GRAVITEX 2021 ABSTRACTS

(in alphabetical order of first names)

Plenary Talks

1. **Alan Coley**

Title: Geometric Horizons

Abstract: In numerical investigations it is crucial to locate a black hole locally. This is usually done utilizing an apparent horizon. An alternative proposal is to identify a geometric horizon (GH), which is characterized by a surface in the spacetime on which the curvature tensor or its covariant derivatives are algebraically special. The GH can be identified by surfaces of vanishing scalar curvature invariants. We briefly discuss GHs and highlight some current research. 1. This approach necessitates the choice of a special null frame, called an algebraically preferred null frame. We employ the Cartan-Karlhede algorithm to completely fix the null frame invariantly, so that the GH can be characterized by the vanishing of certain Cartan scalars. 2. We discuss the GH in the context of the numerical investigation of the physical merger of two black holes.

2. **Alexei Starobinsky**

Title: Bianchi-I type anisotropic cosmological models in Horndeski gravity.

Abstract: Investigation of solutions of anisotropic homogeneous cosmological models, the Bianchi-I type being the simplest of them, in modified gravity theories helps to discover new physical properties of these theories not seen in their FLRW solutions. In this talk, it has been investigated in which Horndeski models of gravity, anisotropy grows with the spatial volume contraction similar to GR, and in which it is damped [1] (the effect first found in some specific Horndeski models in [2]). The latter new phenomenon is absent in the K-essence and/or Kinetic Gravity Braiding Horndeski models and appears only in more general Horndeski models whose Lagrangian includes terms quadratic and cubic in second derivatives of the scalar field, so that the velocity of gravitational waves is not constant. Also the early inflationary stage exhibits an instability with respect to inhomogeneous perturbations, suggesting that the initial state of the universe in these specific models should be locally inhomogeneous near singularity contrary to GR.

1. R. Galeev, R. Muharlyamov, A. A. Starobinsky, S. V. Sushkov, M. S. Volkov. Phys. Rev. D 103, 104015 (2021); arXiv:2102.10981.

2. A. A. Starobinsky, S. V. Sushkov, M. S. Volkov. Phys. Rev. D 101, 064039 (2020); arXiv:1912.12320.

3. **Amanda Weltman**

Title: What we can learn from a growing sample of Fast Radio Bursts : a theorist's wishlist.

Abstract: Over the last 5 years, the amount of data we have about Fast Radio Bursts has grown at a rapid, indeed accelerating rate. The next 5 years promises to bring even more data and, with it, the opportunity to really tackle some key questions both in our understanding of FRB physics and of the Universe on large scales. In this talk we will focus on the role FRBs may play as tools of discovery and provide somewhat of a theorists wishlist for the coming decade of discovery.

4. **Andrew Tolley**

Title: Massive gravity, Galileons and Scalar gravitational radiation.

Abstract: I will review theories of massive gravity and how Galileons arise in their decoupling limit, and discuss some of the theoretical and phenomenological implications.

5. **Christian Boehmer**

Title: Modified theories of gravity - foundations and models.

Abstract: In the first part of the talk I am discussing General Relativity, in particular its basic ingredients and its mathematical structure. This will naturally lead the way to consider various modifications or extensions of General Relativity, many of which have been studied recently. Next I will discuss modified gravity models based on generalised geometries and on actions no longer linear in curvature. The main part of the talk will discuss how these many different theories can be studied using a single unified approach which also shows the equivalence of some of these models. Boundary terms in the action will play a crucial role in establishing the equivalence between

different theories. This setup will also allow us to discuss models where local Lorentz invariance can be broken and also models where local diffeomorphisms can be broken. In general this is done by introducing appropriate length scales.

6. **Claudia de Rham**

Title: Cosmology under the Gravitational Rainbow.

Abstract: The direct detection of gravitational waves marks the beginning of a new era for physics and astronomy with an opportunity the probe gravity at its most fundamental level. I will discuss the interplay between the behaviour of gravity as we observe it on cosmological and astrophysical scales and its embedding within a meaningful quantum theory of gravity, emphasizing the role played by the speed of gravitational waves and its subtle relation to causality. These considerations are relevant for putting constraints on cosmological and gravitational effective field theories and I will provide explicit criteria to be satisfied so as to ensure causality and a standard high energy completion in gravitational effective field theories.

7. **Francisco Lobo**

Title: Beyond Einstein's General Relativity: Hybrid metric-Palatini gravity.

Abstract: Einstein's General Relativity (GR) is possibly one of the greatest intellectual achievements ever conceived by the human mind. In fact, over the last century, GR has proven to be an extremely successful theory, with a well established experimental footing. However, the discovery of the late-time cosmic acceleration, which represents a new imbalance in the governing gravitational field equations, has forced theorists and experimentalists to question whether GR is the correct relativistic theory of gravitation, and has spurred much research in modified gravity, where extensions of the Hilbert-Einstein action describe the gravitational field. In this talk, we perform a detailed theoretical and phenomenological analysis of a largely explored extensions of f(R) gravity, namely, the hybrid metric-Palatini theory. Indeed, it has been established that both metric and Palatini versions of f(R) gravity possess interesting features but also manifest severe drawbacks. A hybrid combination, containing elements from

both of these formalisms, turns out to be very successful in accounting for the observed phenomenology and avoids some drawbacks of the original approaches. We extensively explore these theories in a plethora of applications, namely, the weak-field limit, galactic and extragalactic dynamics, cosmology, stellar-type compact objects, amongst others.

8. **George Ellis**

Title: A brief history of the golden age of research on general relativity.

Abstract: When I started work on general relativity in 1961, many physicists thought it was a dead end subject: anything interesting in it had been done. But the subject bloomed! Particular issues that arose were, 1. The use of Lie groups to determine solutions with symmetries, 2. The use of tetrad methods (null and timelike) and spinors to derive solutions and properties such as the peeling off theorems, 3. The maximal extension of the Schwarzschild solution and discovery of its horizon properties, 4. The discovery of solutions with closed timelike curves, and the study of causal domains 5. Penrose' use of topological methods to derive his singularity theorems via closed trapped surfaces, and their extension to cosmology by Hawking 6. Introduction of covariant methods for fluids and gravitational radiation, including the Raychaudhuri equations, Geodesic Deviation Equation, and Maxwell form of the Bianchi identities. 7.Systematic perturbation methods and dealing with the gauge issue. 8. Systematic development of QFT on a curved spacetime. 9. Numerical relativity was developing but in its infancy. This all laid the foundation for Hawking's black hole results, inflationary universe models, and the wonderful developments in gravitational radiation detection.

9. **Hideki Maeda**

Title: Quest for realistic non-singular black-hole geometries.

Abstract: We propose seven criteria to single out physically reasonable non-singular black-hole models and adopt them to four different spherically symmetric models with a regular center and their rotating counterparts. In general relativity, all such non-singular black holes are non-generic with a certain matter field including a class of

nonlinear electromagnetic fields. According to a criterion that the effective energy-momentum tensor should satisfy all the standard energy conditions in asymptotically flat regions, the well-known Bardeen and Hayward black holes are discarded. In contrast, the Dymnikova and Fan-Wang black holes respect the dominant energy condition everywhere. Although the rotating Fan-Wang black hole contains a curvature singularity, the rotating Dymnikova black hole is free from scalar polynomial curvature singularities and closed timelike curves. In addition, the dominant energy condition is respected on and outside the event horizons in the latter case.

10. **José M M Senovilla**

Title: Area deficits and gravitational energy.

Abstract: Gravity manifests itself as curvature of spacetime, and its strength can be measured by considering the deficit of the volume of small geodesic balls with respect to their counterparts in flat spacetime. The volume deficit and the area deficit of the enclosing boundary are directly related, via the Einstein field equations, to the energy density of matter at the ball's centre. In this talk I consider what happens when the matter energy density vanishes. Volumes and areas still feel the effect of pure gravity, and these changes should still be related to the gravitational strength or, in simple words, to the gravitational energy density.

11. **Kavilan Moodley**

Title: Dark energy with HIRAX 21cm intensity mapping.

