Relativity / 458

Astrophysical Implications of Gravitational Wave Observations (Invited Talk)

Since the Nobel winning discovery of gravitational waves (GWs) by the LIGO-Virgo-Kagra (LVK) detectors from merging compact object binaries, understanding the various astrophysical formation channels of these sources has come to sharp focus. While qualitatively, the processes involved in producing these astrophysical systems are well understood, cutting-edge research is underway to put better constraints on several uncertain aspects that can affect the distribution of properties and expected rate of mergers depending on the formation channel. I will give a brief overview of the various formation channels, their unique characteristics, and the major sources of uncertainties. I will give a broad overview of the current state-of-the art of our theoretical understanding and predictions and discuss possible ways forward, using GWs in different frequency bands with future and upgraded detectors, and using other ongoing and upcoming electromagnetic surveys that can provide the key ingredients to better model GW sources.

Workshop on Astrophysical Relativity / 459

Probing the Accretion/Ejection Geometry of X-ray Binaries Using Spectro-Polarimetry Study

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Workshop on Astrophysical Relativity / 460

Oscillating shocks in the transonic, viscous, variable Γ accretion flows around black holes

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Workshop on Astrophysical Relativity / 461

Imprints of spin on the solution and emission spectrum of accretion flows around black holes

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Workshop on Astrophysical Relativity / 462

Shadow of regular black hole in scalar-tensor-vector gravity theory

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Workshop on Astrophysical Relativity / 463

Spectral energy distributions for transonic accretion flow in non-Kerr spacetime

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Workshop on Astrophysical Relativity / 464

White dwarfs in Gaia survey to constrain the fine-structure constant

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Workshop on Cosmology / 465

Instrumentation for redshifted 21-cm line observations (Invited Talk)

Corresponding Author: saurabh.ascan@gmail.com

Universe has several poorly constrained periods over its evolution. Formation of first stars and galaxies, followed by reionization of the intergalactic medium is one such epoch. Often referred to as "cosmic dawn", observing this period is extremely challenging due to the faint nature of the signals originating from it. The redshifted 21-cm line from neutral hydrogen offers one such possibility to observe the cosmic dawn and extract information about the nature of first stars and galaxies. In this talk, I will discuss our attempts at detecting the 21-cm signal from cosmic dawn. I will elaborate the challenges involved in detecting faint cosmological signals, and how our in-house designed experiments address those challenges. I will finally discuss the recent results from our observations, and explore how 21-cm signal can also be employed to probe other epochs at different redshifts.

Workshop on Cosmology / 466

Gravitational Waves Background from Quintessential Inflation and NANOGrav data (Session 1)

Corresponding Author: nurphoton@gmail.com

Workshop on Cosmology / 467

Reconstructing the universe with machine learning (Session 1)

Corresponding Author: purba16@gmail.com

Workshop on Cosmology / 468

Loop-level contributions of primordial non-Gaussianities and their observational consequences (Session 1)

Corresponding Author: ragavendra@rrimail.rri.res.in

Workshop on Cosmology / 469

A geometrical interpretation of foreground filters for HI intensity (Session 1)

Corresponding Author: quantummechanicskothari@gmail.com

Workshop on Cosmology / 470

Precision Weak Lensing Analysis In CMB Observations For Upcoming Missions (Session 1)

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Workshop on Cosmology / 471

Distinguishing cosmological models through quantum signatures of primordial perturbations (Session 1)

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Workshop on Cosmology / 472

The origin of supermassive black holes at high redshift (Session 2)

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Workshop on Cosmology / 473

Consistency of loop quantum cosmology with the cosmic microwave background bispectrum (Session 2)

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Workshop on Cosmology / 474

Qualitative Stability Analysis of Cosmological models in $f(T, \phi)$ Gravity (Session 2)

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Workshop on Cosmology / 475

A Bayesian Neural Network based ILC method to estimate accurate CMB polarization power spectrum over large angular scales (Session 2)

Corresponding Author: sarvesh@rrimail.rri.res.in

Workshop on Cosmology / 476

HI stacking predictions for upcoming surveys with SKA precursors (Session 2)

Corresponding Author: ph19054@iisermohali.ac.in

Workshop on Cosmology / 477

Cosmology from Cross-Correlation of ACT-DR4 CMB Lensing and DES-Y3 Cosmic Shear (Session 2)

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Workshop on Classical & Quantum Gravity / 478

TBD (Invited Talk)

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Workshop on Classical & Quantum Gravity / 479

Gravitational wave memory for various black hole and wormhole geometries (Session 1)

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Workshop on Classical & Quantum Gravity / 480

Quantum-to-classical transition of leading-order background fluctuations (Session 1)

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Workshop on Classical & Quantum Gravity / 481

Love for an Expanding universe and SdS black holes (Session 1)

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Workshop on Classical & Quantum Gravity / 482

A detection mechanism for black hole memory effect (Session 1)

Corresponding Author: srijitb@iiita.ac.in

Workshop on Classical & Quantum Gravity / 483

Radiative processes of single and entangled detectors on circular trajectories in (2+1) dimensional Minkowski spacetime (Session 1)

Workshop on Classical & Quantum Gravity / 484

Perturbing the perturbed: Quasi-normal mode instability in asymptotically de Sitter black holes (Session 1)

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Workshop on Classical & Quantum Gravity / 485

