South African Gravity Society Conference 2025 (SAGS2025)

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Book of Abstracts

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Charged isotropic solutions with linear barotropic equations of state in Einstein-Gauss-Bonnet gravity

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In the present work we investigate new class of charged isotropic solutions with a linear barotropic equation of state (EoS) in the framework of Einstein–Gauss–Bonnet (EGB) gravity for 5 and 6 dimensional spherically symmetric static distributions. Imposing such a restriction of the EoS, one more further assumption on the metric potentials must be chosen in order to close the system. For example, the constant gravitational potential which is responsible for an isothermal distribution in Einstein gravity and as well as different forms of temporal potential are analyzed. Through graphical analysis we demonstrate that the obtained exact models satisfy the basic elementary astrophysical requirement for physical plausibility.

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On perturbation induced minimal geometric decoupling in space-time and its implications for mass-gap stability

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This study examines mass-gap compact stars formed from neutron star mergers or massive pulsar evolution within the minimal geometric deformation framework. Using a Buchdahl–Vaidya–Tikekar–type metric, we obtain unperturbed static, spherically symmetric solutions with central densities $\sim 10^{15}\,\mathrm{g/cm^3}$ decreasing to zero at radius R. Astrophysical effects such as gravitational radiation or accretion are modeled through a perturbation $g(r) = \sin(\omega r^2)$ with amplitude α and frequency ω. Instead of a fixed EOS, we use a metric ansatz for g_{rr} that generates pressure–density profiles directly. Observational limits from PSR˜J1614–2230 ($1.97^{+0.0}_{-0.04} M_\odot$), PSR˜J0952–0607 ($\approx 2.35 M_\odot$), GW190814, and GW200210 ($M > 2M_\odot$), plus the radius $13.70^{+2.6}_{-1.5}\,\mathrm{km}$ for PSR˜J0740+6620, guide the model space. For α rising from 0 to 0.005, the EOS changes from linear to nonlinear, while varying ω up to $0.06\,\mathrm{km}^{-2}$ at fixed $\alpha = 0.001$ produces minor changes. Without perturbations ($\alpha = 0, \omega = 0$), the M–R curve is smooth, peaking at $M_{\max} \approx 3.5\,M_\odot$ and $R \approx 12\,\mathrm{km}$. For $\alpha = 0.001$ and $\omega = 0.015\,\mathrm{km}^{-2}$, radius fluctuations of $\delta R \approx 0.17\,\mathrm{km}$ occur near $M \approx 2.7\,M_\odot$, $R \approx 13.3\,\mathrm{km}$. Higher α yields stronger oscillations, with $M > 3.5\,M_\odot$ and $R > 12\,\mathrm{km}$. Perturbations soften the EOS, lowering $M_{\max}$ and limiting collapse to black holes. All cases satisfy the Buchdahl bound $\frac{2M}{R} < \frac{8}{9}$, match massive pulsar data, and remain dynamically stable: sound speeds stay subluminal, Γ exceeds the critical value, and anisotropy grows mainly with α. The frequency ω has smaller influence, causing slight radius oscillations without destabilizing the star.

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Exploring techniques to elimante systematic effects in data observed with Hydorgen Epoch of Reionization Array (HERA).

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The 21 cm transition from neutral hydrogen is one of the most promising probes of the Epoch of Reionization (EoR). Precise measurements from this era can better constrain cosmological parameters and shed light on the evolution of galaxies across cosmic time. The new generation of low-frequency radio interferometric arrays, including the Hydrogen Epoch of Reionization Array (HERA), have been built specifically to probe this period.

The main challenge in detecting the 21 cm signal lies in the presence of bright foregrounds, which demand extremely accurate interferometric calibration. However, the non-smooth instrumental response of antennas, caused in part by mutual coupling, introduces non-smooth calibration errors. These are further compounded by the use of incomplete sky models, which are unavoidable given the limited depth and resolution of current source catalogues. The combination of instrumental effects and incomplete models can significantly compromise 21 cm detection.

In this work, we investigate the use of fringe-rate filters to mitigate calibration errors arising from mutual coupling and incomplete sky models. We present the first results from applying these filters to actual HERA observations, demonstrating significant improvements in calibration quality

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Geodesics and Light Deflection in Schwarzschild-like Spacetime from Cosmology-Inspired Modified Gravity

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We investigate cosmology-driven modifications to Schwarzschild-like black hole spacetimes and their impact on photon propagation and gravitational lensing. The effective potential for null geodesics exhibits a single unstable maximum defining the photon sphere, with its radius and stability influenced by the deviation parameter (α) and the angular momentum of the photon (L).Photon trajectories are categorized into capture, escape, and unstable circular paths according to the critical impact parameter (bc). The gravitational deflection angle increases with α, enhancing light bending compared to the standard Schwarzschild case. Weak-field deflection remains largelyunchanged, whereas strong-field regimes exhibit significant deviations. Cosmology-induced modifications introduce potentially observable corrections to light deflection, indicating that forthcoming high-precision astrometric and lensing measurements may provide meaningful constraints. These findings demonstrate the potential to probe modified gravity effects in strong gravitational fields, establishing a connection between astrophysical black holes and cosmology, and offering a pathway to explore how cosmic expansion subtly influences local gravitational phenomena.