Abstract: Observations of redshifted 21-cm emission of neutral hydrogen over a wide range of radio frequencies allow us to access redshifts that encompass a vast comoving volume, including the era of dark energy. In this talk, I will present the Hydrogen Intensity Mapping and Real-time Analysis eXperiment (HIRAX) project, which is a proposed 21cm intensity mapping experiment operating at 400-800 MHz that will measure the evolution of dark energy over the redshift range z=0.8-2.5 by using the characteristic baryonic acoustic oscillation scale as a standard ruler. The HIRAX radio telescope array will be sited in the radio-quiet Karoo astronomy reserve in South Africa and will ultimately comprise 1024 dishes, each six metres in diameter,

placed in a compact configuration. I will discuss the design and project status of HIRAX and its scientific prospects for measuring dark energy.

12. **Latham Boyle**

Title: The two-sheeted universe, CPT, analyticity and the arrow of time.

Abstract: Our universe may be radiation dominated at early times and vacuum energy dominated at late times. By thinking about such a universe – paying special attention to the symmetries and analytical structure of its maximal analytic extension – we are led to a picture in which the universe is two-sheeted, with the sheets related by CPT symmetry. This picture provides novel explanations for (i) the dark matter, (ii) several observed properties of the primordial perturbations, and (iii) the fact that the thermodynamic arrow of time points away from the big bang. I will mention some predictions for forthcoming cosmological probes of neutrinos and primordial gravitational waves, as well as some open issues.

13. **Luciano Rezzolla**

Title: The first image of a black hole.

Abstract: I will briefly discuss how the first image of a black hole was obtained by the EHT collaboration. In particular, I will describe the theoretical aspects that have allowed us to model the dynamics of the plasma accreting onto the black hole and how such dynamics was used to generate synthetic black-hole images. I will also illustrate how the comparison between the theoretical images and the observations has allowed us to deduce the presence of a black hole in M87 and to extract information about its properties. Finally, I will describe the lessons we have learned about strong-field gravity and alternatives to black holes.

14. **Luis Herrera**

Title: Hyperbolically symmetric self-gravitating systems.

Abstract: As is well known, any coordinate transformation that eliminates the singularity of the Schwarzschild solution at the horizon necessarily leads to non-static metrics within the horizon. However, from the physical point of view, one would expect the existence of a static metric in all space-time, assuming that a final state of

equilibrium must be static. Motivated by these arguments, we proposed in a recent article (LH, L. Witten, Adv. Ener. Phys. 2018) a Schwarzschild black hole model composed of two manifolds: one external to the horizon described by the Schwarzschild solution, and one internal to the horizon described by a solution that is not spherical, but hyperbolically symmetric. In this seminar we will analyze this idea in detail as well as a study of geodesics in such space-time. Next, in order to be able to describe a material source for the hyperbolically symmetric spacetime, we will describe static fluids and finally we will discuss the dissipative dynamic regime of these fluids.

15. **Martin Bucher**

Title: Bell's Rocket Problem, Dark Energy, and Solids in General Relativity.

Abstract: Quite some time ago, John Bell posed a problem to his colleagues involving two rockets initially at rest connected by a thin taut thread. Bell's colleagues were asked whether the thread would break after the rockets were simultaneously made to accelerate at a constant rate. No consensus was reached, so that matter was referred to the CERN theory group for arbitration, carried out by a democratic ballot. The majority of CERN theorists, however, got it wrong. We carried out a similar poll among our colleagues with the same result. I shall discuss this and similar paradoxes, and more generally issues concerning solids and their dynamics in the framework of general relativity.

16. **Muhammad Sharif**

Title: Decoupled Compact Structures in Self-Interacting Brans-Dicke Theory.

Abstract: This work aims to extend two isotropic solutions to the anisotropic domain by decoupling the field equations in the framework of self-interacting Brans-Dicke theory. The extended solutions are obtained by incorporating an additional source in the isotropic fluid distribution. We deform the radial metric potential to disintegrate the system of field equations into two sets such that each set corresponds to only one source (either isotropic or additional). The system related to the anisotropic source is solved by employing the MIT bag model as an equation of state. Further, we

determine the set incorporating the isotropic source via Tolman V. We also develop an isotropic solution by plugging well-behaved radial metric potential in Karmarkar's embedding condition to specify the isotropic sector. The junction conditions at the surface of the star are imposed to evaluate the unknown constants appearing in the solution. We examine different physical characteristics of the constructed quark star models by using the mass and radii of Her X-1, PSR J1614-2230 and 4U 1608-52. It is concluded that, in the presence of a massive scalar field, both stellar structures are well-behaved, viable and stable for the chosen values of the decoupling parameter.

17. **Narayan Banerjee**

Title: Cosmology with kinematical quantities: the jerk parameter.

Abstract: As the nature of dark energy, the driver of the present accelerated expansion of the universe, still eludes the universal acceptance, a reconstruction of the kinematical parameters from observational datasets is becoming more important. The deceleration parameter q is an observable now, and is found to be evolving, the next higher order derivative of the scale factor a, namely the jerk parameter j, is a natural kinematical parameter of interest. The present talk will discuss about some attempts to reconstruct the jerk parameter both in a parametric and non-parametric way.

18. **Naresh Dadhich**

Title: Buchdahl Compact Sphere: Gravitational Field energy and Escape Velocity.

Abstract: Buchdahl compactness bound for a static object is given by gravitational potential, $\Phi \leq 4/9$ which interestingly translates into (a) gravitational field energy being less than or equal to half of its non-gravitational matter energy and (b) escape velocity as measured by a static observer, $v^2 \leq 8/9$. These are universal prescriptions irrespective of object being charged or not, and mass to radius ratio is given by $M/R \leq \frac{8/9}{1+\sqrt{1-8\alpha^2/9}}$ where $\alpha = Q^2/M^2$. The extremal limit for the Buchdahl charged sphere is $\alpha^2 = 9/8 > 1$ which is greater than that of black hole. By using the Kerr metric we compute compactness ratio for rotating object as well. This alternative prescription has great advantage because it is determined entirely by the exterior solution which

is unique. We shall also generalize all this to higher dimensions as well as to pure Lovelock gravity.

19. **Nick Kaiser**

Title: The History of Gravitational Lensing in Cosmology.

Abstract: In this talk I describe the highlights of the development of gravitational lensing in cosmology. I start with Newton, who understood light deflection but didn't get cosmology right, and the trail, with some false starts, to Einstein's calculation of light bending by the Sun in GR. I describe application to, and puzzling early results from, quasar-galaxy associations and galaxy-galaxy lensing and how Tyson's group's pioneering measurement of distortion of the "cosmic wallpaper" by clusters of galaxies triggered the development of weak lensing. Finally, I recount the puzzling story of whether the emergence of cosmological structure introduces a bias in apparent distances and hence in cosmological parameter estimation.

20. **Rong Gen Cai**

Title: No inner horizon theorem of black holes with charged scalar hairs and the number of black hole horizon with energy conditions.

Abstract: This talk is based on our recent two papers, 2009.05520 and 2104.03012. Considering a general gravitational theory with a charged scalar field, we prove that there exists no inner Cauchy horizon for both spherical and planar black holes with non-trivial scalar hair. The hairy black holes approach to a spacelike singularity at late interior time. For the hyperbolic horizon case, we show that hairy black hole can only has at most one inner horizon, and a concrete example with an inner horizon is presented. We show that the number of horizons of static black holes are constrained a lot by classic matter satisfied some energy conditions. With very general assumptions, we prove that if the interior of a black hole is dominated by classical matter, there is at most one non-degenerated inner horizon behind the event horizon.

21. **Roy Maartens**

Title: Cosmological surveys with SKAO.

Abstract: I will describe the exciting prospects for advances in cosmology with the advent of the SKAO-MID radio telescope, which is being built in South Africa. SKAO will open a new window on the cosmos and cover larger cosmic volumes than ever before. The combination of optical surveys like Euclid and the Rubin Observatory (LSST) with SKAO in the radio promises to provide excellent precision in measuring Dark Energy and Dark Matter. But in addition, SKAO surveys will deliver a new capacity to make tests of the foundations of our model of the Universe. In particular, I will discuss how the combination of surveys can probe the primordial Universe via fossil signals in the galaxy distribution.

