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The 3rd International Online Conference on Universe

4–6 March 2026 | Online

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The 3rd International Online Conference on Universe

4–6 March 2026 | Online

MDPI

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Welcome from the Chair

Dear colleagues,

After the very successful 2021 and 2023 editions, it is my honour to invite you to join the 3rd International Online Conference on Universe (IOCU 2026), to be held from **4 to 6 March 2026, CET, online**, which will enable you to share and discuss your most recent findings with the global community of scientists and researchers in these fields.

It is a pleasure to still be able to collaborate electronically via this online venue. This internet conference is designed to allow you to present your research to colleagues and interact as fully as possible with all those involved in it. I also hope that you will meet old friends and make new ones here. There will be many fascinating papers to spark everyone's interest.

I hope that this conference will bring together major contributions at the forefront of research in the fields of gravitation, cosmology, field theory, high-energy physics, quantum mechanics, astrophysics and astronomy, etc., and I am confident that yours will be among them. IOCU 2026 will make your presentation accessible to hundreds of researchers worldwide, with active engagement of the audience in question-and-answer sessions and discussion groups that will take place online.

Submitted abstracts will be peer-reviewed by the conference committee. After the conference, authors of accepted contributions are welcome to submit a full proceedings paper (4–8 pages), which will be published free of charge in the *Physical Sciences Forum*. Following the conference, selected contributions will be invited to be submitted for publication in the journal *Universe* (ISSN: 2218-1997, Impact Factor: 2.6) with a **20% discount** on the publication fee.

In recognition of the valuable contributions of the conference's distinguished authors and their exceptional scientific achievements, we are excited to announce that the conference will be presenting **four awards**, including the Best Oral Presentation Awards and Best Poster Awards. Each winner will receive a certificate and a prize of **CHF 300**.

We look forward to seeing you at this exciting event!

Prof. Dr. Lorenzo Iorio
Conference Chair
Ministero dell'Istruzione e del Merito, Fellow of the Royal Astronomical Society (F.R.A.S.), Bari (BA), Italy

Universe (ISSN 2218-1997) is an international peer-reviewed open access journal focused on theoretical, experimental, and observational progress in fundamental and applied physics from circumterrestrial space to cosmological scenarios. The journal focuses on publishing research articles, reviews, and communications, but other article types will also be considered. Our aim is to encourage scientists to publish their research results in as much detail as possible. There is no restriction on the maximum length of the papers.

Impact Factor: 2.6 (2024); 5-Year Impact Factor: 2.6 (2024)

Session Chairs

Prof. Dr. Gerald B. Cleaver
Center for Astrophysics, Space Physics, and Engineering Research (CASPER), Department of Physics, Baylor University, USA

Prof. Máté Csanád
Department of Atomic Physics, Eötvös Loránd University, Hungary

Dr. Paola Marziani
National Institute for Astrophysics (INAF), Astronomical Observatory of Padua, Italy

Prof. Dr. Nicolas Chamel
Institute of Astronomy and Astrophysics, Université Libre de Bruxelles, Belgium, Brussels laboratory of the Universe (BLU-ULB), Belgium

Dr. Jacco Th. van Loon
Lennard-Jones Laboratories, Keele University, UK

Prof. Joan Solà Peracaula
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Prof. Dr. Andreas Fring
Department of Mathematics, City St George's, University of London, UK

Prof. Marcello Abbrescia
Department of Physics, University of Bari, Italy, National Institute for Nuclear Physics (INFN) Section of Bari, Italy

Prof. Dr. Maxim Khlopov
Virtual Institute of Astroparticle Physics, France

Dr. Chunyu Ding
Institute for Advanced Study,
Shenzhen University, China

Invited Speakers

Prof. Dr. Victor Flambaum

School of Physics, University of New South Wales, Australia

Dr. Swayamtrupta Panda

International Gemini Observatory, NSF NOIRLab, Chile

Dr. Sándor Lökös

Institute for Nuclear Physics, Polish Academy of Sciences, Poland,
Hungarian University for Life Sciences, Hungary

Prof. Dr. Carl Bender

Physics Department, Washington University in Saint Louis, USA

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Physics Department, Federal University of Paraíba, Brazil

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Prof. Dr. Andrea Addazi

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Faculty of Mathematics, University of Bialystok, Poland

Prof. Dr. Konstantin Belotsky

National Research Nuclear University MEPhI, Russia

Program Overview

	4 March 2026	5 March 2026	6 March 2026
Morning	Invited Talks from **Session 8:** Cosmology and Particle Physics **Session 1:** Gravitation and Cosmology	**Session 5:** Space and Planetary Sciences **Session 7:** Solar and Stellar Physics	**Session 3:** High Energy Nuclear and Particle Physics
Afternoon	**Session 1:** Gravitation and Cosmology	**Session 6:** Galaxies, Clusters and Compact Objects	**Session 2:** Quantum Gravity and Field Theory **Session 4:** Foundations of Quantum Mechanics

Note: Invited talks from Session 8 (Cosmology and Particle Physics) will be included as 15-minute presentations on the first day of the conference, followed by extended 30-minute discussions in the Satellite Workshop on 9 March 2026. Selected oral presentations from Session 8 will only be featured as part of the Satellite Workshop.

IOCU 2026 Program

4 March 2026

Invited Talks from S8. Cosmology and Particle Physics (Extended discussion will be featured in the Satellite Workshop)

Time: 8:30–12:20 (CET)

Time (CET)	Speaker	Title
8:30–8:40	*Opening Remarks* *Event Chair* *Prof. Dr. Lorenzo Iorio*	
8:40–8:50	*Welcome Speech from Session Chair* *Prof. Dr. Maxim Khlopov*	
8:50–9:05	Prof. Dr. Victor Flambaum Invited Speaker	Dark matter across scales: ultralight fields, Bose star signatures, massive compact composites, and the absorption–ionisation mechanism
9:05–9:20	Prof. Dr. Andrea Addazi Invited Speaker	Resonant graviton-photon and Axion-photon conversions in Cosmological Magnetic Fields
9:20–9:35	Prof. Dr. Sergey Rubin Invited Speaker	Spontaneous formation of two-brane structures and their astrophysical manifestations
9:35–9:50	Prof. Dr. Saibal Ray Invited Speaker	Re-examining the cosmological models of cubic and f(P) gravity with advanced machine learning approaches
9:50–10:05	Prof. Dr. Konstantin Belotsky Invited Speaker	The search for dark matter signal in cosmic rays
10:05–10:15	Break (10 minutes)	

S1. Gravitation and Cosmology

Time (CET)	Speaker	Title
10:15–10:25	*Welcome Speech from Session Chair* *Prof. Dr. Joan Solà Peracaula*	
10:25–11:00	Prof. Dr. Victor Flambaum Invited Speaker	Effects of Dark Matter and Space-Time Variation of Physics Constants in Atomic Phenomena
11:00–11:35	Prof. Dr. Arman Shafieloo Invited Speaker	Status of the Concordance Model of Cosmology
11:35–11:50	Dr. Tanmoy Paul Oral Presentation	Natural validation of first and second law of thermodynamics in cosmology (with/without viscosity)
11:50–12:05	Dr. Simran Arora	Dynamical dark energy parameterizations in VCDM
12:05–12:20	Dhiraj Kuniyal Oral Presentation	A Scalar-Tensor approach to the Dark Universe paradigm: Bayesian Inference and the Hubble tension

S1. Gravitation and Cosmology

Time: 14:00–17:00 (CET)

Time (CET)	Speaker	Title
14:00–14:35	Prof. Dr. Joan Solà Peracaula Invited Speaker	Towards a unified quantum field theory of inflation and dark energy: unstable de Sitter vacuum and running vacuum
14:35–15:10	Prof. Dr. Nick E. Mavromatos Invited Speaker	Axions, Black Holes and Squeezed gravitons: a new route towards detection of quantum gravity?
15:10–15:45	Dr. Adrià Gómez-Valent Invited Speaker	Did dark energy cross the phantom divide? Observational hints and phenomenology
15:45–16:00	Dr. Matteo Califano Oral Presentation	Constraining Cosmology and Binary Black Hole Population Properties with Einstein Telescope Observations
16:00–16:15	Prof. Dr. Konstantin Zioutas Oral Presentation	Planetary dependency: the signature for streaming dark matter
16:15–16:30	Prof. Dr. Orchidea Maria Lecian Oral Presentation	About the qualities of the Schwarzschild and Generalized Schwarzschild geometries
16:30–16:45	Dr. Kirill Zatrimaylov Oral Presentation	Warp Drives, Black Holes, and Wormholes

16:45–17:00	**Miguel Barroso Varela** Oral Presentation	Inflationary dynamics of non-minimally coupled f(R) matter–curvature theories

5 March 2026

S7. Solar and Stellar Physics

Time: 8:25–12:00 (CET)

Time (CET)	Speaker	Title
8:25–8:35	*Welcome from the Session Chair* *Dr. Jacco Th. van Loon*	
8:35–8:50	**Dr. Satenik Ghazaryan** Oral Presentation	Chemically Peculiar stars' strong overabundances of very heavy elements: related to supernovae?
8:50–9:05	**Dr. Amir Michaelis** Oral Presentation	From Single Degenerate Quiescent Helium Accretion to Double Detonation Type Ia Supernova
9:05–9:20	**Zsófia Bora** Oral Presentation	High-Velocity Features in Type Ia Supernovae—A puzzle still waiting to be solved after 26 years
9:20–9:45	**Dr. Silvia Toonen** Invited Speaker	Beyond Isolation: Rethinking Interacting Stars
9:45–10:00	**Dr. Sophie Rosu** Oral Presentation	Apsidal motion in binaries: probing the interiors of stars using tides
10:00–10:15	**Prof. Dr. Costantino Sigismondi** Oral Presentation	Photometry of Antares from 1995 to 2025 with SOHO
10:15–10:25	Break (10 minutes)	

S5. Space and Planetary Sciences

Time (CET)	Speaker	Title
10:25–10:35	*Welcome from the Session Chair* *Dr. Chunyu Ding*	
10:35–11:15	**Prof. Dr. Josep Maria Trigo-Rodríguez** Invited Speaker	First steps in asteroid mining: the need of sample return to identify precious targets
11:15–11:30	**Nóra Takács** Oral Presentation	Beyond Planets: Simulating Exocomet Transits in High-Precision Photometry
11:30–11:45	**Sena Toyonaga** Oral Presentation	Contradictory results in the rock magnetic and SEM-EDS characteristics of the carbonaceous chondrite NWA 11469
11:45–12:00	**Dr. Ákos Kereszturi** Oral Presentation	Planetary science education in Hungary: interdisciplinary methods at university level

S6. Galaxies, Clusters and Compact Objects

Time: 13:30–16:25 (CET)

Time (CET)	Speaker	Title
13:30–13:40	*Welcome from the Session Chairs* *Prof. Dr. Nicolas Chamel & Dr. Paola Marziani*	
13:40–14:05	**Prof. Dr. Renxin Xu** Invited Speaker	Strangeon Stars
14:05–14:20	**Greta Siu** Oral Presentation	Accreting Black Holes in Molecular Clouds
14:20–14:35	**Dr. Krisztina Perger** Oral Presentation	On the Extreme Radio Quiescence of Little Red Dots
14:35–14:50	**Dr. Zhong-Hao Tu** Oral Presentation	Constraining the Equation of State with Glitch Dynamics: Case Study of 2016 Vela Glitch
14:50–15:15	**Dr. Swayamtrupta Panda** Invited Speaker	From Light Echoes to the Hubble-Lemaitre Constant: Quasar variability as a standalone cosmological probe
15:15–15:30	**Nilanjana Nandi** Oral Presentation	The dynamical lineage of ultra-diffuse galaxies from TNG50-1
15:30–15:45	**Dr. Jay V Kalinani** Oral Presentation	Jet-environment interaction after delayed collapse in binary neutron star mergers
15:45–16:00	**Dr. Máté Krezinger** Oral Presentation	High-redshift blazar classification through multi-wavelength data
16:00–16:25	**Dr. Kent Yagi** Invited Speaker	Probing dense matter physics and pressure anisotropy with neutron stars

6 March 2026

S3. High Energy Nuclear and Particle Physics

Time: 10:00–11:50 (CET)

Time (CET)	Speaker	Title
10:00–10:10	*Welcome from the Session Chairs* *Prof. Máté Csanád & Prof. Marcello Abbrescia*	
10:10–10:35	**Dr. Sándor Lökös** Invited Speaker	Entropy and multiplicity of hadrons in the high energy limit within dipole cascade models
10:35–10:50	**Prof. Chunjian Zhang** Oral Presentation	Imaging nuclear structure across energy scales: from heavy to light ions
10:50–11:05	**Alexandra Peryatinskaia Igorevna** Oral Presentation	Numerical model of the dipole phase change in Galactic Cosmic-Ray Anisotropy
11:05–11:20	**Mahesh Kumar Saini** Oral Presentation	The CMS Forward Muon System Upgrade with GEM Detectors
11:20–11:35	**Adarsh Karekkat** Oral Presentation	Ginzburg-Landau Type Model For The Outer Core Of Neutron Stars
11:35–11:50	**Dr. Cecilia Levy** Oral Presentation	The Snowball Chamber: A Multidisciplinary Radiation Detector

S2. Quantum Gravity and Field Theory

Time: 14:00–17:45 (CET)

Time (CET)	Speaker	Title
14:00–14:10	*Welcome from the Session Chair* *Prof. Dr. Gerald Cleaver*	
14:10–14:35	**Dr. Iarley P. Lobo** Invited Speaker	To Deform or to Violate Lorentz Symmetry? Probing Quantum Gravity with high energy particles
14:35–14:50	**Dr. Ritabrata Biswas** Oral Presentation	Barrow Entropy and Quantum-Induced Fractality of Black Hole Horizons
14:50–15:05	**Dr. Abhishek Kumar Mehta** Oral Presentation	Thermodynamic Remnants in Black-hole evaporation
15:05–15:20	**Stuart Marongwe** Oral Presentation	Quantum Gravity outperforms General Relativity: A new chapter in black hole physics
15:20–15:45	Break (25 minutes)	

S4. Foundations of Quantum Mechanics

Time (CET)	Speaker	Title
15:45–15:55	*Welcome Speech from Session Chair* *Prof. Dr. Andreas Fring*	
15:55–16:20	**Prof. Dr. Jean-Pierre Gazeau** Invited Speaker	Spectral-angular parametrization of open qudit dynamics and related purety
16:20–16:45	**Prof. Dr. Carl M. Bender** Invited Speaker	PT-symmetric quantum mechanics: Physics off the real axis
16:45–17:00	**Dr. Alexander Felski** Oral Presentation	A multi-Hamiltonian approach to higher time-derivative theories: An interacting Pais-Uhlenbeck model
17:00–17:15	**Dr. Aritra Ghosh** Oral Presentation	Strong-coupling energetics of a Brownian quantum oscillator: the mean energy, its interpretation, and low-temperature behavior
17:15–17:30	**Prof. Dr. Marta Reboiro** Oral Presentation	Dependence of the Exceptional Points on the Temperature in a Pseudo-Hermitian Hybrid Model.
17:30–17:45	*Discussion and Closing Remarks* *Prof. Dr. Lorenzo Iorio*	

9 March 2026

Satellite Workshop (Morning)

Time: 8:30–12:05 (CET)

Time (CET)	Speaker	Title
8:30–8:40	*Opening & Welcome Remark from Workshop Chair* *Prof. Dr. Maxim Khlopov*	
8:40–9:10	**Prof. Dr. Victor Flambaum** Invited Speaker	Dark matter across scales: ultralight fields, Bose star signatures, massive compact composites, and the absorption–ionisation mechanism
9:10–9:40	**Prof. Dr. Andrea Addazi** Invited Speaker	Resonant graviton-photon and Axion-photon conversions in Cosmological Magnetic Fields
9:40–9:55	**Subhasis Maiti** Oral Presentation	Multi-Messenger Probes of Primordial Magnetogenesis, PBH Dark Matter, and Induced Gravitational Waves
9:55–10:10	**Yuldash Khamraev** Oral Presentation	Mechanisms of Cosmic Ray Flux Suppression During Solar Flare Activity and Solar Storms
10:10–10:20	Break (10 minutes)	
10:20–10:50	**Prof. Dr. Saibal Ray** Invited Speaker	Bouncing Cosmological Model in f (Q, Lm) Modified Gravity: A Few Physically Interesting Features of Cosmic Evolution
10:50–11:05	**Roger Ivan Ayala Oña** Oral Presentation	A supersymmetric model of scalar and spinor fields in a closed isotropic universe
11:05–11:20	**Sushant Yadav** Oral Presentation	Comprehensive Phenomenology of the Dirac Scotogenic Model: Novel Low-Mass Dark Matter
11:20–11:35	**Dr. Manoranjan Dutta** Oral Presentation	A Common Origin of Asymmetric Self-interacting Dark Matter and Dirac Leptogenesis
11:35–11:50	**Raza ur Rehman Mir** Oral Presentation	Dirac Leptogenesis via Scattering Using the CTP Formalism
11:50–12:05	**Suhail Khan** Oral Presentation	Sterile neutrino dark matter from a TeV-scale seesaw

Satellite Workshop (Afternoon)

Time: 14:00–17:40 (CET)

Time (CET)	Speaker	Title
14:00–14:30	**Prof. Dr. Konstantin Belotsky** Invited Speaker	The search for dark matter signal in cosmic rays
14:30–15:00	**Prof. Dr. Konstantin Zioutas** Invited Speaker	Planetary dependency: the signature for streaming dark matter
15:00–15:15	**Qin Han** Oral Presentation	Making robust reionisation 21 cm signal predictions with C21LRT
15:15–15:30	**Ivan Cagnani** Oral Presentation	A background-free search for physics beyond the standard model using atom interferometry
15:30–15:45	**Maxim Krasnov** Oral Presentation	Effects of spontaneous Z2 symmetry breaking or restoration in Gauss–Bonnet gravity
15:45–16:00	**Rudhresh Manoharan** Oral Presentation	Symbolic Regression for Interpretable Cosmological Parameter Inference from the Cosmic Microwave Background
16:00–16:10	Break (10 minutes)	
16:10–16:40	**Prof. Dr. Sergey Rubin** Invited Speaker	Spontaneous formation of two-brane structures and their astrophysical manifestations
16:40–16:55	**Danila Sopin** Oral Presentation	Interaction of heavy multiply-charged particles with light nuclei during Big Bang nucleosynthesis
16:55–17:10	**Luigi Ernesto Ghezzer** Oral Presentation	A signature of dark matter annihilation in cosmic rays using a plastic scintillator detector
17:10–17:25	**Prof. Dr. Bruce M. Law** Oral Presentation	A unified approach to Dark Energy, Dark Matter, and Cosmic Inflation
17:25–17:40	*Discussion and Closing Remarks* *Prof. Dr. Maxim Khlopov*	

Session 1. Gravitation and Cosmology

sciforum-161627: Quasi-Normal Modes of Generic Type D Black Holes via Heun Functions

Ritapriya Pradhan *, Kent Yagi

Department of Physics, University of Virginia, Charlottesville, Virginia, 22903, USA

The increasing diversity and precision of gravitational-wave (GW) observations provide unprecedented opportunities to perform stringent tests of general relativity (GR). Although several conceptual and observational challenges motivate the development of modified theories of gravity, a crucial prerequisite is a complete understanding of all phenomena allowed within GR itself. A key result in this context is the no-hair theorem, whose classical formulation relies on the assumption of asymptotic flatness. When this assumption is relaxed, GR already admits a much richer space of solutions with additional “charges.”

In this work, we investigate asymptotically non-flat black-hole spacetimes within GR, focusing on the full Plebanski–Demianski (PD) class of algebraic type D solutions. This general family of metrics is characterized by up to seven independent parameters: mass, spin, electric charge, magnetic charge, acceleration, cosmological constant, and NUT charge. Our objective is to compute the quasi-normal modes (QNMs) of these black holes in their most general form.

Two notable subclasses—Kerr–de Sitter black holes and accelerating (C-metric) black holes—have previously been shown to yield Teukolsky equations that reduce to the general Heun equation with four regular singular points. Such equations can now be solved efficiently using Mathematica’s Heun function framework, allowing high-precision computation of QNM frequencies within seconds. Heun functions are generalizations of hypergeometric functions; they are the solutions to the general Heun equation.

We extend these results by demonstrating that the Teukolsky equation for the full PD metric also maps to the general Heun equation. Consequently, we obtain a unified method to compute QNM spectra across the entire seven-parameter family and investigate how each parameter influences the oscillation and damping frequencies.

This generalization significantly broadens the landscape of GR-consistent QNM predictions and should be taken into account when interpreting future GW observations and formulating robust tests of GR.

sciforum-161670: Gravitational-Wave Constraints on Neutron-Star Pressure Anisotropy via Universal Relations

Victor Guedes [1,*], Siddarth Ajith [1], Shu Yan Lau [2], Kent Yagi [1]

[1] Department of Physics, University of Virginia, Charlottesville, USA
[2] Department of Physics, Montana State University, Bozeman, USA

Neutron stars may exhibit pressure anisotropy arising from several microphysical processes, including strong magnetic fields, elastic stresses, and viscous effects. In this work, we investigate how pressure anisotropy influences two key observables: the tidal deformability measured in gravitational-wave signals from binary inspirals, and the fundamental quadrupolar mode (f-mode) oscillation frequency associated with stellar perturbations. We model anisotropic neutron stars using a phenomenological quasi-local prescription governed by a single dimensionless anisotropy parameter, allowing us to systematically explore deviations from isotropy. Our analysis demonstrates that, although the universal relation between tidal deformability and f-mode frequency varies with the strength of anisotropy, it remains remarkably insensitive to changes in the underlying equation of state that relates radial pressure to energy density. This behavior mirrors the well-known approximate universality found in isotropic stars. Taking advantage of this anisotropy-dependent universal relation, we perform Bayesian inference to constrain the anisotropy parameter using data from both the gravitational-wave event GW170817 and a simulated GW170817-like event detected by a future network. We show that current data restrict the anisotropy parameter to values of order unity, and that future measurements yield comparable bounds. Notably, these constraints are only weakly influenced by remaining uncertainties in the neutron-star equation of state.

sciforum-164035: Constraining Cosmology and Binary Black Hole Population Properties with Einstein Telescope Observations

Matteo Califano [1,*], Ivan de Martino[2], Daniele Vernieri[3]

[1] Ministero dell' Istruzione e del Merito, Viale Trastevere 76/a, 00153, Rome, Italy
[2] Departamento de Física Fundamental, Universidad de Salamanca, Plaza de merced, s/n, E-37008 Salamanca, Spain
[3] Dipartimento di Fisica "E. Pancini", Università di Napoli "Federico II", Via Cinthia 21, 80126 Napoli, Italy

Third-generation gravitational-wave observatories such as the Einstein Telescope (ET) will enable unprecedented studies of both cosmology and compact-object populations using large samples of "dark sirens," i.e., gravitational-wave events without electromagnetic counterparts. In this presentation, we explore the ability of ET to jointly infer the underlying cosmological model and the mass and redshift distributions of binary black hole (BBH) mergers using one year of observations. We assume a flat ΛCDM cosmology and model the BBH population with a smoothed power-law plus Gaussian mass distribution and a Madau–Dickinson parametrization for the merger-rate redshift evolution. Using mock BBH catalogs generated for different signal-to-noise ratio (SNR) detection thresholds, we perform a hierarchical Bayesian analysis that consistently accounts for selection effects and measurement uncertainties. We find that decreasing the SNR threshold leads to a substantial improvement in the precision of the Hubble constant H_0 and the matter density parameter $\Omega_{m,0}$, primarily due to the inclusion of a larger number of high-redshift events. However, this gain is accompanied by non-trivial degeneracies between cosmological and astrophysical parameters, whose structure evolves with the SNR threshold. This study highlights the importance of joint population–cosmology inference with third-generation detectors and demonstrates the strong potential of the Einstein Telescope to advance dark-siren cosmology while simultaneously deepening our understanding of black hole formation and evolution.

sciforum-155077: Evidence for Dynamical Dark Energy from BAO Data: Testing Double-Crossing Parametrizations

Saddam Hussain

Institute for Theoretical Physics and Cosmology, Zhejiang University of Technology, Hangzhou, 310023, China

Recent BAO (Baryonic Acoustic Oscillation) observations—large-scale clustering features of galaxies that act as a standard ruler for cosmic expansion—from dark energy surveys have reignited the debate over the dynamical nature of dark energy, revealing deviations from the standard LambdaCDM model at more than the 4sigma level. To capture departures from a cosmological constant, several parametric models of the dark energy equation of state have been proposed, often based on series expansions in redshift. These studies consistently suggest phantom behavior, characterized by an equation-of-state parameter, at higher redshifts. Such behavior is theoretically problematic, as it can lead to ghost instabilities, namely negative-energy degrees of freedom that render the theory unstable at the perturbative level.

Since the influence of dark energy naturally weakens at high redshifts, we propose a double-crossing, bell-shaped parametrization of the dark energy equation of state, where the cosmological constant boundary is crossed twice during cosmic evolution. This form is more sensitive to low-redshift dynamics compared to conventional series-based parametrizations. We show that this model exhibits transient phantom behavior (w-1) near the matter–dark energy equality epoch, but evolves into a quintessential regime (w>-1) at present and at higher redshifts, thereby avoiding ghost-related instabilities. Such short-lived phantom behavior at low redshifts may arise from mechanisms such as non-minimally coupled gravity theories. Furthermore, we demonstrate that non-canonical scalar field models interacting with dark matter, when constrained by multiple cosmological probes, favor a quintessential-like evolution with no evidence for phantom behavior, supporting the possibility that modified gravity effects play a role primarily at low-redshift epochs.

sciforum-163613: Memory Effects in the Early Universe: Exact Perturbations in Fractional Scalar Field Cosmology

Daniel APARECIDO VICENTE Oliveira [1,*], Seyed Rasouli [2], João Marto [2], Paulo Moniz [2]

[1] UBI
[2] Universidade da Beira interior

Standard inflationary models, while successful, often require fine-tuned potentials to satisfy current observational constraints on the spectral index (n_s) and the tensor-to-scalar ratio (r). In this work, we propose a generalized cosmological framework based on fractional calculus, where the effective action includes non-local memory terms arising from a modified gravitational coupling. We investigate the dynamics of a scalar field against an n-dimensional Friedmann–Lemaitre–Robertson–Walker (FLRW) background, demonstrating that the fractional order parameter, α, introduces a cumulative friction term, (1 - α)/H^-1, into the background equations.

