International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Topological defects and the early universe: Insights from gravitational theories

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International Journal of Science and Research Archive, 2023, 10(02), 840–854

Publication history: Received on 31 October 2023; revised on 10 December 2023; accepted on 12 December 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.10.2.1044

Abstract

Introduction: In this section, the overview of the topological defects is discussed based on gravitational theories. Along with this, the objectives and the research questions are made. Three hypotheses have been made in this part.

Aim: The aim of the research paper is to determine the impact of the topological defects in the early universe based on insights from the gravitational theory.

Literature reviews: The impact of the topological defects on the early universe is discussed. Critically evaluate the issues faced by the topology and the recommendations are delivered based on that. Along with this, the overview of the gravitational theory and the impact of topological defects in active nematic and cosmology is discussed in this research paper. With the help of the temperature drops and universe expands, phase transactions are taking a positive step for the broken symmetries.

Methodology: Primary quantitative research method has been used in this research study. Descriptive research design and deductive research approaches have been used. Data has been collected from 55 respondents and questionnaires have been made based on 13 questions.

Findings and analysis: Statistical results are helping in hypothesis testing purposes. SPSS software helps to gather information statistically. Therefore, demographic test and variable related test is highlighted in this section. More relevant numerical information has to be collected with the aid of this research study.

Discussion: The study of topological defects and their linking to gravitational theories in the Early Universe is an attractive and crucial field of cosmology. Gravitational theories, specifically inflation, have been involved in amplification the origin and characteristics of these defects, delivering a window into the fundamental physics governing the cosmos.

Conclusion: Observations and theoretical investigations of topological defects not only improve the knowledge of the Universe's early stages but also cover the way for discoveries with far-reaching implications in components physics and cosmology. The significance of the gravitational law is mainly following the planet's motions around the sun.

Keywords: Gravitational theory; Topological defects; Early universe; Crystals

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1. Introduction

Topological defects are mainly configurations of matter that are based on the phase of the transitions in the early universe. As per the comment of Jaime et al. (2021), those configurations depend on symmetric, original, and old phases and topological defects are quasiparticles that is delivering proper stability against perturbations. As per the notion of Gogoi& Goswami (2022), there are various examples of topological defects that are based on domain walls, vortices in superconductors, and skyrmions among the liquid crystals. As commented by Das & Hook (2021), these defects are representing the positions that are based on the field and it is not able to relax among the lower energy state and vacuum state. Thus, continuity, connectedness, and compactness are the three major fundamental concepts for topological defects.

The significance of the gravitational law is mainly following the planet's motions around the sun. As per the comment of Amiri, Mueller & Doostmohammadi (2021), it is helping to evaluate the trajectory of astronomical bodies and helps to predict their motions. Along with this, it is helping to detect the motion of water in oceans and rainfall, and with the help of this theory the radius, mass, rotation, and speed of invisible objects are measured.

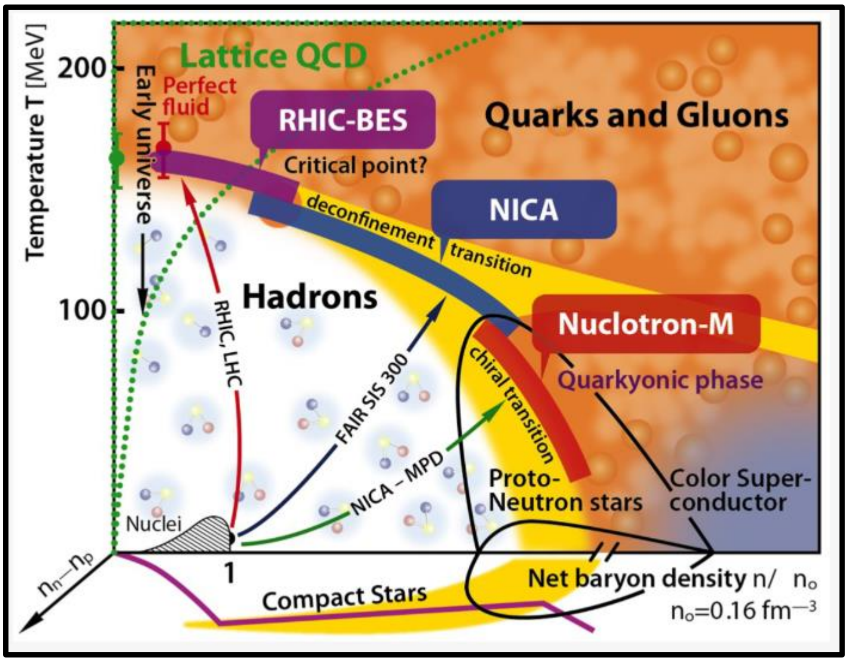

Figure 1 Structural phase diagram of QCD

(Source: Ramberg & Visinelli, 2019)