22. **Sanjeev Dhurandhar**

Title: The Syszygy between Hilbert and Space-based Detectors of Gravitational Waves.

Abstract: Ground-based detectors have made remarkable progress and have detected several black hole and neutron star merger events. Plans are on the build gravitational wave detectors in space. These detectors will observe at low frequency and will complement the ground-based detectors. The Laser Interferometric Space Antenna (LISA) - a ESA-NASA project is an instrument for observing low frequency GW. LISA and the ground based detectors complement each other in an essential way, just as various astronomies such as the optical, radio, etc. complement each other. The LISA configuration forms an unequal arm interferometer in the shape of a giant triangle which is almost equilateral. A major noise source is the laser frequency noise which arises due to phase fluctuations in the laser. Amongst the important noise sources, laser frequency noise is expected to be several orders of magnitude larger than other noises in the instrument. Thus, cancelling laser frequency noise is vital for LISA to reach the requisite sensitivity. Time-delay interferometry is a technique in which the data streams are combined with appropriate time delays in order to cancel the laser frequency noise. This scheme can be interestingly translated to an algebraic-geometric problem posed by David Hilbert in 1890. The laser noise cancelling data combinations form a module over a polynomial ring, well known in the literature, as the first module of syzygies. Groebner basis methods are used to find the generators of the module. The talk will briefly mention the salient features of this approach and also the recent

approaches involving matrix representation theory.

23. **Salvatore Cappozziello**

Title: Non-local gravity cosmology.

Abstract: Recently the so-called Non-Local Gravity acquired a lot of interest as an effective field theory towards the full Quantum Gravity. In this talk, we sketch its main features, discussing, in particular, possible infrared effects at astrophysical and cosmological scales. In particular, we focus on general non-local actions including curvature invariants like the Ricci scalar and the Gauss-Bonnet topological invariant, in metric formalism, or the torsion scalar, in teleparallel formalism. In both cases, characteristic lengths emerge at cosmological and astrophysical scales. Furthermore, it is possible to fix the form of the Lagrangian and to study the cosmological evolution considering the existence of Noether symmetries.

24. **Sergey Chervon**

Title: Chiral Self-Gravitating Models as Equivalent of $f(R,(R)^2,(R))$ ***Modified Gravity .***

Abstract: Modified gravity theory with the derivatives of the first and the second order in Ricci scalar with the action $S = d^4x(-g)f(R,(R)^2,R)$ can be represented as Chiral Self-Gravitating Models (CSGM) of special type, where the potential and the target space metric appropriately defined by the choice of the action for $f(R)$ gravity model with higher derivatives. We consider such models in the spherically symmetric space-time and we present the method of exact solutions construction. We give geometrical analysis of obtained solutions of black holes and wormholes types as well.

25. **Sushant Ghosh**

Title: Testing modified theories of gravity using black holes shadow.

Abstract: The recently got hairy Kerr black holes, because of additional sources or surrounding fluid, like dark matter, with conserved energy-momentum tensor, have a deviation α and primary hair l_0, apart from rotation parameter a and mass M. In the

wake of the EHT observations of the supermassive black hole M87*, a recent surge in interest in black hole shadows suggests comparing the black holes in general relativity (GR) and modified theories of gravity to assess these models' differences. Motivated by this, we take on an extensive study of the rotating hairy Kerr black holes, which encompasses, in particular cases, the Kerr black hole ($\alpha = 0$). In particular, the hairy Kerr black holes possess smaller sizes but more distorted shadows when compared with Kerr black holes. We also estimate the parameters l_0 and a associated with hairy Kerr black holes using the shadow observables. The inferred circularity deviation $\Delta C \leq 0.1$ for the M87* black hole is satisfied, whereas shadow angular diameter $\theta_d = 42 \pm 3\mu\ as$, within 1σ region, for a given choice of α, places bounds on the parameters a and l_0. Interestingly, the shadow axial ratio obeying $1 < D_x \leq 4/3$ is in agreement with the EHT results.

26. **Tjonnie Li**

Title: Status and Prospects for Gravitational-Wave Astrophysics.

Abstract: The detection of gravitational waves from pairs of compact objects has opened up the possibility to observe the Universe not possible before. I will review some of the existing results and discuss several exciting opportunities for gravitational-wave astrophysics.

Contributed Full Length Talks

1. **Adrian Chung**

Title: Searching for ultralight bosons with supermassive black hole ringdown.

Abstract: Ultralight bosons are an encouraging class of dark matter candidate particles, which may form long-lived bosonic clouds surrounding rotating black holes via superradiance. We compute the shifts in the gravitational quasinormal-mode frequencies of supermassive black holes due to the presence of such a bosonic cloud. We then use the modified ringdown waveform of a supermassive black hole from a surrounding bosonic cloud as a novel probe of the existence of a potential ultralight boson of mass

$in[10^{-16}, 10^{-18}]rmeV$. Because the ringdown signal of a binary merger is significantly shorter than the inspiral, our ringdown test of the ultralight boson can probe masses on timescales relatively shorter than inspiral-based, stochastic, or population-based search methods.

2. **Ahmad Borzou**

Title: A Non-Geometrodynamic Quantum Yang-Mills Theory of Gravity Based on the Homogeneous Lorentz Group.

Abstract: In this paper, we present a non-geometrodynamic quantum Yang-Mills theory of gravity based on the homogeneous Lorentz group within the general framework of the Poincare gauge theories. The obstacles of this treatment are that first, on the one hand, the gauge group that is available for this purpose is non-compact. On the other hand, Yang–Mills theories with non-compact groups are rarely healthy, and only a few instances exist in the literature. Second, it is not clear how the direct observations of spacetime waves can be explained when space-time has no dynamics. We show that the theory is unitary and is renormalizable to the one-loop perturbation. Although in our proposal, gravity is not associated with any elementary particle analogous to the graviton, classical helicity-two spacetime waves are explained. Five essential exact solutions to the field equations of our proposal are presented as well. We also discuss a few experimental tests that can falsify the presented Yang–Mills theory.

3. **Ayan Banerjee**

Title: Quark stars in Einstein-Gauss-Bonnet Theory.

Abstract: Recent progress in the determination of both masses and radii of neutron stars have put strong constraints on the equation of state (EoS) above the nuclear saturation density. Within a confining quark matter model, we propose an isotropic star consisting of a homogeneous and unpaired charge-neutral 3-flavor interacting quark matter with $\mathcal{O}(m_s^4)$ corrections in the context of Einstein-Gauss-Bonnet gravity theory. This generalized model depends only on three free parameters: the bag constant B, the interaction parameter a and the Gauss-Bonnet coupling constant α. Given the underlying EoS, we show the possibility of obtaining the maximal neutron star

mass which satisfies the recent observational data for PSR J0751+1807. The numerical analysis of mass-radius relations supports the existence of other massive pulsars with a maximum mass consistent and common radii in the range of $R \lesssim (11 \sim 14)$ Km [*A. W. Steiner, J. M. Lattimer, E. F. Brown, Asstrophys. J. 722, 33 (2010)*]. Furthermore, we discuss the mass vs central mass density ($M - \rho_c$) relation for stability, compactness and binding energy in this gravity theory. Our results thus provide circumstantial evidence in favor of super-massive pulsars in EGB gravity.

4. **Bertha Cuadros-Melgar**

Title: Black hole quasinormal frequencies and shadow radius correspondence.

Abstract: We study the relation between quasinormal modes and geodesic quantities recently brought back due to the black hole shadow observation by Event Horizon Telescope. With the help of WKB method we found an analytical relation between the real part of quasinormal frequencies at the eikonal limit and shadow radius of the same black hole. Some examples fulfilling the correspondence are provided.

5. **Bikash Chandra Paul**:

Title: Emergent Universe with Non-linear Equation in $D \geq 4$.