Crucially, we extend this analysis to linear cosmological perturbations. By enforcing variational consistency, we derive the Fractional Mukhanov–Sasaki equation, which explicitly incorporates memory effects. We solve this equation analytically for power-law inflation, obtaining exact mode functions in terms of Hankel functions. The resulting power spectra reveal that the spectral index and tensor-to-scalar ratio are modified by the fractional parameter, taking the form n_s(α, m) and r(α). We show that these memory effects can naturally suppress the tensor-to-scalar ratio without requiring complex potentials, bringing power-law inflation back into agreement with recent Planck and BICEP/Keck data. This framework offers a novel, mathematically rigorous mechanism to address the "fine-tuning" problems of standard inflation through the lens of non-local gravity.

sciforum-161676: A Scalar-Tensor approach to the Dark Universe paradigm: Bayesian Inference and the Hubble tension

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Persistent discrepancies among low and high redshift probes, most notably, the Hubble tension, motivate systematic investigations of cosmologies involving a dynamical dark energy component, rather than a cosmological constant (Lambda) candidature of the latter which gives rise to the standard Lambda-CDM model. Interacting Dark Energy-Matter (IDEM) scenarios provide a more compelling framework in this direction, especially when viewed through modified gravity or their Scalar–Tensor equivalents, however, in the Jordan frame, such interactions do not arise naturally, as the scalar field is non-minimally coupled to gravity. A conformal transformation to the Einstein frame decouples the gravitational and scalar degrees of freedom, but induces a non-minimal coupling between the scalar field and cosmological matter (including the CDM), thereby generating an IDEM-type interaction when the scalar field acts as dark energy. Within this Einstein-frame Scalar–Tensor formulation, we therefore adopt a scenario in which dark energy interacts exclusively with dark matter, whereas the visible matter component remains minimally coupled to both gravity and the IDEM. Thus, the large-scale dilution rates of the dark matter and the visible matter with the cosmological scale factor differ, and this is in principle feasible as we demonstrate explicitly. We carry out a full Bayesian parameter-inference analysis using the standard Metropolis-Hastings algorithm for the Markov Chain Monte Carlo (MCMC) method, by jointly incorporating the Pantheon+ Type~Ia Supernova sample, Observational Hubble Parameter (OHD) measurements via Cosmic Chronometry (CC), and Baryon Acoustic Oscillation (BAO) data from SDSS-IV and DESI-VI. We present updated constraints on the dark-sector coupling parameter and the Hubble constant, and assess the comparative statistics of this Scalar–Tensor IDEM relative to Lambda-CDM using information criteria such as AIC and BIC. The resulting posteriors and reconstructed expansion history illustrate the framework's impact on the Hubble tension and strengthen its observational viability within Scalar–Tensor gravity.

sciforum-165000: A unified approach to Dark Energy, Dark Matter, and Cosmic Inflation

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The electron Born self-energy (eBse) model assumes a finite-sized electron of radius $R_e = 1.9 \times 10^{-20}$m, determined from electron–positron collisions at LEP. The Born self-energy U_e^B, corresponding to the energy contained in the surrounding electric field, provides a quantitative description of Dark Energy (Astrophys Space Sci **365**, 64 (2020); Phys Sci Forum **2**, 9 (2021)). Specifically, this model explains (i) the magnitude of DE, (ii) the occurrence of a deceleration-acceleration transition at a redshift z ~ 0.8, and (iii) possesses an equation of state w = -1. (In Quantum Electrodynamics the electron is assumed to be a point particle ($R_e = 0$), thus, $U_e^B \sim 1/R_e$ is divergent and is "renormalized away" by assuming that U_e^B is contained within the electron rest mass m_e.) w = -1 implies that two electron Born masses $m_e^B = U_e^B/c^2$ will experience a gravitational repulsion, whereas, m_e^B and an uncharged mass will experience the normal gravitational attraction. m_e^B (~ 40 m_p) is a Dark Matter candidate which provides a good description of the Grand Rotation Curves for the Milky Way and M31 galaxies out to distances of ~ 400 kpc (Sci Rep **14**, 24090 (2024)). (The difference between DE and DM, in this model, is as follows: DE arises from the ***time-dependent*** creation of m_e^B in intergalactic space due to ionization of hydrogen, whereas, DM is a ***time-independent*** effect arising from the presence of a halo of electrons, along with their associated m_e^B, that surrounds a galaxy.) Early in the Universe's expansion history, for electrons and positrons of finite-size, a glass transition occurs at a maximum number density of ~ $1/(2R_e)^3$ corresponding to physical contact between particles. This glass transition possesses properties akin to Cosmic Inflation (Sci Rep **13**, 21798 (2023)). A brief summary of the eBse model and its interconnections to DE, DM, and CI will be provided in this contribution.

sciforum-160978: About the Qualities of the Schwarzschild and Generalized Schwarzschild Geometries

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Schwarzschild solitons and Generalized Schwarzschild solitons have recently been studied on the new metrized smooth metric space of convex functions.

The completeness of geodesics and the Cauchy hypersurfaces are established for Schwarzschild spacetimes after correction [Hawking, S.W.: Commun. Math. Phys. 25, 152–166 (1972).].

The solitons are newly posed on the pseudo-spherical General Relativistic cylinder, with new equations set and uniquely solved.

The uniqueness of Schwarzschild solitons is newly investigated.

The concurrent vector field in General Relativity is newly defined, and the 4-position vector is newly indicated as a concurrent vector field in General Relativity; the Killing vector field is newly determined accordingly to the 4-velocity vector when the configuration of the observer frame is chosen as one solidal with the photon.

New isopoertimetric inequalities and new curvature estimates are provided to hold. New thoerems are proven about these geometries.

The Penrose tipping lightcones are newly written for these spacetimes; the cross-sections are determined accordingly. Accordingly, the Yamabe flow on the S2 sphere is newly proven to converge for submersion from a Schwarzschild spacetime: geodesics spheres are taken into account.

Submersions and immersions are newly discussed when these spacetimes are considered according to the pullback from the metric tensor.

The elements are also gathered for discussion of the Penrose 1965 Theorem.

sciforum-161603: Accretion Induced Mass Evolution of a Schwarzschild Black Hole Under BRB Redshift Parameterized Dark Energy: A Differential Ages Constraint Analysis

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The Schwarzschild black hole (BH) constitutes a fundamental exact solution of Einstein's field equations in general relativity, representing the exterior geometry of a spherically symmetric mass in a vacuum in the absence of a cosmological constant Λ. However, the accelerated expansion of the universe is attributed to dark energy (DE) which is intrinsically linked to a non-zero cosmological constant Λ. Hence, incorporating DE naturally requires the Λ-modified Einstein field equations. To investigate late-time cosmic acceleration, the Biswas Roy Biswas (BRB) parameterization of the dark-energy equation of state has been adopted. This model emphasizes low-redshift dynamics and offers significant flexibility in constraining observational data from SNeIa, BAO and CMB. Using a dataset of eighty five differential age measurements, we obtain the corresponding confidence contours and marginalized distributions for the free parameters. Spherical accretion of BRB type DE onto a Schwarzschild BH within the framework is studied which has been established by Bondi and Michel. Bondi's analysis shows that stationary, spherically symmetric flow becomes critical at the sonic point, where the infall velocity equals the local sound speed. In our formulation, the fluid equations similarly exhibit a singular structure at the sonic point, and only particular transonic solutions remain physically admissible. These solutions determine the Bondi accretion rate for BRB type DE onto the Schwarzschild spacetime. Our results indicate that, over the redshift interval 0 to 3, a Schwarzschild BH could gain approximately 55.331% of its present mass due to the accretion of BRB type DE.

sciforum-161585: An Analysis of Triply Ionised Carbon Absorption in the Spectrum of Q1422+23

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Intervening and intrinsic absorbers leave characteristic signatures on a quasar spectrum because each system removes light at wavelengths set by its own redshift and internal physical conditions. These differences reflect variations in cosmological distance, peculiar velocity, temperature and ionisation state of the absorbing gas. In this study, the spectrum of the high-redshift quasar Q1422+23 (RA 14:24:38.1, DEC +22:56:01), situated close to the bright star Arcturus, is examined with the goal of identifying and analysing triply ionised carbon (C IV) absorption systems along the line of sight. The emission redshift of the quasar is estimated to be about 3.62, placing it at a distance where metal-enriched gas associated with early galaxy formation can be probed in detail. The focus is on the C IV doublet at rest wavelengths 1548.204 Å and 1550.774 Å, a widely used tracer of highly ionised gas in both the intergalactic medium and the circumgalactic regions of galaxies. These lines provide a reliable measure of the ionisation structure and chemical content of the intervening systems. To extract accurate physical parameters, each detected feature is modelled with a Voigt profile that combines Gaussian broadening, caused by thermal motions and small-scale turbulence, with Lorentzian wings arising from natural line broadening. This approach allows a consistent determination of absorber redshift, line-of-sight velocity, cosmological distance, Doppler parameter and the relative contributions of thermal and non-thermal motions. Column densities are also derived to quantify the amount of ionised carbon in each component. The analysis reveals clear variations in redshift, velocity, width and column density among the identified absorption systems. These differences point to a diverse population of ionised structures enriched by earlier episodes of star formation and feedback. The results contribute to a better understanding of how metals are distributed and transported through the high-redshift universe and how the ionised gas evolves over cosmic time.

sciforum-163118: Black hole/Bose gas duality and statistical description of entropy

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The main objective of this talk is to identify black hole solutions that satisfy the third law of thermodynamics. We begin by examining the possibility of finding such solutions within the Einstein–Maxwell–Dilaton models with purely electric, purely magnetic, and electric–magnetic configurations coupled through two independent exponential coupling functions and subsequently analyze their thermodynamic properties. Our primary focus will be on anisotropic Lifshitz and hyperscaling Lifshitz solutions. It was found that for this model, the third law of thermodynamics is valid, while for most ordinary black holes, such as Schwarzschild, rotating, and charged black hole solutions, the third law of thermodynamics is violated.

We establish a duality between the Bose gas and these black brane solutions. This duality provides a statistical description of black hole entropy for various dimensions and anisotropy parameters. Our framework enables the construction of a microscopic statistical description of entropy for a broad class of non-extremal black holes through a generalization of the holographic duality approach. We demonstrate that anisotropy parameters serve as natural regulators of black hole/Bose gas duality.

The first part of the talk is based on the joint paper, "Black brane/Bose gas duality and the third law of thermodynamics", Irina Aref'eva, Igor Volovich, Daniil Stepanenko , 2411.01778 [hep-th], published in Teor.Mat.Fiz. 222 (2025) 2, 276-284, Theor.Math.Phys. 222 (2025) 2, 276-284.

sciforum-161434: Bulk Viscosity and Varying Constants

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When investigating various issues in cosmology and other areas of general relativity, a perfect fluid is usually considered. A perfect fluid is one with negligible viscosity and heat conduction. However, this is only an idealisation, and in more realistic situations, dissipative effects need to be considered. Secondly, there are several "constants of nature" such as Newton's gravitational constant G, the cosmological constant Λ, the speed of light c, the fine-structure constant α, Boltzmann’s constant $\Bar{h}$, Planck’s constant and Fermi’s constant G_F, which may not necessarily be constant, but could be varying. There have been several studies carried out with bulk viscosity together with variable G and Λ. In these studies, the modified energy conservation equation can be split up into the traditional equation, plus an equation involving the parameters G and Λ. However, many authors have split the full equation in such a way that the viscosity appears in the wrong equation. In such a situation, it is not possible to obtain the correct general relativistic limiting case. In this work, the relevant equations are re-analysed, showing that the bulk viscosity needs to be incorporated into the other equation and highlighting how the general relativistic limit is obtained.

sciforum-161053: Chiral cosmological models: Unifying inflation and PBH formation

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Chiral cosmological models (CCM) can be used to describe not only inflation, but also the formation of primordial black holes (PBH) in the early Universe, because these models can produce large amplitude peaks at small scales. CCMs are related to modified gravity models through a conformal transformation of the metric. Two-field CCMs are actively studied. One of the most well-known modified gravity models that leads to such a CCM is the Higgs-R^2 inflationary model, which reproduces the Planck/BICEP observational data, but deviates from more recent data of the Atacama Cosmological Telescope (ACT).

In two-field CCMs with PBH formation, inflation includes two stages. In the first stage, one scalar field evolves, while the second one remains almost constant. This stage satisfies the slow-roll conditions, which allows us to calculate the inflationary parameters using the slow-roll approximation. The second stage of inflation corresponds to the evolution of the second scalar field. The slow-roll regime is violated during a few e-folds after the end of the first stage of inflation. After that, the slow-roll approximation is restored. This breaking of the slow-roll approximation is a necessary condition for PBH formation. The duration of the second inflationary stage affects the mass of these PBHs.

We have constructed new two-field CCMs that are connected with induced and F(R) gravity models. At certain values of the model parameters, these models are in good agreement with ACT observation data and are suitable to describe the formation of primordial black holes with masses similar to those of dark matter candidates. This talk is based on the papers by E.O. Pozdeeva and S.Yu. Vernov (Phys. Part. Nucl. 56 (2025) 542 [arXiv:2407.00999] and arXiv:2509.21220) as well as recent investigations.

sciforum-160334: Construction of slow-roll approximations in the Jordan frame

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Models with nonminimally coupled scalar fields and *F(R)* gravity models are some of the most popular modified gravity models of cosmological inflation. Using the conformal transformation of the metric, one can transform the original modified gravity models to the General Relativity models with minimally coupled scalar fields; in other words, using the Einstein frame. The standard way to construct such modified gravity models is to consider them in the Einstein frame using slow-roll approximation. For the simplest inflationary *F(R)* gravity models, including the Starobinsky $R+R^2$ inflationary model, this method gives precise results, but F(R) gravity models with more complicated functions *F(R)* usually correspond to the inflaton potential given in the parametric form. Such *F(R)* functions usually appear in the models that describe not only inflation, but also primordial black hole formation.

The slow-roll approximation is a method used to analyse the dynamical properties of the early universe during inflation. We propose new versions of the slow-roll approximation for inflationary models with nonminimally coupled scalar fields and *F(R)* gravity models. We investigate the inflationary dynamics in the initial (Jordan) frame without the use of the conformal transformation and rewrite evolution equations in the Jordan frame in a form that is similar to the Friedmann equations in the Einstein frame. The proposed slow-roll approximations are described in the papers by E.O. Pozdeeva, M.A. Skugoreva, A.V. Toporensky, and S.Yu. Vernov, JCAP 05 (2025) 081 and S.V. Ketov, E.O. Pozdeeva, and S.Yu. Vernov, JCAP 12 (2025) 40. This approximation allows us to construct a new inflationary model with the fifth-order polynomial *F(R)* function. This model is in good agreement with the recent observations of the cosmic microwave background radiation obtained by the Atacama Cosmology Telescope. The presentation is based on these papers and recent results.

sciforum-163331: Determination of valid gravity theory from observations of astrophysical black hole images

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Einstein General Relativity Theory is usually used for the interpretation of the experimental cosmological data in the Friedman-Robertso-Worker framework. Meanwhile, the General Relativity Theory is verified only in the Solar system and in the near cosmological environments.

Observations of the black hole images open the unique possibility for this verification in the strong field limit when Newtonian gravitational potential is of the squared light velocity order and when gravitation dominates over astrophysical factors.

Experimental verification of the Einstein General Relativity Theory and different Modified Gravity theory by observations of detailed images of supermassive black holes with the use of projected Space Millimetron Observatory with nano-arcsecond angular resolution. These observations are very crucial for physical interpretation of astrophysical and cosmological data on the Universe and for understanding, in part, the physical origin of enigmatic dark matter and dark energy. Scrutinizing the different gravity theories would be possible in the nearest future after construction of the Space Millimetron Observatory with nano-arcsecond angular resolution.

The very promising astrophysical supermassive black holes for these verifications are the SgrA* at the center of our native Milky Way Galaxy and supermassive black hole M87* at the center of the giant elliptical galaxy M87, which itself is placed in the Virgo galactic cluster. The fist images of these black holes were observed recently by the Event Horizon Telescope collaboration with milli-arcsecond resolution.

It must be accented that the explicit point of this research is the verification of Einstein General Relativity and different modifications of gravity theory in the strong field limit.

sciforum-161593: Dynamical Behaviour of f(Q) Gravity in Bianchi-I Spacetime: Fixed Points, Anisotropy, and Cosmological Implications

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Modified gravity based on the non-metricity scalar Q offers an effective alternative to ΛCDM, with several proposed f(Q) models successfully reproducing the late-time cosmic acceleration inferred from Type Ia supernovae. Current observational anomalies—such as hemispherical temperature asymmetry, the Hubble tension, cosmic voids, dipole modulation, and hints of anisotropic inflation—further motivate exploring departures from the cosmological principle. In this work, we study a broad class of f(Q) gravity models in an anisotropic Bianchi-I background to investigate their dynamical behaviour and cosmological viability. Using dynamical systems techniques, we identify stationary points of the cosmic evolution and classify their stability. Perturbative analyses are performed where applicable. Several fixed points arise only when both f(Q) modifications and anisotropies are considered, highlighting genuinely new cosmological features absent in isotropic or GR-based frameworks. In addition to recovering standard inflationary and late-time accelerating phases, we find that some models naturally support ultra-slow-roll inflation. For certain choices of f(Q), the shear evolves toward a non-zero constant, indicating a universe that gradually becomes more homogeneous, while other models allow complete isotropization depending on initial conditions. Special subclasses exhibit multiple stable attractors, each corresponding to distinct cosmological end-states. Our results demonstrate that f(Q) gravity in Bianchi-I spacetime provides a rich dynamical structure capable of addressing key cosmological tensions while offering novel predictions for both early- and late-time anisotropic evolution.

sciforum-153311: Dynamical dark energy parameterizations in VCDM

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In the context of the theory of minimally modified gravity known as VCDM, one can realize any cosmological behavior at the level of the homogeneous and isotropic background without introducing fatal instabilities for perturbations. The ‘V’ in VCDM represents the variable function ?(?) that is introduced in this framework. Therefore, VCDM provides a theoretically consistent and observationally testable framework of dynamical dark energy parameterizations with or without phantom behaviors. In this paper, we propose the VCDM realizations of various phenomenological parameterizations present in the literature: the Chevallier–Polarski–Linder (CPL), Barboza–Alcaniz (BA), Jassal–Bagla–Padmanabhan (JBP), Exponential (EXP), and Logarithmic (LOG) models. Using the VCDM equations for cosmological perturbations, we test them against the recent cosmological datasets, Planck 2018 and DESI BAO DR2, and then discuss their implications. We find that the equation of state crosses the phantom regime (w -1) at higher redshifts for all the paramterizations, as is also indicated by the DESI DR2 results. In principle, we confirm the phantom crossing of dynamical dark energy in a more stable theoretical framework of VCDM. Moreover, our approach does not rely on prior assumptions regarding the dynamics or microphysical origin of the equation of state, enabling a purely observational investigation into whether the dark energy transition favors a quintessence-like or phantom-like behavior. Together, these developments set the stage for a transformative decade in cosmology, one that may ultimately challenge and reshape our current theoretical paradigm.

sciforum-161625: Dynamical system study of interacting cosmological dark sector in scalar-tensor equivalent modified gravity

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Assertion of the nature and stability of solutions of field equations recast in terms of an autonomous set of variables in a so-called phase space is a crucial requirement for all dynamical systems including the cosmological ones, particularly those which lead to an effective dark universe picture, i.e., with dark energy (DE) and dark matter (DM), and plausible interactions thereof. The latter can be perceived naturally in the equivalent scalar-tensor (ST) formulations of various modified gravity theories, under conformal transformations. Viable cosmologies are indeed shown to emerge from the ST formulations for exponential type scalar field potentials in the conformal (Einstein) frame. Keeping our attention on these potentials, we carry out a rigorous phase space analysis from the perspective of generic exponents as well as in a specific case-by-case manner, by working out the autonomous first-order coupled differential equations from the ST cosmological equations in the Einstein frame, after defining suitable phase space variables. Thesecase studies turn out to be significant not only in working out numerical solutions of the autonomous equations for the physically relevant parametric ranges (which we assert by inspection) and in identifying the attractors in the resulting phase portraits, but also in determining which of the equilibrium solutions change their roles to the stable ones (sink or spiral) in various sub-domains of such parametric ranges. Finally, we demonstrate the robustness of the analysis from a precise match of the stable solutions with the exact analytic ones, as well as from a comparison with the dynamics of the effectively non-interacting cosmological systems, in the respective cases of fixed exponents in the scalar field potential. On the whole we make a concrete step towards establishing stable solutions in the phase space of autonomous variables for a fairly generic scalar-tensor cosmological system which culminates to an interacting cosmic dark sector.

sciforum-162646: Effects of the ekpyrotic mechanism on inflationary phase in loop quantum cosmologies

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In bouncing cosmological models, either classical or quantum, the Big Bang singularity is replaced by a regular bounce. A challenging question in such models is how to keep the shear under control in the contracting phase, as it is well-known that the shear grows as fast as $1/a^6$ toward the bounce, where a is the expansion factor of the universe. A common approach is to introduce a scalar field with an ekpyrotic-like potential, which becomes negative near the bounce, so the effective equation of state of the scalar field will be greater than one, whereby it dominates the shear and other matter fields in the bounce region. As a result, a homogeneous and isotropic universe can be produced. In this paper, we study how the ekpyrotic mechanism affects the inflationary phase in both loop quantum cosmology (LQC) and a modified loop quantum cosmological model (mLQC-I) because in these frameworks, the inflation is generic without such a mechanism. After numerically studying various cases in which the potential of the inflaton consists of two parts, an inflationary potential and an ekpyrotic-like one, we find that, despite the fact that the influence is significant, by properly choosing the free parameters involved in the models, the ekpyrotic-like potential dominates in the bounce region, during which the effective equation of state is larger than one, so the shear problem is resolved. As the time continuously increases after the bounce, the inflationary potential grows and ultimately becomes dominant, resulting in an inflationary phase. This phase can last long enough to solve the cosmological problems existing in the Big Bang model.

sciforum-161047: Exploring Black Hole Dynamics in massive scalar–Gauss–Bonnet Gravity through Numerical Relativity

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Testing the strong-field regime of gravity has become of great interest in the scientific community following the first gravitational wave detections and growing indications that General Relativity (GR) may require modifications in extreme environments. In this context, black holes are remarkably simple yet powerful laboratories, providing a unique opportunity to search for deviations from GR and to constrain extensions of gravity in extreme conditions. A natural framework to explore such deviations is through the inclusion of additional scalar degrees of freedom. Among them, scalar–Gauss–Bonnet (sGB) gravity offers a well-motivated framework, emerging naturally from fundamental high-energy theories such as string theory. While most existing studies have focussed on massless versions of this theory, introducing a scalar field mass is crucial for a more realistic description and may uncover novel dynamical features. Motivated by these considerations, I will present recent black hole simulations in massive sGB theory obtained using Numerical Relativity (NR), a rapidly expanding field that has only recently enabled fully non-linear, dynamical studies of compact objects beyond General Relativity and whose full potential is still being explored. I will first focus on the role of the scalar mass in the spacetime dynamics, as well as the effects of massive scalar perturbations in isolated black holes in the context of quasinormal-mode spectroscopy. Building on this groundwork, I will then introduce preliminary results from fully dynamical black hole merger simulations in massive sGB gravity, a regime that to date has seen only limited exploration and remains largely unexplored in the massive scalar case.

sciforum-156004: Falling test electric dipole in the Schwarzschild geometry

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The infall of a dipole and anti-dipole towards a Schwarzschild Black Hole (SBH), within the context of spherically symmetric spacetime, serves as a model for understanding the gravitational behavior of matter and antimatter. SBH is chosen as a prototype to represent the gravity of our Earth or any spherically symmetric heavenly object. Our findings indicate that in the geometrical units, the acceleration of dipoles and anti-dipoles can be either attracted or repelled, depending on the mass (m) of the gravitating center, dipole moment (P), and distance (r). In the physical units, however, the difference is far from being detectable, at least with the present technology. Therefore, the assumption that they always fall down is valid only by virtue of the huge mass of the Earth. Consequently, the detectability of the dipole correction is highly suppressed for massive central bodies such as the Earth, whereas satellite-based experiments in low-gravity environments may offer the sensitivity required to observe the effect. These results may shed light on the question of what happened to antimatter believed to have formed in the stages of the Big Bang. By providing new insights on the universe's imbalance between matter and antimatter, they may be able to clarify why matter eventually took over and gave rise to planets, stars, and galaxies, as well as our own existence.

sciforum-164073: Forecasting redshift drift measurements from HI 21 cm observations in the SKA era.

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The cosmological redshift drift (Sandage–Loeb effect) offers a unique, model-independent probe of the expansion of the Universe, by directly measuring the temporal fluctuation of cosmic redshift. In this study, we examine the viability of employing the Square Kilometre Array (SKA) to detect the redshift drift signal using neutral hydrogen (HI) 21 cm emission from galaxies and 21 cm absorption from Damped Lyman-α systems. We demonstrate how, by focusing on ultra-high spectral resolutions of 0.001–0.002 Hz and a semi-annual observational baseline, predicted SKA data spanning the redshift range 0 z 1 may attain millimeter-per-second sensitivity to the velocity drift. Simulations show that in samples of more than a billion HI-emitting galaxies, velocity drifts can be restricted at the level of 0.05–0.15 cm s^{-1} every 0.5 yr, whereas HI absorption systems provide complementary but weaker constraints due to their lower number density. Using simulated redshift drift data, we constrain cosmological parameters for a number of dark energy models, resulting in Hubble constant and matter density values that are consistent with existing observations and dark energy equation-of-state parameters close to a cosmological constant. Our findings highlight the ability of SKA HI 21 cm data to directly investigate cosmic acceleration at low redshift, offering a compelling and independent test of dark energy to supplement optical redshift drift investigations at higher redshifts.

sciforum-156850: Impact of dynamical radiation–matter interaction on the interacting Barrow holographic dark energy model

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The Barrow holographic dark energy (BHDE) framework arises from Barrow entropy \cite{ Phys. Rev. D 102 (2020) 123525, Phys. Lett. B 808 (2020) 135643 }, which incorporates possible fractal deformations of the horizon surface and is characterized by the Barrow exponent Δ, thereby modifying the standard holographic dark energy scenario. We have studied the effect of dynamical radiation in the interacting Barrow holographic dark energy (BHDE) model for a non-flat universe. For both open and closed universes (“open” and “closed” refer explicitly to the sign of the spatial curvature parameter k present in the FLRW metric), we derived the evolution equations for the energy density parameters of dark energy, dark matter, and radiation by considering four different types of interactions among the other possible linear phenomenological forms. These coupled differential equations were then solved numerically to examine their behavior with respect to the redshift parameter. The variation of the dark energy equation-of-state parameter with redshift was also explored for the different interaction models. For all four interaction cases, we found that higher values of the Barrow exponent lead to a transition of the dark energy equation-of-state parameter from the quintessence region to the phantom region at late times, corresponding to lower redshift values. We also identified distinct epochs corresponding to dark energy–dark matter, dark energy–radiation, and dark matter–radiation crossings.