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Large-scale structure formation in presence of cosmological magnetic fields

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In this study, we examine how primordial magnetic fields (PMFs) influence the formation of large-scale structure in the universe. Working within a magnetized extension of the standard ΛCDM framework, we include the contributions of PMF energy density and pressure in the evolution equations governing matter perturbations. Our analysis investigates the resulting modifications to the matter power spectrum, the linear density contrast, the structure growth rate f(z), and the combined growth observable fσ8, which links the growth rate to the amplitude of matter fluctuations. These quantities are calculated for a range of PMF amplitudes and spectral indices, and the predictions are compared with recent fσ8 data and power spectrum measurements from galaxy surveys such as BOSS and DES, as well as with CMB constraints from Planck.

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Weak Gravitational Lensing and Black Hole Shadow Characteristics of a Frolov Regular Black Hole with Constraints from EHT Observations

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We investigate the weak gravitational lensing and black hole shadows properties in the vicinity of static regular Frolov black hole.We investigate the bending of light in weak field regimes. The black hole shadow is studied in detail, with constraints on its parameters derived from observational data of the EHT collaboration. Further, we examine the shadow images under a spherically symmetric accretion flow and compute the energy emission rate to understand the black hole radiation characteristics. The obtained results demonstrate how the Frolov black hole difeeres from well-know black hole solutions in General Relativity. This study provides new insight into the impact of modified regular black hole solutions on observational signatures. The fining have significant implication for future astrophysical observations and the testing of alternative gravity theories.

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Absence of Curvature Singularities in Symmetric Perfect Fluid Spacetimes in Einstein-Gauss-Bonnet Gravity

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We investigate higher-dimensional homogeneous and isotropic perfect fluid spacetimes within the framework of Einstein–Gauss–Bonnet (EGB) gravity. By solving the modified field equations, which include higher-order curvature corrections, we derive evolution equations for the scale factor and show that it admits a strictly positive minimum value. This lower bound depends on the spacetime dimension N, the coupling parameter α, and the chosen equation of state. Crucially, this behavior eliminates the possibility of curvature singularities that occur when the scale factor vanishes, such as those found in Big Bang or Big Crunch scenarios.

We demonstrate that this regular behavior is universal across all physically reasonable perfect fluid equations of state, both linear (e.g., radiation or dust-like matter) and nonlinear (e.g., generalized Chaplygin gas). This suggests that singularity theorems can be bypassed in EGB gravity without violating energy conditions. Furthermore, the appearance of a bounce in the collapsing region implies the potential formation of regular black holes, preventing the central singularity via higher-dimensional geometric effects.

In our analysis, we identify N=9 as a critical dimension, where the minimum scale factor reaches its peak for fixed α, indicating maximum repulsive effect from Gauss–Bonnet corrections. Numerical analysis and plots support this claim, emphasizing the influence of dimensionality on the avoidance of singularities. These findings underscore EGB gravity as a viable model for constructing non-singular cosmologies and regular gravitational collapse scenarios.
Keywords: FLRW spacetimes, Einstein–Gauss–Bonnet gravity, curvature singularities, bouncing cosmologies, higher dimensions
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Kosmulator: A new MCMC framework for fitting modified and alternative gravity models to cosmological observations

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In this talk, I'll introduce Kosmulator —a new, fast, and transparent MCMC framework for cosmological inference currently in development. Kosmulator allows researchers to swap cosmological models on the fly for fitting theoretical predictions to observational data. Modified-gravity models are implemented as simple Python callables, meaning transitions from ΛCDM to linear or fully non-linear MG variants require only small mathematical changes, with no re-wiring of likelihoods. Under the hood, Kosmulator integrates CLASS, CLIC, and AlterBBN for theory predictions and supports Zeus/EMCEE MCMC engine samplers, vectorised model evaluations, and high-performance MPI parallelisation. It also includes practical tools for modern analysis workflows: dynamic parameter safeguards, automated convergence and autocorrelation checks, and real-time visualisation (trace plots, corner plots, and best-fit overlays).

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Constraining the Teleparallel Universe

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The latest DESI results, suggesting a dynamical dark energy equation of state, have reinvigorated interest in modified teleparallel theories, such as $f(T)$ gravity, as viable alternatives to the standard cosmological model. These models, grounded in torsion rather than curvature, offer elegant alternatives for explaining cosmic acceleration without invoking dark energy. In this talk, I present a systematic investigation of several popular and novel $f(T)$ models, examining their viability in light of current observational data. By applying recent cosmological datasets, including Type Ia Supernovae, Plank 2018, BAO, and Hubble parameter measurements, we derive constraints on key model parameters and explore the sensitivity of each model to different datasets. The analysis not only highlights which forms of $f(T)$ are most favored by data but also identifies unique signatures that could distinguish torsion-based gravity from curvature-based frameworks. This work contributes toward the broader goal of building a consistent, observationally viable theory of gravity beyond the standard paradigm.

