MAGIC 2025 - 2nd Workshop on Matter, Astrophysics, Gravitation, Ions and Cosmology

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Science of the Cosmos

Book of Abstracts

Contents

1

Spectral instability in fundamental mode and high overtones

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We propose a criterion for the emergence of instability in the quasinormal modes, particularly the fundamental mode, as recently observed by Cheung et al., identifying it as a universal feature in black hole perturbations. The instability manifests as an exponentially growing spiral that deviates from quasinormal frequencies due to a slight perturbation moving away from the compact object. We begin by examining a specific case involving a truncated Pöschl-Teller potential, where we derive the conditions for the onset of instability. Our analysis reveals that while the fundamental mode remains stable in this scenario, instability arises for high overtones (n » 1). This result is then generalized to a broader class of potentials through two mathematical frameworks: one based on poles in the black hole's reflection amplitude and the other on zeros in the transmission amplitude. We also revisit and extend a toy model with disjointed perturbations to the effective potential, showing that such configurations invariably induce instability in the fundamental mode, with the resulting outward spiral always occurring counterclockwise. Our numerical results, which align well with analytical predictions, support our findings by accurately capturing the spiral's period and the relative frequency deviation.

2

Neutron Stars as the Generators of Baryonic Dark Matter Particles

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The discrepancy between the average measured lifetime of trapped ultracold neutrons τtrap = (877.75 ± 0.28stat + 0.22/-0.16syst) s and the average beam measured lifetime of neutrons (τbeam = 888.0 ± 2.0 s) is well beyond the error margins. In the trap experiments, the neutron lifetime was determined by directly counting the surviving neutrons. In the beam experiments, the neutron lifetime was determined by counting the protons resulting from the three-body decay of neutrons into free protons and electrons, plus antineutrino, but the two-body decay of neutrons, which does not produce free protons, was missed. If the Branching Ratio (BR) for the two-body decay (compared to the three-body decay) would be about 1%, this would explain the puzzle. However, until recently it was considered that this theoretical BR is by several orders of magnitude smaller than 1%. In our recent paper we showed that the previously known theoretical BR was significantly underestimated and that the actual theoretical BR is about 1%. Thus, the puzzle of the neutron lifetime has been solved completely. In that paper it was also demonstrated that the enhanced two-body decay of neutrons has profound cosmological implications. Namely, it is the mechanism by which neutron stars are slowly but continuously producing baryonic dark matter particles. It was also shown that there is astrophysical evidence of this process.

3

Coarray Fortran Adaptive Mesh Refinement Code for Numerical Modeling of the Interaction between the Relativistic Wind of the Accretion Disk and a Molecular Cloud

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When simulating relativistic gas flows, complex flows are often formed in zones that are much smaller than the entire calculation domain. The processes that take place outside such zones may greatly affect not only the behavior but also the formation of the complex flows. The use of adaptive mesh refinement technique is a universal method of domain discretization in computing such multi-scale flows. In talk will propose original the Patch-Block-Structured Adaptive-Mesh-Refinement (AMR) technique for multi-scale modeling of special relativistic hydrodynamics flows. To use this technique, the numerical method was redesigned in a special way for using Coarray Fortran technology. Was showed that we have an almost linear 45-fold speedup with 48 Coarray Fortran images on 48 cores. This parallel code on base original AMR technique is used to simulate the interaction of a relativistic wind with clouds in the interstellar medium.

This work was supported by the Russian Science Foundation (project 23-11-00014).

4

Hybrid Optimization of Experimental Parameters in Space Weather Using Machine Learning

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Space weather, driven by solar and geomagnetic activity, significantly impacts satellite communications, power grids, and navigation systems. Accurate modeling and prediction of space weather phenomena require the optimization of experimental parameters, which often involve complex interdependencies and dynamic changes. My PhD research focuses on developing a hybrid optimization approach that integrates machine learning techniques with traditional physics-based models to enhance the precision and efficiency of space weather experiments.