On the propagation of gravitational waves in matter-filled Bianchi I universe (Session 1)

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Workshop on Classical & Quantum Gravity / 486

Some classical aspects of Ellis-Bronnikov wormholes embedded in a warped background. (Session 2)

Corresponding Author: smnphy@gmail.com

Workshop on Classical & Quantum Gravity / 487

Analytic three-dimensional hairy charged black holes and thermodynamics (Session 2)

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Workshop on Classical & Quantum Gravity / 488

An Effective Theory model for Black Hole Membranes from Constraints of Symmetry (Session 2)

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Workshop on Classical & Quantum Gravity / 489

Unified Insights in Gravity Theories: Asymptotic Symmetries and Celestial Holography (Session 2)

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Workshop on Classical & Quantum Gravity / 490

Particle creation in a dynamical gravitational wave background (Session 2)

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Workshop on Classical & Quantum Gravity / 491

High-energy corrections to CGHS model: a systematic procedure (Session 2)

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Workshop on Classical & Quantum Gravity / 492

Emergent Spin in Quantum Cosmology of Bianchi Type-I Universe (Session 2)

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Workshop on Gravitational Waves / 493

TBD (Invited Talk)

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Workshop on Gravitational Waves / 494

Can LIGO Detect Non-Annihilating Dark Matter?

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Workshop on Gravitational Waves / 495

Tidal heating as a direct probe of Strange matter inside Neutron stars

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Workshop on Gravitational Waves / 496

A novel test of strong field gravity using binary black hole ringdowns

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Workshop on Gravitational Waves / 497

Bayesian framework to infer the Hubble constant from cross-correlation of individual gravitational wave events with galaxies

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Workshop on Gravitational Waves / 498

Tidal deformation of dynamical horizons in binary black hole mergers and its imprint in their gravitational radiation

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Workshop on Astrophysical Relativity / 499

Seeing Hot and Energetic Universe through X-ray Eyes (Invited Talk)

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X-rays are the signatures of the high-energy Universe. The X-ray band probes extreme environments in the Universe, such as those near black holes or the surface of neutron stars. Observations in X-ray energies of the sky provides the opportunity to study such exotic objects in the Universe, allowing the exploration of physical processes in extreme conditions. Many space missions and instruments were realized since 1960s that contributed to the present understanding of the physics of various astronomical sources. A steady progress in technological development has put X-ray astronomy in the mainstay of astronomy and astrophysics. In this talk, I will provide an overview of the observational X-ray astronomy as well as current and future X-ray missions that have provided some path breaking scietific results to shed new lights on the nature of various astronomical sources as well as the physical mechanisms by which the X-rays are emitted. I will also briefly mention about India's first X-ray polarimetry instrument POLIX onboard XpoSat satellite that will soon be launched.

Workshop on Astrophysical Relativity / 500

Inclination distributions in tidal disruption events by spinning supermassive black holes

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Workshop on Astrophysical Relativity / 501

Massive, magnetized compact stars: Theory and Simulation

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Workshop on Astrophysical Relativity / 502

Gravitational analog of Gertsenshtein-Zeldovich effect.

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Workshop on Astrophysical Relativity / 503

Astrophysical significance of tidal interaction between white dwarfs and intermediate-mass black holes

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Workshop on Astrophysical Relativity / 504

Spectral and timing properties of GX 17+2 using AstroSat and NICER simultaneous view

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Workshop on Astrophysical Relativity / 505

Impact of the net vertical magnetic field on thick accreting torus around black holes

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Workshop on Astrophysical Relativity / 506

Investigation of black holes in analogous and astrophysical regimes

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Workshop on Astrophysical Relativity / 507

A deeper insight into the accretion scenario of BH-ULXs with XMM-Newton

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Workshop on Cosmology / 508

The dynamics of Dark matter and the halo from Cluster to Dwarf scales (Invited Talk)

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Workshop on Cosmology / 509

Non-linear joint density-velocity evolution in f(R) theories of modified gravity (Session 1)

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Workshop on Cosmology / 510

Dynamical system analysis in teleparallel gravity with boundary term (Session 1)

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Workshop on Cosmology / 511

Synchrotron radiation from cosmic string wakes. (Session 1)

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Workshop on Cosmology / 512

A semi-analytical treatment of coupled CDM-massive neutrino perturbations in diverse cosmological backgrounds (Session 1)

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Workshop on Cosmology / 513

A new method to simultaneously determine the reionization history and power spectrum (Session 1)

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Workshop on Cosmology / 514

The possibility of Q-balls as cosmological and galactic dark matter (Session 1)

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Workshop on Cosmology / 515

Loop contributions to the scalar power spectrum due to quartic order action in ultra slow roll inflation (Session 2)

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Workshop on Cosmology / 516

A Local Perspective on Hubble Tension from Cosmological N-body Simulations (Session 2)

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Workshop on Cosmology / 517

Signature flip in deceleration parameter: A thermodynamic phase transition? (Session 2)

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Workshop on Cosmology / 518

Non-linear regression with errors on both axes and its implications on Hubble tension (Session 2)

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Workshop on Cosmology / 519

Dark energy in light of the early JWST observations (Session 2)

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Workshop on Cosmology / 520

Towards a possible solution to the Hubble tension with Horndeski gravity (Session 2)

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