Using data from the Cosmic Chronometer, Baryon Acoustic Oscillation, and Pantheon+ samples, we constrained several cosmological parameters of the interacting BHDE model. The estimated Hubble parameter values in our model are higher than those predicted by the ΛCDM model. This result suggests that our framework could provide useful insights for future studies involving high-redshift data and may contribute to resolving the Hubble tension problem. A statistical comparison between our models and the ΛCDM model has also been carried out.

sciforum-163968: Impact of Painleve–Gullstrand coordinates on the thermodynamics of Kiselev black holes

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We investigate the implications provided by the modified Painleve–Gullstrand coordinates in the context of quintessence for the Kiselev black hole. In this regard, we set up a fully static line element in terms of lapse and shift functions, while also including the deformation parameter, which signals deviation from the standard Painleve–Gullstrand metric. We address two specific issues related to the problems of radiation and dust, as furnished by the corresponding barotropic index parameter, and study the related consequences by performing a range of analyses to explore the influence imposed by quintessence. We perform a thermodynamical analysis of our results by determining the Hawking temperature and entropy for the cases of radiation and dust. The results are obtained in closed form and show their sensitivity to quintessence. We set up a framework wherein we compare the effect of the deformation parameter on the velocity of an infalling particle. We analyze and comment on the dependence of the quintessence parameter on the mass and charge of the Kiselev black hole. We show explicitly the entropy behaviour for the radiation and dust cases in the plots made with respect to the variation in black hole mass M and black hole charge Q for the quintessence parameter \alpha.

sciforum-161147: Inflationary dynamics of non-minimally coupled f(R) matter–curvature theories

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This study examines how inflationary dynamics are affected by f(R)-theories with a non-minimal coupling between matter and curvature. Both positive and negative corrections to the minimal coupling of General Relativity are considered, and a robust numerical method is developed that evolves the metric and the inflaton field in this modified theory beyond slow-roll. Through a stability analysis, we find that positive models are inherently unstable during slow-roll, whereas negative ones can accommodate a stable attractor de Sitter solution. Using the amplitude of the scalar power spectrum from the latest data releases, we constrain the scale of the non-minimal coupling to be above 10^{13} GeV. In light of the 2018 Planck, BICEP/Keck and the recent Atacama Cosmology Telescope data for the scalar spectral index and tensor-to-scalar ratio, strong constraints on the coupling strength force the effects of these modified theories to be, at most, slightly above the perturbative level. Furthermore, we determine that the choice of the perfect fluid matter Lagrangian does not impact the inflationary observables at the pivot scale. Finally, we present the predicted observables for different inflationary potentials and show that even though classical gravity is still preferred by the data, there are areas of the parameter space that are viable for non-minimally coupled inflationary models.

sciforum-160467: Interacting Dark Energy as an Open Quantum System: Phenomenology and Late-Time Cosmic Acceleration

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Persistent tensions in the Hubble parameter (H_0) and the matter clustering amplitude (S_8) motivate theoretical extensions beyond the non-interacting dark sector assumed in ΛCDM. From an effective field theory perspective, a non-zero Yukawa interaction between a scalar dark-energy field ϕ and fermionic dark matter ψ is technically natural unless prohibited by symmetry. In this work, we construct a microphysically consistent framework in which such an interaction emerges dynamically rather than being imposed phenomenologically.

We model the dark sector as an open quantum system, in which the scalar field constitutes a reduced subsystem that exchanges energy and information with an environmental dark-matter bath. Unlike a closed (unitary) quantum system, tracing over the fermionic degrees of freedom induces irreversible effects captured by a Lindblad evolution equation for the scalar density matrix. The scalar potential undergoes spontaneous symmetry breaking once the dark-matter density falls below a critical scale, inducing a time-dependent vacuum expectation value. The resulting interaction kernel $Q(a)$ and coupling profile $\beta(a)$ are therefore not free parameters, but consequences of the underlying symmetry-breaking and dissipative microphysics.

The resulting phenomenology is distinctive: the expansion history remains close to ΛCDM, while structure growth is modified through a late-time activation of the coupling. We test this against current large-scale structure and background probes using RSD, BAO, SN Ia, and CMB priors. A dynamical analysis—which self-consistently evolves both the background and perturbations—favours a late transition ($a_c \simeq 0.47$) and ($\beta_0 \simeq 0.52$). The model naturally suppresses the growth amplitude to $\sigma_{8,0} \simeq 0.59$ while simultaneously raising the inferred Hubble constant to $H_0 \simeq 69.6\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$, suggesting that the H_0 and S_8 discrepancies may trace distinct physical origins. This places observationally inferred coupling strengths in direct correspondence with radiative stability constraints, making the next generation of spectroscopic surveys a decisive test of this class of models.

sciforum-163843: Machine Learning Models for Gravitational Wave Classifcation

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Transient noise artifacts, or glitches, pose a serious challenge for gravitational-wave astronomy. These artifacts can overlap with real gravitational-wave signals and lead to inaccurate parameter estimation. As existing detectors are upgraded and new detectors come online, the ability to accurately identify and classify glitches will become increasingly important. While there are existing methods for handling glitches, many are computationally expensive, and as data volumes grow, the cost of removing or mitigating these glitches increases significantly.

This motivates the following question: can machine learning serve as an effective tool for glitch classification and mitigation? Using labeled data from Gravity Spy, we expand and balance our dataset using generative adversarial networks (GANs). We then evaluate a variety of convolutional neural networks (CNNs) and vision transformer architectures to assess their performance in classifying gravitational-wave glitches. Hyperparameters such as learning rate and weight decay are optimized using Optuna to achieve optimal performance. Model performance is evaluated using standard classification metrics, including accuracy, precision, recall, F1 score, and confusion matrices.

By comparing a diverse set of models, we examine the trade-offs between model complexity, interpretability, and classification performance. These results provide guidance for selecting appropriate machine learning models for future gravitational-wave detector characterization pipelines, while doing so at a computationally affordable cost.

sciforum-162462: Natural validation of first and second law of thermodynamics in cosmology (with/without viscosity)

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The purpose of this talk is two-fold: (1) in the first part, I will discuss why thermodynamics is important in cosmology, and then, (2) I will show that the laws of thermodynamics (including the second law) become naturally satisfied during the entire cosmic evolution of the universe, from inflation to the late dark energy era, without imposing any exotic condition. The first part is based on how the matter fields inside the horizon exhibit a flux during the cosmic expansion of the universe. Regarding the thermodynamic laws in cosmology, they are individually shown for two different class of gravitational theories: (a) having one thermodynamic degree of freedom, and (b) having more than one thermodynamics degrees of freedom. These make the inter-connection between cosmology and thermodynamics more concrete. Consequently, it also shows why the matter fields are not in thermal equilibrium with the apparent horizon during most of the cosmic era of the universe, except for the fluids with $\omega = -1/3$, leading to the transitions of the universe from an accelerating to a decelerating era and vice versa. The effect of viscosity on thermodynamic laws will be discussed, as well. We will explicitly show that viscosity makes universe expansion more irreversible compared to the case in the absence of viscosity.

The following papers may be treated as reference for this talk.

REF-1: Phys.Rev.D 111 (2025) 4, 043544

REF-2: Phys.Rev.D 111 (2025) 8, 083540

sciforum-162054: Noether Symmetries and Inflationary Scenarios in Ghost-Free f(R,G) Gravity

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Despite the well-known problem of the appearance of ghost degrees of freedom in gravitational models containing the Gauss–Bonnet invariant, there are special modifications in which this disadvantage can be eliminated. Such models include ghost-free generalizations of the Einstein–Gauss–Bonnet theory. Despite the mathematical attractiveness and theoretical validity of ghost-free f(R, G) models, their cosmological viability is often investigated using external reconstructive approaches that do not rely on the internal structure of the theory. In this paper, we propose an alternative method based on the use of internal model relationships defined by Noether symmetries. This approach makes it possible to significantly narrow down the class of acceptable theories and obtain explicit functional forms of scalar field potentials consistent with both the symmetric requirements and the ghost-free nature of the model. By applying the Noether symmetry method to a homogeneous and isotropic cosmological background, it is possible to obtain a set of allowable potentials with a nontrivial dynamic structure. These potentials are considered as physically motivated candidates for describing the early Universe. Based on them, a study of the inflationary dynamics of the model is conducted, based on the slow-roll parameters and spectral indices. The values obtained are compared with observations from the Planck mission and the Atacama Cosmology Telescope.

sciforum-160499: Phase Transition in Anisotropic Cosmology: Bouncing Model in f(R,T) Gravity

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In this study, we investigated the Bianchi type-V model in the context of f(R, T) gravity.

Here, we have considered the f(R, T)=R+2f(T), where f(T)= λT where λ is an arbitrary constant, R is the Ricci scalar, and T is the trace of stress energy momentum tensor. We have made the assumption that the cosmic jerk parameter, j, is precisely proportional to the negative of the deceleration parameter, q, namely in order to solve the field equations. The conversation covers a variety of situations including the Hubble parameter (H), the spatial volume (V), the deceleration parameter (q), the energy density (ρ), the pressure of matter (p), and the cosmological constant (Λ). We investigate a bouncing point, the moment of transition between contraction to expansion. The value of the expansion scalar θ describes a smooth, bounded transition between contraction and expansion which represents a bouncing universe (avoiding Big Bang singularity) and also represents a bouncing universe with maximum expansion rate due to modified gravity. The model also diagnoses the de Sitter universe, where exponential expansion is driven by a cosmological constant or dark energy. The model looks at the physical and geometrical behavior of the model, as well as the exact solutions under the anticipated jerk parameter condition, and summarizes key findings.

sciforum-153330: Planetary dependency: the signature for streaming dark matter

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The discovery of dark matter (DM) by Zwicky (1933) remains inconsistent within known physics. Astonishingly, a number of solar system observables exhibit unexpected “planetary dependencies”, even though no remote force beyond gravity exists. Question: Are persisting local mysteries also signals from the dark sector? Gravitational focusing of DM streams has short focal ranges since the impact goes with 1/(speed)2. Also, the inner mass distribution of solar system bodies acts as a gravitational lens, with amplification of streams being up to ~109, compared to few % for isotropic DM. The analysis of a number of observations within the solar system fits in the streaming DM scenario following gravitational lensing effects by solar system bodies. More specifically, analyzing secondaries from cosmic rays (CRs) points to streaming DM with the secondaries coming from the parent massive DM due to their self-annihilation, decay or interaction with ordinary matter. The secondaries provide the time stamp of the DM. New direct measurements of more CRs species can strengthen this result. All CR telescopes may have taken relevant data worth re-analyzing; the same applies to the data from direct DM searches. This is because only streaming DM can result occasionally in otherwise anomalous “planetary dependencies”. This is a new opportunity to unravel DM signatures hidden in existing data. This proposal is model-independent. So far the direct DM searches expect an annual distribution, while the underlying noise usually has a seasonal variation. In this proposal we overcome this noise problem by projecting the measured events (signal and noise), e.g., instead of on365 days, on the 88 and 225 days of the orbital periodicity of Mercury and Venus, respectively. So far the DM Axionantiquarknugget model by ZHITNITSKY is the inspiring favourite, while this approach is open to any other DM model.

Further reading: https://doi.org/10.22323/1.474.0035; https://arxiv.org/abs/2506.17676v2

sciforum-161188: Recent progress in the Pre-Big Bang Scenario

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I will discuss recent progress in string cosmology. Incorporating all-order α' corrections leads to a far richer and more self-consistent picture of the pre-Big Bang universe. Within this more complete framework, the early universe can evolve smoothly through a genuinely non-singular bounce, allowing a continuous transition between two dual cosmological phases without encountering the usual curvature singularity. This mechanism provides a natural way to resolve the classical Big Bang singularity while remaining firmly grounded in string-theoretic principles. Moreover, when an appropriate potential is introduced for the dilaton, the same setup can stabilize the string coupling at late times, preventing it from running to strong coupling. This dynamical stabilization enables the emergence of realistic cosmological epochs, such as matter domination or even a period of de Sitter-like accelerated expansion, within a unified string-inspired description. These theoretical developments significantly broaden the phenomenological landscape. During the high-curvature string phase, small variations in the sound speed of cosmological perturbations can dramatically boost the production of primordial black holes, potentially bringing their abundance into the open window for dark matter. Likewise, recent hints from NANOGrav of a stochastic gravitational-wave background can be naturally accommodated by non-minimal versions of the pre-Big Bang scenario, in which stringy corrections enhance gravitational wave production. Taken together, these results suggest that genuinely stringy effects may leave measurable traces in today's universe, offering a promising bridge between fundamental theory and near-future observations.

sciforum-161186: Reparametrization Invariance and the Phenomena of Dark Energy and Dark Matter

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The nature of dark energy (DE) challenges our comprehension of the cosmos, appearing as the source responsible for the Universe's accelerating expansion. This work considers the Einstein Cosmological Constant (Λ_E) as a manifestation of DE, interpreted through the lens of Reparametrization Invariant Scaling Symmetry (RISS). Within this paradigm, Λ_E emerges as a "kinetic energy" term, derived from relative temporal motion, setting it apart from the conventional kinetic energy based on spatial relative motion.

Central to this exploration is the scale factor $\lambda(t)$, representing a reparametrization capable of rendering Λ_E dynamically within the extended equations of Einstein's General Relativity (EGR) as $\Lambda = \Lambda_E \lambda^2$. Through meticulous derivations, the governing equations of $\lambda(t)$ and its interplay with Λ_E are articulated. Imposing reparametrization symmetry on the equations of motion reveals a new avenue for addressing the missing mass problem evident at galactic and extragalactic scales. Here, improper/non-affine (non-co-moving) temporal parameterizations introduce fictitious forces, whose presence is reconciled through the symmetry framework.

This symmetry-based approach naturally yields the MOND-like relationship $g^2 \sim (a_0 g_N)$, where g denotes gravitational acceleration, a_0 represents the fundamental MOND acceleration, and g_N is the Newtonian acceleration. The theoretical predictions for Λ_E and a_0 demonstrate remarkable alignment with their observed magnitudes, lending credence to this interpretation. This synthesis underscores a potential unifying principle in our understanding of dark energy and dark matter phenomena.

sciforum-161521: Scalar Field Cosmology with Logarithmic Deceleration Parameter

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In this study, we present an alternative framework for understanding the dynamics of late-time cosmic acceleration. Central to our research is a specific methodology for modeling the expansion history of the universe and the nature of dark energy by a logarithmic parametrization of the deceleration parameter q(z). This specific form facilitates a model-independent reconstruction of the expansion history, allowing the cosmic evolution to be determined empirically, yet it remains fully consistent with scalar-field-driven dark energy models within the framework of General Relativity.

Our theoretical structure is built upon Scalar Field Cosmology, where cosmic dynamics are governed by a minimally coupled scalar field (ϕ) possessing a generalized potential $V(\phi)$. This potential is meticulously designed to coherently reproduce the observed late-time acceleration phase of the universe. The logarithmic form of q(z) allows for the reconstruction of all fundamental dynamic quantities in a closed analytical form. This analytical tractability is crucial for theoretical analysis and direct comparison with observations.

To constrain the model's free parameters, we utilized a robust and extensive set of observational data. This includes Cosmic Chronometers (CCs), high-precision Standard Candle (SC) observations from Type Ia Supernovae (specifically the Pantheon+ sample), Baryon Acoustic Oscillation (BAO) data, and the strong constraint provided by the R19 local Hubble constant prior. All datasets were meticulously combined and analyzed through a combined χ^2 minimization procedure, ensuring the maximization of the model's observational consistency and statistical power.

The results unequivocally demonstrate a clear evolutionary transition from a past decelerating phase to the current accelerating phase. The reconstructed transition redshift (z_t) is found to lie within the interval $z_t \approx 0.70$–0.90, which is remarkably consistent with modern cosmological findings. The high degree of consistency between our model and the observational data proves that the logarithmic deceleration mechanism can provide a successful explanation for the universe's evolution.

sciforum-161693: Semi-classical Dark Universe from a Bose–Einstein condensate in a Spatially Averaged domain

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We explore the potential resolution of the so-called dark universe conundrum via the unification of the cosmological dark components, namely, dark matter (DM) and dark energy (DE), from a semi-classical fluid description of a Bose–Einstein condensate (BEC) of light bosons. Specifically, such a unification, which implies the same fundamental origin of DM and DE, has indeed been shown to be accountable from the BEC energy density, identified with the corresponding probability density, whereas the associated (Bohmian) quantum potential can account for the DE density semi-classically. The 'macroscopic' BEC wave-function can be chosen such that the BEC energy density resembles that of a CDM. Nevertheless, as illustrated in some of our earlier works, neither the BEC density equals the total effective CDM density, nor the quantum potential equals the total DE density, as the entire bulk of the universe contents (including the visible baryons) back-reacts on the metric structure of space–time due to the quantum-corrected Raychaudhuri–Friedmann equations. Such a quantum back-reaction crucially constrains the BEC mass, wherefrom one can infer that the BEC acts almost as an axion-like scalar field DE, rather than as a DM! However, in those works the inhomogeneous part of the BEC density has been ignored, at large scales, taking the view that it would not affect the background cosmological evolution. Examining the effect of this inhomogeneous part on large-scale cosmology of course requires standard techniques of averaging of inhomogeneities over a suitably chosen domain. The latter may conceivably be much lesser than the spread of a Gaussian, which can serve as the BEC wave-function, as shown in the earlier works. We carry out the averaging here and show that, despite having corrections to the cosmological solution obtained earlier, the BEC mass bound from the quantum back-reaction remains intact, and so does the above inference.

sciforum-161677: Signatures of Wormhole Spacetime in Shadow and Quasi-Normal Nodes

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Observational evidence, including LIGO, EHT, and astrophysical results, are yet to confirm the existence of the black hole horizon. Also, it has been pointed out by several research groups that the LIGO observations of merger and ringdown and shadow observed by EHT do not exclude horizon-less exotic compact objects. We present stability analysis and light propagation in wormhole spacetimes for which we have considered a couple of wormhole geometries. The motivation behind these choices lies in the fact that the geometries may be constructed out of ordinary matter where the violation of energy conditions are relaxed compared to the standard 4D GR framework. We investigated the geometrical structure of the spacetime and concentrated on null geodesics with the aim of exploring the shadow features. The shadow characteristics in a framework where the space is devoid of any sources between the compact object and the observer has been observed. In addition to this, we have also studied the effect of the environment in particular plasma on the shadow characteristics. Finally, we explore the stability under scalar perturbation; studying the time domain profile, we find the quasi-normal frequencies. By comparing the characteristics of the shadow images and the quasi-normal frequencies, we identify the features that could serve as discriminants for similar compact objects.

sciforum-161465: Simultaneous fitting of ACT data and NANOGrav 15-year data in entropic cosmology

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NANOGrav 15-year data hint towards an alternative inflationary scenario, as opposed to the usual slow-roll one (as the usual slow-roll inflation predicts a low amplitude of gravitational waves around the NANOgrav frequency range), for describing the early time dynamics of the universe. The modified inflation should be such that it leads to a blue-tilted primordial tensor power spectrum around the NANOGrav frequency range, but maintaining the Planck constraints over the CMB scales. Regarding the constraint over CMB scales, the recent the Atacama Cosmology Telescope (combined with the Planck 2018 and BAO) refines the constraint on inflationary observables, compared to the Planck-only 2018 measurements. Based on these observations, we are interested to simultaneously fit these two through the thermodynamic route of cosmology. The entropy of the apparent horizon is considered to be four-parameter generalized entropy (which is able to generalize the other known entropies proposed so far). In particular, we will show that four-parameter generalized entropy proves to be compatible with these observations for common range of entropic parameters. After the inflation ends, the entropic energy density (coming from the generalized entropy) decays to relativistic particles and leads to standard Big Bang cosmology. Therefore we argue that if the future observatories can detect the signal of primordial GWs, then our theoretical expectation carried in the present work may provide a possible testbed for generalized entropic cosmology.

sciforum-160741: Testing General Relativity using Binary Black Hole Orbital Frequency Evolution on the Time-Frequency plane

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General relativity (GR) lays the foundation for successfully explaining the current gravitational wave (GW) observations. We present a method for studying the orbital frequency evolution of GWs from binary black hole (BBH) systems based on their energy distribution on the time-frequency plane. The orbital frequency evolution of BBH systems is determined by the individual masses and spins of the component black holes and the governing gravity theory. If a beyond-GR theory of gravity governs the BBH orbital evolution for the same set of binary parameters, the time-frequency pixel energies will exhibit a different frequency evolution from what is predicted by GR. We develop a new consistency test to check whether GR explains the BBH orbital evolution. Through numerical simulation of beyond-GR theory of gravity, we demonstrate the efficiency of this new method in detecting any possible departure from GR in the framework of second-generation GW interferometers. Further, we discuss the utility of our method in probing missing physics in the GW waveform models. We apply our test to the GW190814 and GW190412 data from the LIGO-Livingston detector, assuming that the analyzing template waveform does not include higher-order modes. The lack of subdominant modes results in an incomplete representation of the GW signal, leading to systematic biases in the frequency evolution of the signal.

sciforum-161503: The Evolution of dark energy in a model of a gas of thin tubes of a massless scalar field

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The large body of observational data accumulated to date records significant discrepancies between early and late cosmological measurements. Among the most discussed cosmological parameters with existing deviations in measurements, at early and late times, for example, are the Hubble constant, H0, and parameter S8, which characterizes the measure of growth of cosmic structure. One of the possible modifications of ΛCDM, capable of resolving the tensions H0 and S8, is associated with the development of dark energy (DE) models, in which the equation of state parameter w can influence the growth rate of the cosmological structure. Models with this property include, for example, the gas of thin tubes of a massless scalar field (TToMSF), since the parameter of its equation of state \$w\$ depends on the density of the gas, namely, for rarefied gas TToMSF w→-1 and for compressed gas w→1. In this case, changes in the density of the TToMSF gas, which may be associated, for example, with its gravitational interaction with non-uniformly distributed baryonic matter, during the period of baryon acoustic oscillations (BAOs), should lead to the implementation of local equations of state with different values and different laws of change of parameter w.

In this work, we investigated how the trajectories of a test null string change as it moves in the evolving gravitational field of a thin tube of a massless scalar field, and how these trajectories can influence the accelerated expansion of the TToMSF gas.

sciforum-156220: The New Shell Solutions of General Relativity and Their Main Consequences

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In recent years, a new class of exact solutions of the Einstein field equations of general relativity in the presence of matter, in the static and spherically symmetric case, was discovered and analyzed by analytical and numerical means. In this talk, these new solutions are described in the case of the polytropic equations of state, and their main conceptual consequences for the structure of the theory are discussed.

As a consequence of the development of these solutions, new aspects of the concept of spacetime singularity were uncovered, namely that there exist previously unsuspected repulsive singularities, as well as new facts about the existence and character of the gravitational field within spherically symmetric vacuous cavities. The existence of these new solutions also led to new and radically different conclusions about the concept of gravitational collapse, as well as about the internal geometry and structure of black holes.

The analysis of limits of sequences of shell solutions that approach the exterior geometries of black holes and the formation of event horizons led to a completely unexpected connection with the quantum aspects of physics. We were able to reproduce, by purely classical means, the two main conclusions of the study of quantum mechanics in the background geometry of the exterior Schwarzschild solution, representing a naked black hole. This led to the conclusion that general relativity seems to contain remnants of some underlying quantum structure.

There is some ongoing work further exploring this connection of general relativity with quantum field theory, for which it is necessary to use the Euclidean lattice formulation of this theory. This connection is made directly with the standard model of particle physics through the spontaneous symmetry breaking mechanism involving the Higgs field. This can be qualitatively commented on if there is time and interest.

sciforum-163252: Two-fluid Cosmological Models in LRS Bianch type I Spacetime

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In this paper, we present a detailed investigation of two-fluid cosmological models formulated within the anisotropic Bianchi type I spacetime. The framework considers the universe to be filled with two distinct components: a standard barotropic fluid representing ordinary matter and radiation and a dark energy component introduced to account for the late-time accelerated expansion of the universe. Both interacting and non-interacting scenarios between the two fluids are examined, allowing us to assess how the exchange or absence of energy–momentum transfer influences the overall cosmological dynamics.

Einstein field equations are solved explicitly for each case, and the evolution of key physical and geometrical parameters—such as directional Hubble rates, expansion scalar, shear scalar, and the density parameters—is analyzed with reference to recent observational data. Our results indicate that the proposed models are most accurately described by quintessence-type dark energy, exhibiting behavior consistent with a dynamically evolving equation of state. A significant outcome of the analysis is that the total density parameter Ω remains invariant irrespective of whether the fluids interact, underscoring the robustness of the model.

Furthermore, the asymptotic behavior of the cosmological parameters aligns with the predictions of the standard ΛCDM model. In particular, we demonstrate that the deceleration parameter approaches $q \to -1$ and the jerk parameter tends to $j(t) \to 1$ as cosmic time $t \to \infty$, indicating a smooth approach toward a de Sitter phase. These outcomes suggest that the constructed two-fluid Bianchi type I models provide a viable theoretical framework compatible with current cosmological observations.

sciforum-163899: Warp Drives, Black Holes, and Wormholes

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As was shown by Ellis in gr-qc/0411096, one can establish a correspondence between the Schwarzschild metric and a warp drive-type metric, making it possible to consider a warp drive in a black hole background. We elaborate upon this result and demonstrate that the black hole's gravitational field can alleviate the violations of energy conditions, reducing the amount of negative energy required to sustain a warp bubble. Besides, we demonstrate that the black hole horizon is effectively absent for the observers inside the bubble, making it possible for them to send a light signal from the inside to the outside; however, the front wall of the warp bubble would emit Hawking radiation, possibly making the bubble unstable. The warp bubble would also possibly increase the black hole's entropy.