Abstract: We consider a higher dimensional Einstein gravity with a non-linear equation of state (EoS) to obtain cosmological models that permits a universe which is singularity free. We consider the EoS $p = f(\rho)$ which is equivalent to three different types of barotropic fluids. The emergent universe (EU) model is obtained here in $D \geq 4$ initially non-interacting. However, an observed universe emerged from this phase once the fluids are interacting at $t = t_i$. The assumption of the EU is that the universe began from a static Einstein universe phase. In the paper we show that the throat of a dynamical wormhole permits such phase in the infinitely past which encompass the present observed universe satisfactorily.

6. **Bivudutta Mishra**

Title: Stability analysis of two-fluid dark energy models.

Abstract: In this paper, we have studied the stability of the cosmological models with dark energy and combination of matter fields and dark energy in an anisotropic space time. The pressure anisotropy along the spatial directions are derived and its stability in each direction has been examined. The four models presented here, show its stability on certain spatial direction. The role of matter field on the stability analysis has been obtained. The positive and negative value of cosmic string completely changed the stability behavior of the model. The presence of a magnetic field disturbs the stability aspects of the models at least in an early epoch.

7. **Byron Brassel**

Title: Radiating stars with composite matter distributions.

Abstract: We discuss the junction conditions for a generalised matter distribution in a radiating star. The internal matter distribution is a composite consisting of barotropic matter, null dust and a null string fluid in a shear-free spherical spacetime. The external matter distribution is a combination of a radiation field and a null string fluid. We find the boundary condition for the composite matter distribution at the stellar surface which reduces to the familiar Santos result with barotropic matter. We also find the boundary condition for the general spherically symmetric geometry in the presence of shear and anisotropy for a generalised matter distribution, and extend these notions to higher dimensions.

8. **Cecilia Nagy**

Title: Spherically symmetric, static black holes in nonminimally coupled k-essence theory.

Abstract: We investigate spherically symmetric, static spacetimes in an effective field theory action of scalar-tensor theory. For the description we apply a 2+1+1 spacetime decomposition. Detailed analysis is carried out in the k-essence subclass of Horndeski theories where $G_2 = G_2(\phi; X)$, $G_4 = G_4(\phi)$ (while $G_3 = 0$, $G_5 = 0$) and when the metric is characterized by one independent function depending on the radial coordinate. Specializing $G_4(\phi)$ and the radial dependence of the scalar field we have obtained new spacetime solutions characterized by a parameter, which in the simplest case has the interpretation of mass or tidal charge, the cosmological constant and a

third parameter. These solutions represent naked singularities, black holes with scalar hair or have the double horizon structure of Schwarzschild-de Sitter spacetime. One of the solutions obtained for the function G4 linear in the curvature coordinate, in certain parameter range exhibits an intriguing logarithmic singularity lying outside the horizon. The hairy black hole solutions evade the unicity theorems by being asymptotically nonflat even in the absence of the cosmological constant.

9. **Dmitry Bushuev**

Title: Womholes in Palatini kinetic theory.

Abstract: We discuss wormhole solutions in the Palatini two-parameter kinetically coupled scalar-tensor theory. This theory contains the Einstein frame, in which the basic theory is solvable. This allows to construct exact solutions analytically and investigate their property. Due to violation of NEC, typical solutions are wormholes, in which singularities of the solutions of Einstein frame are transformed into the wormhole throats. This opens the way, in particular, to clarify nature of the boundary condition in singularities of General Relativity.

10. **Durmus Demir**

Title: Gravitational Naturalization of Effective Field Theories.

Abstract: Effective field theories, introduced to probe the UV physics on the basis of scale separation, get moved towards the UV by their quadratic and quartic UV sensitivities. They have also their gauge symmetries explicitly broken by the UV scale. In this talk, we show that the UV scale in flat spacetime and curvature in curved spacetime enjoy a Poincare resemblance, and the requirement of gauge symmetry restoration turns this resemblance to an equivalence relation. This equivalence relation naturalizes effective field theories by inducing general relativity through their quartic and quadratic UV terms. The resulting setup has field theories and gravity at the same loop level, and puts them in a concord. This concord has various implications, like necessity of new particles beyond the known ones. Reference: Durmus Demir, Gen. Rel. Grav. 53 (2021) 2, 22 [arXiv: 2101.12391 [gr-qc]].

11. **Elham Ghorani**

Title: On the initial singularity in Kantowski-Sachs spacetime.

Abstract: The emergent universe scenario is a proposal for resolving the Big Bang singularity problem in the standard Friedmann-Lemaitre-Robertson-Walker cosmology. In the context of this scenario, the Universe originates from a nonsingular static state. In the present work, considering the realization of the emergent universe scenario, we address the possibility of having a nonsingular Kantowski-Sachs type static state. Considering four and five-dimensional models (with and without brane), it is shown that both the existence and stability of a nonsingular state depend on the dimensions of the spacetime and the nature of the fluid supporting the geometry.

12. **Gabriel W. Joseph**

Title: Cosmology with variable G and nonlinear electrodynamics.

Abstract: In a bid to resolve lingering problems in cosmology, more focus is being tilted towards cosmological models in which physical constants of nature are not necessarily real constants but vary with cosmic time. In this paper, we study a cosmological model in nonlinear electrodynamics with Newtonian gravitational constant G, which is not a constant but varies in terms of a power law of the scale factor of the universe. Hence, the evolution of the scale factor $a(t)$ is studied in this model, which depends on a fine-tuning term of nonlinear electrodynamics, (α). Finally, we verify the stability of the model using the speed of sound.

13. **Gareth Amery**

Title: Some applications of local isometric embeddings.

Abstract: Local isometric embeddings of spacetimes have a long history in gravity theories, from the earliest attempts to understand Riemannian geometry, through to higher dimensional cosmologies. They also have been successfully used to generate new exact solutions. We provide two novel applications of this theory, the one technical and the other conceptual. Following the work of Stephani who generated new exact solutions via embeddings into Euclidean spaces, we apply the theorems of Dahia and Romero in the particular case of a constant curvature 5-dimensional bulk and

generate new exact solutions to the 4-dimensional Einstein field equations, with potential application to gravastar models. We then demonstrate that one may use the embedding theorem of Dahia and Romero for a 4-dimensional spacetime embedded into a vacuum 5-dimensional bulk, to show that this allows one to "re- geometrize" the otherwise ad hoc imposition of energy-momentum conservation in trace free gravity. In this scenario, not only the 4-dimensional geometry, but also the energy-momentum content and conservation law are an artefact of the geometry of the embedding.

14. **Gopikant Goswami**

Title: FLRW Accelerating cosmological models.

Abstract: In this research work, we present a review of FLRW accelerating models with constant and varying dark energy equation of state parameter ω_{de} for spatially flat universe. The models fit well with Λ CDM model at present. We discuss a range of both quintessence and phantom models. In a particular, we discuss a Phantom models with hyperbolic expansion law. In this model, the universe interred into accelerating phase with a big rip in ω_{de} at transition red shift $z_t = 0.81$. Before this, it was decelerating. The Hubble parameters and distance modulus of distant SNIa supernova's, obtained on the basic of the models , correspond to observational data sets up to the high degree of closeness from the point of view of Chi squire results.

15. **Hemza Azri**

Title: Nonadiabatic perturbations during affine inflation.

Abstract: The talk aims to address the possible generation of nonadiabatic (entropy) perturbations during inflation. These modes (called isocurvature) are known to be, generically, sourced by multiple fields' effects. In the framework of affine gravity, we distinguish two sources of entropy perturbations that may not be suppressed in the long-wavelength limit. The first is merely induced by the presence of more than one scalar and arises even in the minimal coupling limit. The second source, however, is restricted to nonminimal interaction. Unlike the case of metric gravity, and due to the absence of anisotropic stresses, the second source disappears for a single scalar, showing that nonminimal couplings become relevant to nonadiabatic perturbations only when more than one scalar field is considered. Hence, the notion of adiabaticity

is not affected by the transition to minimal coupling, contrary to the metric gravity case where it is confused by changing the frames. In general, the presence of isocurvature modes may enhance the fit at low-multipoles in the cosmic microwave background anisotropies.

16. **Louis Perenon**

Title: Multitasking the growth of structures.