This study explores machine learning methods such as neural networks and ensemble learning to predict solar activity, geomagnetic disturbances, and ionospheric variations. By incorporating optimization algorithms like Genetic Algorithms and Bayesian Optimization, the research aims to fine-tune experimental setups and parameter selection, ensuring adaptability to real-time changes in space weather conditions.

Through this innovative combination of data-driven methods and theoretical modeling, the work addresses key challenges in space weather prediction, such as handling sparse datasets, improving model generalization, and reducing computational overhead. The insights gained are expected to contribute to a better understanding of solar-terrestrial interactions and provide practical solutions for mitigating space weather risks.

Participating in the MAGIC workshop will allow me to connect my research to broader astrophysical phenomena, such as the role of strong magnetic fields in compact stars and the stochastic gravitational wave background. By presenting my findings and engaging with experts, I aim to foster interdisciplinary collaboration and explore potential applications of machine learning in astrophysical contexts.

5

Isolated stellar mass black holes in the galaxy: method, first detection, and implications

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According to theoretical estimates, our Galaxy contains about 100 million black holes, a large majority of which should be isolated. Yet, not a single isolated black hole had ever been unambiguously detected. After a brief review of the subject, the powerful technique of astrometric microlensing to detect isolated stellar mass black holes will be described. We used this novel technique of astrometric microlensing to unambiguously detect the first isolated stellar mass black hole. The superb astrometric capability of HST allowed us to measure the deflection caused by the black hole, and thereby measure its mass. Our measured mass of 7 solar mass, coupled with the fact that it emits no light confirmed its black hole nature. The implications of this detection and the status of our ongoing program to detect isolated black holes will be discussed. Future telescopes such as the Roman telescope should detect a large number of such isolated black holes.

6

Studying the Kick Velocity Model during the Formation of Binary Pulsars

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The kick velocity that arises during the binary interaction plays a vital role in determining the fate of binary pulsars. This work aims to explore the evolutionary link between the final orbital parameters of binary systems where one of the components experiences a mass change and a kick is imparted. Our study suggests that variations in the orbital period distributions can be explained by a kick velocity model resulting from the dynamical effects of an accretion induced collapse (AIC) of white dwarfs. Our model predicts that, 23% of binary pulsars in the Galactic disk with orbital periods POrb1 ≥ 2 are relevant for the pre-AIC orbital process. This implies that the kick velocity that arises during the AIC process plays a crucial role in disrupting or surviving the binary pulsars. The results of this study provide insight into the dynamics of binary pulsars and the role of kick velocities in their evolution.

7

Interacting Models of Dark Energy and Dark Matter in Einstein scalar Gauss Bonnet Gravity

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We study the dynamics of the interacting models between the Gauss-Bonnet
(GB) coupled scalar field and the dark matter fluid in a homogeneous and isotropic background. A

key feature of GB coupling models is the varying speed of gravitational waves (GWs). We utilize recent constraints on the GW speed and conduct our analysis in two primary scenarios: model-dependent and model-independent. In the model-dependent scenario, where determining the GW speed requires a specific GB coupling functional form, we choose an exponential GB coupling. We adopt a dynamical system analysis to obtain the necessary constraints on the model parameters that describe different phases of the universe and produce a stable late-time accelerating solution following the GW constraint, and find that to satisfy all these constraints, fine-tuning the free parameters involved in the models is often needed. In the model-independent scenario, the GW speed is fixed to one, and we construct the autonomous system to identify the late-time stable accelerating critical points. Furthermore, we adopt a Bayesian inference method using late-time observational data sets, including 31 data points from cosmic chronometer data (Hubble data) and 1701 data points from Pantheon+ and find that all the observational constraints can be satisfied without finetuning. In addition, we also utilize simulated binned Roman and LSST data to study the evolution of the universe in the model-independent scenario. We find that the model shows significant deviation at higher redshifts from ΛCDM and fits the current data much better than ΛCDM within the error bars.