We also generalize the Ellis scheme to the case of Morris-Thorne wormholes and prove that Alcubierre warp drives cannot traverse humanly traversable wormholes and can only pass through those that either have a horizon or violate the flare-out condition. In addition, we consider warp drives in a de Sitter universe, and demonstrate that in this case, it's possible to interpret the warp bubble just as rearrangement of vacuum energy, in contract to exotic "negative energy". We discuss the implications of our results.

Session 2. Quantum Gravity and Field Theory

sciforum-164010: Universal Wavefunction and Entropy in Minisuperspace Quantum Gravity

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One of the canonical approaches to quantum gravity is quantum geometrodynamics. It arises from the quantization of Hamiltonian constraints. This method gives rise to the Wheeler–DeWitt equation, which can be solved in minisuperspace models to obtain the wavefunction of the universe. Despite its long history, this approach still faces fundamental challenges: operator ordering ambiguity, the problem of time, and the lack of a clear probabilistic interpretation remain open issues. In our work, we discuss how studies of entropy may shed some light on these difficulties.

We study a toy model of the Wheeler–DeWitt equation for a Friedmann–Lemaître–Robertson–Walker (FLRW) universe with a non-zero cosmological constant and matter content consisting of a massive scalar field coupled to gravity. We construct the universal wavefunction using a spectral expansion method, which allows us to obtain numerical solutions on the entire domain while avoiding instabilities. This approach enables a detailed analysis of the wavefunction and provides access to both gravitational and matter degrees of freedom without the use of the slow-roll approximation.

Based on the obtained universal wavefunction, we discuss possible entropy measures and their implications, as well as the potential role of matter–geometry entanglement as an indicator of the quantum-to-classical transition. We conclude with a comment on the use of entropy-related quantities as arrows of time.

sciforum-160013: Signatures of non-classicality in gravitational waves through bipartite detections

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Using arguments based on fundamental principles, Freeman Dyson concluded that the individual measurement of the graviton is physically impossible. Considerable research has been dedicated to find the graviton through single-point detections, all of which supports Dyson's conclusion. The community of gravitational physicists still search for the graviton through means of single-point detections; however, there is a much greater possibility of successfully finding the graviton through bipartite detections. Our research follows up on the paper "Measurement-induced entanglement entropy of gravitational wave" by Preston Jones, Quentin G. Bailey, Andri Gretarsson, and Edward Poon in *Physics Letters B* and explores other possible methods of finding signatures of non-classicality in gravitational waves. The calculations performed to produce their Figure 2 are updated from Mathcad to Python to be more readily available for use in other measures of non-classicality. Bipartite detections allow for the observation of the measurement-induced entanglement entropy, which is a signature of non-classicality in gravitational waves. Bunching is another potential signature of non-classicality that can easily be observed in bosons with bipartite detections through Hanbury-Brown and Twiss experiments but is complicated by the optical equivalence theorem. However, bipartite detections also present the opportunity to observe anti-bunching, a purely quantum mechanical effect, which would prove that gravity is quantized. Bipartite detections are very likely the key to find the smoking gun for the quantization of gravity.

sciforum-153538: Post-Newtonian Effective Field Theory Approach to Entanglement Harvesting, Quantum Discord and Bell's Nonlocality Bound Near a Black Hole

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Black holes, as characterized by the Hawking effect and Bekenstein-Hawking entropy, can be treated as a compact object carrying nontrivial quantum information obscured behind the event horizon. Thus, the black hole may convey and retract its quantum information to the nearby quantum probes via the surrounding mediator fields. In this paper, we investigate the effects of a quantum black hole on the reduced states of a pair of static qubit-type Unruh-DeWitt (UDW) detectors acting as a probe, using three complementary quantum information measures: concurrence characterizing entanglement harvesting, quantum discord, and Bell's nonlocality bound. This sheds light on the nature of the quantum state of the black holes. By treating the black hole as a tidally deformable thermal body under the quantum fluctuation of the mediator fields as observed in \cite{Goldberger:2019sya, goldberger2020virtual, biggs2024comparing}, we employ a post-Newtonian effective field theory (PN-EFT) to derive the reduced states of the UDW probes analytically. Based on this, we can easily obtain all three quantum information measures without encountering the complicated Matsubara sum of infinite thermal poles, as in the conventional approach based on quantum fields in curved spacetime. By tuning the relative strengths in the action of PN-EFT, we can extract the effects of the black hole on the entanglement, quantum correlation, and nonlocality bound of the UDW probe systems. Our PN-EFT approach can be extended to include the backreaction on the black holes in future studies by taking the higher-order PN corrections into account.

sciforum-161902: Barrow Entropy and Quantum-Induced Fractality of Black Hole Horizons

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At quantum scales, the classical description of spacetime no longer holds: the metric tensor develops intrinsic quantum fluctuations and cannot be treated as a smooth continuous field. Consequently, a black hole horizon also fails to remain an ideal smooth null hypersurface. Instead, it acquires quantum “wiggles,” corresponding to soft degrees of freedom—low-energy excitations capable of storing information as soft hair. These irregularities prevent the horizon from acting as a smooth two-dimensional surface at the Planck scale, giving it a highly jagged or fractal character. To model this deviation from smoothness, Barrow [Phys. Lett. B 808 (2020) 135643] proposed that the horizon is described by a fractal dimension, d=2+Δ , 0Δ1, with Δ quantifying the geometric deformation. For such a surface, the effective area scales as Aeff∝Rgd, instead of the classical A_{Cls}∝(R_g)^d. Based on the Bekenstein–Hawking argument that entropy counts horizon-covering Planck cells, this fractal surface increases the microscopic degrees of freedom, leading to the modified Barrow entropy S_B∝(A / A_{Pl})(1+Δ/2). Using the first law dM=T_BdS_B, the corresponding temperature becomes a multiple of T_H. The heat capacity remains negative for all 0Δ1, so the thermodynamic instability of the Schwarzschild black hole persists. However, the reduced temperature suggests a slower evaporation process and the possible formation of a long-lived remnant. Geometrothermodynamics is reconstructed using this new fractalized entropy.

sciforum-153061: Comments on Celestial CFT and AdS_{3} String Theory

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Abstract based on: arxiv.org/abs/2410.02620

In a recent work, \citet{ogawa2024celestial} proposed a model for celestial conformal field theory (CFT) based on the H_{3}^{+}-Wess-Zumino-Novikov-Witten (WZNW) model. In this paper, we extend the model advanced by \citet{ogawa2024celestial}, demonstrating how it can holographically generate tree-level MHV scattering amplitudes for both gluons and gravitons when analytically continued to the ultra-hyperbolic Klein space $\mathbf{R}_{2}^{2}$, thereby offering an alternative to celestial Liouville theory. We construct a holographic dictionary in which vertex operators and conformal primaries in celestial CFT are derived from their worldsheet counterparts in Euclidean AdS_{3} (bosonic) string theory. Within this dictionary, we derive the celestial stress-energy tensor, compute the two- and three-point functions, and determine the celestial operator product expansion (OPE). Additionally, we derive a system of partial differential equations that characterises the celestial amplitudes of our model, utilising the Knizhnik--Zamolodchikov (KZ) equations and worldsheet Ward identities. In the Appendix, we provide a concise introduction to the H_{3}^{+}-WZNW model, with emphasis on its connection to Euclidean AdS_{3} string theory.

This talk is structured as follows. In Section \ref{sec:Holographic-Reconstruction-of}, we begin by stating the postulates of our holographic dictionary, and move to the derivation of its consequences, starting with the holographic derivation of tree-level MHV amplitudes for both pure Yang-Mills theory and Einstein's gravity. In Section \ref{sec:Correlation-Functions,-Operator}, we will demonstrate how our construction uniquely determines the two- and three-point functions as well as the celestial OPE. Additionally, we will examine a system of partial differential equations characterising the celestial amplitudes, derived from our holographic dictionary in frequency space, and, in Section \ref{sec:Discussion}, we summarise our findings and discuss potential avenues for further research stemming from this work.

sciforum-164015: Cosmological Constant or Cosmological Curvature Parameter? A Conformal Reinterpretation of Λ

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Observations across multiple cosmological probes indicate that the Universe possesses a non-zero cosmological constant, typically associated with vacuum energy density. However, the large discrepancy between observationally inferred and theoretically predicted vacuum energy densities, together with recent analyses in which combined SnIa, H(z), BAO, LSS, BBN, and CMB datasets mildly prefer models with a time-dependent cosmological parameter [1], shows the need to re-examine the assumption that Λ represents the constant vacuum energy density.

In this study, interaction field equations derived from an action incorporating bulk influence, which reduce to the Einstein field equations in the flat-background limit [2], are utilized. A comparison of this set of equations reveals that the effective cosmological parameter is associated with the normalized bulk conformal curvature term, giving rise to an evolving effective Λ influenced by the vacuum energy structure rather than by a fixed density. This framework provides a new perspective on the interpretation of the cosmological parameter and offers a natural reframing of the cosmological constant problem, in which the small observed value of Λ can be understood as reflecting the weak curvature of the bulk while remaining consistent with current observational trends.

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sciforum-161157: Effects of Effective Dark Energy in Astrophysical Plasma

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We study the application of Lorentz kinematic transformations deformed by critical velocity to a continuity equation. This generates a source structure for the continuity equation that is indistinguishable from a Nernst–Planck equation. In this case, the fluid flow is the source of excited states. This makes the fluid a type of self-source, where the flow is a force that compensates for its crystallization into excited states. Therefore, we can understand that the kinematic transformation adds a stress term to the fluid dynamics, which can be understood as a sort of dark energy.

We studied the effects of the currents that arise. Specifically, the dissipative and convective currents, which play a role of self-induction and mutual induction, are capable of generating local phase transitions in the fluid.

This construction is a step toward building a theory of gravity based on a theory of two self-interacting fluids. In future work, we will clarify the role of vorticity, include viscosity effects, and relate this to Helmholtz–Hodge decomposition. We will also clarify the dynamic role of critical velocity as a fundamental state and its effect on the causal structure of the fluid, in addition to investigating a possible condition of non-integrability, which should severely affect the construction of the causal structure.

sciforum-159691: Entanglement harvesting between Unruh DeWitt detectors in the de Sitter spacetime

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We investigate the generation and harvesting of entanglement between two identical, comoving Unruh–DeWitt detectors in cosmological de Sitter spacetime. Initially, the detectors are unentangled and interact locally with a complex scalar field, through which an effective coupling between them emerges. Our analysis considers two types of complex scalar fields, the conformally invariant field and the massless minimally coupled field, both of which exhibit distinct physical behaviours in curved spacetime. By tracing out the scalar-field degrees of freedom, we construct the reduced density matrix of the detector pair. The eigenvalues of this matrix encode the transition probabilities between the energy levels of the detectors and allow us to compute the negativity, which serves as a quantitative measure of the entanglement generated at late times.

We present a detailed comparison of the entanglement-harvesting capabilities of the two complex fields, highlighting both their similarities and their qualitative differences. To place our findings in context, we also contrast them with the well-studied case of a real scalar field. Our results show that complex fields and nonlinear couplings significantly enhance the robustness of entanglement harvesting, allowing entanglement to persist over a broader parameter range. This indicates that the structure of the underlying field theory plays a crucial role in determining the efficiency of entanglement generation in curved spacetime.

sciforum-154505: Entanglement Measures in Quantum Field Theory

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This talk lies at the interface between field theory and foundations of quantum mechanics. I will be speaking about a quintessential quantum mechanical phenomenon, entanglement, mostly in the context of quantum field theory in 1+1D. In this setting, I will introduce some of the most studied bipartite entanglement measures that are investigated in the context of many-body quantum physics: entanglement entropy, Rényi entropies, logarithmic negativity and symmetry-resolved measures. I will explain what the study of entanglement measures signifies within quantum field theory, especially how such measures are effective probes for a wide range of universal properties from identifying critical points and gapped phases to classifying quantum states according to area or volume laws, quantifying the speed of thermalization after a quantum quench, or identifying symmetries and their breaking. I will illustrate some of these points with results from my own work of the past 20 years, particularly the branch point twist field technique that I co-pioneered with J. L. Cardy and B. Doyon in our paper https://arxiv.org/abs/0706.3384. This method relates all measures of entanglement mentioned above to correlation functions of local fields and has enabled us to apply known techniques to compute correlators to the investigation of entanglement measures. Also see the recent review https://arxiv.org/abs/2403.06652.

sciforum-159562: Localization of the Elko Field on the Bloch Branes

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In this work, we investigate the localization properties of Elko spinor fields on the Bloch brane, a thick brane scenario generated by two interacting scalar fields and characterized by a rich internal structure. We begin by studying the dynamics of a free (massless) Elko field in the five-dimensional Bloch brane background and derive the corresponding Schrödinger-like equation governing the Kaluza–Klein modes. Our analysis shows that, due to the specific geometric features and the non-trivial warp factor of the Bloch brane, the zero mode of a free Elko field is not normalizable and therefore cannot be localized on the brane.

To resolve this issue, we introduce a non-minimal coupling term into the five-dimensional Elko spinor field action. By considering different forms of coupling between the Elko field and the background scalar fields, we demonstrate that the inclusion of such a coupling significantly alters the effective potential of the system and allows for the localization of the Elko zero mode. We identify the explicit conditions under which a normalizable and physically acceptable zero mode can be trapped on the brane.

Furthermore, we examine how the internal structure of the Bloch brane influences the localization mechanism. Our results reveal that the brane's internal layers play a crucial role in shaping the effective potential felt by the Elko field, thus affecting both the localization behavior and the profile of the zero mode. This study provides deeper insight into the realization of dark-matter-motivated Elko fields in thick brane models.

sciforum-159275: Quantum Gravity outperforms General Relativity: A new chapter in black hole physics

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Background: The Event Horizon Telescope (EHT) provides unprecedented horizon-scale images of supermassive black holes, offering a unique testing ground for theories of gravity. The Nexus Paradigm (NP), a quantum gravity model, posits a quantized spacetime with a halved Schwarzschild radius and makes distinct predictions for observable features like the dark depression and emission ring.

Methods: We perform a rigorous Bayesian statistical analysis to test the NP against EHT observations of Sgr A* and M87*. Using Gaussian likelihoods and priors informed by mass–distance uncertainties, we compute the posterior distribution for the angular scale parameter Θ_g and assess the model's goodness of fit via the χ^2 statistic. We directly compare the NP to General Relativity (GR) using Bayes factors.

Results: The NP demonstrates remarkable agreement with the data, achieving a combined fit at a 4.37σ confidence level (99.997%). Predictions for the dark depression, emission ring, and base diameter all agree with observations at the 0.1σ level. In stark contrast, GR's prediction for the dark depression is inconsistent at the $\sim 13\sigma$ level. The Bayes factor overwhelmingly favors the NP over GR, at approximately 10^{36}.

Conclusion: Our analysis provides strong statistical validation for the Nexus Paradigm as a viable quantum gravity framework. These results underscore the power of EHT observations to probe the quantum nature of spacetime and challenge classical gravitational models in the strong-field regime.

sciforum-163862: Quantum Mode Mixing in the Teo Rotating Wormhole: From Casimir Emission to Superradiance

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Rotating traversable wormholes allow the effects of frame-dragging and rotation to be studied in the absence of event horizons. We develop a quantum field-theoretic treatment of massless scalar perturbations in the rotating Teo spacetime (an exact, stationary, horizonless, traversable wormhole with two asymptotically flat regions). Using the Bogoliubov transformation formalism, we construct "in" and "out" mode solutions in the two asymptotic regions and compute the Bogoliubov coefficients ($\alpha\omega m$,$\beta\omega m$) that quantify mode mixing. The effective radial potential induced by rotation and frame-dragging forms an asymmetric scattering barrier. This asymmetry permits an exact analytic evaluation of reflection and transmission amplitudes via the barrier penetration exponent, yielding closed-form expressions for the Bogoliubov coefficients, mean particle number, superradiant amplification, and the two-mode entanglement entropy $S\omega m$ as functions of the rotation parameter a. Because the spacetime is stationary, particle creation and amplification arise purely from geometric asymmetry rather than explicit time-dependence. Co-rotating and counter-rotating modes experience inequivalent scattering, rendering the process intrinsically non-reciprocal. We thus identify a stationary geometric analog of the recently proposed Asymmetric Dynamical Casimir Effect, in which rotation and frame-dragging replace moving boundaries as the source of asymmetric mode mixing. Our results unify classical superradiant scattering, quantum Bogoliubov amplification, and asymmetric Casimir physics within a single horizonless geometry, demonstrating that neither horizons nor time-dependent metrics are necessary for quantum particle creation from the vacuum. The framework opens the door to future studies of higher-spin fields, slowly varying rotation, and semiclassical backreaction effects.

sciforum-160017: Semi-Classical Model of Detector Efficiency in the Context of Bipartite Gravitational-Wave Detection

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Current research into the quantization of gravity has focused primarily on single-point graviton detections. This approach neglects non-classical properties that arise from entanglement between gravitons whose arrivals are coincident at separate detector sites. In developing a bipartite quantum-mechanical framework for the detection of gravitational waves, a necessary step is to characterize detector efficiency for graviton particles. Utilizing the geodesic deviation equation, we construct a model of the detector's departure from free fall in flat spacetime. This model enables us to compute the mean graviton number registered by a single detector, providing a semi-classical measure of effective detector efficiency. We find that low detector efficiency results in resolvable measurement-induced entanglement in bipartite gravitational-wave detections. This work follows up on ``Measurement-induced entanglement entropy of gravitational wave detections" (Physics Letters B, 2025) by Preston Jones, Quentin G. Bailey, Andri Gretarsson and Edward Poon, which states that low theoretical efficiencies present a challenge for detecting production-induced entanglement. In contrast, for bipartite detections of gravitational waves involving measurement-induced entanglement, the entanglement occurs at the time of measurement. Low detector efficiencies therefore become an asset for revealing non-classical signatures, since quantum effects are more prominent as a result of the reduced graviton number associated with low detector efficiency.

sciforum-164028: Sensitivity Analysis of Satellite Constellations to Quantum Fluctuations in the Gravitational Field

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Our research explores the sensitivity of satellite constellations to fluctuations in the quantum gravitational field, with the aim of quantifying their potential impact on critical operations and precision measurements. The main objective is to quantify the potential impact of hypothetical quantum effects on the precise orbital dynamics of satellite constellations. The methods employed will involve the development of a sophisticated computational model using MATLAB. Our model will simulate the trajectories of various satellite constellation configurations in two distinct gravitational frameworks: one based on classical general relativity and the other incorporating theoretical models of quantum gravitational fluctuations. The main task is to meticulously analyze and compare the resulting differences in key orbital parameters, including position, velocity, and orbital period, between these two scenarios. This comparative analysis is crucial in determining whether the minute stochastic perturbations resulting from quantum gravity could accumulate over time and measurably affect the performance and objectives of current and future high-precision satellite missions, such as those related to Earth observation, global navigation satellite systems (GNSSs), or space-based gravitational wave detectors. The expected results have provided essential insights into the potential need to integrate quantum gravitational corrections into very high-precision astrodynamics and will contribute significantly to ongoing theoretical and experimental efforts to unify quantum mechanics and general relativity at the macroscopic scale.

sciforum-164809: Thermodynamic Remnants in Black-hole evaporation

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In this presentation, I will demonstrate a natural and seamless occurrence of remnant scenarios within the confines of the original computation of Hawking. Hawking in his seminal work demonstrated that the black-hole evaporates thermally at a temperature inversely proportional to its mass $T_H = 1/M$; hence, it is unclear as to what happens in the final stages of the black-hole evaporation as $M \to 0$ due to it being a divergence of the black-hole temperature. A natural resolution to this issue is via remnant scenarios where a black-hole ceases evaporation at some temperature. There have been several attempts over the years to improve upon the computations of Hawking and realize the remnant scenario. However, these attempts rely on implementing extra constraints inspired from various theories of Quantum Gravity or Generalized Uncertainty Principles (GUPs). But we have demonstrated that these constraints are not essential and the remnant configuration can arise simply from the conformal symmetry that emerge in the $M\to 0$ limit of the theory. I will also show that the event horizon is dual to a matrix model which provides a physical mechanism for the formation of remnants. Note that matrix models are actually fermionic theories; therefore, this is suggestive of fermionization of the black-hole event horizon as well.

Session 3. High Energy Nuclear and Particle Physics

sciforum-164644: Imaging nuclear structure across energy scales: from heavy to light ions

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Atomic nuclei are self-organized, many-body quantum systems bound by strong nuclear forces within femtometre-scale space. The shape and orientation of colliding nuclei play a crucial role in determining the initial conditions of the quark–gluon plasma (QGP), which influence key observables such as anisotropic and radial flow. In this talk, I will present an "imaging-by-smashing" approach using soft probes that are directly sensitive to the structure of colliding nuclei, from large to small systems, in high-energy nuclear collisions [1,2,3]. We present the measurements of , fluctuation, and – correlations in isobar-like $^{238}U+^{238}U$ and $^{197}Au+^{197}Au$ collisions at 193 and 200 GeV, respectively. Our results reveal prominent differences in these observables between the two systems, particularly in the most central collisions. We also present the first measurements of in $^{16}O+^{16}O$ and $d+^{197}Au$ collisions, providing insight into the impact of nucleon–nucleon correlations and further shedding light on the initial conditions of QGP droplets. Comparisons with the state-of-the-art hydrodynamic calculations enable us to extract the nuclear shape parameters across energy scales [4,5]. This interdisciplinary research enhances our understanding of the initial conditions in high-energy collisions and provides new insights into the evolution of nuclear structure across energy scales.

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sciforum-161892: Semileptonic decays of B_c involoving vector mesons in self-consistent covariant light-front quark model

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We present an extensive and systematic investigation of the semileptonic $B_c \to V$ decays within the self-consistent Covariant Light-Front Quark Model (CLFQM), a framework that provides a covariant and internally consistent description of hadronic transition dynamics in heavy–heavy meson systems. Traditional light-front approaches often suffer from ambiguities associated with spurious ω-dependence and zero-mode contributions, which can distort the extraction of physical form factors. The self-consistent CLFQM addresses these challenges by imposing explicit self-consistency conditions on the light-front vertex functions, thereby eliminating spurious contributions and ensuring that the resulting hadronic matrix elements are covariant and free from model artifacts. Within this refined theoretical framework, we compute the complete set of vector and axial-vector form factors for the $B_c \to V$ transitions and examine their behavior across the entire kinematic range. To achieve a stable and reliable representation of their q^2-dependence, we employ a model-independent z-series expansion. Using these form factors, we present numerical predictions for a variety of physical observables, including branching fractions, forward–backward asymmetry, lepton-polarization fractions, etc. The results highlight the improved internal consistency and predictive capability of the self-consistent CLFQM and offer updated Standard Model benchmarks for B_c semileptonic channels. This study contributes to a deeper understanding of nonperturbative QCD effects in heavy meson systems and supports ongoing experimental and theoretical efforts aimed at probing heavy-quark dynamics and testing lepton-flavor universality.

sciforum-155122: The Snowball Chamber: A Multidisciplinary Radiation Detector

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The Snowball Chamber is a novel concept for rare event detection based on the controlled use of supercooled liquids. In this detector, purified liquids such as water are held below their freezing point in a metastable state, where localized energy depositions—such as those from nuclear recoils—can trigger rapid, visible crystallization events. This process results in a unique “snowball” signature, which can be used to detect rare interactions such as those potentially induced by dark matter or other forms of ionizing radiation.
Beyond its immediate particle physics applications, the Snowball Chamber also can serve as a platform for studying the dynamics of phase transitions in extreme environments. Supercooled liquids are of particular interest in planetary science and astrobiology, as they may exist beneath the icy surfaces of moons like Europa or Ganymede. Understanding how radiation, pressure, and impurities affect nucleation and freezing in such metastable systems could shed light on the thermal behavior of extraterrestrial oceans—and their potential for harboring life.
In this presentation, we introduce the operating principles of the Snowball Chamber, report on early experimental tests of supercooling stability and nucleation behavior, and discuss future directions. These include both optimization of the detector for rare event searches and the use of the system as a terrestrial analog for radiation-induced crystallization in planetary environments.
This work thus represents a multidisciplinary opportunity at the intersection of particle detection, thermodynamics, and planetary exploration.

sciforum-161950: Asteroseismology of Proto-Quark Stars

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According to the Bodmer–Witten hypothesis, ordinary nuclear matter is just a metastable state of the so-called strange quark matter. If it already exists in the universe, it can manifest as quark stars. Since this type of compact star has properties somewhat similar to neutron stars, one might think of them as potential candidates satisfying modern pulsar measurements. In this work, we study the radial and non-radial oscillations of hot and lepton-rich quark stars, i.e., instants after their potential birth in supernovae events. In order to calculate their fundamental-mode frequencies, we use a density-dependent quark mass framework for microphysics to build the equation of state, solve the eigenvalue problem to determine their radial stability, and use the full general-relativistic perturbative framework of non-radial oscillations. We found that their dependencies on the gravitational masses, compactness, and energy densities display remarkable differences compared to widely studied protoneutron stars. In order to quantify these differences, we build and propose some universal relations correlating all these stellar parameters. As expected, similar hadronic universal relations depart from our results. In this sense, our findings may serve as a smoking gun to distinguish strange quark stars from ordinary nuclear neutron stars using upcoming gravitational-wave data in the multimessenger astronomy era.

sciforum-153172: Constrained Neutrino Masses and Flavour Observables from a Dual-Seesaw Framework.