Abstract: The study of cosmic acceleration and understanding its nature is nowadays one of the important branches in the field of cosmology. Searches to perfect our knowledge of gravity has triggered a vast amount of research material as much on the theoretical side than the observational one. Now more than even with upcoming large scale galaxy surveys such as SKA or EUCLID. In this context, I would like to present a model independent approach trace departures from the predictions of the standard model of cosmology using the growth of structures. We use Gaussian process reconstruction of forecasts data in particular highlighting the benefits of the multitasking approach.

17. **Mikhail Khlopunov**

Title: Five-dimensional gravitational waves from the binary system on a three-brane.

Abstract: In odd-dimensional spacetimes, extraction of the emitted part of gravitational field of a localized source is obscured by violation of the Huygens principle. Indeed, the odd-dimensional retarded Green's functions are localized not only on the light cone but also inside it. Therefore, while the gravitational radiation of a source must propagate with the speed of light, its total retarded gravitational field propagates with all velocities up to that of light, making the calculation of gravitational radiation in odd dimensions a non-trivial task. Here we consider a simplified model consisting of two point masses moving on a three-brane embedded in five-dimensional spacetime and moving under the interaction only through a massless scalar field living on the same brane, while gravitational radiation is emitted into the full five-dimensional bulk. Such a system admits stable elliptical orbits and the interaction field is free from the problems mentioned above. We use the Rohrlich-Teitelboim approach to radiation,

based on the splitting of the on-shell energy-momentum tensor to extract the radiative component of the retarded gravitational field. The source term consists of the local contribution from the point particles and the non-local one from the energy-momentum of the scalar field. The contribution from the latter is computed using the DIRE approach in the post-Newtonian expansions. In the non-relativistic limit, we find an analog of the quadrupole formula containing the integral over the entire history of the particles' motion, preceding the retarded moment of time. We analyze the gravitational radiation of the circular binary and the corresponding orbital evolution.

18. **Misba Afrin**

Title: Shadow cast by rotating black holes with a cosmological constant.

Abstract: By interpreting the cosmological constant (*Lambda*) as the vacuum energy, and under a minimum amount of assumptions, leads to a deformation in the vicinity of a black hole and a new Kerr–de Sitter solution [B. Carter, 1973, Les Houches Summer School of TheoreticalPhysics: Black Holes pp. 57–214]. The new Kerr–de Sitter solution is a more straightforward and has richer geometric structure than the original one [J. Ovalle, E. Contreras, and Z. Stuchlik, 2021, Phys. Rev. D 103, 084016]. Interestingly, there exist minimum (M_{min}) and maximum (M_{min}) mass such that M_{min}&lt;M&lt;M_{min}, we have the event horizon, two cosmological horizons and as well as the Cauchy horizon. For $M = M_{min}$, we have a extremal case where the event and cosmological horizons degenerate. Further, we investigate the black hole shadow and associated observables viz. the shadow radius R_s, area A, deformation δ_s and oblateness D. We also estimate the parameters Λ and a of the new Kerr de-Sitter black hole from its shadow observables. The shadow observables of the new Kerr de-Sitter black hole are found to significantly deviate from the corresponding observables of the Kerr de-Sitter black hole over an appreciable range of the parameter space $(a/M - \Lambda/M^{-2})$. Also, the circularity deviation ΔC of the new Kerr de-Sitter black hole is studied in the $(a/M - \Lambda/M^{-2})$ parameter space and is found to be influenced by the distance of observer from the black hole.

19. **Nikodem Poplawski**

Title: Universe in a black hole with spin and torsion.

Abstract: We consider gravitational collapse of a spherically symmetric sphere of a fluid with spin and torsion into 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 and replaces it with a nonsingular bounce. Quantum particle production during contraction strengthens torsion in opposing shear. Particle production during expansion can produce enormous amounts of matter and generate a finite period of inflation. 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 in size then the previous cycle, until it reaches the cosmological size and expands indefinitely. Our universe might have therefore originated from a black hole existing in another universe.

20. **Pankaj Kumar**

Title: Inflation with logarithmic scalar field in Brans-Dicke theory.

Abstract: We study Brans-Dicke theory with a logarithmic form of Brans-Dicke scalar field within the framework of the flat Friedmann-Robertson-Walker metric. We obtain the expression for the deceleration parameter and plot its graphs against the cosmic scale factor. We observe that the universe starts with decelerated expansion and experiences an early time phase transition from decelerated phase to accelerated phase. After a very short period, the accelerated expansion ends in a decelerated expansion showing the inflationary era of the cosmic evolution. Further, we study the stability of the model using the squared sound speed method, plot the squared sound speed against cosmic time t for radiation and matter dominated eras for various values of the model parameters, and discuss the effects of the parameters on the stability of the model. We observe that for suitable values of the parameters, our model is stable separately in radiation and matter dominated eras.

21. **Paolo Cremonese**

Title: Breaking the mass-sheet degeneracy with gravitational wave interference in lensed events.

Abstract: The mass-sheet degeneracy is a well-known problem in gravitational lensing which limits our capability to infer astrophysical lens properties or cosmological

parameters from observations. In my talk, I will show how the lensed wave forms are affected by the mass-sheet degeneracy, differentiating between the geometrical optics, wave optics and interference regimes, focusing on ground-based gravitational waves detectors. I will show that, in the interference regime, and in part in the wave-optics regime, the mass-sheet degeneracy can be broken with only one lensed waveform thanks to the characteristic interference patterns of the signal. Then, through template matching, I will illustrate how well the mass-sheet degeneracy can be broken. The results prove that, within present GW detector sensitivities and considering signals as strong as those which have been detected so far, the mass-sheet degeneracy can lead to a 1σ uncertainty on the lens mass of $\sim 12\%$. With these values the MSD might still be a problematic issue. But in case of signals with higher signal-to-noise ratio, the uncertainty can drop to $\sim 2\%$, which is less than the current indeterminacy achieved by dynamical mass measurements.

22. **Parbati Sahoo**

Title: Traversable wormholes in the traceless $f(R;T)$ gravity.

Abstract: Wormholes are tunnels connecting different regions in space-time. They were obtained originally as a solution for Einstein's General Theory of Relativity and according to this theory, they need to be led by an exotic kind of anisotropic matter. In the present sense, by exotic matter we mean matter that does not satisfy the energy conditions. In this article, we propose the modeling of traversable wormholes (i.e., wormholes that can be safely crossed) within an alternative gravity theory that proposes an extra material (rather than geometrical) term in its gravitational action, namely the traceless $f(R;T)$ theory of gravitation, with R and T being respectively the Ricci scalar and trace of the energy-momentum tensor. Our solutions are obtained from well-known particular cases of the wormhole metric potentials, namely redshift and shape functions. In possession of the solutions for the wormhole material content, we also apply the energy conditions to them. The features of those are carefully discussed.

23. **Pradyumn Kumar Sahoo**

Title: Energy conditions in modified f(Q) gravity.

Abstract: A complete theory of gravity impels us to go beyond Einstein's General Relativity. One promising approach lies in a new class of teleparallel theory of gravity named $f(Q)$, where the nonmetricity Q is responsible for the gravitational interaction. The important roles any of these alternative theories should obey are the energy condition constraints. Such constraints establish the compatibility of a given theory with the causal and geodesic structure of space-time. In this work, we present a complete test of energy conditions for $f(Q)$ gravity models. The energy conditions allowed us to fix our free parameters, restricting the families of $f(Q)$ models compatible with the accelerated expansion our Universe passes through. Our results straight the viability of $f(Q)$ theory, leading us close to the dawn of a complete theory for gravitation.

24. **Praveen Kumar Dhankar**

Title: Entropy corrected interacting holographic dark energy model with extended Chaplygin gas in higher dimension.

Abstract: In this work, we discuss the progression of logarithmic corrected interacting holographic dark energy in higher dimensions. We calculate the equation of state parameter with scale factor defined by a power law and found that it transits universe from a quintessence ($\omega_\Lambda > -1$) to phantom ($\omega_\Lambda < -1$) era. Further we define correspondence between entropy corrected holographic dark energy(ECHDE)and extended Chaplygin gas to reconstruct the potential and dynamics of the scalar field in the presence of the ECHDE.