8

Late Time Phenomena in f(T,\mathcal{T}) Gravity Framework: Role of H_0 Priors

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This study explored the behavior of the $f(T,\mathcal{T})$ cosmological model with the use of various data set combinations. We also compared the results for this model between the Pantheon+ (without SH0ES) and the Pantheon+\&SH0ES (with SH0ES) data sets. Additionally, we incorporated data from BAO along with H_0 priors. We observed that integrating SH0ES data points leads to a higher estimation of H_0 than Pantheon+ (without SH0ES). In our analysis, we employed two recently published values of H_0 that have added to the ongoing tension regarding H_0. These priors significantly influence all cosmological parameters in our studies. We perform an extensive MCMC analysis for every combination of data sets, providing constraints on all cosmological parameters included in the model. We also computed the χ^2_{min} value for each combination of data sets to evaluate the chosen model against the standard ΛCDM model. After determining the best-fit values for the cosmological and model parameters in each of the combinations, we plotted the cosmological background parameters. Based on the behavior of these background cosmological parameters, we conclude that our selected models reflect the late-time cosmic dynamics of the Universe.

9

Shadow Images of Schwarzschild Black Holes

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Black holes are among the most extraordinary and intriguing objects in the Universe. Within the framework of General Relativity, one of the most well-established modern physical theories, the study of these objects can be carried out using the simplest solution, known as the Schwarzschild metric. This solution describes a static and spherically symmetric black hole, enabling the analysis

of the gravitational influence of extremely massive bodies on the surrounding spacetime. We investigate the trajectories of photons emitted from an accretion disk toward an asymptotic observer. Subsequently, graphs are presented that illustrate the orbits of the photons, allowing the study of the paths they travel from the accretion disk to the observer. Additionally, we explore the shadows of a Schwarzschild black hole.

10

An alternative approach for dark matter and its distribution function

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The formalism of the Kinetic Theory of Relativistic Gases provides a geometrical framework to obtain the distribution function of the matter components. Such distribution function possesses the symmetries of the space-time in which it is embedded. In this talk we present the distribution function for a matter component in a Friedmann-Robertson-Walker (FRW) universe. Once the more general properties of the distribution function for a collisionless gas are derived, we will study the cosmological evolution of this gas in a homogeneous, isotropic and spatially flat universe. We will find that the gas behaves like radiation at early times and like dust at late times. This opens the question of whether the dark matter of the universe can behave like this relativistic kinetic gas. Therefore, we will analyze the cosmological implications of a component of dark matter with these properties at both, background level and linear perturbations. We found that the standard Cold Dark Matter model can be described by the distribution function associated to a FRW universe after a transition stage at early times from a radiation-like to dust-like matter.

11

A new symmetry for the imperfect fluid in relativistic astrophysics

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We will address the existence of a new symmetry for an imperfect
fluid by introducing local four-velocity gauge-like transformations for the case when there is vorticityˆ1. A similar tetrad formulation as to the Einstein-Maxwell spacetimes formalism presented in previous manuscriptsˆ2,3 will be developed in this manuscript for the imperfect fluids. The four-velocity curl and the metric tensor will be invariant under these kinds of four-velocity gauge-like local transformations. While the Einstein-Maxwell stress-energy tensor is locally gauge invariant under electromagnetic gauge transformations, the perfect fluid stress-energy tensor will not be invariant under four-velocity gauge-like local transformations. We will dedicate our analysis to the imperfect fluid stress-energy tensor that will be invariant under local four-velocity gauge-like transformations when additional transformations are introduced for several variables included in the stress-energy tensor itself. We will also pay special attention to the construction of a vorticity stress-energy tensor invariant under local four-velocity gauge-like transformations. An application on neutron stars will be developed in order to show the simplifications brought about by these new tetradsˆ4,5,6

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12

Torsional four-fermion interaction and the Raychaudhuri equation

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The intrinsic spin of fermions can generate torsion in spacetime. This gives rise to an effective four-fermion interaction that fermions experience within a fermionic distribution. This interaction is expected to become significant when densities become large, such as in early-universe cosmology or in compact astrophysical objects like neutron stars. In this contribution, I will discuss the role of this interaction in a gravitationally collapsing fermionic distribution. Our specific aim is to explore if this interaction can provide a repulsive contribution and prevent the formation of the final singularity. We consider a collapsing distribution of fermions which incorporates both chiralities. We use the Raychaudhuri equation and the focusing condition for congruences to carry out our investigation. Using reasonable assumptions, we establish that a repulsive contribution arises depending on how torsion couples with different chiralities. Also, the interaction term will behave analogous to an exotic matter (dark matter) component, having an effective negative equation of state, and the effect of the interaction starts to dominate as the collapse proceeds, accelerating or decelerating the collapse depending on the relative signs of the geometrical interaction between different species of fermions.