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Understanding the origin of neutrino masses and their mixing patterns remains a central challenge in particle physics, as it provides key insights into the limitations of the Standard Model (SM) and potential avenues for new physics. Flavour symmetries, combined with seesaw mechanisms, offer a promising framework to address these questions while yielding testable predictions in current and future experiments. Motivated by these considerations, we present a novel framework for neutrino masses and mixing based on the interplay of Type-I and Type-II seesaw mechanisms under non-Abelian A_4 discrete flavour symmetry. The framework is consistent with the normal hierarchy (NH) of neutrino masses and is governed by three real parameters that span the entire model and its predictions. It determines the neutrino mass eigenvalues and Majorana phases. The model further constrains the effective Majorana mass ($m_{\beta\beta}$) relevant for neutrinoless double beta ($0\nu\beta\beta$) decay and the branching ratio of the dominant $\mu \rightarrow e \gamma$ charged lepton flavour violating decay. Both observables are sensitive to the underlying parameters and provide indirect tests of the model. Overall, this minimal A_4 symmetric framework demonstrates that a small set of parameters, guided by symmetry and seesaw dynamics, can lead to predictive outcomes. The interplay between theoretical predictions and low-energy observables highlights the model's relevance and accessibility to future experimental investigations.

sciforum-158432: Dark Neutron Decay in Nuetron Stars

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One of the unsolved mysteries in the particle physics is the "neutron decay puzzle". Discrepancies between the neutron lifetime measured in beam and bottle experiments suggest that exotic decay channels and/or the involvement of dark matter may be in play. The proposed dark decay of the neutron may explain the existence of a wide range of objects produced from the mixing of neutron stars with dark matter, , including objects with small masses and radii, as well as those in the mass gap region. This hypothesis can more generally explain the existence of other compact objects with both small masses and radii that are to the left of and below the classical MR diagrams. In particular, we consider the case of neutron decay into a dark particle of mass m_x=939 MeV according to the hypothesis formulated by Grinstein. We consider this dark matter to interact both with itself and with neutrons, thus defining the equation of state of the neutron and dark matter mixture. In this study, we found that with the appropriate combination of interaction parameters, both masses larger than 2 solar masses can be simultaneously predicted, and at the same time, the compact objects XTE and HESS can be reproduced in a self-consistent way.

sciforum-163224: Dirac Leptogenesis via Scattering using CTP Formalism

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We investigate the generation of the matter–antimatter asymmetry in the early universe, prior to the electroweak phase transition, by extending the Standard Model with three right-handed neutrinos that complete Dirac mass terms and two heavy scalar fields. This constitutes a minimal and well-motivated Beyond-the-Standard-Model framework, since the Standard Model alone cannot account for neutrino masses or produce the observed baryon asymmetry due to insufficient CP violation. Using the Closed Time Path (CTP) formalism, we analyze-2-by 2 scattering processes mediated by heavy off-shell scalars. Since these scalars remain off-shell throughout, the post-inflationary temperature of the universe does not need to be high enough to produce them on-shell.

In this setup, right-handed neutrinos depart from thermal equilibrium, generating a lepton asymmetry that is subsequently converted into the observed baryon asymmetry via sphaleron processes. We compute the resulting baryon-to-photon ratio and compare it with the observational value reported by the Planck mission. We also compare the predicted contribution of the right-handed neutrinos to the effective number of relativistic species N_{eff} with current cosmological bounds, confirming the model's consistency with observations.

The use of the CTP formalism eliminates the need for Real Intermediate State (RIS) subtraction, leading to a more consistent and elegant treatment. Furthermore, by incorporating quantum statistical factors, we demonstrate that viable asymmetry generation is achievable even with only two right-handed neutrino flavours. Consequently, the mechanism is generic and does not rely on specific particle species such as leptoquarks or other particular Standard Model extensions.

sciforum-161440: Exploring Flavours with Quarkonia Candidates

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Lepton Flavour Violation (LFV) is one of the important topics of High-Energy Physics in recent days and Υ is one of the suited candidates to explore the early universe. Upsilons decay into muons through the annihilation of the bound state of quarks and gluons. Since the discovery of these particles, they have drawn much attention in understanding their characteristics experimentally and theoretically. The radiative and the lepton flavour-conserving decays are already well established via observations in small systems. On the other hand, their lepton flavour violating part is still unexplored in colliders and also in BSM physics. Also, this quarkonium candidate shows unique behaviour at high temperatures and densities. The colliders are also probing the LFV decays in the search of NP. Motivated by the study of the LFV decays, we will present and discuss various LFV decays of Upsilons, incorporating the contribution of the Z' boson. Here, we have also constrained the maximum allowed values of the New Physics (NP) quark couplings to predict the upper bound of the LFV branching ratios. The NP couplings are constrained with the available experimental data using the chi-square fitting technique. Connections of BSM physics with QCD avenues will be also presented and discussed.

sciforum-161426: Finite-Size Effects on the Density-Driven Deconfinement Phase Transition in QCD

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We investigate finite-size effects on the density-driven deconfinement phase transition (DPT) in Quantum Chromodynamics (QCD) using a model of coexisting hadronic and quark–gluon plasma (QGP) phases in a finite volume. The QGP phase is modeled via the MIT bag approach, explicitly incorporating the color-singletness constraint to account for the color confinement. As a continuation of our previous work, in the present study, we will analyze the first and second chemical derivatives of the order parameter across a range of quark chemical potentials *(μ)*, at fixed temperature *(T)* and for several volume *(V)* selections, to determine the effective transition point in a finite volume. Our results reveal that the effective transition chemical potential $\mu_c(V)$ shifts to higher values as the system size decreases, highlighting the pronounced influence of finite-volume effects. Moreover, the rapid variations in the order parameter and its chemical susceptibility at the transition in large volumes, are rounded off in small volumes, and the transition region is smeared out, acquiring a width $\delta\mu(V)$ which increases with decreasing volume. These findings provide a comprehensive understanding of how finite-volume constraints influence the QCD phase structure, offering important insights for interpreting results from heavy-ion collisions and other high-energy experiments where the system size is inherently limited.

sciforum-160367: Ginzburg–Landau-Type Model For The Outer Core Of Neutron Stars

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Background: Neutron star outer cores contain superfluid neutrons and superconducting protons. Their mutual interaction, mediated by vortex–flux-tube dynamics, affects both the rotational and magnetic evolution of the star. Understanding the structure and energetics of these topological defects is therefore relevant for models of glitch dynamics and magnetic field evolution.

Methods: We model the neutron–proton system with a two-component Ginzburg–Landau framework, treating neutrons as a neutral condensate and protons as a charged one. By solving the coupled Ginzburg–Landau equations, we obtain the modified core profiles of vortices and flux tubes and quantify how inter-species coupling alters their structure. The corresponding interaction energies are computed to characterise mixed configurations.

Results: The numerical calculations identify regimes in which vortices and flux tubes attract (i.e., display pinning behaviour) or repel, depending on the coupling parameters of the two condensates. Furthermore, we identify constraints on the choice of coupling parameters required to achieve stable configurations for this system.

Conclusions: A microscopically calibrated two-component Ginzburg–Landau model can reproduce key mesoscopic features of vortex–flux-tube interactions in the outer core. While our model is phenomenological, it shows that the resulting forces may be of sufficient magnitude to influence glitch dynamics as well as the coupled rotational–magnetic evolution of neutron stars.

sciforum-163841: Modeling the QCD equation of state throughout the thermal deconfining phase transition from hadronic matter to a Quark–Gluon Plasma

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This work investigates the thermal deconfining phase transition from a hadronic gas composed of massive pions to a quark–gluon plasma (QGP) described by the Polyakov–Nambu–Jona-Lasinio (PNJL) model with two light quark flavors. The PNJL model extends the Nambu–Jona-Lasinio (NJL) approach, including chiral symmetry dynamics and the Polyakov loop, allowing a more realistic description of the QGP phase. A temperature-dependent switching function (SF) is used to ensure a smooth crossover between the hadronic and QGP phases. We analyze the temperature dependence of key thermodynamic quantities, including the pressure, energy density, entropy density, and the square of the speed of sound, and study the influence of pion and quark masses on the equation of state (EOS). This analysis provides a better understanding of the interplay between particle properties and the thermodynamic properties of the system, helping to provide a more comprehensive and accurate picture of the thermal behavior of hadronic matter at zero chemical potential, including its response to changes in temperature and energy. This is essential for interpreting heavy-ion collision results and simulating early-universe conditions. Our analysis results are systematically compared with available lattice QCD data, providing valuable insights and allowing us to assess the accuracy of the model and its ability to describe strongly interacting matter at high temperatures.

sciforum-164032: Numerical model of the dipole phase change in Galactic Cosmic-Ray Anisotropy

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Experimental measurements of the large-scale anisotropy of Galactic cosmic rays (CRs) reveal a sharp change in the phase of the dipole component at energies around 100 TeV. Most traditional interpretations invoke macroscopic diffusion models of CR propagation or the influence of nearby sources; however, such approaches often do not adequately account for the local magnetic-field structure at the observer, which can substantially distort the measured anisotropy. Here we treat the anisotropy as a generic consequence of the local magnetic-field properties and the particle transport regime and therefore expect it to manifest at arbitrary locations in the Galaxy, rather than being specific to the vicinity of the Solar System. The source distribution and the local field parameters primarily determine the characteristic energy and the width of the dipole-phase transition region.

In this work, we model CR transport microscopically by numerically integrating particle trajectories in an interstellar magnetic field represented as the superposition of a uniform regular component and an isotropic turbulent component with a Kolmogorov spectrum. The turbulent field is generated using a harmonic method. The anisotropy is computed using the backtracking method to construct a sky map of the arrival intensity, followed by a multipole decomposition and extraction of the dipole term. We show that the sharp phase change is naturally associated with a crossover in the propagation regime. At energies where the Larmor radius is smaller than the turbulence correlation length, particles remain tied to local field lines and the dipole phase aligns with the local magnetic-field direction. Once the Larmor radius exceeds the correlation length, transport approaches standard three-dimensional diffusion, and the phase stabilizes along the direction set by the large-scale regular field. Our numerical results indicate that the position and the width of the phase-transition region are determined primarily by this transport-regime crossover.

sciforum-161279: Spin–orbit effect in low-energy heavy-ion collisions

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The spin–orbit (SO) coupling is fundamental to the description of the nuclear shell structure. However, its dynamical role in heavy-ion collisions remains a crucial, but not fully understood, aspect of nuclear physics. While static properties are well-constrained, the influence of the SO force on energy dissipation and collective motion during collisions requires deeper investigation. We address this using microscopic three-dimensional Time-Dependent Hartree–Fock (TDHF) calculations with the SKY3D code, employing the SLy4, Sv-bas, and SkM* interactions. This study performs a systematic survey of central collisions across a broad mass range ($Z = 6–36$), covering isotopes with neutron numbers from $Z - 4$ to $Z + 4$, at center-of-mass energies defined slightly above the Coulomb barrier. We focus on the collective density oscillations of the forming dinuclear system. By analyzing the time evolution of the relative distance R, we extract the oscillation period T and the corresponding restoring force coefficient k via the relation $k = 4\pi^2\mu / T^2$. Our analysis reveals that k is strongly correlated with the total nucleon number A. Interestingly, the impact of the SO coupling is clearly mass-dependent: for lighter systems, the SO interaction enhances the restoring force, whereas for heavier systems, the restoring force is stronger when the SO interaction is excluded. Notably, results with the SLy4, Sv-bas, and SkM* interactions exhibit a distinct peak in k around $A \approx 60$ in the absence of SO coupling, reflecting significant structural variations. These findings clarify the signatures of spin-dependent dynamics and offer critical constraints for improving the time-odd components of nuclear energy density functionals.

sciforum-158724: Study of the effect of the area and curvature terms in the quark and gluon density of states on the transition temperature

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This study investigates the effects of adding the area and curvature terms to the volume term in the quark and gluon density of states on the transition temperature, at which the deconfinement phase transition occurs. The analysis begins with the computation of the partition function of both the Hadronic Gas (HG) and the Quark–Gluon Plasma (QGP) projected onto the SU(3) color-singlet representation, using the projection method, within the quark and gluon density of states given by the Multiple Reflexion Expansion (MRE) approximation. We consider the transition between a Hadronic Gas (HG) phase, consisting of massive pions, and a Quark–Gluon Plasma (QGP) phase, which includes gluons, massless up and down quarks, and massive strange quarks along with their antiquarks, in the framework of the Bag model and the phase coexistence model. We then examine the variations in the pressure of both the Hadronic Gas (HG) and the Quark–Gluon Plasma (QGP) phases, with the aim of determining the transition temperature in different cases of contributing terms in the quark and gluon density of states: considering the contributions of the volume term only, volume and area terms, volume and curvature terms, and the combination of the three volume, area and curvature terms.

sciforum-163265: The CMS Forward Muon System Upgrade with GEM Detectors

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The 2012 landmark discovery of the Higgs boson by the ATLAS and CMS experiments marked the beginning of the new era for the LHC to precisely characterise this particle to validate and push the boundaries of the Standard Model through exploration at the highest available energies. To fully exploit the scientific potential of the LHC, both the accelerator and its detectors are undergoing extensive upgrades as part of the High-Luminosity LHC (HL-LHC) project, corresponding to an expected number of 140 to 200 simultaneous proton–proton interactions per bunch crossing by the end of the decade. A central element of this effort is the reinforcement of the forward muon system, for which CMS is deploying three new GEM-based muon stations: GE1/1, GE2/1, and ME0. These detectors combine excellent spatial resolution (~250 μm), high-rate capability (>1 kHz/cm^2), and radiation tolerance, while providing additional coordinate measurements and redundancy in combination with the existing Cathode Strip Chambers (CSCs) and RPCs. The GE1/1 station consists of 144 triple-GEM modules, arranged in super-chambers in both CMS endcaps, covering the range 1.55 $|\eta|$ 2.18. The GE2/1 station, with 72 GEM chambers composed of 288 modules, extends coverage approximately over 1.62 $|\eta|$ 2.43. The six-layer ME0 station, covering approximately 60 m^2, will be installed behind the new high-granularity calorimeter (HGCAL) during the third Long Shutdown (LS3) and will extend the CMS muon system's pseudo-rapidity coverage from $|\eta|$ 2.4 to $|\eta|$ 2.8. Full system of GE1/1 and a few GE2/1 stations are contributing to the data taking in Run-3 with an operational efficiency above 95%. GEM technology efficiently rejects background and improves the precision of the muon bending angle measurement. This work presents an overview of the muon spectrometer upgrade of the CMS with GEM detectors, including operational experience and performance of the GEM station.

sciforum-161214: Unraveling the SMEFT Flavor Structure through cLFV Searches at Future Lepton Colliders

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Future lepton colliders provide a uniquely clean and high-precision environment to probe charged lepton flavor violation (cLFV) at energy scales far beyond the reach of current experiments. Such facilities are particularly well suited to explore flavor-violating interactions with suppressed Standard Model backgrounds and well-controlled systematic uncertainties. In this work, we investigate a broad class of LFV operators in the Standard Model Effective Field Theory (SMEFT) framework across multiple collider configurations, focusing on multi-TeV electron–positron and muon machines envisioned for the next generation of high-energy lepton programs. Our analysis incorporates realistic assumptions about detector performance, particle identification, and beam polarization, enabling an accurate characterization of both the signal and the dominant Standard Model backgrounds. We explore the interplay between center-of-mass energy, integrated luminosity, and polarization configurations in enhancing LFV sensitivity, demonstrating how different collider setups provide complementary access to operator structures and chiral couplings. In addition to a traditional cut-based approach, we evaluate the impact of multivariate techniques and optimal observable strategies in extracting maximal information from kinematic distributions. Preliminary projections indicate that next-generation lepton colliders can improve sensitivity to LFV interactions relative to indirect limits derived from rare tauon decays. These results highlight the decisive role of future lepton collider programs in establishing a comprehensive global effort to uncover new sources of lepton flavor violation and in mapping the SMEFT flavor landscape with unprecedented precision.

Session 4. Foundations of Quantum Mechanics

sciforum-162101: Separation of variables and correlation functions: from spin chains to CFT

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Integrable quantum spin chains are fundamental models that are also widely used for the exploration of foundational aspects of quantum mechanics, offering a perfect arena to study key quantities such as entanglement, information scrambling, and quantum correlations. Yet, the utilised theoretical methods here still face major obstacles, especially for the computation of correlation functions. Recent years have seen substantial progress in the development of the powerful separation of variables (SoV) approach to quantum integrable models, which allows one to factorise the wavefunctions, opening gateways to many applications as well as clarifying the structure of the model's Hilbert space. In this talk, I will review the main results achieved in this program based on a series of recent papers with my collaborators. In particular, I will present the explicit construction of the SoV framework for integrable spin chains with gl(N) symmetry. I will explain how the SoV basis arises in this general setting, providing a representation-theoretic understanding of the method. I will then address a longstanding problem in the field, namely the computation of the SoV measure. I will show how our approach leads to a complete solution of this problem and, as a direct consequence, to new highly compact determinant representations for a broad class of physical quantities, including correlation functions and wavefunction overlaps. Furthermore, I will demonstrate the power and versatility of SoV in four-dimensional integrable conformal field theories, with a particular emphasis on the fishnet theory. In this context, I will present new results on the Yangian symmetry for a large and previously unexplored class of Feynman graphs. Finally, I will outline promising applications of these methods to the computation of exact correlators in planar N=4 super Yang–Mills theory and discuss several open directions for future research.

sciforum-163845: Dependence of the Exceptional Points on the Temperature in a Pseudo-Hermitian Hybrid Model.

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In this study, we analyze the temperature dependence of Exceptional Points (EPs) in a pseudo-Hermitian hybrid model composed of a superconducting flux qubit (SFQ) interacting with an ensemble of nitrogen-vacancy (NV) color centers in diamond [1–2]. This model is relevant not only due to its experimental realizability [1], but also as a representative example of a many-body Hamiltonian exhibiting a nontrivial interplay of distinct physical effects.

The interaction between the NV ensemble and the SFQ is modeled by introducing an asymmetry parameter [2] that modifies the balance between the creation and annihilation processes of NVs coupled to the SFQ. This asymmetry accounts for the presence of impurities within the NV ensemble, such as P1 centers [3].

As reported in [4], temperature effects on the zero-field splitting states of the NV ensemble are negligible below T=200 KT = 200~\mathrm{K}T=200 K. Therefore, we assume that temperature has an insignificant effect on the NV ensemble. This is not the case for the SFQ, as superconductivity is well known to be strongly temperature-dependent.

We investigate how the location of the EPs and the extent of each symmetry phase evolve with temperature by explicitly incorporating the temperature dependence of the superconducting gap in the SFQ . To characterize the system's evolution and the impact of thermal effects, we analyze several observables, including the survival probability, expectation values of spin components, spin squeezing, and the SU(2) Wigner function. The initial state is prepared as a spin coherent state for the NV ensemble, with the SFQ in its ground state.

Our results show that increasing temperature tends to expand the region of parameter space corresponding to the exact-symmetry phase [5].

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sciforum-161131: A multi-Hamiltonian approach to higher time-derivative theories: An interacting Pais–Uhlenbeck model

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Despite appealing theoretical features, higher time-derivative theories (HTDTs) are notoriously plagued by issues of instability—most prominently the emergence of ghost states, which signal the presence of unbounded-from-below Hamiltonians or non-normalisable states, that threaten the physical viability of these theories. Consequently, the construction of ghost-free representations is a central aim.

The Pais–Uhlenbeck (PU) model, a canonical example of a fourth-order differential system, is a paradigmatic example of an HTDT and encapsulates their essential challenges and features. Using its multi-Hamiltonian structures in conjunction with the Lie symmetries of the dynamical equation, one can construct distinct, but compatible, Poisson bracket formulations that preserve the system's dynamics. Amongst other possibilities, this framework allows the recasting of models in a positive definite manner while leaving the dynamical flow unchanged, thus resolving the ghost problem. The application of the outlined approach has successfully demonstrated the construction of ghost-free representatives for the PU theory.

Introducing interactions to HTDTs generally challenges their stability further and poses a difficult problem. Going beyond the PU model, we here analyse an interacting extension of the system that admits closed-form solutions. This model suggests promising directions for the systematic construction of stable interacting HTDTs, future generalisations to field-theoretic settings, and further investigation into the quantisation of positive-definite PU models. A connection to an integrable realisation of the generalised Hénon–Heiles system (tied to Lax's fifth-order KdV flow) is discussed.

sciforum-161369: Quantum Biology: Quantum Phenomena in Living Systems in a Cosmic Context

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Quantum biology is an emerging interdisciplinary field that investigates the fundamental quantum mechanisms underlying biological processes and their potential roles in the emergence and sustainability of life beyond Earth. While classical biochemistry successfully describes many aspects of life, experimental and theoretical evidence increasingly suggests that quantum effects such as coherence, tunneling, and entanglement play crucial roles in processes such as photosynthesis, enzyme catalysis, olfaction, and magnetoreception. In photosynthesis, energy transfer occurs through quantum coherence in pigment–protein complexes, while enzyme catalysis can involve proton or electron tunneling. Olfactory sensing may rely on electron tunneling, and magnetoreception in birds involves spin dynamics and entanglement in cryptochrome proteins. This work provides an in-depth analysis of these mechanisms, emphasizing how they might operate under cosmic conditions, including extreme temperatures, high-radiation, microgravity, and low-energy environments. Understanding these processes offers insights into the limits of quantum coherence in extreme environments, the potential emergence of life in diverse planetary and interstellar settings, and the fundamental principles governing complex systems. Additionally, potential applications in quantum-inspired technologies and biomimetic systems are discussed, highlighting how principles observed in living organisms can guide the design of novel quantum devices. By examining quantum mechanisms in both terrestrial and cosmic contexts, this work bridges physics, biology, and astrobiology, emphasizing the universal relevance of quantum principles to life across the cosmos.

sciforum-163896: Strong-coupling energetics of a Brownian quantum oscillator: the mean energy, its interpretation, and low-temperature behavior

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In this talk, I will discuss the notion of thermally averaged mean energy of a quantum harmonic oscillator strongly coupled to a heat bath, defined as the expectation value of the bare-system Hamiltonian in the canonical Gibbs state of the composite system, i.e., the system and bath taken together with their interactions. This quantity differs fundamentally from the thermodynamic internal energy obtained from the reduced partition function and provides an alternative perspective on the strong-coupling energetics. Using the Brownian quantum oscillator as a paradigmatic example, I will show how this mean energy can be consistently interpreted within the frameworks of quantum thermodynamics and stochastic energetics. Based on the fluctuation–dissipation theorem, I will first show how the Lehmann–Kubo representation of the generalized susceptibility allows one to interpret the mean energy as the bare oscillator's energy contained within the dressed eigenmodes of the composite system. I will then show, using the quantum Langevin equation, that the mean energy obeys an exact energy-balance relation consistent with the framework of stochastic energetics, even in the presence of non-Markovian dissipation. Finally, I will discuss analytical results for Ohmic dissipation with a Drude cutoff and show that, at low temperatures, the thermal part of the mean energy exhibits the same universal power-law behavior as the thermodynamic internal energy. The remaining difference between these two notions of energy is a temperature-independent contribution originating from system-bath correlations, highlighting the persistent role of the environment deep into the quantum regime.

sciforum-163639: Time advance and probability conservation in PT-symmetric quantum mechanics and the square well potential

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When excited states decay with energy $E_0-i\Gamma$, the time evolution operator $U(t)=e^{-iHt}$ does not obey $U^{\dagger}(t)U(t)=I$. Nonetheless, probability conservation is not lost if one includes both decay and excitation with energy $E_0+i\Gamma$, though it takes a different form. Specifically, if the eigenspectrum of a Hamiltonian is complete, then due to CPT symmetry, a symmetry that holds for all physical systems, there must exist an operator V that effects $VHV^{-1}=H^{\dagger}$, so that $V^{-1}U^{\dagger}(t)VU(t)=I$. As a consequence, because of probability conservation, the time delay associated with decay must be accompanied by an equal and opposite time advance for excitation. Thus, when a photon excites an atom, the spontaneous emission of a photon from the excited state must occur without any decay time delay at all. An effect of this form, together with an associated negative time delay, have recently been reported by Sinclair et al., PRX Quantum 3, 010314 (2022), and Angulo et al., arXiv:2409.03680 [quant-ph]. We show that the non-relativistic square well problem with a real potential possesses PT symmetry in both the bound and scattering sectors, with complex conjugate pairs of energy eigenvalues in the scattering sector. In addition, we show that the square well scattering threshold branch point is an exceptional point (a characteristic of systems with an antilinear symmetry such as PT), a point at which the Hamiltonian becomes of non-diagonalizable, and thus manifestly non-Hermitian, Jordan-block form. The square well potential, one of the oldest known quantum-mechanical systems, provides an explicit realization of how antlinearity is more general than Hermiticity.

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sciforum-164023: Uncertainty Relations in Non-Hermitian Systems

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The Heisenberg–Robertson uncertainty relation is a standard tool in quantum mechanics, but its use in non-Hermitian settings is not straightforward, especially in regimes with complex spectra and exceptional points. In this context, we study uncertainty relations for pseudo-Hermitian, in particular PT-symmetric Hamiltonians by introducing a metric operator in all spectral regimes. As a simple and widely used test case, we focus on a non-Hermitian two-level toy model with balanced gain and loss, which shows the transition from an exact PT-symmetric phase to a symmetry-broken phase through an exceptional point.

The chosen method is based on the explicit construction, in each regime, of a positive-definite metric operator that induces a modified inner product and defines the physical expectation values and variances. On this basis, we derive generalized Heisenberg–Robertson uncertainty relations for selected observables of the two-level model and compute their behavior in the exact, broken, and exceptional-point regions. In parallel, we construct a description in terms of a Lindblad master equation for the corresponding open two-level system and use it as a reference to compare with the non-Hermitian effective dynamics.

We find that the metric-based formulation restores an uncertainty relation with the same formal structure as in the Hermitian case, whereas the direct use of the standard inner product can lead to ill-defined quantities, in particular in the symmetry-broken phase and at the exceptional point. The comparison with Lindblad dynamics shows agreement between the metric-based description and features such as PT-symmetry breaking and decoherence. These results indicate that, even for a two-level toy model, an appropriate metric is necessary to obtain consistent uncertainty bounds and dynamical predictions from pseudo-Hermitian Hamiltonians.

Session 5. Space and Planetary Sciences

sciforum-163767: Beyond Planets: Simulating Exocomet Transits in High-Precision Photometry

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The detection of exocomets provides a unique window into the small-body populations and dynamical evolution of extrasolar planetary systems. While spectroscopic signatures of exocomets have been identified in several debris-disk systems (e.g. Ferlet et al. 1987; Kiefer et al. 2014), photometric detections remain relatively rare and challenging due to their transient, asymmetric, and often aperiodic nature. However, previous studies have shown that exocomet transits can produce characteristic light-curve signatures that are, in principle, detectable in high-precision photometric data (Lecavelier des Etangs et al. 1999; Rappaport et al. 2018).

We explore simplified models of dusty exocomet transits, focusing on how different cometary structures may influence the observed shape of stellar light curves. The study relies on numerical simulations to examine the combined effects of absorption and scattering by circumstellar dust across a range of wavelengths. By considering various plausible dust properties and observing configurations, we aim to assess which photometric features could serve as reliable indicators of exocometary activity in transit observations (Kálmán et al. 2024).

