Spinor field in cosmology and astrophysics

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Outline

Introduction : Aim and scope 3/25

The Einstein equations connect geometry with matter:

$$G_{\mu\nu} = \kappa T_{\mu\nu}. \tag{1}$$

Here $G_{\mu\nu}$ is the Einstein tensor describing the space-time geometry which may be spherically or cylindrical or axially symmetric or homogeneous and isotropic or anisotropic depending on the type of problem in question. $T_{\mu\nu}$ is the energy-momentum tensor of the material field that can be scalar, electromagnetic or spinor fields, perfect fluid, dark energy, dark matter etc. Equation (1) constitutes a self-consistent system in which matter serves as the source field for space-time, while space-time acts as the platform for matter to exist. Therefore, to elucidate any new discoveries, one may alter the distribution of matter, the geometry of space-time, or both.

Introduction: Aim and scope 4/25

The left hand side of (1) can be changed by considering $F(R)$, $F(R, T)$, Gauss-Bonnet theory or introducing Weyl or Lyra's geometry. The matter part can be changed for example introducing spinor field, interacting terms or DE and well as considering different types equation of state corresponding to various source fields:

$$p = f(\varepsilon), \tag{2}$$

where ε and p are the energy density and pressure, respectively.
Due to its capacity to simulate various types of source fields, including perfect fluid, dark energy, dark matter spinor field can significantly contribute to our understanding of different phenomena related to the evolution of space-time. Considering this, we have investigated the influence of spinor fields on the evolution of the universe.

Introduction: Aim and scope 5/25

In present-day cosmology, numerous theoretical models have been studied to account for the universe's accelerated expansion. Observational evidence from the Type Ia supernova (SNIa), Cosmic Microwave Background (CMB), Baryon Acoustic Oscillations (BAO), Surveys for growth of Large-Scale Structure (LSS), etc. has confirmed the acceleration of our universe. Even two and a half decades after discovering the accelerated universe, the reason behind it is still a mystery. However, it has been considered that an exotic component with negative pressure is responsible for the acceleration. Namely, it is called dark energy (DE); presently, it contains around two-thirds of the energy density of the universe.
Since a large number of observational data is available in free resource, it gives a unique opportunity to compare theoretical results with them. Taking this into account we have started a new project along this line.

Results 6/25

Within the scope of a FLRW model the role of nonlinear spinor field in the evolution of the universe was studied. The results are compared in Cartesian and spherical coordinates. We also compare our results with the data from Sternberg Astronomical Institute (SAI) Supernovae Catalog. Since the observational data are given in terms of Hubble constant (H) and red-shift (z) we rewrite the corresponding equations as a functions of z. The task is to find the set of parameters for the mathematical model of an isotropic and homogeneous Universe that fits best with the astronomical data obtained from the study of supernovae: magnitude (m), red-shift (z) [1, 2].

Results 7/25

In the context of spherically symmetric spacetime, we examine the influence of different fields, including a scalar field, an electromagnetic field, and an interacting system where scalar and electromagnetic fields on the development of a configuration exhibiting spherical symmetry. This paper addresses substances that conform to the barotropic equation of state. A simple method was proposed that allows for preliminary estimates of the behavior of metric functions if the components of the source's energy-momentum tensor are known [3].

Within the framework of cylindrical symmetric space-time, the role of a spinor field, dependent on time and the radial coordinate, in the formation of various astrophysical objects is investigated. It is shown that the presence of nontrivial off-diagonal components of the stress-energy tensor imposes certain restrictions on both the spacetime geometry and the spinor field [4].

Results 8/25

Within the framework of an anisotropic Bianchi type-II cosmological model, the role of a nonlinear spinor field in the evolution of the universe is studied. The components of the stress-energy tensor along the main diagonals are not equal even in the absence of spinor field nonlinearity and off-diagonal components are not trivial. It is shown that spacetime can be either rotationally symmetric or isotropic [5].