This work contributes to the understanding of how torsion-driven effects in dense fermionic systems might resolve the final singularity formation, and may have implications for the end-states of stars, such as neutron stars or other dense astrophysical objects.

13

Initial Conditions and Evolution for Spherically Symmetric Collapse

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Spherical collapse in general relativity has been studied with different methods, especially by using a priori given equations of state that describe the collapsing matter as a perfect fluid. We propose an alternative perspective, in which the initial density of the perfect fluid is given as a polynomial function of the radial coordinate that is regular everywhere inside the fluid. We then solve the corresponding differential equations, including the TOV equilibrium condition, using a 4-th order Runge-Kutta method and obtain a consistent model with a central perfect-fluid core surrounded by dust. Then, we analyze numerically the evolution of these initial conditions using the Ollinsphere code and obtain as a result a dynamical process in which the dust implodes into the central core to form a collapsed configuration. The density and pressure of the resulting matter distribution satisfy the standard physical conditions. The model is also consistent with the Buchdahl limit and the speed of sound conditions, even by using realistic values of compact astrophysical objects such as neutron stars.

14

Simple and direct formulae for galactic receding speeds and luminosity distances

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With our corrected cosmic red shift formula and Hubble-Hawking model of cosmology [1], we have developed a direct relation for fitting the accelerating model of luminosity distances (LD) [2-6] having $H_0 \cong 2.92 \times 10^{-19}\left(2.725\right)^2 \cong 66.9$ km/sec/Mpc. If $z_{new} \cong \frac{E_{emitted}-E_{Observed}}{E_{emitted}} \cong \frac{\lambda_{Observed}-\lambda_{emitted}}{\lambda_{Observed}} \cong \frac{z}{z+1}$ and $1+z \cong \frac{1}{1-z_{new}}$, $\left(LD\right)_{z_{new}} \cong (z+1)\left[\frac{sinh(z_{new})}{1+sinh(z_{new})}\right]\left[exp\left[sinh\left(z_{new}\right)\right]\right]^{\frac{3}{2}}\left(\frac{c}{H_0}\right)$. See our two 2 page PDF submitted by email for Fig. 1, Fig.2, the attached data table, http://www.atlasoftheuniverse.com/cosmodis and https://cosmocalc.icrar.org/. Proceeding further, currently believed galactic receding speed ratio can be expressed as, $\frac{V_{Gal}}{c} \cong \left[\frac{sinh(z_{new})}{1+sinh(z_{new})}\right]\left[exp\left[sinh\left(z_{new}\right)\right]\right]^{\frac{3}{2}}$. Thus luminosity distances can be expressed as $\left(LD\right)_{z_{new}} \cong (z+1)\left(\frac{V_{Gal}}{H_0}\right)$. Comoving distances (CD) can be expressed as, $\left(CD\right)_{z_{new}} \cong \frac{V_{Gal}}{H_0}$. By considering the fitted power factor $\frac{3}{2} \cong 1.5$ of $\left[exp\left[sinh\left(z_{new}\right)\right]\right]$ as a combination of $2\left(\Lambda_{dark}+\Lambda_{matter}\right) \cong 2\left(0.7+0.05\right) \cong 1.5$, there is a scope for understanding cosmic acceleration as a true nature of current cosmic expansion rate. In that case, accelerating model of cosmology must accommodate the corrected cosmic red shift definition $z_{new} \cong \frac{z}{z+1}$ without affecting the basics of Lambda model. But, directly and indirectly, (1) as the proposed formulae are independent of cosmic acceleration parameters, (2) as there exist no arbitrary parameters in the formulae and (3) as the estimated data is within the acceptable range - with further study and by considering the corrected cosmic red shift formula, true nature of cosmic expansion rate can be understood. It needs an unbiased review.