The above figure is showing the structural phase diagram for the QCD and the net baryon density n normalized to the cold nuclei baryon density no, and the schematic phase diagram for QCD matter. As per the notion of Ramberg &Visinelli (2019), the gravity theory is mainly explaining the development of the quantitative theory for gravity and determining the attraction forces among two bodies. As stated by D'Eramo (2023), Newton's law of gravitation is playing a significant role and delivering a proper understanding of the universe. As commented by Lin (2020), on Earth, gravitational forces are crucial for doing all kinds of activities in the Earth's atmosphere such as flow and rainfall. As per the comment of Güllü & Övgün (2022), there is a connection among high energy cosmology, physics, and GW physics that is investigated with the help of the facets and done with the help of the various perspectives. Therefore, different types of physical techniques in the early universe are getting generated with the help of the GWs.

With the help of the temperature drops and universe expands, phase transactions are taking a positive step for the broken symmetries. As per the notion of Jain (2023), the pre-Big Bang scenario assumes that a specific application of superstring theory underlies gravity and cosmology. In the thoughts of Likéné et al. (2022), this scenario proposes that the Big Bang precedes a highly perturbative starts state from which the Universe develops. As mentioned by Karmakar, Gogoi & Goswami (2023), the dilaton, a further massless mode in string theory, is dynamic in the early Universe despite its potential to be fixed at later times. As an outcome, dilaton gravity provides the massless sector of string theory to which the graviton belongs. Thus, during the dilaton-driven phase, this model results in the generation of an enhanced quasi-thermal graviton spectrum.

A particular realization of M-theory in which spacetime has 11 dimensions serves as the inspiration for the ekpyrotic model. As per the notion of Howard et al. (2020), the GWs' equation for movement does not depend on the potential of the scalar field, whereas the cosmic perturbations do. The spectrum of GWs appears to be quite blue, suggesting that primordial GWs are insignificant on scales relevant to modern cosmology.

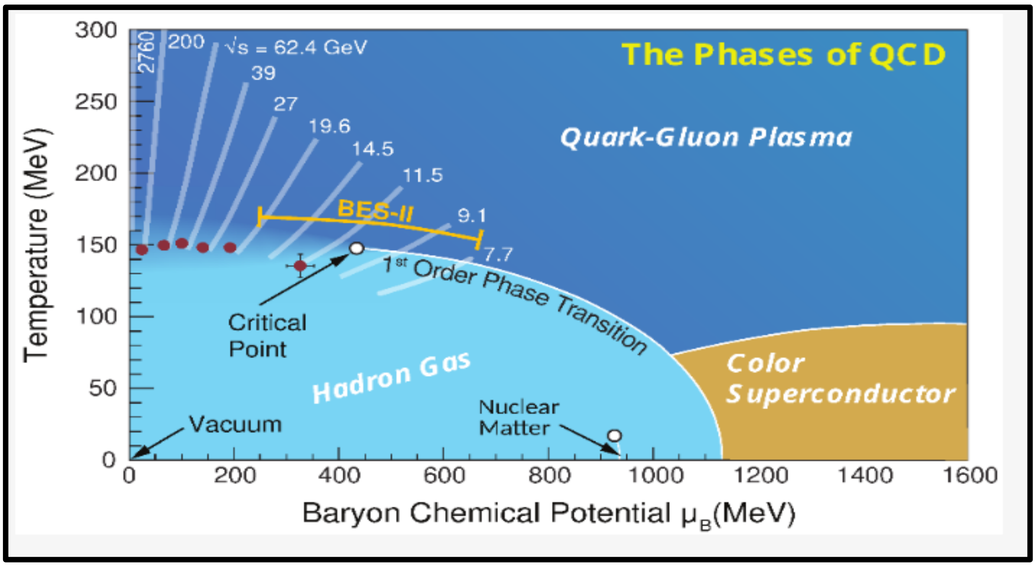

Figure 2 The phases of QCD

(Source: Dunsky et al. 2022)