Within the scope of a spherically symmetric FLRW cosmological model we have studied the role of nonlinear spinor field in evolution of the universe. In this case energy-momentum tensor (EMT) of the spinor field possesses nontrivial non-diagonal components independent neither on spinor field nonlinearity nor on the value of parameter k defining the type of curvature of the FLRW model. The presence of such components imposes some restrictions on the spinor field [6, 7, 8].

Results 9/25

Within the scope of a Bianchi type-I (BI) cosmological model we study the interacting system of spinor and electromagnetic fields. In some earlier studies it was found that in case of a pure spinor field the presence of nontrivial non-diagonal components of energy-momentum tensor (EMT) leads to some severe restrictions both on the space-time geometry and/or spinor field itself, whereas in case of electromagnetic field with induced nonlinearity such components impose severe restrictions on metric functions and the components of the vector potential. It is shown that in case of interacting spinor and electromagnetic fields restrictions are not as severe as in other cases and in this case a nonlinear and massive spinor field with different components of vector potential can survive in a general Bianchi type-I space-time [9, 10].

Results 10/25

We examine the role of a nonlinear spinor field in the evolution of the Universe within the framework of a Bianchi type-I and LRS Bianchi type-I cosmological models with Lyra's geometry. Previous research has explored the nonlinear spinor field in various anisotropic and isotropic cosmological models, revealing that the presence of nontrivial, non-diagonal components of the spinor field's energy-momentum tensor imposes severe restrictions on both the space-time geometry and the spinor field itself. In our current study, we find that while these restrictions still apply, the introduction of Lyra's geometry significantly influences the evolution of the Universe. This influence arises from the fact that the invariants of the spinor field are dependent on the parameter of Lyra's geometry [11, 12, 13] .

Results 11/25

We discuss the static, spherically symmetric Einstein-spinor field system in the possible presence of various spinor field nonlinearities. We take into account that the spinor field energy–momentum tensor (EMT) has in general some off-diagonal components, whose vanishing due to the Einstein equations substantially affects the form of the spinor field itself and the space-time geometry. In particular, the EMT structure with any spinor field nonlinearities turns out to be the same as that of the EMT of a minimally coupled scalar field with a self-interaction potential. Therefore, many results previously obtained for systems with such scalar fields are directly extended to the Einstein-Dirac system. Some special solutions are obtained and discussed, in particular a solution for the Einstein–Dirac system (which lacks asymptotic flatness) and some examples with spinor field nonlinearities [14].

Results 12/25

An interacting system of gravitational and spinor field is studied within the scope of FLRW and Bianchi type-I cosmological models. It was found that if the spinor field nonlinearity describes an ordinary matter such as radiation, the presence of nonminimality becomes essential and leads to the rapid expansion of the Universe, whereas if the spinor field nonlinearity describes a dark energy, the evolution of the Universe is dominated by it and the difference between the minimal and non-minimally coupled cases becomes almost indistinguishable. Hence it should be argued that non-minimal coupling can be viewed as an alternative way to describe the accelerated mode of expansion of the Universe [15, 16].

Results 13/25

We constrain the model parameters using the latest observational datasets, including Type Ia supernovae from the binned Pantheon compilation, Hubble parameter measurements from cosmic chronometers (CC) and Sloan Digital Sky Survey (SDSS), including baryon acoustic oscillation (BAO) data. Employing Markov chain Monte Carlo (MCMC) sampling techniques, we obtain best-fit values that indicate the spinor GCG model provides a competitive and viable alternative to the Lambda-CDM, particularly in the late-time universe. Furthermore, the model predicts a lower present-day Hubble constant, offering a potential resolution to the Hubble tension. The results highlight the rich phenomenology of spinor fields and their possible role in the dynamics of dark energy through space-time interaction [17, 18].