15

Simple and direct formulae for Lambda model of 'adot'and 'Hubble parameter'

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With our corrected cosmic red shift formula and Hubble-Hawking model of cosmology, we have developed direct relations for fitting the adot and Hubble parameter. Hubble-Hawking model of current Hubble parameter can be expressed as, $(H_0)_{HH} \cong 2.92 \times 10^{-19}\,(2.725)^2 \cong 66.9$ km/sec/Mpc. If $z_{new} \cong \frac{E_{emitted}-E_{Observed}}{E_{emitted}} \cong \frac{\lambda_{Observed}-\lambda_{emitted.}}{\lambda_{Observed}} \cong \frac{z}{z+1}$ and $1+z \cong \frac{1}{1-z_{new}}$, Lambda model of $(a_{dot})_z \cong \left[\frac{\sqrt{exp(0.5(z_{new}+sinh(z_{new})))(1+z)}}{1+2z_{new}}\right](H_0)_\Lambda$. Thus Lambda model of Hubble parameter (HP) can be expressed as, $(H_z)_\Lambda \cong \frac{(a_{dot})_z}{a} \cong (1+z)\,(a_{dot})_z \cong \left[\frac{\sqrt{exp(0.5(z_{new}+sinh(z_{new})))}}{1+2z_{new}}\right](1+z)^{\frac{3}{2}}\,(H_0)_\Lambda$. For example, if z=1100, obtained $(a_{dot})_{1100} \cong 1274.6$ km/sec/Mpc and $(H_{1100}) \cong 1403355.27$ km/sec/Mpc. Corresponding Lambda model values are, $(a_{dot})_{1100} \cong 1272.2$ km/sec/Mpc and $(H_{1100}) \cong 1400680.00$ km/sec/Mpc. See our two page PDF submitted by email for Table 1, Fig. 1 and https://cosmocalc.icrar.org/. With reference to our Hubble-Hawking model, $\left(\frac{H_z}{H_0}\right)_{HH} \cong \frac{T_z^2}{T_0^2} \cong (1+z)^2$. Hence, $\frac{(H_z)_\Lambda}{(H_z)_{HH}} \cong \Bigg[\frac{\sqrt{(1-z_{new})exp(0.5(z_{new}+sinh}}{1+2z_{new}}$ One very interesting observation is that, Lambda model of cosmic age up to recombination can be expressed as, $(t_z)_\Lambda \cong \frac{\sqrt{1+z}}{(H_z)_{HH}} \cong \left[\left((1+z)^{\frac{3}{2}}\right)(H_0)_\Lambda\right]^{-1}$. Thus, $(t_z H_z)_\Lambda \cong \left[\frac{\sqrt{exp(0.5(z_{new}+sinh(z_{new})))}}{1+2z_{new}}\right]$. With further study and by considering the corrected cosmic red shift formula, true nature of cosmic expansion rate can be understood. It needs an unbiased review.

16

On the possible role of Planck length in nuclear physics

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Considering our 4G model of final unification, we have noticed a simple relation for Planck length in terms of nuclear physical constants. It's published version can be expressed as, $\sqrt{\frac{G_N\hbar}{c^3}} \cong \left(\frac{m_p^2}{(m_n-m_p)m_e}\right)\left(\frac{2\pi R_0^2}{3ct_n}\right) \cong \left(\frac{m_p^2}{(m_n-m_p)m_e}\right)\left(\frac{V_0}{2R_0 ct_n}\right)$ where $R_0 \cong 1.24$ fm, $V_0 \cong \frac{4\pi}{3}R_0^3$ and $t_n \cong$ Neutron lifetime. This relation seems to be more simple and more meaningful compared to all available unified relations in current physics literature. Based on this relation, there is a scope for understanding the role of Planck scale in nuclear physics. This relation seems to highlight the importance and accuracy of the nuclear charge radius and neutron lifetime. We are working in this direction. We appeal the science community to circulate and recommend our work for further research.