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Exploring Quantum Corners: How Curved Momentum Space Shapes BTZ Black Holes

Author: Partha Nandi[1]

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In this talk, I will discuss how quantum features of spacetime can leave imprints on classical gravity within a controlled semiclassical framework. Focusing on (2+1)-dimensional gravity with a negative cosmological constant, I use this lower-dimensional setup as a tractable model to explore the role of curved momentum space, a structure often anticipated in quantum gravity. Starting from a first-order action, I derive an effective configuration-space description where geodesic motion becomes mass-dependent, signaling a mild violation of the equivalence principle. Coupling this modified matter sector to Einstein gravity, I then construct a perturbative correction to the BTZ black hole solution. The resulting ADM mass, Hawking temperature, and entropy acquire explicit corrections governed by the momentum-space geometry. These findings provide a concrete illustration of how Planck-scale kinematic effects can backreact on classical spacetimes, offering new insights into semiclassical aspects of gravity.

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Cosmic dynamics and observational constraints in $f(Q)$ gravity with affine equation of state

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We study the cosmological implications of barotropic fluid satisfying affine equation of state (EoS) in the General relativity and $f(Q)$ gravity framework. We describe the impact of affine EoS on the cosmic evolution in the model and derive the observational constraints on the model parameters. The models of General relativity and $f(Q)$ gravity may unify the scenario in which the universe transits from the decelerated expansion into the accelerated expansion. The model parameters are constrained by the Bayesian analysis based on χ^2 minimization technique with the observational

data of the Cosmic chronometer and Supernovae type Ia. The affine EoS model in the General Relativity possess quintessence kind of dark energy while it possess phantom kind of dark energy in the $f(Q)$ gravity. The present day values of the cosmological parameters along with the current age of the universe are compatible with the observations. We also probe the possibility of setting up the solution of General relativity model into the $f(Q)$ gravity.

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On Embedding Conditions

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We provide a survey of both existence results and explicit solutions for Local Isometric Embeddings into higher dimensional Euclidean and more general pseudo-Riemannian geometries. Of particular interest are recent results establishing that, for analytical spacetimes, the Euclidean co-dimension is at most two. This casts new light on the Karmarkar condition for class one pseudo-Euclidean embeddings and its analogues for class two embeddings into pseudo-Euclidean spaces, and more general embedding spaces, from which we derive a new embedding condition.

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Observational constraints of diffusive dark-fluid cosmology

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In this manuscript, the background and perturbed cosmic dynamics have been investigated using an interacting dark fluid model, which assumes energy exchange between dark matter and dark energy through a diffusion mechanism. After we solve the background expansion history for the late-time Universe, the full set of linear perturbation equations is driven using the $1+3$-covariant approach. We take into account the recent measurements of Baryon Acoustic Oscillations (BAO) from the Dark Energy Spectroscopic Instrument (\textit{DESI BAO DR2}), cosmic chronometers (\text{CC}), and the compilations SNIa distance moduli namely: \textit{Pantheon plus + SH0ES} (\textit{PPS}), \textit{DESY5}, \textit{Union3}, together with the redshift space distortion (\textit{RSD}) and growth rate f from VIPERS and SDSS collaborations for statistical analysis of the work. We then seek to constrain the cosmological parameters: H_0 in km/s/Mpc, Ω_m, r_d, M, σ_8, $_8$, and the interaction term Q_m through the MCMC simulations. As a result, a comparison of the H_0 and S_8 values predicted by ΛCDM and diffusive models with the cosmological surveys from late- and early-time measurements. To evaluate the viability of the dark-fluid model in describing cosmic dynamics, the numerical results of background cosmological quantities are presented. These results show that the dark fluid behaves like the Chaplygin gas (CG) that drives cosmic acceleration when Q_m is negative, while for positive Q_m, it exhibits characteristics of a quintessence-like phase. From the perturbation evolution equations, the numerical results of density contrast, $\delta(z)$, growth rate, $f(z)$, and redshift space distortion, $f\sigma_8(z)$ are presented, demonstrating the impact of energy diffusion between dark matter and dark energy for the cosmic structure growth. Using the AIC and BIC Bayesian methods, a detailed statistical analysis has been performed.

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Quantum Gravity Outperforms General Relativity: A New Chapter in Black Hole Physics

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The direct imaging of supermassive black holes by the Event Horizon Telescope (EHT) has provided an unprecedented opportunity to test the foundations of gravitational physics. In this work, we present the first Bayesian statistical analysis of the Nexus Paradigm (NP) —a quantum gravity framework that models spacetime as a lattice of entangled spinorial modes —against the EHT's observations of Sagittarius A*and M87.* The NP predicts distinctive horizon-scale features, including a halved Schwarzschild radius and quantized orbital structures, leading to precise angular diameter predictions for the dark depression, emission ring, and base diameter. Using mass-to-distance priors and Gaussian error likelihoods, we demonstrate that NP aligns with the observed EHT features at a confidence level exceeding 4σ, while General Relativity (GR) underestimates the dark depression size. The resulting Bayes factor of ˜10^{36} decisively favors NP over GR in this context. These results suggest that quantum entanglement of spinorial modes may underlie the emergence of spacetime geometry, with black hole shadow observations offering a direct empirical probe of quantum gravity. This work not only marks a critical step in bridging GR and quantum mechanics but also establishes a new empirical avenue for testing fundamental physics, paving the way for next-generation EHT observations and gravitational wave astronomy to further challenge and refine our understanding of spacetime.