25. **Rajesh Kumar Dubey**

Title: Hubble's Constant and Hubble Tension with Signals from GW170817 Standard Siren and GW190814 Dark Siren.

Abstract: The local universe expansion rate is one of the most fundamental and essential cosmological parameters. This value which is known by the name of Hubble's Constant is scientifically measured by electromagnetic sources called distance ladder. Surprisingly, using Gravitational Wave (GW) analysis this value can be measured making GW sources another significant method to act as standard sirens with their electromagnetic counterparts from their host galaxy. The gravitational wave event

GW 170817 was the outcome of the merger of two different neutron stars. The electromagnetic event was recorded from the host galaxy NGC4993. The GW170817 has been a considerable success in this direction measuring the value of universe acceleration H0 = 70.0+12.0 8.0 kms1 Mpc1 The results obtained from this GW event is analysed and compared with the other observations done with traditional methods of CMB and Cosmic Distance Ladder. Another event in this series GW190817 is Compact Binary Coalescence involving a 22.2 - 24.3 Solar Masses Blackhole and a compact object with a mass of 2.50 - 2.67 Solar Masses. The EM counterpart of this event is unknown so far and hence the event is named Dark Siren. The detection of gravitational waves from merger event GW190814 reveals a different picture. The Hubble's value observed with this even is close to H0 = 75+59 13 km s1 Mpc1 .The source GW190814 which involves a massive black hole and the other compact object as the lightest black hole or the heaviest neutron star was localized to 18.5 deg2 at a distance of Mpc. The diversity of the two events can be used to measure the expansion rate of the universe. This can also be used to verify this rate in different directions of the universe. The results obtained from the two different types of Gravitational waves, originating from two different types of mergers gives two different results for a single cosmological parameter. This in addition to giving answer to the value of Hubble's constant, also gives rise to Hubble's tension.

26. **Ranjan Sharma**

Title: Electromagnetic and anisotropic extension of Buchdahl bound.

Abstract: A model for a charged star as a generalization of the uniform density Schwarzschild interior solution is constructed. The unique feature of the model is that the geometry of associated t =constant hypersurface, when embedded into four-dimensional Euclidean space, turns out to be spheroidal rather than spherical. The new solution is utilized to obtain an analogue of the Buchdahl compactness bound. When the charge is set to zero, the solution goes over to the Schwarzschild uniform density fluid sphere and the bound $2M/R \leq 8/9$ is regained. A maximum bound on compactness is also proposed for a selected class of exact solutions describing anisotropic fluid spheres. [Journal references: 1. An electromagnetic extension of the Schwarzschild interior solution and the corresponding Buchdahl limit, Ranjan Sharma, Naresh Dad-

hich, Shyam Das and Sunil D. Maharaj, Eur. Phys. J C (2021) 81, 79. 2. Anisotropic generalization of Buchdahl bound for specific stellar models, R. Sharma, A. Ghosh, S. Bhattacharya and S. Das, Eur. Phys. J C (2021)].

27. **Sagar Dey**

Title: Gravastars model under the framework of Rastall gravity.

Abstract: Gravastars have been considered as a serious alternative to black holes in the past couple of decades. Stable models of gravastar have been constructed in many of the alternate gravity models besides standard General Relativity (GR). The Rastall theory has been a popular alternative to GR, specially in the cosmological and astrophysical context. Here we consider a gravastar model in Rastall gravity. The mathematical solutions in different regions have been obtained along with calculation of matching conditions. Various important physical parameters namely, the energy density, proper length, total energy and entropy for the shell have been calculated and plotted to see their variation with radial distance. The pressure within the interior core region is assumed with a constant negative matter-energy density which provides a repulsive force over the entire thin shell region. The shell is assumed to be made up of fluid of ultrarelativistic plasma which follows the Zeldovich's conjecture of stiff fluid. It is also assumed that the pressure is proportional to the matter-energy density according to Zeldovich's conjecture, which cancels the repulsive force exerted by the interior region. The exterior region is completely vacuum which is described by the Schwarzschild-de Sitter solution. The stability of the gravastar model is investigated using the surface redshift against the shell thickness and maximizing the entropy of the shell within the framework of Rastall gravity.

28. **Sanjay Mandal**

Title: Stability analysis of viscous fluid models in $f(Q)$ gravity.

Abstract: The standard formulation of general relativity fails to describe some recent interests in the universe. It impels us to go beyond the standard formulation of gravity. The $f(Q)$ gravity theory is an interesting modified theory of gravity, where the gravitational interaction is driven by the nonmetricity Q. This study aims to examine the self-stability of the cosmological models with the presence of bulk viscosity effect

in the cosmological fluid within the framework of $f(Q)$ gravity. We construct three bulk viscous fluid models, i.e. (i) for the first model, we assuming the Lagrangian $f(Q)$ as linear dependence on Q, (ii) for the second model the Lagrangian $f(Q)$ as a polynomial functional form, and (iii) the Lagrangian $f(Q)$ as a logarithmic dependence on Q. We discuss all the energy conditions for each model, which helps us to test the self-consistency of our models. Finally, we present the profiles of the equation of state parameters to test the models' present status.

29. **Sebastiájera Valencia**

Title: Pancakes as opposed to Swiss Cheese.

Abstract: We examine a novel class of toy models of cosmological inhomogeneities by smoothly matching along a suitable hypersurface an arbitrary number of sections of "quasi flat" inhomogeous and anisotropic Szekeres-II models to sections of any spatially flat cosmology that can be described by the Robertson-Walker metric (including de Sitter, anti de Sitter and Minkowski spacetimes). The resulting "pancake" models are quasi-flat analogues to the well known spherical "Swiss-cheese" models found in the literature. Since Szekeres-II models can be, in general, compatible with a wide range of sources (dissipative fluids, mixtures of non-comoving fluids, mixtures of fluids with scalar or magnetic fields or gravitational waves), the pancake configurations we present allow for a description of a wide collection of localized sources embedded in a Robertson-Waker geometry.

30. **Siddheshwar Kadam**

Title: Late time cosmic acceleration in $f(T, B)$ gravity.

Abstract: In this paper, we have derived the field equations of $f(T, B)$ gravity, an extension of teleparallel gravity, in an isotropic and homogeneous space-time. In the basic formalism developed, the dynamical parameters are derived by incorporating the hybrid scale factor. The scale factor chosen behaves as an early deceleration and late time acceleration. The model behaves as an accelerating model at least at the late time of cosmic evolution. The geometrical parameters and the scalar field reconstruction are performed to further validate the model. Further, the stability of the model is also presented.

31. **Simran Arora**

Title: Constraining $f(Q,T)$ gravity from energy conditions.

Abstract: We are living a golden age for experimental cosmology. New experiments with high accuracy precision are been used to constrain proposals of several theories of gravity, as it has been never done before. However, important roles to constrain new theories of gravity in a theoretical perspective are the energy conditions. Throughout this work, we carefully constrained some free parameters of two different families of $f(Q,T)$ gravity using different energy conditions. This theory of gravity combines the gravitation effects due to the torsion through the nonmetricity function Q, and manifestations from the quantum era of the Universe in the classical theory (due to the presence of the trace of the energy-momentum tensor T). Our investigation unveils the viability of $f(Q,T)$ gravity to describe the accelerated expansion our Universe passes through. Besides, one of our models naturally provides a phantom regime for dark energy and satisfies the dominant energy condition. The results here derived strength the viability of $f(Q,T)$ as a promising complete theory of gravity, lighting a new path towards the description of the dark sector of the Universe.

32. **Srija Chakraborty**

Title: Exploring supermassive blackholes with LISA.