The above figure is showing a QCD phase diagram based on thermodynamics parameters space. As commented by Dunsky et al. (2022), a hypothetical QCD phase diagram for both the temperature T and baryonic potential of the B thermodynamic factor space has been examined in the above figure. The graphic shows the corresponding collision force ranges for several accelerator facilities, particularly the RHIC Beam Energy Scan program. In this research paper, the research problem is based on first-order topological issues that are determined based on continuous functions and topological spaces. In the thoughts of Nwabuzor et al. (2021), these typical conditions are delivering the equalities among the functions. Along with this, the research paper is facing issues in delivering a proper relationship between the topological defects and gravitational theory.

1.1. Aim

The aim of the research paper is to determine the impact of the topological defects in the early universe based on insights from the gravitational theory.

1.2. Research Objectives

- ***RO1:*** To determine the impact of the topological defects in the early universe
- ***RO2:*** To evaluate the importance of the gravitational theory in physics
- ***RO3:*** To analyze topological defects in active nematics and cosmology
- ***RO4:*** To detect the issues related to the topological aspects and provides recommendations for mitigating those issues

1.3. Research Questions

- ***RQ1:*** What is the impact of the topological defects on the early universe?
- ***RQ2:*** What is the importance of gravitational theory in physics?
- ***RQ3:*** How do topological defects are creating impacts on cosmology and active nematics?
- ***RQ4:*** What are the issues for the topological defects and what are the possible ways to mitigate those issues?

1.4. Hypothesis

- H1: There is a positive relationship between the topological defects and gravitational theory.
- H2: Topological defects and quantum field theory are highly correlated with each other.
- H3: Topological defects in the early universe and cosmology are positively correlated with each other.

This research paper is playing a significant role in different aspects of physics those are includes cosmology, condensed matter physics, and quantum field theory. Along with this, the concepts of the topological defects of the early universe have been discussed in this research paper that has been created a significant role. The positive relationship between topological defects and gravitational theory and quantum field theory has been discussed.

2. Literature Review

2.1. Critically evaluate the impact of topological defects in the early universe

Topological defects are stable arrangements of matter that were created during phase transitions in the very early Universe. As stated by Karmakar, Gogoi& Goswami (2023), even though these configurations are in the previous, symmetric phase, they continue to exist after the phase transition to the new, asymmetric phase is complete. On the other hand, Stadnik et al. (2020) have stated that spacetime locations where the underlying field the order parameter in condensed matter physics or the Higgs field in particle physics is frustrated are represented as topological defects. As commented by Cheng et al. (2022), due to topological obstacles, it cannot relax into the vacuum state, which has the lowest energy. Thus, topological defects are quasiparticles with considerable resilience against disturbances due to their topological structure. Examples of topological flaws include skyrmions, domain walls, dislocations in crystals, vortices in superconductors and superfluid's, and strings and monopoles in liquid crystals.

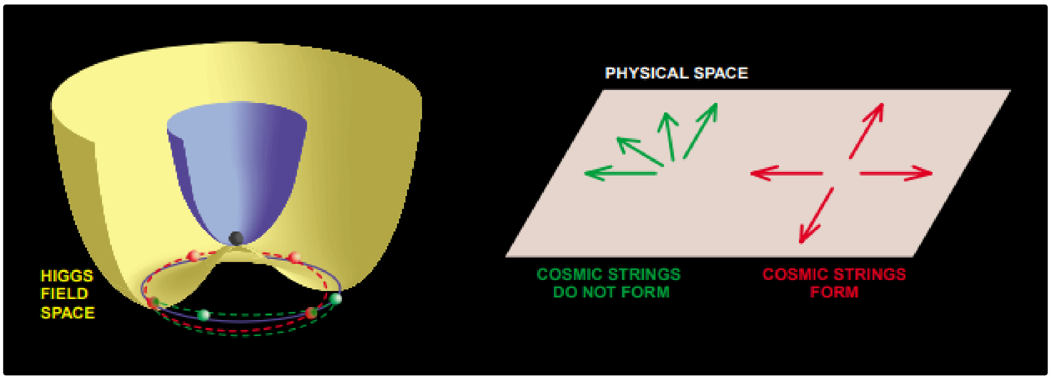

Figure 3 Scalar Higgs field

(Source: Angelescu, Goertz & Tada, 2022)