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On the Dynamics of Interacting Dark Energy

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Interacting dark energy (IDE) models are cosmological models in which dark matter and dark energy interact in a non-gravitational manner, and have been introduced to address long-standing theoretical and observational tensions in cosmology. We discuss recent developments in the field, highlighting both the relevance and potential pitfalls of these models. In particular, we discuss how certain sections of the parameter space may lead to dynamics that alleviate the coincidence problem and allow phantom crossings, while other sections lead to negative energy densities, future big rip singularities, and other exotic behaviours. We find a general theoretical preference for IDE models in which energy flows from DE to DM. Finally, we compare the background dynamics of our IDE model with some of the latest cosmological data.

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Gravitational waves and matter

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Gravitational waves (GWs) passing through matter induce shear into the matter flow, and this shear flow acts as a source of GWs. The consequences include GW echoes and damping of the GW signal together with heating of the matter. These effects have astrophysical applications: core collapse supernova, neutron star mergers, black hole mergers, and primordial GWs.

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Effects of variations in cosmological initial conditions on the Simba-C simulation

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The formation and evolution of the Universe's large-scale structure (LSS) are strongly influenced by the statistical properties of primordial density fluctuations. While cosmological hydrodynamical simulations, such as Simba-C, have become indispensable tools for modeling galaxy formation and cosmic web morphology, they generally adopt a fixed concordance ΛCDM initial power spectrum. This assumption limits exploration of how early-universe physics imprints itself on present-day structures. In this work, we systematically vary key parameters of the primordial spectrum—including the baryon density (Ω_b) and dark matter density (Ω_{dm}), and will vary the amplitude (A_s), spectral index (n_s)—to probe their impact on the evolution of halos, voids, filaments, and clustering statistics. We generate the linear matter power spectra using CLASS (Cosmic Linear Anisotropy Solving System), and initialize density fields with MUSIC (MUlti-Scale Initial Conditions) for Simba-C simulations. We will utilize a set of modified runs to analyze the resultant differences in the matter power spectrum, halo mass function, two-point correlation function, and cosmic web topology, with aims to quantify the sensitivity of LSS formation to inflationary features and non-standard cosmologies.

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Multiwavelength Studies of Strong Gravitational Lensing: The Case of HCOSMOS01

Author: Ansofi Pretorius[1]

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Strong gravitational lensing is the dramatic, observed deflection of light in the presence of massive foreground lenses that perturb the surrounding spacetime. In general, strong gravitational lensing is a versatile probe of the mass distributions and dark matter content of the lenses that also offers a means of constraining the Hubble parameter and testing General Relativity [1]. We exploit high-resolution near-infrared images from the Hubble Space Telescope (HST) to model strongly lensed systems to recover the physical properties of the lenses and the lensed sources. We also explore the possibility of including theories of modified gravity in our lens modelling algorithms. In this work, we focus on the first strongly lensed system identified in the COSOMOS field, HERMESJ100144+025709 (otherwise referred to as HCOSMOS01)[2]. The HST image of the system of interest, taken at 1.1 µm, formed part of proposal ID 12488 (PI: M. Negrello) in Cycle 19. Similar to proposal ID 15242 (PI: L. Marchetti) in Cycle 25, and proposal ID 16015 (PI: L. Marchetti) in Cycle 26, high resolution follow-up observations were conducted to confirm the lensing nature of 281 candidate systems identified in the wide-area extragalactic surveys conducted with the Herschel Space Observatory [3]. From our analysis, we present the results of modeling the surface brightness profile of the lens and the reconstruction of the lens and source. We also present the best estimates for the photometric and spectroscopic redshifts of the source, upon modelling the spectral energy distribution of the source as a modified greybody [4], using the available Atacama Large Millimeter/submillimeter Array (ALMA) data [5] and Dark Energy Spectroscopic Instrument (DESI) spectra [6]. Lastly, we provide a critical discussion on the use of lens modeling softwares, such as PyAutoLens [7], as a means of exploring how various dark matter distributions and mass profiles, including fiducial models derived from modified theories of gravity, affect the resultant lens modeling and source reconstruction.

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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 non-minimal inflation after the release of the PLANCK 2018 data.

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On Constraining the R_h=ct Universe with RSD and OHD Measurements

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We present new constraints on the $R_h = ct$ cosmological model derived from redshift space distortion (RSD) data. In contrast to the standard ΛCDM framework, the $R_h = ct$ universe imposes a linear expansion and enforces the condition $R_h = ct$ at all cosmic times, leading to distinct predictions for the growth rate of cosmic structure. Using a comprehensive sample of RSD measurements across a broad range of redshifts, we test the $R_h = ct$ model's viability as an alternative to ΛCDM by comparing its predictions against observation through statistical inference. Our analysis demonstrates that the $R_h = ct$ universe fails to provide an adequate description of the growth history, yielding a significantly poorer fit than ΛCDM under standard likelihood analyses. These results highlight the strong constraining power of RSD data and reinforce the conclusion that the $R_h = ct$ model cannot account for the observed dynamics of large-scale structure formation.