Abstract: We study hydrodynamical simulations of galaxy formation, based on the GADGET-3 code, and investigate supermassive black hole binaries coalescence at 5.5&*amp* and for the thermal feedback model to be between 100 to 500 in the same chirp mass range. We stress the comparisons to be made between simulations of same resolution: kinetic with R_{smooth}= 1ckpc/h and thermal with R_{smooth}=0.5 ckpc/h. For each model, we estimate the expected characteristic strain of gravitational waves emitted by supermassive black hole binary mergers, the time to coalesce, and the expected number of resolved events and compare our predictions with the LISA sensitivity and resolution. We further investigate the host galaxy properties for the events detectable by LISA and make predictions of the electromagnetic counterparts expected events to be detected by other electromagnetic instruments operating along the proposed operational time of LISA and present a panoramic view of merger events through different

detectors.

33. **Susmita Jana**

Title: Constraints on the non-minimal coupling of Electromagnetic fields from astrophysical observations.

Abstract: Strong gravity regions, like the neighborhood of black holes or neutron stars, can induce non-minimal couplings between electromagnetic fields and gravity. In these regions, gravitational fields behave as a non-linear medium in which the electromagnetic fields propagate. For a system of mass M, and size R, the surface potential scales as M/R. Pulsar timing array, Double pulsar Shapiro delay, and Event horizon telescope probe that largest surface potentials [10 -4 - 10 -2]. With many future experiments, it is possible to constrain the non-minimal coupling between electromagnetic fields and gravity. As a step in this direction, we consider the non-minimal coupling of EM field tensor through Riemann tensor for a dynamical black-hole, described by the Sultana-Dyer metric. The non-minimal coupling leads to modified dispersion relations of photons, which get simplified at E/L >> 1 regime, where E and L are two conserved quantities obtained by taking into account the symmetries of the metric. We calculate polarization-dependent photon deflection angle and arrival time from these dispersion relations, which we evaluate considering different astrophysical sources of photons. We compare the analytical results with the current astrophysical observations to constraint the non-minimal coupling parameters to Riemann tensor more stringently.

34. **Warren Naidoo**

Title: Constraining dark energy and modified gravity models with HIRAX and combined large-scale structure surveys.

Abstract: Current observations of the universe suggest that the cosmic energy budget is dominated by dark energy (DE) which accounts for approximately 70% of the energy budget and a further 25% of this energy distribution is from the dark matter (DM) distribution. Cosmic microwave background (CMB) radiation experiments have already provided a wealth of information constraining the current cosmological model.

Galaxy surveys have also provided valuable information on the evolution of the universe at later times. Next generation experiments will probe these tracers to much higher precision providing unprecedented constraints on the various cosmological parameters of the Λ-CDM model as well as test various exotic models. We investigate the ability of the HIRAX experiment to constrain cosmological model parameters, dark energy equation of state parameters and modified gravity models. In particular, we study how the HIRAX 21cm survey can be combined with other large scale structure probes such as CMB lensing and galaxy surveys to place even tighter constraints on these models.

35. **Wei-Ming Dai**

Title: Reconciling Hubble Constant Discrepancy from Holographic Dark Energy.

Abstract: With the increased accuracy of Hubble constant predicted by LCDM Cosmological model and the model-independent determinations from late-time local measurements, a significant tension of more than 4 sigma has led to various models in the theoretical solutions. We propose holographic dark energy (HDE) as a physical resolution.

36. **Yin-Zhe Ma**

Title: How much primordial tensor perturbation is allowed?

Abstract: The presence of a significant amount of gravitational radiation in the early Universe affects the total energy density and hence the expansion rate in the early epoch. A red-tilted power spectrum of primordial gravitational waves would result in more modes of small-scale relativistic degree of freedom which acts like relativistic species. In this talk, I will present a physical model to connect the number of relativistic degrees of freedom Neff with the amplitude and shape of the primordial tensor power spectrum, and use the cosmic microwave background temperature and polarization data from Planck and the BICEP2/KECK Array and the primordial deuterium measurements from damped Lyman- systems to constrain this model. I will show that with this relation imposed, the tensor power spectrum is highly constrained.

The current constraint excludes the possibility of a fourth neutrino species at more than 5-sigma C.L.

Flash Talks

1. **Aleksei Nikolaev**

Title: Universal cosmological solutions in Lovelock gravity.

Abstract: Using geometrical approach we obtain Friedmann equations for Lovelock gravity in terms of independent Riemann tensor components. By analysis of these equations we show: a) general solution - the solutions which depended from Lovelock polynomial order, dimensions and coupling constants b) Universal solutions - the solutions which not depended from Lovelock polynomial order, dimensions and coupling constants.

2. **Amarkumar Agrawal**

Title: Bouncing cosmology in extended gravity and its reconstruction as dark energy model.

Abstract: In this paper we have presented a bouncing cosmological model of the universe in an extended theory of gravity. The dynamical behavior of the model obtained from the flat FLRW space-time and the violation of null energy condition have been shown. The geometrical parameters show singularity behavior at the bouncing epoch. The parameters involved in the scale factor play a major role in the bouncing behavior. In addition the coupling parameter that resulted in the minimal matter-geometry coupling in the extended gravity has a significant role in avoiding the singularity of the equation of state parameter at the bouncing epoch. The model remains stable throughout including the bouncing epoch.

3. **Anirban Chanda**

Title: Wormholes satisfying NEC in $f(R,T)$ Modified Gravity.

Abstract: Wormhole solutions obtained by Morris and Thorne in general relativity (GR) is investigated in a modified theory of gravity. In the gravitational action, we

consider $f(R,T)$ which is a function of the Ricci scalar (R) and the trace of the energy-momentum tensor (T). In the framework of a modified gravity described by $f(R,T) = R + \alpha R^2 + \lambda T\beta$, where α, β, and λ are coupling constants, MT wormhole (WH) solutions with normal matter are obtained for a relevant shape function. We have considered two different values of β leading to two forms of $f(R,T)$-gravity. The energy conditions are probed at the throat and away from the throat of the WH. It is found that the coupling parameters, α and λ in the gravitational action play an important role in deciding the matter composition in the wormholes. It is found that for a given λ, WH exists in the presence of exotic matter at the throat when $\alpha = 0$ in the modified gravity. Two different shape functions are considered to obtain WH solutions that are permitted with or without exotic matter. It is noted that in a modified $f(R,T)$ gravity MT WH is permitted with normal matter which is not possible in GR. It is demonstrated that a class of WH solutions exist with anisotropic fluid for $\lambda = -8\pi$. However, for flat asymptotic regions with anisotropic fluids WH solutions cannot be realized when $\lambda = -8\pi$. All the energy conditions are found consistent with the hybrid shape function indicating existence of WH even with normal matter for $\lambda \to 0$.

4. **Busra Cicek**

Title: The Relationship of Virial Theorem with Physics Problems: A Literature Review.

Abstract: Virial theorem is the theorem that examines the kinetic and potential energies of a fixed system and the distribution of mass, dimensions and velocities of dark systems, which are widely used in non-reactive mechanics and astrophysics [10]. In addition to the gravitational field, this theorem includes other fields such as the electromagnetic field and the pressure field [11]. The classical mechanical derivation of the Virial Theorem has been successfully applied to related physics problems over the past centuries. It is especially used in astrophysics, cosmology, molecular physics, quantum mechanics and statistical mechanics [12]. Considering the limitations, the virial theorem appears to be a viable theorem used to study bound states and quantum mechanical systems in general. When the virial theorem is compared with the quantum and classical mechanics theorems accepted in history, it is seen that this

theorem is derived from them. The quantum mechanical virial theorem in nonreactive form is related to the values of kinetic energy and the directional derivative of potential energy. The relationship between the quantum mechanical virial theorem defined by the Relativistic Hamiltonian for a system is computed the expected values of directional derivatives of kinetic and potential energy. Computation is also found in virial theorems and wave equations (Schrödinger, Salpeter, Dirac, Klein-Gordon) in quantum mechanics, including relative and unrelated Hamiltonians [13]. The relative modification of the theorem, the Lorentz transform corresponding to the momentum and kinetic energy of the particle, is also related to the kinetic energy in the form of a tensor (Eshelby stress) at the microscopic level through the Virial theorem. Pressure effects are also used in classical physics on the variability of mass and energy flows. [14, 15].

5. **Cecilia Nagy**

Title: Can high frequency gravitational waves modify the Vainshtein mechanism?