The resulting synthetic light curves reproduce the characteristic asymmetric “shark-fin” transit profiles associated with exocomets, while revealing a strong wavelength dependence driven by dust properties. We show that multi-band photometry significantly enhances the ability to distinguish exocomet transits from other aperiodic dimming events, such as stellar activity or circumstellar disk structures. In particular, color-dependent transit depths and timing shifts provide constraints on grain size evolution and material composition within the cometary tail.

This work highlights the potential of exocomet transit simulations as a useful tool for interpreting photometric observations and for guiding future searches for exocomets. In particular, upcoming missions such as ARIEL, with its multi-wavelength observing capabilities, may offer new opportunities to identify and characterise dusty cometary transits in extrasolar systems (Tinetti et al. 2021).

sciforum-160483: Contradictory results in the rock magnetic and SEM-EDS characteristics of the carbonaceous chondrite NWA 11469

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A combined rock magnetic study and scanning electron microscopy (SEM) were conducted on the NWA11469 carbonaceous chondrite. The studied meteorite was purchased in 2016 in Mauritania, and no detailed analysis of its magnetic mineralogy has yet been published. This study aims to identify the magnetic minerals in NWA 11469 by integrating SEM observations with mineral information inferred from rock magnetic experiments, providing a foundation for future magnetic investigations. Rock magnetic measurements, including hysteresis, IRM acquisition, and thermomagnetic analyses, were performed using an MMVFTB at the University of Burgos. Complementary mineralogical observations were conducted with a JEOL JSM-6480LAII SEM–EDS at Kobe University. Hysteresis measurements of NWA 11469 show a “pot-bellied” shape consistent with mixture grains and dominant MD grains, supported by Day-plot Mrs/Ms = 0.04–0.1; Hcr/Hc = 4.5–5). IRM data showed that 70–80% of the magnetic contributors saturate below 300 mT, indicating low-coercivity phases (magnetite/Fe–Ni), while 20–30% reflect high-coercivity components likely related to, e.g., goethite. Thermomagnetic curves exhibit inflection points near 580 °C and 800 °C, attributed to major Fe phases, and show irreversible behavior, suggesting oxidation-related mineral (e.g., magnetite) formation. SEM-EDS observations confirm kamacite, taenite, pyrrhotite, goethite, and ferrihydrite, but no magnetite was detected. Some discrepancies emerged between the magnetic and SEM–EDS datasets. Goethite and pyrrhotite, although clearly recognized by SEM/EDS, were not observed during the thermomagnetic experiments, likely because their weak magnetization was masked by the strongly magnetic Fe–Ni alloys. Conversely, magnetite was not verified by SEM, likely because its nanometric SD-sized grains fell below the SEM resolution limit. These discrepancies emphasize the complementary strengths of the two approaches: magnetic methods can detect nanoscale contributors that are hidden from SEM, whereas SEM–EDS provides direct mineral identification. Integrating both datasets, therefore, yields a more comprehensive understanding of the mixed magnetic mineral assemblages in NWA 11469.

sciforum-158743: Deliquescence probability under varying dust and climate conditions on present-day Mars

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Liquid water availability is an important aspect of Mars habitability studies; however, current conditions allow only transient, localized liquid formation. Perchlorate salts have been identified across Martian latitudes and might deliquesce under ideal conditions. Deliquescence occurs when temperature and relative humidity exceed salt-specific thresholds. Atmospheric dust shapes near-surface microclimates where brine formation is possible and understanding how dust conditions influence deliquescence is essential for identifying when and where brines may form on Mars.

I used the Mars Climate Database v6.1 to model near-surface conditions in three climate scenarios. “Climatology” scenario represents a standard Martian year; “Warm” scenario sets dust opacity to the observed maximum (excluding global dust storms); “Cold” scenario corresponds to a clear atmosphere with dust opacity set to the minimum observed over Mars years 24-35. The model ran on a 3.75° x 5.625° latitude-longitude grid for one year. I selected the region where the overall deliquescence chance was the highest, between 73.125° W - 5.625° W and 33.75° N – 71.25° N. To compare the possibility of deliquescence between scenarios, I calculated the percentage of ideal days per year.

In the climatology scenario, deliquescence probability was the highest at 10 PM =–12 AM, with lower chances at 2 AM and 6 AM, and a secondary peak at 4 AM. In the warm scenario, the maximum probability occurred at 2 AM–4 AM, followed by a sharp decline. Between 6 PM–12 AM, the probability increased gradually. In the cold scenario, the probability increased after 8 PM, peaking at 12 AM, with lower values at 2 AM and 6 AM, and a small peak at 4 AM. Overall, the warm scenario shifted the peak to later in the night. Cold and climatology scenarios behaved similarly, with climatology yielding more ideal days except for 12 AM.

sciforum-161638: Planetary science education in Hungary: interdisciplinary methods at university level

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A wide range of information on the characteristics of various landforms on different planetary bodies has been obtained from exploration missions conducted over the last few decades. Indictors of tectonic, volcanic, glacial, fluvial, and lacustrine activities were found on several solid surface bodies. Under the Planetary Science course at Eötvös Loránd University of Sciences (ELTE), a collaboration on educational methodologies between the Astronomy and Earth Science departments has been developed. The presentation modes were shaped to make BSc and MSc students familiar with the research methods and approaches used to address specific questions in this domain. A comparative evaluation of the surface landforms, along with their background characteristics (like gravity, temperature range, atmospheres, solid surface material composition), was also performed.

The whole curriculum was built based on groups of processes and surface conditions and not on planetary bodies to compare the same process under different environments. The main messages encouraged the students to integrate current knowledge with concepts from other classical university courses like physics, chemistry, geography, petrology, etc., while also pointing to existing knowledge gaps to be discovered in the future. As an additional optional part of the curriculum, students could suggest specific test types or even missions to clarify these unknown aspects (related physics and Earth science subjects are indicated in brackets). Details of the curriculum will be presented at the meeting.

sciforum-161702: Remote characterization of interstellar comet 3I/ATLAS: confirming its natural origin and similitude with Trans-Neptunian Objects and CR chondrites

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3I/ATLAS is the third interstellar object identified crossing our solar system, and the second one exhibiting a cometary appearance. Pre-and post-perihelion photometric observations, inner coma imagery, and a spectroscopic comparison with CR and CH carbonaceous chondrites will be presented. The spectral similarities found are consistent with 3I/ATLAS, being a carbonaceous object, likely enriched in native metal and undergoing significant aqueous alteration during its approach to the Sun, like the hydrated chondrites widely observed in the Solar System(Trigo-Rodríguez et al., 2019). The extensive corrosion experienced due to its porous nature and the presence of reactive minerals, experiencing energetic Fischer–Tropsch reactions, makes it develop a new kind of cryovulcanism, similar to the pristine Trans-Neptunian Objects in our own planetary system. We proposed that the combination of elevated metal abundance and abundant water and ice can account for the unusual coma morphology and chemical products reported to date, particularly the overabundance of Ni in the coma (Trigo-Rodríguez et al. 2025). In consequence, the study of interstellar objects such as 3I/ATLAS, gravitationally scattered eons ago, provides unique opportunities to study physico-chemical processes occurred in minor bodies of our own Solar System, including transitional bodies similar to trans-Neptunian objects from the Solar System. I envision that the ESA's planned Comet Interceptor mission, and future sample return missions to new interstellar visitors exhibiting DeltaV favorable encounter conditions, can provide a pleyade of new information on the formation of planetary systems across our galaxy. Given the extraordinary catalytic potential of carbonaceous chondrites to promote complex organics under aqueous alteration (Rotelli et al., 2016), such discoveries could promote a significant breakthrough in our knowledge on the ubiquity of organic life in the Universe.

References:

Rotelli L. et al. (2016) Nature Sci. Rep., 6:38888.
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Session 6. Galaxies, Clusters and Compact Objects

sciforum-163796: Accreting Black Holes in Molecular Clouds

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Isolated stellar-mass black holes traversing dense regions of the interstellar medium, such as molecular clouds, are expected to accrete ambient gas. This accretion process can ionize surrounding gas, carving out a low-density ionized cavity within the cloud. The accreting black holes may also possess accretion discs and jets, producing cosmic rays and triggering hadronic and leptonic interactions. In this work, we show that the number of black holes residing in molecular clouds is proportional to the size of the cloud and we estimate the specific black-hole number density to be $\sim 1.2 \times 10 ^{-5}$ per solar mass of cloud, i.e., at least 10 black holes in massive molecular clouds with mass 8.4×10^5 solar mass. We then estimate the accretion process by Bondi–Hoyle–Lyttleton accretion and the effects brought about on the cloud structures, such as the formation of ionization cavities, and on the production of energetic particles. We show that the accretion rate log($\dot{M}$) [g/s] can reach up to 18 and the ionization cavity can reach up to 1 pc, occupying a substantial region of smaller molecular clouds. We discuss the consequences of the presence of ionization cavities in molecular clouds of different sizes, hence the implications for (i) cloud fragmentation and star formation and (ii) the inhomogeneity in the cloud environment for cosmic-ray transport in molecular clouds.

sciforum-163493: FORS2 Spectroscopy of a Pure Sample of Narrow-Line Seyfert 1 Galaxies

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Narrow-Line Seyfert 1 (NLS1) galaxies exhibit narrow permitted Hβ lines (FWHM 2000 km/s) and strong Fe II multiplets with low black hole (BH) masses ($10^8 M_\odot$) and high Eddington ratios. The BH masses and predominantly disk-like hosts suggest that NLS1s are early-stage Active Galactic Nuclei (AGN). They host the lowest-mass super-massive BHs that can launch relativistic jets and offer insights into the conditions necessary for jet formation. Available optical spectral catalogues have low S/N ratios, and classifying NLS1s using them is challenging. Using FORS2 observations of ~100 candidate NLS1s, we aim to classify the sources and perform detailed spectral modelling of Hβ, [OIII], and the Fe II pseudo-continuum using Gaussian, Lorentzian and Voigt profiles. Based on preliminary results, we found 16 changing-look AGN and a contamination fraction of ~28% in our data. We study how, in NLS1s, the broad Hβ line profile transitions from a Lorentzian to a Keplerian motion-dominated Gaussian with increasing BH mass, to determine whether this change is an essential part of intraclass evolution. By modelling the lines with Voigt profiles, we test whether the sources previously best described by Lorentzian or Gaussian functions are dominated by the turbulent or Keplerian component, respectively. In this talk, I will present the spectral analysis of NLS1s and changing-look AGN and discuss our findings and future plans.

sciforum-163872: Gamma-Ray Emission in Narrow-Line Seyfert 1 galaxies: A Fermi LAT study

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Narrow-line Seyfert 1 galaxies (NLS1s) are a class of active galactic nuclei (AGN) and were long believed to be radio-silent and incapable of producing relativistic jets; however, recent studies have demonstrated otherwise. The Fermi Large Area Telescope (LAT) made a groundbreaking discovery by detecting gamma-ray emission from the NLS1 source PMN J0948+0022, providing clear evidence that some of these sources can host relativistic jets in this class of AGN. This challenged the idea we had of NLS1s and their diversity.

Over the years, many new sources have been discovered, and my researchers have focused on analyzing these findings by systematically searching for additional gamma-ray-emitting NLS1s using data from the Fermi-LAT. For this, a series of analyses are run to evaluate the test statistic (TS) value, which provides a measure of the significance of potential detection.

This poster will present an overview of narrow-line Seyfert 1 galaxies (NLS1s), the methodology applied in this study, relevant previous findings, the analysis procedure, and the automation of code used to conduct the analysis. Current results will be discussed, highlighting the test statistic (TS) values obtained thus far. As this project represents ongoing research, additional TS values will be identified over time, culminating in a more comprehensive analysis.

sciforum-161714: High-resolution radio imaging of the distant blazar J1429+5406

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Our understanding of jet kinematics in high-redshift ($z \geq 3$) quasars is still rather limited, based on a sample of less than about fifty objects. It is difficult to perform such measurements for multiple reasons. In this work, we present very long baseline interferometry (VLBI) observations of the surprisingly rich radio jet structure of the powerful blazar J1429+5406 at $z=3.015$, observed at five different frequencies (1.7–15 GHz) between 1994 and 2018. While the outer jet components at ~20–40 milliarcsecond (mas) angular separation from the core show no apparent proper motion, three components within 10 mas distance exhibit significant proper motions of (0.045–0.16) mas year^{-1}, including one that is among the fastest-moving jet components at $z \geq 3$ known to date. The core brightness temperature well exceeds the equipartition limit, indicating Doppler-boosted radio emission. Based on the proper motion of the innermost component, we derive a small jet inclination with respect to the line of sight (within about 5°), confirming the blazar nature of the source. Recently, we analysed new high-sensitivity VLBI measurements of this blazar taken by the Very Long Baseline Array in 2024. At 1.5 GHz, the radio map clearly reveals a complex, extended structure around the source, reaching up to ~400 mas, rarely, if ever, seen in a high-redshift blazar. Here, we discuss possible explanations of this peculiar radio structure.

sciforum-163993: Studying gas flows in the SUNBIRD starburst galaxies and LIRGs

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Gas flows are an important aspect of feedback and the regulation of star formation in galaxies. Nearby starburst galaxies and luminous infrared galaxies (LIRGs) provide extreme environments, where feedback and the changes due to it can be studied in great detail. Understanding the gas flows in these galaxies will help us to understand galaxy evolution better. I will present the results from my recently completed PhD thesis. We studied the resolved gas flows in a sample of 12 nearby ($0.0073 \leq z \leq 0.0374$) starburst galaxies and luminous infrared galaxies in the SUperNovae and starBurst in the InfraReD (SUNBIRD) survey with long-slit spectra from the Southern African Large Telescope. We found evidence of ionized and neutral non-circular gas flows (which includes outflows, inflows and extraplanar gas) in all 12 galaxies at varying velocities. No previous measurements of gas flows had been made for five galaxies (ESO 428-G023, ESO 550-IG025, IRAS 18293-3413, NGC 1819 and NGC 3508). The non-circular gas flow velocities of the 12 galaxies range between 35-182 km/s for the ionized gas and 61-403 km/s for the neutral gas and originate from the nucleus for most of the galaxies. Our results also showed that none of the gas flows are strong enough to leave the galaxies and could possibly cool down to form more stars. This suggests that for these starburst galaxies and LIRGs, even though their star-formation rate is enhanced and gas is flowing outwards, star formation is not necessarily quenched by this, and could continue in the future via the galactic fountain model.

sciforum-163618: The ‘forgotten’ neutrons: implications for the propagation of high-energy cosmic rays in magnetized astrophysical and cosmological structures

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Cosmic rays (CRs) are accelerated in astrophysical systems, such as starburst galaxies, active galactic nuclei and large-scale shocks. These accelerators are usually embedded in the overdense part of the cosmic web, i.e., galaxy clusters and filaments, which are threaded with magnetic fields. Many studies only model the the transport of charged particles in magnetic fields and ignore the secondary neutrons. We explored an alternative route for CR escape—assisted by temporary charge neutral particles, i.e., neutrons. These neutrons are produced in the hadronic interactions of CR protons, and with the aid of time dilation, they may traverse distances larger than galactic scales before decaying into protons. We capture this alternative CR escape channel with a stochastic Poisson term in the transport equation, which also accounts for other processes that attenuate CR flux. We model the CR escape with the neutron-assisted channel for several test cases, representing host sites being a galaxy, galaxy cluster, and filament. We find that the neutron-assisted escape channel is most efficient for ultra-high-energy cosmic rays (E >~ 1e18 eV) and may modify the energy spectrum of CRs at the highest energies. I will present our methodology for modelling CR escape and highlight the importance of incorporating the physics of neutron-assisted CR escape.

sciforum-161519: X-Ray Dips and Polarisation Angle Swings in GX 13+1: constraining the geometry of the outer disk region

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For several decades, broadband spectroscopy and fast X-ray timing have been the primary tools for investigating the rich and often intricate phenomenology of nonpulsating neutron stars in X-ray binaries with weak magnetic fields. However, available information has been insufficient to unambiguously disentangle the relative contributions of the different emitting regions, since different geometries and physical scenarios can produce similar signatures. Nowadays, X-ray polarimetry provides the missing, independent set of observables—polarization degree and angle—that are directly sensitive to understanding the nature and geometry of the emission regions. GX 13+1 is among the most peculiar systems of this class. We observed it with the Imaging X-ray Polarimetry Explorer (IXPE) over four distinct epochs, enabling the first polarization measurements during dips. A joint analysis of IXPE observations demonstrated that the polarization properties varied in response to intensity and spectral hardness changes associated with the dips, indicating the presence of multiple components contributing to the polarized X-ray emission. In particular, during dips, when the flux is lowest because the central region, hosting the spreading layer, boundary layer, and central neutron star regions, is obscured, the measured polarization can be attributed either to an extended accretion disk corona or to a disk wind component. Both of these emitting regions, if partially obscured, may explain the observed changes in the polarization angle. I will present the results of the IXPE observations, focusing on a recent observation conducted during the source's long periodic dip, which confirms that polarization tracks changes in the geometric configuration, thereby validating theoretical scenarios that have long been proposed solely on the basis of dipping phenomenology.

sciforum-161488: Anisotropic Neutron Star W-mode

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Typically, pressure inside a neutron star is assumed to be isotropic. However, pressure anisotropy, the difference in pressure between the radial and tangential directions, may arise from strong magnetic fields, viscosity, and elasticity. Neutron-star quasi-normal modes are oscillations with significant damping over time. These modes are classified according to their restoring force. Previous studies showed that pressure modes (p-modes) can become unstable when the neutron star becomes anisotropic. This drove us to study the behaviour of another mode, the w-mode, in anisotropic neutron stars. W-modes are driven mostly by spacetime oscillations with only minor matter perturbations. In this talk, I report the first ever calculation of anisotropic w-modes. Unlike p-modes, we found w-modes to be stable for multiple equation of states in the presence of pressure anisotropy. We have also discovered an equation-of-state-independent relation for w-mode frequency that may potentially help with probing the neutron-star interior without knowing its exact equation of state. This numerical stability finding is further supported by a semi-analytic analysis that ensures stability beyond the scope of the numerical work. We have also found that an approximation scheme that is known to work well for isotropic neutron stars w-modes ceases to be valid when pressure anisotropy is introduced.

sciforum-161264: Challenges and Advances in Dwarf Galaxy Simulations

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Dwarf galaxies, although intrinsically faint and containing only modest stellar populations, provide an unusually sensitive testing ground for understanding how structure emerges in a cosmological context. Their shallow gravitational potentials make them particularly responsive to environmental influences and internal feedback, allowing researchers to probe physical processes that are harder to isolate in larger systems. Over the past decade, advances in numerical modeling—ranging from finely resolved hydrodynamic calculations to large-volume N-body suites—have offered increasingly detailed views of their kinematic evolution, star formation cycles, and dark matter configurations. Modern simulations now reproduce several of the empirical relationships observed in nearby dwarfs, including trends connecting mass, size, chemical enrichment, and luminosity. However, uncertainties in how feedback is implemented still produce noticeable variation among models. A long-standing tension involves the predicted shape of central dark matter profiles. Many simulations generate steep cusps, even though observations frequently point to shallower cores. Energetic stellar activity has been proposed as a mechanism for reshaping these regions, yet its effectiveness depends sensitively on resolution and feedback prescriptions. Another unresolved issue concerns the unexpectedly small number of known satellites in the Local Group compared with the abundance of low-mass halos in ΛCDM predictions. Recent work indicates that many such halos may host extremely faint systems that elude current surveys. Large simulation programs such as FIRE, APOSTLE, and NIHAO pursue these questions with differing assumptions and numerical strategies. Each captures certain aspects of dwarf galaxy evolution, but none fully replicates the diversity seen observationally. Considering results from multiple frameworks remains essential for constructing a comprehensive picture of how these small galaxies form, evolve, and interact with their environments.

sciforum-161678: Constraining the Equation of State with Glitch Dynamics: Case Study of 2016 Vela Glitch

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Glitches in neutron stars originate from the sudden transfer of angular momentum between superfluid components and the observable crust. By modeling this glitch dynamics—including vortex motion, mutual friction, and angular momentum exchange—we can probe the dense matter equation of state. We match theoretical predictions of glitch rise times, overshoot patterns, and relaxation timescales to the well-documented observations of the 2016 Vela glitch. Our model incorporates microphysical parameters such as the mutual friction coefficient \(\mathcal{B}\), which in the core arises from electron scattering off magnetized vortices and in the crust from Kelvin wave excitation during vortex–lattice interactions. Our Markov Chain Monte Carlo analysis of the timing residuals reveals detailed glitch dynamics: the crustal superfluid couples on timescales of ~100 seconds, the core exhibits overshoot behavior due to strong central behavior, and the inner crust shows weak entrainment, with $\sim70\%$ of free neutrons remaining superfluid. The modeled rise times are consistent with the observed upper limit of 12.6 seconds, and the observed overshoot requires strong crustal friction but weak core friction, supporting a spatially varying \(\mathcal{B}\). These findings highlight the importance of microphysical modeling and demonstrate the potential of future high-cadence timing observations to further constrain the internal dynamics and composition of neutron stars.

sciforum-159946: Feature-Rich Representations of GRB Light Curves for Microlensing Classification

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Gamma-ray burst (GRB) light curves contain a remarkable level of temporal complexity, reflecting both the physics of the relativistic outflow and potential gravitational distortions caused by intervening compact objects. Gravitational microlensing, in particular, can imprint subtle yet measurable modifications on the temporal profile of a GRB. A central challenge, however, lies in reliably detecting these signatures within large GRB data sets, where the differences between lensed and non-lensed events may be difficult to identify by inspection alone.

In this study, we demonstrate that the temporal features inherently present in GRB light curves carry sufficient information to distinguish microlensed bursts from their unlensed counterparts. To explore this, we generate an extensive suite of simulated GRB light curves representing both lensed and non-lensed classes. Using the Cesium package and other feature extraction tools, we extract a comprehensive set of features that characterize key aspects of the temporal behavior, including variability patterns, statistical moments, and other descriptors of morphological evolution. These features serve as input to a machine learning (ML) pipeline designed to identify lensing-induced signatures.

We evaluate several ML algorithms on this feature space. Our results demonstrate that light curves themselves contain rich and discriminative information,and that feature-based ML approaches are capable of exploiting this information effectively. Our work highlights the potential of such methods for future observational applications, including automated searches for GRB lensing.

sciforum-163938: Flagging super-Eddington candidates among gamma-ray-emitting AGN

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The quasar Eigenvector-1/Main Sequence (E1/MS) is a practical roadmap that organizes AGN spectral diversity by accretion state, letting us compare objects in a common, physically motivated trend. Past applications of the E1/MS sequence made it possible to identify the effects of intrinsic viewing angle, black hole mass, and luminosity. We propose an E1/MS-driven framework to clarify the accretion status of gamma-ray-emitting AGN with an emphasis on radio-loud narrow-line Seyfert 1s (NLSy1s) and Population A sources. We argue that the E1/MS context is ideal for flagging super-Eddington candidates among radio-loud NLSy1s and other Population A sources that also host relativistic jets. An optimal strategy would be to place gamma-ray AGN on E1 using optical/UV spectroscopy, to derive disk-based bolometric luminosities from line or IR reprocessing (or jet-quiet SED states), and to correct single-epoch black hole masses for orientation and radiation pressure biases. This strategy should identify super-Eddington candidates and reflect a physical link between accretion state and gamma-ray efficiency: dense broad-line region/torus photon fields in high-Eddington-ratio systems should boost the external Compton emission, whereas mass loading and radiative drag shape moderate bulk Lorentz factors in gamma-ray emitters observed with VLBI. We apply the method based on the E1/MS criteria to targets for which high-S/N optical and UV spectra as well as multi-frequency coverage are available.

sciforum-160910: High-redshift blazar classification though multi-wavelength data

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High-redshift radio-loud active galactic nuclei (AGN) are key laboratories for studying the formation of the earliest galaxies and supermassive black holes. Among them, blazars, AGNs with relativistic jets oriented close to the line of sight, appear to dominate at redshifts above four. Blazars can be used to obtain an estimate of jetted AGN. However, distinguishing blazars from misaligned radio sources remains challenging, particularly given the limited number of known high-redshift radio quasars. In general, the jet orientation can be inferred from X-ray data and milliarcsecond (mas)-scale angular resolution radio measurements. The latter can be achieved by very long-baseline interferometry (VLBI) imaging. VLBI is suitable for distinguishing between compact, high-brightness temperature radio emission of blazars and the more extended structures of misaligned jetted AGN. Previous high-resolution VLBI studies revealed that some of the radio sources among blazar candidates in fact show unbeamed radio emission on mas scales. For this reason, it is extremely important to compare the classifications obtained with different methods and from different wavelength bands. We found that the combination of multi-band (radio, optical, and X-ray) data and the combination of different classification methods is able to properly recover all the oriented sources present in high-redshift radio quasar samples.

sciforum-163906: Impact of Equation of State Parameters on the Complexity of Anisotropic Stellar Models

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In this work, we investigate the role of equation of state (EOS) parameters in governing the complexity of static, self-gravitating stellar systems. Employing Herrera's definition of complexity for static, spherically symmetric configurations within the framework of general relativity [L. Herrera, Phys. Rev. D 97, 044010 (2018)], we study three anisotropic stellar models constructed using the Vaidya–Tikekar background geometry together with different equations of state. The complexity factor provides a useful tool for probing the internal structure of self-gravitating astrophysical objects. For static, spherically symmetric fluid distributions with anisotropic pressure, complexity is fundamentally associated with energy density inhomogeneity and the anisotropic distribution of stresses. The complexity factor, defined through the orthogonal splitting of the Riemann tensor, quantifies the interplay between pressure anisotropy and density inhomogeneity within the system.

The Vaidya–Tikekar metric is an important exact solution of Einstein's field equations that is widely used in relativistic astrophysics to model compact stellar objects such as neutron stars and strange stars. In this model, the interior spacetime of a static, spherically symmetric star is assumed to be pseudo-spheroidal rather than perfectly spherical. The Vaidya–Tikekar metric, previously shown to effectively describe compact and dense stellar objects, is adopted as the underlying spacetime geometry.