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Constraining Interacting Dark Energy Model with Cosmological Data

Authors: Rethabile Thubisi[1]; Amare Abebe[1]; Shambel Sahlu[1]

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We study the observational signature of non-gravitational interaction between the dark components of the cosmic fluids. We explore a phenomenological model of interacting dark energy and dark matter, characterised by a non-linear coupling term of the form $Q = 3H\xi\left(\frac{\rho_{dm}\rho_{de}}{\rho_{dm}+\rho_{de}}\right)$. This form of interaction naturally interpolates between linear regimes at early and late times, while avoiding divergences in the energy exchange term. We derive the background cosmological evolution equations and analyse the impact of the interaction on key observables, including the expansion history, the growth rate of structure, and the cosmic microwave background anisotropies. Using recent observational data sets including Planck CMB measurements, Type Ia supernovae, and BAO data, we constrain the interaction parameter and assess the model's potential to alleviate cosmological tensions.

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Investigating cosmic phenomena in Einstein-Gauss-Bonnet gravity

Author: Chevarra Hansraj[1]

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In this talk, I will begin by providing an overview and substantiation of EGB theory. Then I will explore two critical features of modified gravitational systems: curvature singularities and mass gaps. Investigations into these features are central to our understanding of the structure and stability of compact objects in higher-dimensional gravity settings and for comparisons to classical GR. We first look at N-dimensional cosmology within the perfect fluid EGB framework, investigating the nature of singularities and the evolution of the Universe under nonstandard conditions. Using a transformation, we show that no curvature singularity is possible. Further, we provide a geometrical explanation for the mass gap phenomenon in 5D EGB black holes via spacetime decomposition. We show for self-similar radiation collapse, the central singularity is not a sink for timelike geodesics and is extendable. These studies clearly demonstrate how the Gauss-Bonnet invariant affects the nature of the final state of collapse in this modified theory.

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Scalar Field and Quintessence in Late-Time Cosmic Expansion

Author: Aroon Beesham[None]

The persistent Hubble tension - marked by a notable disparity between early- and late-universe determinations of the Hubble constant H_0 —poses a serious challenge to the standard cosmological framework. Closely linked to this is the $H_0 - r_d$ tension, which stems from the fact that BAO-based estimates of H_0 are intrinsically dependent on the assumed value of the sound horizon at the drag epoch, r_d. In this study, we construct a scalar field dark energy model within the framework of a spatially flat FLRW model to explore the dynamics of cosmic acceleration. To solve the field equations, we introduce a generalized extension of the standard ΛCDM model that allows for deviations in the expansion history. Employing advanced Markov Chain Monte Carlo techniques, we constrain the model parameters using a comprehensive combination of observational data, including Baryon Acoustic Oscillations, Cosmic Chronometers, and Standard Candle datasets from Pantheon Type Ia

Supernovae (SNe Ia), Quasars, and Gamma-Ray Bursts (GRBs). Our analysis reveals a transition redshift from deceleration to acceleration at $z_{\rm tr} = 0.69$, and a present-day deceleration parameter value of $q_0 = -0.64$. The model supports a dynamical scalar field interpretation, with an equation of state parameter satisfying $-1 < \omega_0^\phi < 0$, consistent with quintessence behavior, and signaling a deviation from the cosmological constant. While the model aligns closely with the ΛCDM scenario at lower redshifts (z
$lesssim 0.65$), notable departures emerge at higher redshifts (z
$gtrsim 0.65$), offering a potential window into modified early-time cosmology. Furthermore, the evolution of key cosmographic quantities such as energy density ρ^ϕ, pressure p^ϕ, and the scalar field equation of state highlights the robustness of scalar field frameworks in describing dark energy phenomenology. Importantly, our results indicate a slightly elevated value of the Hubble constant H_0 for specific data combinations, suggesting that the model may provide a partial resolution of the current H_0 tension.

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Kerr metric inside and out

Author: Haidar Sheikhahmadi[1]

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The maximum mass of a neutron star is a fundamental issue in astrophysics, as it critically constrains the equation of state of ultra-dense matter. While the Tolman-Oppenheimer-Volkoff (TOV) limit provides a theoretical upper bound for non-rotating stars, most observed neutron stars are rotating. This talk examines how rapid rotation alters the maximum mass limit, pushing it beyond the classical TOV value. We will explore the theoretical challenges in modelling these stationary configurations and present a novel discussion on the consequences for the observed mass distribution of compact objects, particularly the mass gap between the most massive neutron stars and the least massive black holes.