The above figure is representing the complex scalar for the temperature-dependent potentials V. Defects can take many different forms, including textures, monopoles, domain walls, cosmic threads, and other 'hybrid' species. As opposed by Angelescu, Goertz & Tada (2022) the symmetry characteristics of the matter and the characteristics of the phase transition dictate the type of defect that is created. In the thoughts of Dvali, Funcke& Vachaspati (2023), the idea of symmetry breaking is a key component of particle physics theories that aim to integrate all fundamental interactions. As commented by Ahmed et al. (2023), the gravitational interaction would have been the first force to start taking on its own characteristics as the cosmos grew and cooled, followed by all other forces that are currently understood. Thus, the spontaneous breakdown of fundamental symmetries is realized as a phase shift in the early universe when the typical hot Big Bang scenario is used.

2.2. Critically examine the issues that occur for topological defects

Topological solitons are easily produced while making the crystalline semiconductors utilized in modern electronics, and in that setting, they almost always have negative effects. As per the comment of Zhang et al. (2022), such crystal transitions are known as topological defects because of this. As opposed by Masia-Roiget al. (2020), old-fashioned telephone handset cables, which are often wound clockwise, are one of the simplest and most typical examples of a topological soliton. As commented by Hiramatsuet al. (2021), years of picking up the phone may cause some of the cables to coil in the opposite anticlockwise direction. When this happens, a recognizable bigger loop will separate the two coiling ways. On the other hand, Digal & Mamale (2022) have stated that this strange-looking, neither clockwise nor anticlockwise transition loop is a prime illustration of a topological soliton. Thus, the complicated situation, that meets the definition of a topological soliton must at some point display the same straightforward problem of reconciliation as the twisted phone cable.

The rich and fascinating mathematical features of such boundary regions, however, are obscured by the language, which largely refers to solid-state phenomena. On the other hand, Karpov et al. (2019) have stated that there are mainly four topological relationships those are included order, proximity, separations, and continuity. As per the notion of Reig et al. (2019), the topological data model, in general, controls spatial interactions by presenting spatial objects as an underlying graph of topological primitives, including nodes, faces, and edges. Thus, a topological soliton is preferred in the majority of non-solid-state applications due to its more uplifting connotation and mathematical richness.

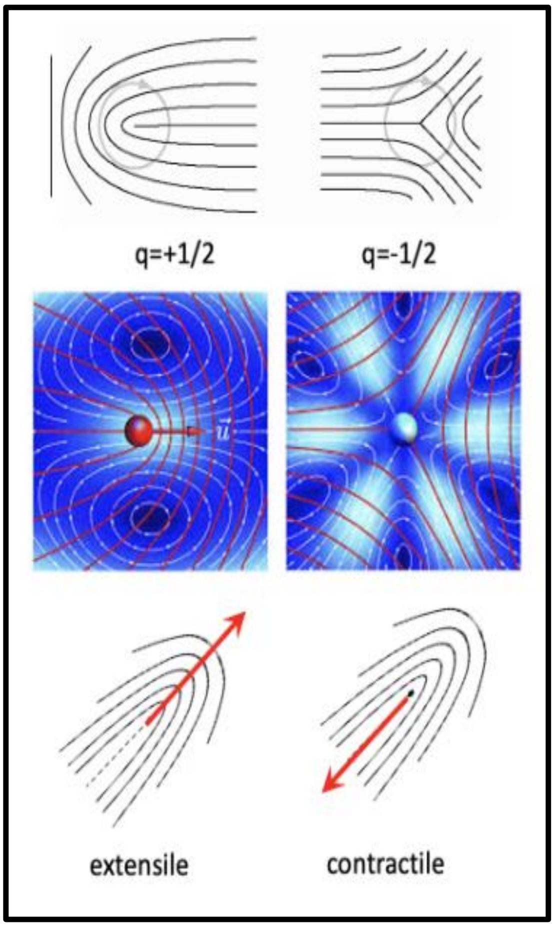

Figure 4 Topological defects in liquid crystals

(Source: Amiri, Mueller &Doostmohammadi, 2022)

The above figure is showing the topological defects in the active nematic liquid crystals and that is based on extensile and contractile. As stated by Amiri, Mueller & Doostmohammadi (2022), examples include connectedness, compactness, and, in the case of a flat domain, the number of border components. On the other hand, Buoninfante, Miyashita & Yamaguchi (2022) have stated that the qualitative characteristics that define the relative position of spatial objects are described by topological relationships and examples include disjunct, meet, and overlap. Therefore, a property that is preserved by a homeomorphism is referred to as a topological property.