In this model, we perform a systematic analysis of the impact of EOS parameters on the complexity factor and its individual contributions. Our results demonstrate a strong dependence of the complexity factor on the EOS parameters. In particular, we observe that the complexity of anisotropic stellar configurations increases monotonically with increasing EOS parameters for all equations of state considered. Using current observational data of the pulsar *4U-1608*, we show the impact of the EOS parameter in our model, supported by graphical depictions. These findings underscore the crucial influence of the equation of state on the structural complexity and internal organization of relativistic compact stars.

sciforum-158787: Jet–environment interaction after delayed collapse in binary neutron star mergers

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Binary neutron star (BNS) mergers are among the most powerful engines in the universe, capable of producing both gravitational waves and short gamma-ray bursts (SGRBs). In this talk, I will present general relativistic magnetohydrodynamic (GRMHD) simulations that, for the first time, self-consistently capture the full sequence from merger to jet launching for the delayed collapse scenario. In our models, the merger forms a metastable massive neutron star (MNS) that eventually collapses into a black hole (BH). We explore different MNS lifetimes of about 25 ms and 50 ms—long enough to allow the emergence of magnetically driven polar outflows prior to collapse. When the BH forms, the resulting jet interacts dynamically with this earlier ejecta, producing shock heating and possible observable electromagnetic signatures. Using an unprecedentedly low-numerical-density floor that scales as r^-6, we are able to follow the jet propagation out to distances of about 1e4 km, revealing how the surrounding environment—shaped by the MNS lifetime—strongly influences jet collimation, the terminal Lorentz factor, and Poynting-flux luminosity. For comparison, I will also discuss a non-collapsing scenario, in which the long-lived MNS drives a dense, slow outflow that effectively chokes any potential relativistic jet, reinforcing the need for a BH central engine. These results provide a unified picture for the delayed collapse scenario, linking merger dynamics, outflows and jet formation, and potential impact on observable transients—an essential step toward end-to-end modeling of short gamma-ray burst progenitors in the multi-messenger era.

sciforum-161204: On gravity at large (galactic) scales

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The baryonic Tully–Fisher relation $\log M_{bar}=c+b\log V_{flat}$ links the baryonic mass of spiral-galaxies with their asymptotic velocity. Flat rotation curves suggest extra-gravity at galactic scales, which is explained by dark matter. However, astrophysicists point to facts/data that contradict the DM-hypothesis (P.Kroupa). Instead, the MOND-model is advocated, which requires b=4. M_{bar} includes stars, atomic/molecular gas, and HI/HeI/H_2; for dwarfs, HII-component is important (intergalactic radiation ionizes, as N.Gnedin notes). Conducting calculations is hard and requires assumptions/modeling; in [1] slope b≈3 was obtained for spirals (V_{flat}≈45...280km/s). Slope b=2 appears in modeling [2;App.G] (except for dwarfs); this indicates $F\sim M_{bar}/R$ gravity;.This is possible for one 5D-variant of Teleparallelism with 4th-order gravity and expanding brane-universe [3]: Newton's law transforms to F/m=GM/(LR) when R>L (L is brane's co-moving thickness along the extra-dimension). This model, called MOGA, unlike MOND, preserves the momentum/angular momentum and stability of three-body systems (Toxvaerd S. arXiv:2512.03823; MOdifiedGravityAttraction).

For thin (SO_2-symmetry; 1/R-model) disks, the force/acceleration in the disk-plane, at radius R, depends on the mass M_R inside R: $F(R)/m=GM_R/(LR)$; on the axis (uniform discs, radius a; 'test-mass' m): $F(Z)/m=GMZ/(La^2)\ \ln(1+a^2/Z^2)$. For balls/bulges, one finds (let GMm/L=1): $F(R)=3/(8a)\{a/R+R/a-0.5(a/R-R/a)^2\ \ln[(R+a)/|R-a|]\}=R/a^2\{1-(R/a)^2/5-...-3(R/a)^{2n}/[(2n-1)(2n+1)(2n+3)]-...\}=1/R\{1-(a/R)^2/5-...\}$.

Logarithmic potential growth stops when "underdensities" appear, and voids should be objects with negative masses. Our MW-galaxy resides in the KBC-void (among the largest—redshift z is small!) with a shift from its center. Defocussing caused by the KBC-void provides some extra-dipoles (redshift-dependent).

1. Ponomareva A.A. etal. MNRAS.**474**(2018)4366(hal-02117129f). 2. Valageas P., Schaeffer R. Astron.Astrophys.**345**(1999)329(arXiv:astro-ph/9812213). 3. Zhogin I.L. Space,Time&Fund.Inter.#2(2025)40(stfi.ru/journal/STFI_2025_02/STFI_2025_02_Zhogin.pdf).

sciforum-161304: On the Extreme Radio Quiescence of Little Red Dots

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Observations with the James Webb Space Telescope (JWST) led to the discovery of a new population of high-redshift sources, referred to as little red dots (LRDs). These are a mysterious class of objects that appear to be extremely compact in size, show excess ultraviolet emission, have a red optical continuum in the rest-frame, and exhibit broad line spectral features. They were discovered as part of an effort to characterise distant galaxies that might represent an early stage in galaxy evolution. Since their discovery, there has been significant interest in understanding the physical processes behind the observed characteristics. Are these galaxies rapidly forming stars? Do they host accreting supermassive black holes that power active galactic nuclei? Or do they represent another type of galaxy altogether? As radio observations are crucial in distinguishing between these possibilities, an extensive sample of LRDs were studied utilising radio maps from the Faint Images of the Radio Sky at Twenty-centimeters (FIRST) survey and the Very Large Array Sky Survey (VLASS). Investigating both the individual and statistical properties of LRDs in radio wavebands, the results were compared to and discussed with respect to those of known high-redshift AGN. Due to their extreme quiescence in the radio regime, we discuss various scenarios and hypoteses to explain the 'LRD phenomenon'.

sciforum-158857: Reflecting the Reflection: Impact of Returning Radiation in Black Hole X-ray Binary Spectra

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X-ray reflection spectroscopy is a powerful tool for exploring the innermost regions of accreting black hole systems. The X-ray spectra of black hole X-ray binaries (XRBs) typically consist of three components: thermal emission from the accretion disk, Comptonized emission from a hot corona, and a reflection component resulting from the illumination of the disk by the corona. Modeling the reflection features provides key information about the black hole's spin and disk's parameters.

A phenomenon known as returning radiation (i.e., disk emission that is bent back onto itself by the black hole's strong gravity) can significantly affect the reflection spectra, particularly for sources in the high-soft state. However, current XSPEC reflection models do not fully account for this effect. We present a new reflection model that self-consistently includes returning radiation. To isolate its effects, we adopt a standard disk–corona configuration but disable the corona, allowing the reflection spectrum to arise solely from returning radiation, including higher-order reflections. Compared to widely used models such as relxillNS, our model naturally produces a harder high-energy reflection spectrum without requiring a Comptonized component. Our results demonstrate that returning radiation alone can account for the observed reflection features of XRBs in the soft state and should therefore be considered an important component. Including returning radiation in spectra modeling also enables us to explore its impact on black hole spin measurements and test General Relativity in the strong-field regime.

sciforum-160554: Spectroscopic study of Ultra-long GRB 220627A

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The ultra-relativistic, highly collimated jets generated by Gamma-Ray Bursts (GRBs) provide crucial insights into particle emission. These jets also reveal the physical mechanisms driving the rapid release of high-energy gamma-ray photons. We discuss time-resolved spectroscopy and flux variability for the ultra-long GRB 220627A. The analysis spans a duration exceeding 1200 seconds using Fermi telescope data. Two prompt emission episodes observed by Fermi-GBM, separated by more than 500 s, were analyzed. Due to its unique characteristics, GRB 220627A serves as an excellent source for studying particle emission processes, small-scale variability, and the properties of its central engine. To investigate gravitational lensing, the time bins of the first episode were correlated with those of the second episode. A coherent relationship was observed between flux and photon spectral distribution. This relationship was modeled using an exponentially cut-off power law model for both episodes. The MeV-to-GeV photon ratio detected by LAT is inconsistent between the two episodes. High-energy gamma-ray photons were only detected by LAT for up to 700 seconds, which further rules out gravitational lensing but suggests that the progenitor underwent a burst into an ultra-long GRB with two episodes. Our findings from spectral analysis reveal characteristics most consistent with those of an ultra-long GRB. Parameters such as isotropic energy, spectral signatures, and burst duration align with the established limits for a blue supergiant progenitor, as described in the literature.

sciforum-163456: Study of Activity Processes in the Universe Using Medium-Sized Telescopes

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The microvariability in AGNs was firstly announced and received with skepticism at the beginning of the 1960s, when a few sources were studied with a single-channel photoelectric photometer and the biggest Palomar telescopes. The availability and utilization of CCD cameras breathed new life into small telescopes. For many decades, the variability time-scales from minutes to years have been studied for many blazars using CCD cameras and small telescopes. In the last 30 years, we have been conducting a systematic study of over seventy blazars at the Abastumani Observatory on Mt. Kanobili using CCD cameras and two dedicated medium-sized 125 cm RCh and 70 cm meniscus telescopes. The observations were also conducted using the Calar-Alto 123 cm telescope.

From the middle of the 1990, over 4500 observing nights, we collected in BVRI bands about 600000 images. Among the studied blazars are thirty Northern Sky TeV sources such as Mrk421, Mrk 501, 1ES 0229+200, 1ES 0502+675, 1ES 0647+250, 1ES 0806+52.4, PG 1553+113, 1ES 1959+650, 1ES 2344+51.4, etc., and well-known classical sources such as BL Lacertae, 3C 454.4, 3C 279, S5 0716+714, CTA 102, AO 0235+164, 3C 66A, OJ 287, S4 0954+658, ON 231, 3C 273, PKS 1510-089, and 3C 345.

All images were reduced in MIDAS using DaoPhot II. The typical differential photometric accuracy for an R=15.0 star-like source in a 180 sec exposure is around one percent. A maximum variation for TeV sources up to 1.5 magnitude in the R band was detected, while a few other classical sources showed variations over five magnitudes. Pronounced microvariability at the level of 5% was detected in the case of BL Lacertae and S5 0716+714.

sciforum-163811: Study of Open Star Cluster Berkeley 6 and S1

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We investigate the physical relationship between the open clusters Berkeley 6 (Be 6) and S1 using astrometric and photometric data from *Gaia* Data Release 3 (DR3). Previous studies have suggested that S1 may be a physical companion or substructure associated with Berkeley 6, motivating a detailed kinematic and photometric comparison. We analyze stellar proper motions, parallaxes, and *Gaia* G, BP, and RP photometry within a spatial region encompassing both clusters.

Probable cluster members are identified using Vector Point Diagrams (VPDs) combined with the HDBSCAN density-based clustering algorithm applied in proper-motion space, allowing probabilistic membership determination while minimizing field-star contamination. High-confidence members are subsequently examined through color–magnitude diagrams (CMDs) constructed from *Gaia* photometry. The CMDs of both groups reveal a well-defined and nearly identical main sequence, with no statistically significant differences in turn-off features or sequence dispersion.

Further constraints are obtained via **manual isochrone fitting** using PARSEC stellar evolution models. Although the fit is not exact—owing to observational scatter and residual field contamination—a single isochrone provides a **reasonable and consistent representation** of the combined stellar population. The derived parameters suggest an age of approximately 200 Myr, sub-solar metallicity ($Z \approx 0.008$), and a heliocentric distance of about 2.9 kpc.

The strong agreement in proper-motion distributions, CMD morphology, and broadly consistent physical parameters indicates that Berkeley 6 and S1 are unlikely to be independent clusters, instead representing different regions or substructures of a single, extended open cluster. This study demonstrates that the combined use of *Gaia* DR3 astrometry and HDBSCAN-based membership selection is an effective approach for investigating the physical association and internal structure of nearby open clusters within the Galactic disk.

sciforum-163486: The dynamical lineage of ultra-diffuse galaxies from TNG50-1

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The formation and evolution of the ultra-diffuse galaxies (UDGs) continue to remain a puzzle. Similarities and differences in the morphological and the kinematical properties of the UDGs with their possible precursors, namely low-surface brightness (LSB), L*-type high-surface brightness (HSB) and dwarf galaxies, may provide crucial constraints on their origin and evolution. To investigate the possible formation scenario of the UDGs, we selected samples of UDGs, LSBs, HSBs and dwarfs from the TNG50-1 sub-box of the IllustrisTNG simulation. We studied individual galaxy cutouts to evaluate the intrinsic shapes of their dark-matter (DM) and stellar components, orbital and kinematical properties related to their stellar velocity dispersion. Further, we constructed mock integral-field spectroscopic data using the SimSpin code to extract the stellar kinematic moment maps. We find that the isolated UDGs are prolate rotators similar to the dwarf population, while the tidally bound UDGs can exhibit both prolate- and oblate-rotating shapes. The DM and stellar velocity anisotropy properties of the UDGs suggest that they reside in a cored, dwarf-like halo and may be classified by early-type galaxies. Finally, the stellar kinematic properties suggest that both the UDGs and the dwarfs are slow-rotators having low to nearly no-rotations in contrast to the late-type, disc-dominated, fast-rotating LSBs and HSBs. Therefore, we may conclude that the UDGs and the dwarfs possibly have a common dynamical lineage.

sciforum-161666: The effect of triaxiality on the dynamics of triple supermassive black holes in a cosmological context

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The hierarchical nature of galaxy formation in the ΛCDM framework often leads to the formation of multiple supermassive black holes (SMBHs) in the galactic nuclei. The timescale over which galaxies merge, plays a crucial role in shaping the dynamical evolution and the merger dynamics of their central SMBHs, which may result in the formation of a triple (or multiple) SMBH system. While the evolution of binary SMBH is well studied, the long-term dynamics of triple SMBH systems, particularly in non-spherical potentials, still remain less understood. In this work, we investigate the impact of triaxial shape of galaxies in the dynamical evolution of triple SMBHs with initial conditions drawn from the ROMULUS25 cosmological simulation, using different high-resolution gravitodynamical N-body simulations. We explore different orbital configurations and host galaxy shapes, tracking the orbital evolution from a galactic inspiral phase to the formation of hard binaries at sub-parsec separation, and use the observed hardening rates to project the time of coalescence. In all cases, the two most massive SMBHs form a rapidly hardening binary that coalesces within a fraction of a Hubble time, while the third black hole either forms a stable hierarchical triple system with the heavier binary, or remains on a wide orbit.

sciforum-163788: White dwarf mass accretion in AGN accretion disk

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Many galaxies show strong star formation activity in their central regions. In galaxies that also host an active galactic nucleus (AGN), star formation may occur locally within the AGN accretion disk itself. Low-mass stars constitute the majority of the stellar population, and as they reach the end of their life cycles, they evolve into white dwarfs. We therefore expect to find a population of white dwarfs embedded in and comoving with the AGN accretion disk. The disk provides a dense environment in which white dwarfs can efficiently accrete gas and grow in mass. As their mass approaches the Chandrasekhar limit of 1.4 solar masses, the temperature becomes high enough to trigger runaway nuclear fusion, eventually leading to a Type Ia supernova. Type Ia supernovae are crucial both as standard candles for cosmology and as major contributors to the chemical enrichment of the universe. In this work, we investigate the population of white dwarfs in AGN disks, their mass growth through accretion, and their eventual collapse into Type Ia supernovae. We show that the accretion of white dwarfs in AGN disks is a viable channel for producing type 1a supernovae. We discuss the resulting consequences for the evolution of the AGN and its accretion disk, the chemical enrichment of galactic centers, and the universality of Type Ia supernovae as standard candles.

Session 7. Solar and Stellar Physics

sciforum-163435: High-Velocity Features in Type Ia Supernovae—A puzzle still waiting to be solved after 26 years

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High-velocity (25-30000 km/s) lines (HVFs) of Ca II were first discovered in the spectrum of SN1994D in 1999, and since then, they have been proven to be ubiquitous. Despite this, their exact origin remains unclear to this day. They appear to form in a higher-velocity layer above the photosphere (10-15000 km/s) and show varying strengths and velocity evolutions from object to object.

We used early-phase optical and near-infrared spectra of 56 Type Ia supernovae, observed over the span of 15 years by the Hobby–Eberly Telescope (McDonald Observatory, Texas) to determine the velocity, strength, and evolution of these features.

After using SYNOW to model the high-velocity features of these spectra, we compare them to Gaussian fits of the lines. We look at how velocity determination from the Gaussian fitting of spectral lines compares to velocities gained from the modelling of spectra. We confirm a connection between the light-curve width and the strength (and velocity) of the HVFs, with slow decliners showing stronger (and faster) high-velocity lines. We also demonstrate how high-velocity (HV) and normal-velocity (NV) Wang subtypes have differently behaving high-velocity features, which leads to interesting possibilities in the discussion of the progenitor systems of Type Ia supernovae.

sciforum-161206: A Polarimetric Method for Identifying Member Stars in the Open Star Clusters (a case of NGC 1817 and NGC 7380)

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Polarimetric observations serve as an effective diagnostic tool for studying the interstellar medium and identifying stellar membership of an open star cluster. Starlight becomes linearly polarized due to the dichroic extinction from aligned asymmetric interstellar dust grains. The resulting polarization signatures differ for member and non-member stars of the cluster. This makes polarimetry a valuable tool for separating member stars from the foreground or background field.

The open star clusters NGC 1817 and NGC 7380, representing intermediate-age and young stellar environments, respectively, offer important laboratories for exploring star formation, stellar evolution, and cluster dynamics. However, uncertainties in membership determination continue to affect the accuracy of their derived properties. In this study, I will present a method based on linear polarization of stars that can be used to evaluate and refine the membership probabilities of stars in open star clusters. Using the polarimetric technique, I have calculated the membership probability of stars of the cluster NGC 1817 and NGC 7380. A good correlation is found between my results and previously estimated probabilities of members from the proper motion technique. From this study, one can infer that the polarization property can be used for deriving the membership probability. Additionally, I will discuss some drawbacks of this technique.

sciforum-161075: A Unified Maxwell-Bloch Framework to Model Flaring Behaviour in Maser-Hosting Regions

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Periodic maser flares in high-mass star-forming regions provide a sensitive probe of the physical conditions in these environments. The methanol maser source G9.62+0.20E is a benchmark object, exhibiting multiple long-lived periodicities and a rich variety of flare morphologies, from highly asymmetric to nearly symmetric profiles across different velocity components. In previous work, we showed that the Maxwell-Bloch equations operating in the fast-transient superradiance regime, driven by narrow periodic pump excitations, can reproduce the asymmetric flares in this source while yielding consistent environmental parameters for the masing gas.

We recently extended that framework by demonstrating that the same Maxwell–Bloch equations can also accounts for the symmetric flares observed in maser-hosting regions such as G9.62+0.20E. Using a common set of physical conditions (e.g. temperature, collisional timescales) across components, we fit representative symmetric and assymetric flares and show that modest changes in the pump modulation and coherence history are sufficient to explain the full range of observed light-curve shapes, without invoking distinct environments for each periodicity. This consistent modelling of both symmetric and asymmetric flares in a single benchmark source strengthens the case for superradiance as a general framework for flaring in maser-hosting regions and motivates its application to other flaring systems.

sciforum-163953: Apsidal motion in binaries: probing the interiors of stars using tides

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The apsidal motion in close eccentric binaries is a means to unveil the internal structure of stars. I make use of it to test the internal mixing processes in stars with the stellar evolution code GENEC.

The apsidal motion is the slow precession of an eccentric orbit with time. Its rate depends on the tidal interactions occurring between the stars through k2, a measure of the star's inner density profile. The apsidal motion rate is commonly derived from the eclipses' times of minima, made possible thanks to high precision TESS/Kepler observations. I propose an innovative approach: derive the apsidal motion rate from radial velocities obtained over a long timescale combined with light curves to get high-accuracy consistent physical and orbital parameters for the binaries. I highlight recent results concerning the two most massive binaries studied this way.

Confronted to observations of massive stars, standard non-rotating single star models usually predict stars with too low a density contrast; the well-known k2-discrepancy. I built bespoke GENEC stellar evolution models including tidally-enhanced/suppressed rotational mixing for the twin massive binary HD 152248. The models reveal the instabilities allowing to reproduce the stellar density profiles: advecto-diffusive models better reproduce k2 than magnetic models. A large overshooting is necessary to converge towards the observed k2, yet alone is not sufficient. While a change in metallicity or mass-loss rate has no significant impact on k2, a larger initial helium abundance allows to better reproduce the k2. Yet, a super-solar helium abundance is not observationally supported. These analyses highlight the need for a process in the stars that slows down the increase of their radius with time. It paves the way for the next generation of models.

sciforum-161568: Blazhko and Binary RR Lyrae modulations from wavelet analysis

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Phase modulation (PM) method has been introduced to study periodic variability within variable stars by converting phase shifts into time delays of the traveled light path known as the light time travel effect (LTTE). This method was highly successful in detecting binary companions and in studying Blazhko-type modulation in RR Lyrae and δ Scuti stars. However, both binary motion and intrinsic Blazhko modulation introduce periodic phase variations, which can produce very similar signatures in the PM time-delay curves, particularly when the period ranges of the two effects overlap or when both effects may be present simultaneously. As a result, some stars might be misclassified as Blazhko or Binary type stars. One way to discriminate between the tow effects is to adopt the O-C diagram to test for binarity, although recent studies show the complexity of this approach in the presence of other intrinsic variations. Another approach is to examine the multiplets seen in the Fourier transform . In this work, we investigate an other method to distinguish between intrinsic Blazhko and binary orbital modulations using Wavelet analysis for characterizing the behavior of the modulation over a wide range of time scale, the time series are decomposed into time–frequency space to determine both the dominant modes of variability and how those modes vary in time. By carefully investigating some RR Lyrae stars where the two effects have been confused or simultaneously present, the wavelet analysis turned out to be a powerful tool to separate the two effects and to investigate other types of intrinsic variations present in RR Lyrae stars like period breaks and secular period changes .

sciforum-163838: Bolometric light-curve modeling reveals extremely high ejecta masses in SLSNe-I

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Bolometric light-curve modeling reveals extremely high ejecta masses in SLSNe-I

I present the bolometric light-curve modeling of 98 hydrogen-poor superluminous supernovae (SLSNe- I) using three power input scenarios of the *Minim* code: the magnetar model, and the constant-density and the steady-wind versions of circumstellar interaction scenario (CSM models). Quasi-bolometric fluxes were constructed from ZTF *g*- and *r*-band photometry, while ejecta velocities were estimated from spectroscopic measurements. The modeling indicates that 14 events favor the magnetar scenario, the light curves of 39 objects are better described by circumstellar interaction, and 45 events show consistent light curves with either mechanism. Magnetar fits yield spin periods and magnetic field strengths in agreement with previous studies, but imply substantially larger ejecta masses. The mean ejecta mass for magnetar-powered models is 34.25 $M_\odot$ (in the range between 1.53 and 198.1 $M_\odot$), while circumstellar interaction models produce even higher values, with mean masses of 116.82 $M_\odot$ for the constant-density case and 105.99 $M_\odot$ for the steady-wind case. These large ejecta masses arise in part from the assumption of an electron-scattering opacity of $\kappa = 0.2$ and from higher inferred ejecta velocities. Overall, the results suggest that SLSNe-I, regardless of whether they are powered by a central engine or circumstellar interaction, originate from the explosions of extremely massive progenitor stars.

sciforum-161586: Chemical Equilibrium and Plasma Chemistry Framework of the Saha Ionization Equation

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The Saha ionization equation is conventionally introduced in the context of astrophysics as a means of calculating ionization balance in stellar atmospheres. However, its origins are thoroughly rooted in classical chemical equilibrium and plasma chemistry. The present study reinterprets the Saha equation as a high-temperature version of normal chemical equilibrium, representing the reversible process of the neutral atom's transformation into an ion and a free electron as a thermodynamically controlled chemical reaction. With the inclusion of temperature, pressure, ionization potential, electron density, and partition functions, the structure of the Saha formulation resembles that of the conventional equilibrium constants and Gibbs free energy relations of chemical thermodynamics.

This chemically based view shows that stellar ionization is not just a physical process but a natural extension of chemical principles operating under extreme conditions. The discussion emphasizes the importance of plasma chemistry in determining the relative populations of atomic and ionic species, consequently dictating opacity, spectral line strengths, and radiative transfer in stellar photospheres and chromospheres. The Saha equation, when viewed from a chemical perspective, offers a unifying framework starting from laboratory thermodynamic behavior through to the astrophysical plasma environment. In this manner, the concept of an astrochemical pathway is reinforced by establishing the continuity between microscopic chemical reactions and macroscopic stellar properties throughout successive stages of stellar evolution.

sciforum-162600: Chemically Peculiar stars' strong overabundances of very heavy elements: related to supernovae?

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For many years, detailed observational and statistical study of chemically peculiar stars has shown that the overabundance of heavy radioactive chemical elements in their atmospheres is not well understood. We try to explain the overabundance of a few of them by the explosion of possible supernovae in binary or multiple-stellar systems, i.e., to search for a chemically peculiar star and pulsar pair by traceback motion study in the galaxy. We analyzed trajectories of 529 chemically peculiar stars in our sample and 28 pulsars from the ATNF catalogue, with ages that do not exceed 100 Myr, and obtained several possible candidate pairs (CP star plus pulsar), which may have been at the same place at the same time. Moreover, our traceback study of them with the young stellar clusters (Hunt and Reffert, 2023) led to the identification of several possibly parental stellar groups. However, more detailed studies are needed to estimate the ages of chemically peculiar stars and detect their locations of formation, as well as using statistical methods to assess whether the possible supernova ejection is the result of coincidence or not. Obviously, modeling of the best chemically peculiar star–pulsar pairs will also allow us to explain the processes occurring in these stars.

sciforum-161523: From Single Degenerate Quiescent Helium Accretion to Double Detonation Type Ia Supernova

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We investigate the sub-Chandrasekhar mass double detonation pathway as a viable mechanism for Type Ia supernovae, focusing on systems arising from single degenerate carbon–oxygen (CO) white dwarfs (WDs) that accrete helium. Building upon our previous one-dimensional study of recurrent helium novae (Hillman et al. 2025), we modeled the secular evolution of a 0.7 M⊙ WD. This WD was evolved through steady helium accretion at a relatively slow rate of 10−8 M⊙ yr−1 until it reached a critical mass of 1.1 M⊙. This detailed evolution yielded realistic, time-evolved temperature and composition profiles within the WD and its helium layer.

These time-evolved profiles were then mapped into the multi-dimensional hydrodynamic code FLASH, which incorporates a sophisticated reaction network for nuclear burning in both the helium shell and the CO core. The simulations were initiated by introducing a localized, modest temperature perturbation near the base of the helium shell. This subtle trigger robustly instigated an outward-propagating helium-shell detonation. The resulting inward-propagating shock wave from the helium detonation converged strongly near the center of the CO core, igniting a secondary, catastrophic carbon–oxygen detonation that completely unbinds the star.