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Anisotropic Cosmological Perturbations in LRS Bianchi Type I Spacetimes

Author: Heba Abdulrahman[None]

In this work, we investigate the dynamics of density perturbations in anisotropic Bianchi Type I cosmologies with a positive cosmological constant. While the standard ΛCDM model, based on the homogeneous and isotropic FLRW metric, provides a successful framework for large-scale cosmology, persistent observational discrepancies and theoretical challenges motivate the exploration of alternative background geometries. Anisotropic Bianchi Type I cosmologies offer a well-defined deviation from isotropy, and this work aims to understand how density perturbations evolve within such backgrounds. We specifically focus on scenarios where the Universe isotropizes, thereby providing crucial insights into the potential role of early universe anisotropies and the robustness of the standard cosmological picture. This analysis is conducted using the 1+3 and 1+1+2 covariant formalisms.

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From a collapsing radiating star to an evaporating black hole: A smooth transition from classical to quantum entropy

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We present a robust mechanism, where the geometrical free-gravitational entropy of an isolated astrophysical radiating star undergoing continual gravitational collapse (where gravity dominates over all other fundamental forces), as measured by an external observer, makes a smooth transition to the Bekenstein-Hawking entropy at the onset of the horizon formation and in the late times of black hole evaporation. It is interesting to note that both in the classical collapsing phase and the semi classical evaporating black hole phase, the matter is radiated via the Vaidya exterior that surrounds the collapsing radiating star as well as the evaporating black hole (BH) thus formed. As the entropy of a BH is several orders of magnitude greater than the ordinary thermodynamic entropy of the original star, so the BH entropy is basically independent of the nature of the interior matter. Therefore, our result, being independent of the interior matter dynamics of the collapsing star, clearly indicates that the Bekenstein-Hawking entropy and its non-extensive nature indeed originates from the Riemannian geometry, which dictates the free-gravity entropy in general relativity.

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Gravitational waves from Cosmic Strings

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Cosmic strings, which are one-dimensional topological defects formed during early universe symmetry breaking, can generate a stochastic gravitational wave background (SGWB) detectable across LIGO, LISA and PTA bands. The SGWB generated by cosmic string networks described by the Velocity-Dependent One-Scale (VOS) model will be explored. We will consider both existing analytical treatments (Sousa et al. 2020) as well as a new numerical scheme. By numerically evolving the characteristic length and RMS velocity through radiation and matter eras, and solving the Boltzmann-type equation for loop number density, the full spectrum of gravitational waves from cosmic strings may be constructed. We will also discuss ongoing extensions such as implementing gravitational back reaction, improved loop production functions and realistic cosmological transitions.

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Confronting the Universe's Accelerating Expansion: Insights from a Hybrid Scale Factor

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The Lambda Cold Dark Matter (ΛCDM) model is a well-known cosmological model that has been used to investigate the acceleration of the universe. In our earlier study, we introduced a modified scale factor (Aydiner et al., 2022) to examine the universe's accelerating expansion without relying on the conventional dark energy framework of the lambda-cold-dark matter model. In order to test

the viability of the Modified Scale Factor (MSF), we constrained the model using the observational Hubble parameter (OHD) and the distance modulus measurements (SNIa) and a combination of the data sets. Through numerical simulations and observational constraints, our findings demonstrated that the MSF model aligns well with empirical data, offering a competitive alternative to ΛCDM. Specifically, we explore its implications for cosmic evolution beyond the previously considered data sets, assess its predictive power in a broader observational context, and investigate potential refinements that improve its consistency with large-scale structure observations.

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Isotropic compact distributions in $f(G, B)$ gravity

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In an effort to contribute to the current search for a modified gravity theory consistent with all observed phenomena, Boehmer and Jensko noted an obscure fact that the Ricci scalar can be decomposed into a bulk and a boundary term. This is then used to construct an action inspired by the idea of nonmetricity where the affine connection does not commute in the lower indices as in GR. The bulk and boundary terms can both be written in terms of the connection. The boundary term is impactful in the construction of cosmological models however they may be neutralised to study compact objects. We investigate stellar structure within this framework. At first we probe the implications of a vanishing bulk term through the presence of peculiar geometries. Next we consider the vacuum solution and it turns out that two branches of solutions exist. The simplest cases of constant potentials is examined and finally we develop an exact solution with variable density however despite the reasonable physical properties the model does not admit a finite boundary nor a regular centre. The singularity at the centre may be dealt with by the insertion of another reqular fluid in the central core while our cosmological fluid envelopes the core.

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Tidal deformability of strange stars with Buchdahl potential

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Following its many successes in developing physically viable stellar models, the Buchdahl ansatz is invoked in the context of 5-dimensional Einstein-Gauss-Bonnet (EGB) gravity accompanied by a strange star equation of state to develop an anisotropic fluid distribution. The analytical model serves as a useful testbed for the phenomenon of tidal deformability in light of data from the GW170817 event. The exact model constructed yields gravitational redshift values coinciding with the ranges usually attributed to neutron stars for a range of well studied pulsars. Significant increase in density was evident in the core regions of the star. All the physical quantities for the 5D EGB model satisfied elementary tests for applicability to realistic stars. In addition, it was observed that while the EGB invariants influenced the stellar distribution profoundly in contrast the corresponding Einstein model displayed deficiencies. The model was analysed for stability as well as obeying the energy conditions. The mass-radius profiles were well behaved in general within the radius of applicability. Finally, our analysis reveals that as the parameter β, associated with strange matter, increases, the equation of state becomes stiffer, allowing for more massive stars with greater tidal deformability. Notably, both cases comfortably meet the GW170817 constraint of $\Lambda_{1.4} < 800$, in line with current observations.