Abstract: In the simplest tensor-scalar theories the weak field gravitational potentials are modified compared to general relativity whose predictions are well tested. The Vainshtein mechanism is able to avoid this effect within a certain radius by introducing a nonlinear term in the action with second derivatives of the scalar field. In general relativity, Isaacson showed that the high frequency gravitational wave perturbations backreact to the background spacetime. For instance, the Schwarzschild background perturbed by high frequency gravitational waves results in the Vaidya spacetime. In cubic galileon models, we include high frequency gravitational and scalar wave perturbations and derive the field equations governing their backreaction to the background, and to the gravitational potentials of spherically symmetric and static objects.

6. **Chevarra Hansraj**

Title: Semi-tetrad decomposition of spacetime with conformal symmetry.

Abstract: We study the kinematical and dynamical properties of a general spacetime that admits a conformal Killing vector. A 1+1+2 decomposition of the spacetime is performed using the fluid 4-velocity and a preferred spatial direction in the 3-space.

A brief overview of this formalism is presented. We compare our results with the 1+3 decomposition of Maartens et al. [Maartens, R., Mason, D. P. and Tsamparlis, M., J. Math. Phys. 27, 2987 (1986)], and find new results owing to the further decomposition. This provides new insights into the behaviour of the acceleration, expansion, shear and vorticity scalars which are not possible in the 1+3 decomposition. The general energy momentum tensor for an anisotropic fluid is considered and decomposed using the semi-tetrad covariant approach. We take the Lie derivative along the conformal Killing vector and apply to Einstein's field equations. We also find a system of equations that must be satisfied by the thermodynamical variables when a conformal symmetry exists applied to the perfect fluid case. We show that the conformal factor satisfies a damped wave equation with a potential. [For details : Hansraj, C., Goswami. R., Maharaj, S. D., Gen. Relativ. Gravit., 52 63 (2020)].

7. **Priyanka Giri**

Title: Cold aberrations and locking of Central Interferometer of Advanced Virgo+.

Abstract: The target sensitivity of Advanced Virgo for O4 is about 90-120 Mpc for the BNS range. To achieve this several hardware upgrades are under process. One of the most relevant concerns installation of the Signal Recycling Mirror which forms an additional marginally stable cavity along with the power recycling cavity already present in Advanced Virgo. Therefore to compensate for these (cold) optical aberrations new Central Heating benches were installed by the TCS subsystem. I will describe the installation and pre-commissioning of CO_2 central heating which assists the lock of DRMI by compensating for the (cold) optical aberrations and the procedure followed for locking the Dual Recycled Michelson Interferometer along with the tuning of CO_2 central heating.

8. **Samuel Barroso Bellido**

Title: Entanglement Entropy at Critical Point in the Multiverse.

Abstract: Recently the entanglement entropy between universes has been calculated, an entropy which somehow describes the quantumness of a homogeneous multiverse. The third quantization formalism of canonical quantum gravity is used here. I will

show improvements of the results in a more general scenario, studying what happens at critical points of the evolution of a classical universe. We infer the relation of that entanglement entropy with the Hubble parameter of single universes.

9. **Santosh Lokahare**

Title: F(R G) Gravity Cosmological Model with Variable Deceleration Parameter.

Abstract: In this paper we have studied the cosmological model framed in an isotropic background in the F(R G) theory of gravity. The field equations are derived and the dynamical parameters are studied with a scale factor that favors early deceleration and late-time cosmic acceleration. The model is showing an accelerating behaviour that can be confronted from the behaviour of geometrical parameters. The scalar field reconstruction and the stability analysis are also performed.

10. **Shafqat Ul Islam**

Title: Deflection of light in strong field limit by Bardeen black hole in novel $4D$ ***EGB gravity.***

Abstract: Einstein-Gauss-Bonnet (EGB) theory is the most extensively studied higher curvature theory, whose Lagrangian contains in combination with the Einstein term contain the quadratic curvature GB terms. Glavan and Lin in D. Glavan and C. Lin, Phys. Rev. Lett. 124, 081301 (2020) formulated a non trivial $4D$ Einstein-Gauss-Bonnet (EGB) gravity by re-scaling the GB coupling constant α by $\alpha/(D-4)$ and taking the limit $D \to 4$. In view of this, we consider gravitational lensing by Bardeen black hole in the $4D$ EGB gravity theory to calculate the light deflection coefficients in strong-field limits $\bar{a}$ and $\bar{b}$, while former increases with increasing GB parameter α and charge q, later decreases. We also studied the effect of α and charge q on the deflection angle α_D, angular position θ_∞ and impact parameter for photon orbits u_m. We compare our results with those of analogous black holes in General Relativity (GR) and also the formalism is applied to discuss the astrophysical consequences in the case of the supermassive black holes Sgr A* and M87*.

11. **Shobhit Giri**

Title: The Geodesics Stability and Quasinormal Modes of a Non-Commutative Schwarzschild Black Hole by Employing Lyapunov Exponent.

Abstract: We study the stability of circular geodesics in the gravitational field of a non-commutative geometry inspired Schwarzschild black hole spacetime so-called a non-commutative Schwarzschild black hole (NCSBH). The Lyapunov exponent especially coordinate time Lyapunov exponent (λ c) is crucial to investigate the stability of these equatorial circular geodesics of a massive and massless test particle. By means of these exponents, the stability or instability of circular orbits are discussed by analyzing the variation of the Lyapunov exponent with the radius of these orbits for different values of the non-commutative parameter (α). In the case of null circular orbits, the instability exponent is calculated and thus presented to discuss the instability of null circular orbits. Further, by relating parameters corresponding to null circular geodesics (i.e. angular frequency and Lyapunov exponent), the quasinormal modes (QNMs) for a massless scalar field perturbation in the eikonal approximation are evaluated and also visualized by relating the real and imaginary parts. The nature of scalar field potential by varying non-commutative parameter (α) and angular momentum of perturbation (l) are also observed and discussed accordingly.

12. **Shubham Kala**

Title: Optical properties of a regular rotating black hole in non-minimally coupled Einstein-Yang-Mills theory in the presence of plasma.

Abstract: We study the null geodesics of the regular and rotating magnetically charged black hole in non-minimally coupled Einstein-Yang-Mills theory surrounded by plasma medium. The effect of magnetic charge and Yang-Mills parameter on the effective potential and radius of photon orbits has investigated. We then study the shadow of regular and rotating magnetically charged black hole along with observables in presence of plasma medium. The presence of plasma medium affects the apparent size of the shadow of regular rotating black hole in comparison to vacuum case. Variation of shadow radius and deformation parameter with yang mills and plasma parameter has examined. Furthermore, the deflection angle of the massless

test particles in weak field approximation around this particular black hole spacetime in presence of homogeneous plasma medium has investigated. Thereafter, we compared the obtained results with Kerr-Newman and Schwarzschild black hole solution in general relativity (GR).

13. **Syed Naqvi**

Title: Freely falling bodies in standing wave spacetime.

Abstract: The phenomena of standing waves is well known in mechanical and electromagnetic setting where the wave has the maximum and minimum amplitude at the antinodes and nodes, respectively. In context of exact solution to Einstein Field equations, we analyze a spacetime which represents standing gravitational waves in an expanding Universe. The study the motion of free masses subject to the influence of standing gravitational waves in the polarized Gowdy cosmology with a three-torus topology. We show that antinodes attract freely falling particles and we trace the velocity memory effect.

14. **Uma Papnoi**

Title: Shadow of charged rotating black hole surrounded by perfect fluid dark matter.

Abstract: We analysed the shadow cast by charged rotating black hole (BH) in presence of perfect fluid dark matter (PFDM). We studied the null geodesic equations and obtained the shadow of the charged rotating BH to see the effects of PFDM parameter charge Q and rotation parameter a is noticed that the size as well as the shape of BH shadow is affected due to PFDM parameter charge and rotation parameter. Thus it is seen that the presence of dark matter around a BH affects its spacetime. We also investigated the influence of all the parameters (PFDM parameter) BHs charge Q and rotational parameter a on effective potential energy emission by graphical representation and compare all the results with the non rotating case in usual general relativity.