We report a total 56Ni yield of ≃0.64M⊙, an intermediate-mass element (Si-Ca) mass of ≃0.41M⊙, and maximum ejecta velocities approaching ∼22,000 km s−1. These key characteristic values are consistent with observations of normal, cosmologically useful Type Ia supernovae. Our results compellingly demonstrate that recurrent helium accretors, systems typically characterized by long quiescent timescales, can evolve under subtle, "quiet" conditions to trigger robust double detonations, firmly supporting their role as viable and important progenitors of sub-Chandrasekhar mass Type Ia supernovae.

sciforum-161571: Multi-Period Magnetic Activity in Solar-Type Stars

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We present a preliminary analysis of magnetic activity cycles in a sample of solar-type stars for which both primary and possible secondary magnetic cycles were identified from long-term chromospheric activity indicators. Magnetic cycle periods were estimated using time series of the S-index and Bisector Inverse Slope (BIS) for stars selected from the catalogue of Gaia Radial Velocity (RV) standard stars. Significant periodicities were determined using the Generalized Least Squares (GLS) periodogram. Eight stars in the sample show possible evidence of secondary magnetic cycles. For these stars exhibiting dual-cycle signatures, we computed the period and amplitude ratios to investigate the potential coexistence of distinct dynamo modes. The period ratios span a broad range from 0.3 to 2.2, suggesting both shorter secondary cycles—consistent with the 1.6-year solar quasi-biennial oscillations—and longer secondary cycles relative to the primary one, which may indicate possible cycle dominance switching or beating dynamo behavior. The amplitude ratios range from 0.1 to 1.4, implying that, in some stars, the secondary signal is weak and possibly noise-dominated, while in others it is comparable in strength to the primary cycle. Although preliminary, these results support the idea that multi-periodic magnetic activity is not uncommon among solar-type stars and may offer valuable constraints for dynamo theory.

sciforum-163952: Photometry of Antares from 1995 to 2025 with SOHO

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Antares, a long-period variable supergiant, has been known since antiquity. It is the hearth of the Scorpion constellation. It is red and rivals Mars (Ares in Greek), from which its name is derived.

The study of its light curve is mostly based on Northern hemisphere observations, when the star is low above the Summer Southern horizon. Its nature as a long-period variable star is therefore not fully known due to the incompleteness of the long-term sample available. Catalogues and manuals of the 20th century classified Antares as an Irregular Variable.

The photometric observations of Antares are complicated by the absence of nearby stars of comparable luminosity and by heavy airmasses in the line of sight. The AAVSO database reports for Antares only 1/18 observations of the other naked-eye supergiant Betelgeuse, before its 2020 great dimming.

The application of airmass correction to naked-eye observations with distant comparison stars is required for Antares, but it is not yet a common practice among scientists.

We examine the AAVSO V-band data and our AAVSO-SGQ series (2012-2025) of visual observations, complementing thirty years (1995-2025) of SOHO observations made with the coronograph LASCO C3, each year on 2nd December, to have all stars within 1° of C3 field of view, with vignetting and diffraction acting as systematic effects.

Antares variability measured with SOHO encompasses 0.4 magnitudes and 30 years. V-band data start in 1983 and have large gaps in time and range over 0.9 magnitudes. SGQ series spans over 0.6 magnitudes, with the same personal equation. A Markovian process may affect the visual data, showing an overall brightening in the last decade, partially explainable with a small variability of Spica, used as reference star.

The detection of periods and their modulations is possible by integrating SOHO with other independent measures, and we discuss some preliminary analyses.

sciforum-164024: Rythmic flaring regions in the maximum of solar cycle XXV

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After the celebrated active region (AR) 3664, whose flares produced aurorae down to the Mediterranean area on 10-11 May 2024, AR3697 had a rhythmic behavior, which allowed us to predict flares' timings with accuracy down to the hour in June 2024. Similar behavior was registered in AR4274 and AR4299 in November-December 2025, and again it produced the largest flare of 2025, on 11 November 2025, with geo-effectiveness again reaching locations significantly far from the magnetic poles. Moreover, these active regions maintained their characteristics (timing and flaring directions) after two whole solar rotations.

An elevated degree of sympatheticity with nearby AR has been also verified: in nearby regions, they triggered other flares or they were excitated to flare, with a connecting time of up to one hour. Sympathetic flares are usually considered when they are less than 20 minutes apart, but the predictability of such events extended this timescale.

The flaring events of 8 December 2025 with the AR4299 and the nearby giant complex AR4294-96-98 are analyzed in detail, with particular attention given to the sequence M1.1 at 13:05UT in AR4294 and C4.82 in AR4299 at 14:06UT: the propagation of the perturbing wave was visible through the excitation of spotless plages between the two classified ones. These observations were made with the H-alpha telescope.

The cooling phases of the flare X1.95 from AR4299 and M5.05, X1.2 and X5.16, sources of Solar Particle Events (SPEs) from AR 4274 (the same region one rotation before), and the one M9.75 of AR3697 (SPE and Ground Level Enhancement) are also analyzed in X-rays from GOES Satellite data.

Session 8. Cosmology and Particle Physics

sciforum-164050: Symbolic Regression for Interpretable Cosmological Parameter Inference from the Cosmic Microwave Background

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The Cosmic Microwave Background (CMB) provides a precise snapshot of the early Universe and encodes detailed information about the fundamental parameters governing cosmological evolution. Conventional approaches to cosmological parameter inference rely on Bayesian sampling techniques combined with numerical Boltzmann solvers, which, while powerful, often obscure the underlying functional relationships between cosmological parameters and observable features of the CMB power spectrum.

In this work, we investigate **symbolic regression** as an interpretable machine-learning framework for cosmological parameter inference from CMB temperature and polarization power spectra. Using the PySR algorithm, we search for compact, closed-form analytic expressions that relate cosmological parameters to features of the CMB power spectrum, enabling transparent and physically interpretable mappings between theory and observation. Unlike black-box neural networks, symbolic regression yields explicit mathematical expressions that can be directly analyzed and compared with theoretical expectations.

We evaluate the accuracy, complexity, and stability of the recovered symbolic models across multiple cosmological parameters and benchmark their performance against expressions obtained using the AI Feynman algorithm. While AI Feynman performs effectively in low-dimensional settings, we find that its performance degrades as the dimensionality and complexity of the parameter space increase. In contrast, PySR demonstrates greater robustness and flexibility in higher-dimensional regimes relevant to realistic cosmological inference problems.

Our results show that symbolic regression can recover accurate and compact analytic relationships while providing direct physical insight into the structure of the CMB parameter space. This work highlights symbolic machine learning as a promising complementary approach to traditional inference methods and contributes toward more interpretable and physics-informed analyses of cosmological data.

sciforum-161394: A Common Origin of Asymmetric Self-interacting Dark Matter and Dirac Leptogenesis

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We present a framework in which the origin of the baryon asymmetry of the universe is linked to the dynamics of an asymmetric and self-interacting dark sector, while neutrinos remain Dirac fermions. The model extends the Standard Model by introducing three right-handed neutrinos, a pair of dark fermions, and two heavy scalar doublets that mediate interactions between the visible and dark sectors. A global $U(1)_{B-L}$ symmetry, consistent with a possible ultraviolet gauged completion, ensures the Dirac nature of neutrinos at the renormalisable level. The out-of-equilibrium and CP-violating decays of the heavy scalar doublets generate equal and opposite asymmetries in left-handed and right-handed neutrinos. Because the Yukawa couplings of Dirac neutrinos are tiny, the left–right equilibration occurs only after sphaleron freeze-out, allowing the asymmetry stored in left-handed neutrinos to be partially converted into baryon asymmetry. The same heavy-scalar decays that generate the lepton asymmetry also induce a dark-sector asymmetry, naturally linking the cosmic abundances of visible and dark matter. The dark sector contains a light MeV-scale gauge boson associated with a secluded $U(1)_D$ symmetry. This mediator efficiently depletes the symmetric dark matter component and provides the self-interactions required to address small-scale structure anomalies, while interacting only feebly with the Standard Model through a highly suppressed kinetic portal. The framework offers a coherent and testable connection between Dirac leptogenesis, asymmetric dark matter, and self-interacting dark-sector dynamics.

sciforum-161878: Making robust reionisation 21 cm signal predictions with C21LRT

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The redshifted 21 cm line signal is a unique probe for the Epoch of Reionisation (EoR)—it enables tomographic studies, which track the evolution of the averaged intergalactic medium (IGM) properties and their fluctuations. Accurate modelling of the 21 cm global and power spectrum signals is crucial for interpreting measurements from current and forthcoming 21 cm experiments. Theoretical predictions usually post-process reionisation simulations with optical depth approximation, which treats local line broadening and peculiar velocities approximately and often leads to divergences due to its velocity gradient term. I will present our cosmological 21 cm line radiative transfer (C21LRT) formulation, which explicitly accounts for local 21 cm line emission and absorption, Doppler shifts by peculiar velocity, broadening of the line, and the radiation transfer effects. We will adopt the IGM properties from reionisation simulations as inputs and assess the accuracy of the optical depth approximation for predicting 21 cm global signals and power spectra. I will demonstrate how our C21LRT delivers robust results for the redshift-space distortion (RSD) effects in the 21 cm power spectrum. I will show where the optical depth approach remains valid (for length scales of 1 -10 cMpc at mid-reionisation) and highlight the need to fully quantify the uncertainties with further exploration across a wider EoR parameter space using our C21LRT code.

sciforum-163617: Mechanisms of Cosmic Ray Flux Suppression During Solar Flare Activity and Solar Storms

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Galactic cosmic rays (GCRs) are continuously propagating high-energy charged particles originating outside the Solar System, whose intensity near Earth is significantly modulated by solar activity. One of the most prominent manifestations of this modulation is the transient reduction in GCR intensity known as a Forbush decrease (FD), which typically occurs in association with coronal mass ejections (CMEs), interplanetary shocks, and solar flare activity. This paper provides a comprehensive review of the primary physical mechanisms responsible for the suppression of cosmic ray flux during FD events. These mechanisms include magnetic shielding caused by enhanced interplanetary magnetic fields embedded within CMEs, shock-driven disturbances, and increased turbulence in the heliosphere. Observational data obtained from ground-based neutron monitor networks and space-borne instruments are analyzed to illustrate typical FD temporal profiles, recovery phases, and amplitude variations. The observed decreases in cosmic ray intensity generally range from approximately 3% for weak events to more than 20% for strong solar disturbances. Four illustrative figures are presented, showing characteristic FD events, schematic diagrams of CME–Earth interactions, shock structures, and large-scale heliospheric magnetic field configurations. The results emphasize the dominant role of strengthened interplanetary magnetic fields in deflecting and scattering low-energy GCRs, thereby reducing their access to the inner heliosphere. This study contributes to a deeper understanding of cosmic ray modulation processes and their relevance to space weather forecasting and heliophysical research.

sciforum-162805: Multi-Messenger Probes of Primordial Magnetogenesis, PBH Dark Matter, and Induced Gravitational Waves

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The origin of the large-scale magnetic fields permeating the Universe and the nature of dark matter are two of the most enduring open questions in modern cosmology. In this work, we investigate a unified early-universe scenario in which both phenomena arise naturally from a single primordial magnetogenesis mechanism. We show that the generation of primordial magnetic fields during the post-inflationary era not only provides seeds for the coherent magnetic fields observed today on cosmological scales, but also enhances curvature perturbations at intermediate wavelengths. These amplified perturbations become sufficiently large to trigger the formation of primordial black holes (PBHs), which can contribute substantially—if not dominantly—to the present dark-matter abundance. The same enhanced scalar fluctuations responsible for PBH formation inevitably induce a stochastic background of gravitational waves (GWs). We analyze the spectral features of this induced GW background and demonstrate that it carries a detailed imprint of the underlying magnetogenesis model and the expansion history of the Universe, particularly during non-standard reheating phases. By combining constraints from large-scale magnetic fields, PBH abundances, and induced GWs, we establish a powerful multi-messenger approach for probing the physics of the early Universe.
Furthermore, we highlight how upcoming and next-generation gravitational-wave detectors—such as LISA, DECIGO, BBO, and the SKA pulsar-timing array—can measure or tightly constrain the predicted GW signal. Such observations offer a unique opportunity to reconstruct the spectral behavior of the induced GWs and thereby uncover information about the reheating dynamics and the primordial magnetic field spectrum. Our results emphasize that jointly analyzing electromagnetic, gravitational-wave, and early-universe cosmological signatures provides an exceptionally sensitive pathway to uncovering the mechanisms that shaped cosmic magnetism and the origin of dark matter.

sciforum-159722: A background-free search for physics beyond the standard model using atom interferometry

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Atom interferometry provides a unique platform for testing fundamental physics. Building on the successful realization of the gravitational Aharonov-Bohm (gAB) effect in a large-baseline atom interferometer, I propose a next-generation experiment adapting this precise setup by adding a controllable electric potential. This experiment enables a background-free search for Beyond Standard Model (BSM) physics manifesting as a phenomenological composition-dependent coupling to both a gravitational and an electric potential ($\mathcal{L}_{BSM} \propto q \varphi_g \varphi_e$). I show that the analogous Standard Model (SM) effect, a gravitationally-modified Stark shift, vanishes identically due to parity conservation; as the atomic ground state has even parity, the expectation value of this interaction is zero. To detect the target microradian-scale signal beneath milliradian-scale technical noise and gigaradian-scale inertial backgrounds, the experimental design integrates three crucial solutions: (1) a simultaneous dual-isotope (^{85}Rb/^{87}Rb) interferometer to reject technical common-mode noise, (2) optimal spin-squeezed states providing N$^{-2/3}$ sensitivity scaling to surpass the Standard Quantum Limit, and (3) a four-point differential quadrature ($\pm V_0, \pm k_{\text{eff}}$) to algebraically cancel the dominant inertial phase and all k-odd systematics. A Monte Carlo analysis validates this complete protocol's robustness against systematics and projects a realistic path to a 5-sigma discovery within a 3-month integration time. This model-independent search, particularly sensitive to neutron-coupled forces like U(1)$_{B-L}$ gauge bosons, constitutes a high-precision null test that further solidifies the Aharonov–Bohm intuition that potentials are more fundamental than fields.

sciforum-163570: A signature of dark matter annihilation in cosmic rays using a plastic scintillator detector

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In this contribution, I will present a novel detection technique for low-energy antideuterons in cosmic rays, a promising signature of dark matter annihilation. Sub-GeV antideuterons represent an exceptionally clean channel for dark matter searches: their secondary production through conventional astrophysical processes (inelastic collisions of primary cosmic rays with interstellar medium) is extremely rare at low energies, making the expected background essentially negligible. Consequently, even a few detected events would constitute a significant signal potentially attributable to dark matter annihilation or decay in the Galactic halo. Current dark matter models predict antideuteron fluxes several orders of magnitude above the astrophysical background in the sub-GeV range, motivating the development of novel detection techniques optimized for this energy window.

PLASTICAMI is a segmented plastic tracker designed to identify a distinctive "double pion-star" topology characteristic of antideuteron annihilation: when an antideuteron stops in hydrogen-rich plastic, one antinucleon annihilates promptly, while the second survives with kinetic energy, travels several centimeters, and annihilates after nanoseconds. This spatial separation and timing delay between two annihilation vertices creates a unique double-vertex signature. The detector consists of 30 segmented plastic scintillator layers (3×3 m^2) stacked with gaps to resolve these displaced vertices, combined with external Cherenkov veto layers based on the newly characterized FB118 wavelength-shifting plastic for efficient background rejection. Geant4 simulations demonstrate 90% efficiency for identifying antideuterons while rejecting 99% of proton background. Considering atmospheric and geomagnetic effects for Antarctic balloon flights, two missions could achieve sensitivity of $\sim2\times10^{-6}$ (m^{2}sr s GeV/n)$^{-1}$ in the 100-600 MeV/n range, enabling exploration of theoretically motivated dark matter scenarios. Construction of a prototype detector subsystem is ongoing at INFN-TIFPA, utilizing SiPM photodetectors from FBK and custom front-end electronics.

sciforum-163547: A supersymmetric model of scalar and spinor fields in a closed isotropic universe

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In this talk, a closed isotropic universe with scalar and spinor fields is considered within the framework of the extended phase space approach. This approach implies the derivation of the Schrödinger equation for the wave function of the universe from the path integral with the Faddeev–Popov effective action, including gauge fixing and ghost terms, instead of the Wheeler–DeWitt equation. In the path integral, we use a mixed representation: a coordinate representation for gravitational variables (the lapse function and scale factor) and the so-called holomorphic representation for scalar and spinor fields. In the first step, the scalar field is assumed to be conformal. It enables us to find exact solutions to the Schrödinger equation for special gauge conditions. We consider a set of supersymmetric multiplets of scalar and spinor fields to cancel vacuum divergences and to determine vacuum energy in a closed universe. In the next step, the scalar field is slightly non-conformal. In a time-dependent gravitational field, it gives rise to scalar particle production. In its turn, it acts as a perturbation and results in transitions between quantum states in the Early Universe. Making use of the perturbation theory technique, it is possible to compute probabilities of transitions between states with different energy values.

sciforum-164835: A unified approach to Dark Energy, Dark Matter, and Cosmic Inflation

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The electron Born self-energy (eBse) model assumes a finite-sized electron of radius $R_e = 1.9 \times 10^{-20}$m, determined from electron-positron collisions at LEP. The Born self-energy U_e^B, corresponding to the energy contained in the surrounding electric field, provides a quantitative description of Dark Energy (Astrophys Space Sci **365**, 64 (2020); Phys Sci Forum **2**, 9 (2021)). Specifically, this model explains (i) the magnitude of DE, (ii) the occurrence of a deceleration-acceleration transition at a redshift $z \sim 0.8$, and (iii) possesses an equation of state $w = -1$ (in Quantum Electrodynamics the electron is assumed to be a point particle ($R_e = 0$); thus, $U_e^B \sim 1/R_e$ is divergent and is "renormalized away" by assuming that U_e^B is contained within the electron rest mass m_e). $w = -1$ implies that two electron Born masses $m_e^B = U_e^B/c^2$ will experience a gravitational repulsion, whereas m_e^B and an uncharged mass will experience the normal gravitational attraction. m_e^B ($\sim 40\ m_p$) is a Dark Matter candidate that provides a good description of the Grand Rotation Curves for the Milky Way and M31 galaxies out to distances of ~ 400 kpc (Sci Rep **14**, 24090 (2024)) (the difference between DE and DM, in this model, is as follows: DE arises from the ***time-dependent*** creation of m_e^B in intergalactic space due to ionization of hydrogen, whereas DM is a ***time-independent*** effect arising from the presence of a halo of electrons, along with their associated m_e^B, that surrounds a galaxy). Early in the Universe's expansion history, for electrons and positrons of finite size, a glass transition occurs at a maximum number density of $\sim 1/(2R_e)^3$ corresponding to physical contact between particles. This glass transition possesses properties akin to Cosmic Inflation (Sci Rep **13**, 21798 (2023)). A brief summary of the eBse model and its interconnections to DE, DM, and CI will be provided in this contribution.

sciforum-161475: Comprehensive Phenomenology of the Dirac Scotogenic Model: Novel Low-Mass Dark Matter

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The Standard Model (SM) of particle physics, despite its tremendous success, fails to explain two key observations: the nonzero masses of neutrinos and the existence of dark matter. These fundamental shortcomings clearly indicate the need for new physics beyond the Standard Model (BSM). Among the viable frameworks addressing these challenges, the Scotogenic mechanism proposed by Ernest Ma in 2006 provides a compelling setup in which neutrino masses are generated radiatively at one loop, while a discrete Z_2 symmetry simultaneously guarantees the stability of a dark matter candidate. This framework naturally links neutrino mass generation and dark matter within a unified setup. This idea has since been generalised to the Dirac scotogenic framework, where small Dirac neutrino masses are generated radiatively through the introduction of new fields together with the additional discrete symmetries or the global $U(1)_{B-L}$ symmetry already present in the SM. The Dirac scotogenic model offers an elegant framework for generating small Dirac neutrino masses radiatively at the one-loop level. A single abelian discrete symmetry, Z_6, simultaneously preserves the Dirac nature of neutrinos and ensures the stability of the dark matter candidate, emerging as an unbroken subgroup of the *445* $U(1)_{B-L}$ symmetry. In this work, we present a comprehensive study of the phenomenological consequences of this construction, focusing on electroweak vacuum stability, charged lepton flavor violation, and dark matter constraints. After incorporating current theoretical and experimental bounds, we find that the model not only remains viable but also permits novel low-mass scalar and fermionic dark matter regimes—distinct from those in the canonical Majorana scotogenic scenario. These features position the framework as a compelling bridge between neutrino physics, dark matter, and BSM cosmology.

sciforum-160399: Dirac Leptogenesis via Scattering Using the CTP Formalism

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We investigate the generation of the matter–antimatter asymmetry in the early Universe, prior to the electroweak phase transition, by extending the Standard Model with three right-handed neutrinos that complete Dirac mass terms and two heavy scalar fields. This constitutes a minimal and well-motivated Beyond-the-Standard-Model framework, since the Standard Model alone cannot account for neutrino masses or produce the observed baryon asymmetry due to insufficient CP violation. Using the Closed Time Path (CTP) formalism, we analyze 2→2 scattering processes mediated by the heavy off-shell scalars. Since these scalars remain off-shell throughout, the post-inflationary temperature of the Universe does not need to be high enough to produce them on-shell.

In this setup, right-handed neutrinos depart from thermal equilibrium, generating a lepton asymmetry that is subsequently converted into the observed baryon asymmetry via sphaleron processes. We compute the resulting baryon-to-photon ratio and compare it with the observational value reported by the Planck mission. We also compare the predicted contribution of the right-handed neutrinos to the effective number of relativistic species N_{eff} with current cosmological bounds, confirming the model's consistency with observations.

The use of the CTP formalism eliminates the need for Real Intermediate State (RIS) subtraction, leading to a more consistent and elegant treatment. Furthermore, by incorporating quantum statistical factors, we demonstrate that viable asymmetry generation is achievable even with only two right-handed neutrino flavours. Consequently, the mechanism is generic and does not rely on specific particle species such as leptoquarks or other particular Standard Model extensions.

sciforum-161178: Effects of spontaneous Z_2 symmetry breaking or restoration in Gauss–Bonnet gravity

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This work presents a comprehensive investigation of the formation and cosmological implications of domain walls within the framework of Einstein–Gauss–Bonnet (EGB) gravity. A pivotal feature of this model is the capacity for the scalar field Lagrangian to undergo a spontaneous process of Z_2 symmetry breaking and restoration. This phase transition is a fundamental prerequisite for the formation of topological defects, specifically domain walls, which arise as solitonic solutions interpolating between the distinct vacua of the theory. We perform a detailed numerical analysis of the dynamics of a neutral scalar field non-minimally coupled to the Gauss–Bonnet invariant, exploring its behavior across different cosmological backgrounds. Our findings demonstrate that the coupling to the Gauss–Bonnet term facilitates the formation of the static domain wall in terms of proper distance in a de Sitter (inflationary) background. Furthermore, we extend our analysis to a radiation-dominated epoch, where we identify that expansion leads to the "melting" of these walls. To assess the potential observational signatures of this scenario, we calculate the predicted spectrum of stochastic gravitational waves generated by the network dynamics using the CosmoLattice package. Additionally, we study the production of primordial black holes, which could be associated with the collapse of domain wall structures. Regrettably, our calculations indicate that the direct observational detection of such domain walls from this model lies beyond the reach of foreseeable experiments.

sciforum-161517: Interaction of heavy multiply-charged particles with light nuclei during Big Bang nucleosynthesis

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Long-lived or stable heavy multiply-charged particles X, predicted in various Beyond-the-Standard-Model (BSM) scenarios, can significantly affect Big Bang Nucleosynthesis (BBN). The neutralization process of such states via the capture of light primordial nuclei N (e.g., p, d, t, 3He, 4He) leads to the formation of bound states XN (electrically neutral dark atoms, negatively charged dark ions or positively charged anomalous isotopes) and a shift in the ratios of the primordial abundances of ordinary light elements. The dependence of reaction rates on the charge of the heavy particle and the deviations from the standard BBN predictions are studied using a combination of analytic and numerical estimates. The cross-section of the first stage of the dark recombination may be calculated numerically in the dipole approximation. The finite size of the nucleus in the shell of the dark atom is taken into account. The rates of further reactions are strongly affected by strong nuclear forces and can be estimated by scaling the experimental data for the corresponding ordinary nuclear fusion processes. The reduced Coulomb barrier and modified reduced masses are considered. Changes in the reaction network are predicted for high charges. To avoid contradictions with the observed ratios of the primordial abundances, the fine-tuning of the model parameters (charge, mass, and baryon-to-photon ratio) may be required.

sciforum-161036: Sterile neutrino dark matter from a TeV-scale seesaw

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We investigate the phenomenological aspects of a feebly interacting sterile neutrino dark matter candidate within a low-scale seesaw framework. The Type-I seesaw model is augmented by a second complex scalar doublet (Φ_{ν}), which couples exclusively to the heavy right-handed neutrinos and the lepton doublet, thereby generating the neutrino Dirac mass term while the first scalar doublet is responsible for giving mass to the remaining Standard Model particles. The lightest sterile neutrino (N_1) acts as a feebly interacting massive particle (FIMP), produced via decays of $W^\pm$, Z and extra scalars present in the setup. We point out that $W^\pm$ and Z contributions were overlooked in the previous studies, which actually dominate the N_1 production by a factor of $\sim 10^{13}$ and solely determines the relic abundance. Incorporating them leads to several novel consequences for the DM phenomenology like a new non-thermal condition which leads to smaller Yukawa couplings. We thoroughly discuss the enhancement possibilities of N_1's mass, which is controlled by the small vacuum expectation value (v_{ν}) of the second Higgs doublet. After incorporating the latest Lyman-α forest observations, this setup can accommodate both warm and cold dark matter scenarios. We also discussed the dominant role of SM gauge bosons in dark matter production through heavy-light mixing ($V_{ij} = \frac{M_{D_{ij}}}{M_{N_{j}}}$), which leads to interactions between the heavy right-handed neutrinos with the W and Z bosons. In the context of the FIMP scenario, however, the dark matter couplings are inherently required to be extremely small to remain out-of-equilibrium. So, the out-of-equilibrium condition is the holy grail of the freeze-in mechanism.

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