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A model independent approach to the cosmology of f(R) dark energy

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Over the last decade, much attention has been given to the study of modified gravity theories to find a more natural explanation for the late-time acceleration of the Universe. Particular attention has focused on the so-called f(R) dark energy models. Instead of focusing on a particular f(R) model, we present a completely model-independent approach to study the background dynamics and the growth of matter density perturbations for those f(R) models that mimic the Lambda cold dark matter (ΛCDM) evolution at the background level. We do this by characterizing the dynamics of the gravitational field using a set of dimensionless variables and using cosmography to determine the expansion history. We then illustrate the integrity of this method by fixing the cosmography to be the same as an exact ΛCDM model, allowing us to test the solution. We compare the exact evolution of the density contrast and growth index with what one obtains from various levels of the quasi-static approximation, without explicitly choosing the form of f(R). We find that on quasi-linear scales, the difference between what one obtains from the exact equations and the quasi-static approximation can be as much a 15%.

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Implications of a vanishing Gauss-Bonnet invariant in f (G) gravity: the quadratic case

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It is well known that Lovelock polynomials including the special case of second order Gauss-Bonnet (G) invariants are topological and do not contribute to the dynamics of physical entities in four spacetime dimensions. Efforts to include higher curvature effects through dimensional regularization schemes in four dimensions are ongoing though several mathematical hurdles must be overcome. Another direction to incorporate higher curvature is to investigate functional forms of the Gauss-Bonnet invariants through the so-called f(G) gravity. This is the object of our study. We exploit an important property of the Lovelock terms that of containing up to second order derivatives irrespective of the order of the polynomial. The linear order f (G) = G corresponds to
Einstein gravity in 4 dimensions and standard EGB gravity for higher dimensions. However the next level the pure quadratic case f (G) ~ G2 offers intriguing possibilities. But before we probe this we note a little known fact that the Gauss-Bonnet term itself contains up to second order derivatives of the metric potentials. This then opens up the interesting question of which spacetime geometries will cancel the higher curvature effects in the four dimensional spacetime manifold but not in the physics. The derivatives of G still live on in the thermo-dynamical quantities and influence their behavior. We identify such geometries that produce this effect and examine how the physical properties are impacted. (Geometrically we will be living in a 4D Einstein world but physically we will be feeling the effects of extra curvature through the GB contributions).

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Constraining inflationary flow equations with the spectral index relation n - 1 = -2/N

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Constraining inflationary flow equations with $n_s - 1 = -2/N$

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Abstract

This work presents an approach to inflationary cosmology that incorporates the spectral index relation $n_s - 1 = -2/N$ directly into the Hubble slow-roll hierarchy. Traditional methods treat slow-roll parameters as independent, potentially leading to trajectories inconsistent with CMB observations.

We use the spectral index as a constraint to determine the third slow-roll parameter λ_3 throughout the evolution, ensuring trajectories remain observationally consistent. The constrained system is implemented numerically and compared with standard approaches.

This method aims to provide a more reliable connection between theoretical inflation models and observational constraints while maintaining the full dynamical structure of flow equations.

Keywords: inflationary cosmology, slow-roll approximation, spectral index, numerical methods

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Cosmic Censorship: A study on the behaviour of regular black holes

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The Weak Cosmic Censorship Conjecture (CCC) generally states that all singularities must be hidden behind the event horizon. Consequently, this conjecture forbids the destruction of event horizons in singular black holes, since their removal would expose naked singularities. Regular black holes, by contrast, contain no curvature singularities and are therefore not subject to the consequences of the cosmic censorship conjecture. As such it is not evident if their exists any mechanism which either prevents or permits the destruction of their event horizons. In this study, we investigate the possibility of removing the horizons of regular black holes, by considering a particular class known as \emph{black bounces}. These geometries regularize the singular Kerr-Newman family by introduction of the real regularization parameter l and the mapping $r^2 \to r^2 + l^2$. To probe the stability of their event horizons, we employ a Wald-like \emph{gedanken} experiment, whereby we attempt to have a black hole assimilate a test particle such that the resulting spacetime contains no event horizon. To facilitate our investigation, we introduce the concept of \emph{saturation}, with which we are able to quantify the notions of extremality and near-extremality. This allows us unify the treatment of both saturated and under-saturated regimes without the need for case-specific expressions or arguments. Within this framework, we find that the Kerr-Newman black bounce admits two distinct channels (I and II) for removal of the event horizon, in contrast to the single channel available to its singular counterpart. We demonstrate that both of these channels can, in principle, lead to destruction of the event horizon, however, only if the black hole is not at the point of extremality. Moreover, we show that a strict enforcement of the test particle conditions requires that the black hole reside near the brink of collapse in order to be susceptible to horizon removal. We conclude by comparing our findings to a similar analysis conducted on the regular Bardeen and Hayward black holes, upon which it is demonstrated that all three candidates exhibit similar behaviour in the context of horizon removal.