Comparison of best-fit $H(z)$ of the spinor field GCG model 14/25

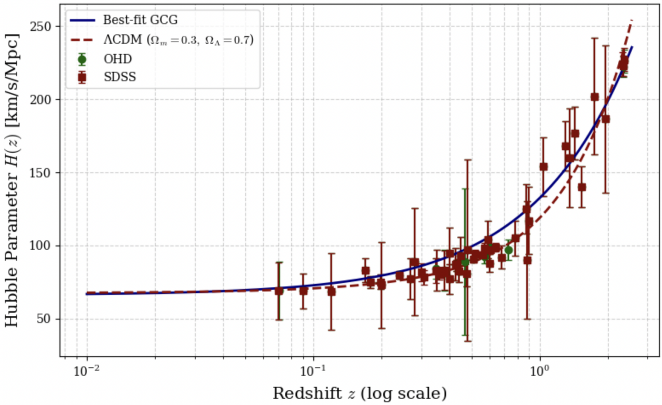

Figure: Comparison of best-fit $H(z)$ of the spinor field GCG model to the Hubble data sets (OHD+SDSS) along with Lambda CDM model.

best-fit theoretical distance modulus 15/25

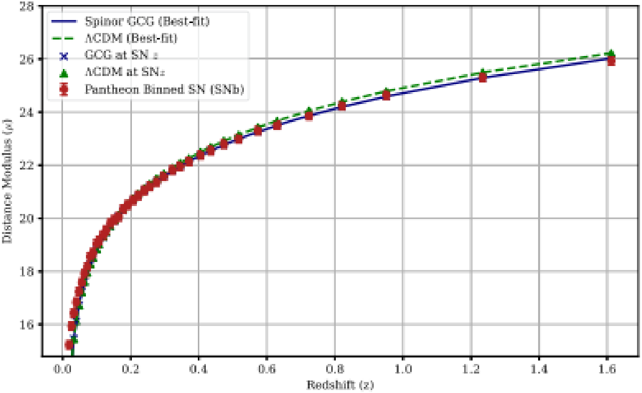

Figure: Comparison of the best-fit theoretical distance modulus $\mu(z)$ curves from the spinor field GCG model and the standard CDM modelwith the Pantheon binned SN (SNb) data.

Publications 16/25

1 Bijan Saha, Evgeniy I. Zakharov, Victor S. Rikhvitsky, *"Spinor field in a spherically symmetric Friedmann Universe"* *Discrete & Continuous Models & Applied Computational Science* **28**(2) 132–141 (2020) DOI: 10.22363/2658-4670-2020-28-2-132-141

2 Arsenii S. Gavrikov, Bijan Saha, Victor S. Rikhvitsky, *"Applying Friedmann models to describe the evolution of the Universe based on data from the SAI Supernovae Catalog"* *Discrete & Continuous Models & Applied Computational Science* **28**(2) 120–131 (2020) DOI: 10.22363/2658-4670-2020-28-2-120-131

3 B. Saha, *"Static spherically symmetric space-time: some remarks"* *Romanian Journal of Physics*, **66**, 113 (2021)

4 B. Saha, *"Spinors in cylindrically symmetric space-time"* *Universe* , **6**, 152 (2020) DOI:10.3390/universe9050243

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5 B. Saha, *"Spinor field in Bianchi type-II Universe" Romanian Journal of Physics*, **68**, 101 (2023)

6 B. Saha, *"Spinor field in FLRW cosmology" Universe* , **9**(5), 243 (2023) DOI:10.3390/universe9050243

7 B. Saha, *"Spinor field in FLRW cosmology: spherically symmetric case" Journal of Experimental and Theoretical Physics*, **167** (1), 49 - 58 (2025) DOI: 10.31857/S0044451025010043

8 Bijan Saha, *"Static spherically symmetric space-time and nonlinear spinor field" Mathematical Modeling and Geometry* **8** (2) 1 - 13 (2020) DOI:10.26456/mmg/2020-821

Publications 18/25

9 B. Saha, *"Interacting Spinor and Electromagnetic fields in cosmology" Space Time and Fundamental Interactions*, (1), 22 - 26 (2024) DOI: 10.17238/issn2226-8812.2024.1.22-26

10 B. Saha, *" Maxwell-Dirac system in cosmology" International Journal of Modern Physics A*, **39**(29), 2450117 (17 pages) (2024) DOI: 10.1142/S0217751X24501173

11 B. Saha, *"Spinor field in cosmology with Lyra's geometry: Bianchi type-I model" Space Time and Fundamental Interactions* (1), 187 - 195 (2025) DOI: 10.17238/issn2226-8812.2025.1.187-195