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The Meszaros effect with viscous dark matter

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Tensions between cosmological simulations and astronomical observations may be resolved by extensions to the ΛCDM paradigm. We consider the possibility that dark matter may self-interact and possess viscosity. Including dissipative effects in cosmic fluids will modify their clustering properties which could have observable effects on the formation of large-scale structure. We analyse the evolution of density perturbations during the radiation and matter eras and examine the impact of shear viscosity on the Meszaros effect.

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Averaged Scalar Field Cosmologies in LRS Bianchi Models

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This talk examines scalar field cosmologies driven by a generalized harmonic potential, focusing on Locally Rotationally Symmetric (LRS) Bianchi I, III, and V spacetimes, as well as their isotropic limits.

We begin by reviewing the averaged dynamics of Bianchi I and III models, which offer accessible examples of anisotropic cosmologies. Building on this foundation, we present new results for the Bianchi V case, where the geometry introduces additional complexity.

A central idea is that the Hubble parameter acts as a time-dependent perturbation. As it decreases, the discrepancy between full-system solutions and their time-averaged counterparts becomes negligible. That means that oscillatory features in the system can be smoothed out, allowing us to recover the same long-term behaviour with a simpler, averaged description.

This averaging approach provides both conceptual clarity and practical simplification, making it a valuable tool for studying scalar field dynamics in anisotropic cosmological settings.

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Unification of Conformal and Fuzzy Gravities with Internal Interactions

Author: George Zoupanos[None]

The Unification of Conformal and Fuzzy gravities with Internal Interactions is based on the following two facts. The first is that the tangent group of a curved manifold and the manifold itself do not necessarily have the same dimensions. The second is that both gravitational theories considered here have been formulated in a gauge theoretic way. Here we would like to start by reviewing the gauge theoretic approach of gravities commenting in particular their diffeomorphism invariance. Then we will review the construction of the Conformal Gravity and the Noncommutative (Fuzzy) Gravity using the gauge theoretic framework. Finally based on an extension of the four-dimensional tangent group we will present the Unification of both Gravities with the Internal Interactions.

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Anisotropic model in scale-dependent gravity

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The cosmological dynamics of a scalar-dependent gravitational model, whereby both the Newtonian coupling constant \(G \) and the cosmological constant \(\Lambda \) vary as functions of cosmic time, were examined within the framework of a spatially homogeneous anisotropic Bianchi type-I cosmological model. The dimensionless variables, including the normalized Hubble parameter $h = H/H_0$, energy mass, and dark energy density Ω_m and Ω_Λ, facilitated the transformation of the modified gravitational field equations into a closed system of five first-order, coupled differential equations in redshift space, with $g = G/G_0$ and $Z = dg/dz$ were numerically integrated using a fourth-order Runge-Kutta method, employing initial conditions that were consistent with Planck data. The model's predicted values for the deceleration parameter $q(z)$, the effective equation of state $w_{\text{eff}}(z)$, the statefinder parameters $r(z)$ and $s(z)$, and the $Om(z)$ diagnostic were juxtaposed with those derived from the concordance ΛCDM model. The study indicates that, within this scenario, the universe has transitioned from a decelerating phase in the past to an accelerating phase currently, with w_{eff} approaching -1 at low redshifts. The statefinder and Om diagnostics confirm that the scalar-dependent gravity model closely approximates ΛCDM in late epochs, permitting slight deviations that indicate fluctuations in G and Λ. The findings suggest that scale-dependent gravitational couplings in anisotropic backgrounds may provide a coherent and convincing alternative explanation for the late-time acceleration of the universe.

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Timelike Geodesics and Their Flows in Black Hole Spacetimes

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Canonical transformations and Hidden Symmetries in the ΛCDM and Scalar field Cosmology

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Entanlement in gravitational pair creation and laboratory analogues

Author: Adria delhom[None]

Pair creation phenomena due to external background fields are predicted in many contexts. In particular, gravitational scenarios such as expanding universes or black hole spacetimes predict the spontaneous generation of entangled quanta. In this talk we will outline the main mechanisms behind these phenomena, highlighting its quantum features, and showing how they extend in a straightforward manner to laboratory setups. We will then discuss recent predictions and experiments allow us to probe the quantum aspects of particle creation phenomena.

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Radiating stars inspired by Naresh Dadhich

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Introduction to Analogue Gravity

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Tomographic Mapping of Cosmic Structure Growth with HIRAX and Rubin-LSST

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This project focuses on how well the Hydrogen Intensity and Real Time Analysis Experiment (HIRAX) and Rubin Legacy Survey of Space and Time (LSST) will do in constraining cosmological parameters relating to the large-scale structure (LSS) of the universe. Neutral hydrogen (HI) and weak gravitational lensing are used as tracers in this work. The parameters constrained in this project are the growth rate, $f\sigma_8$, and HI bias, $b\sigma_8$, using the Fisher matrix formalism. Furthermore, these parameters are estimated across a range of redshift bins to illustrate and understand the evolution of the LSS of the universe.