12 B. Saha, *"Spinor field in Bianchi type-I cosmology with Lyra's geometry" Journal of Mathematical Physics*, **66**(10), 102501 (2025) DOI: 10.1063/5.0270836

13 Bijan Saha, *"Spinor Field in Cosmology with Lyra's Geometry" Mathematical Modeling and Geometry* **13**(1) 1 – 9 (2025) DOI:10.26456/mmg/2025-1311

Publications 19/25

14 K.A. Bronnikov, Yu.P. Rybakov, and Bijan Saha, *" Spinor fields in spherical symmetry. Einstein-Dirac and other space-times" EPJP* **135** 124 (2020). DOI 10.1140/epjp/s13360-020-00150-z

15 Bijan Saha, *"Interacting self-consistent system of spinor and gravitational fields IJMPA* **35** 2040047 (2020). DOI: 10.1142/S0217751X20400473

16 Bijan Saha, *"Non-minimally coupled nonlinear spinor field in FRW cosmology Astrophys. Space Sci.* **365** 68 (2020). DOI: 10.1007/s10509-020-03780-y

Publications 20/25

17 Mahendra Goray, B. Saha, *"Observational Constraints on a Spinor Field Generalized Chaplygin Gas Model in a Spherically Symmetric FLRW Spacetime"* *EPJC* **85**(10), 1146 (2025).
https://doi.org/10.48550/arXiv.2509.09733

18 B. Saha, Mahendra Goray, *"Exploring Spinor Field MCG Dark Energy in FLRW Spacetime: Observational Constraints and Comparison with ΛCDM"* *EPJP*, (2025), Springer (Under Review).
https://arxiv.org/abs/2506.16323

Publications 21/25

Total publications - more than 200, in referred journals 125.
Last 5 years total 32 papers, in referred journal 14, (3 Q1, 6 Q2, 2 Q3).
SCOPUS - total citations 2093, since 2020 - 174, H-index = 25
Web od Science - total citation 2031, H-index = 25
Google Scholar - total citation 3290, since 2020 - 725, H-index 29, since 2020 - 15, i-10 index - 67, since 2020 - 25
Research Gate - total citation 2589, H-index 27
TopScientist - top 2% worldwide since 2020.

Teaching experience 22/25

Associated Professor, Department of experimental physics, RUDN - 2001 - 2002

Associated Professor, Department of Higher Mathematics, Dubna University - 2007 - 2008

Associated Professor, Institute of Physical Researches and Technology, RUDN - 2017 - 2025

Professor, Institute of Physical Researches and Technology, RUDN - 2025

Editorial board member, Discrete & Continuous Models & Applied Computational Science

Work as reviewer in many international journals.

Teaching experience 23/25

Read courses on Electrodynamics (3 rd course) and Quantum Mechanics (3 rd and 4 th courses) at IPIT, RUDN
and additional courses on General Relativity and Cosmology (IPIT, RUDN)
During last 5 years I was supervisor for 11 B.Sc., 1 M.Sc. students in RUDN and 9 students in Inter University Center, JINR (together with V. Rikhvitsky). Was opponent to 1 Ph.D. thesis (Ufa) and external examiner for 2 Ph.D. theses (India). At present I have 2 B.Sc. stdents, 3 M.Sc. students and 1 Ph.D. student.
During this time I took part in 9 conferences in Peter, Kazan (KFU) and Moscow (RUDN, Bauman)

Future Plan 24/25

As it was mentioned earlier, spinor field can play crucial role to explain different stages of evolution of the Universe. So we continue our quest in the field of cosmology and astrophysics with spinor field being the source of gravitational field.

It was found that the introduction of Lyra's geometry brings significant novelty in the solution as invariant of spinor fields become more complicated and EMT of spinor field does not conserve. I plan to continue this study with other Bianchi models.

No matter what theoretical results we get, unless it is consistent with observational data theories become useless. Taking this into account we have started a new project where theoretical results were compared with the observational one. We will continue it both in cosmology and astrophysics.

Thank You!