2.3. Analyze the impact of the topological defects on cosmology and active nematics

Topological flaws in active nematic liquid crystals not only determine the director's overall structure but also serve as local sources of motion, behaving like propelled particles. In the thoughts of Kralj, Kralj & Kralj (2021), spacetime places where the underlying field is frustrated are represented by topological defects. On the other hand, Zeng et al. (2021) have stated that due to topological obstacles, it cannot relax into the vacuum state, which has the lowest energy. As per the comment of Jaime (2021), the study of the universe's overall structure, which includes both global topological characteristics and more local geometrical qualities like curvature, is known as cosmic topology. Hence, by depicting the physical connections between devices and the data flow within the network, network topology aims to provide you with a broad picture of the network. It distinguishes between a psychological and physical connection.

3. Methodology

In this research paper, primary quantitative research methods have been used for data collection purposes. Along with this, descriptive research design and deductive research approaches have been used in this research paper. In the thoughts of Gogoi& Goswami (2022), it is the highly used method for doing market research and delivering primary research for focusing on data collection purposes. Questionnaires have been made based on the 13 questions and responses have been collected from 55 responses. As per the comment of Das & Hook (2021), Primary quantitative data collection methods are mainly based on case studies and focus groups. SPSS software has been used for data collection and analysis purposes additionally, with the help of the SPSS ANOVA test, regression analysis, and frequency analysis have been done. Along with this, descriptive and demographic analyses have been conducted in this research paper.

4. Results

4.1. Demographic Analysis

4.1.1. Gender

Table 1 Gender

What is your gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	1.8	1.8	1.8
	Female	14	25.0	25.0	26.8
	Male	14	25.0	25.0	51.8
	Prefer not to say	27	48.2	48.2	100.0
	Total	56	100.0	100.0	

(Source: SPSS)

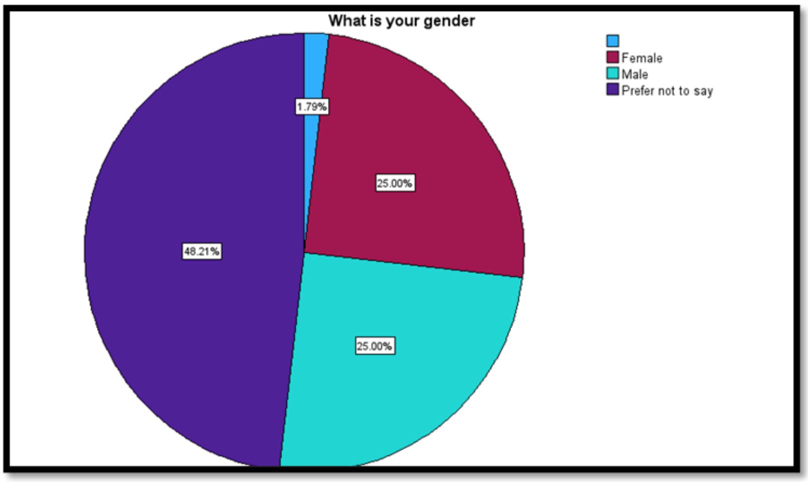

Figure 5 Gender

(Source: SPSS)

Table 1 helps to analyze the frequency of the participants based on their gender. Therefore, according to this table 14 female and 14 male participants are taking part in this process. After that, 27 participants are not preferred to take part in this data collection process.

Figure 5 analyzes the response rate of the participants according to their gender. Therefore, 25.-% of male respondents is allowed to take part coin this process. Therefore, 25.0% of female percipients take part in this process.

4.2. Age Group

Table 2 Age Group

What is your age group?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	1.8	1.8	1.8
	20 to 30 years	14	25.0	25.0	26.8
	31 to 40 years	14	25.0	25.0	51.8
	41 to 50 years	14	25.0	25.0	76.8
	51 to 60 years	13	23.2	23.2	100.0
	Total	56	100.0	100.0	

(Source: SPSS)

Table 2 is based on the age group of the participant. 9 respondents belong between 20 years 30 years of age group; therefore, 14 participants belong between the 31 to 40 years of age group. After, that, 41-50 years age group participants have carried out 14 frequencies of their responses. Additionally, 13 participants belong to the 51-60 years age group.

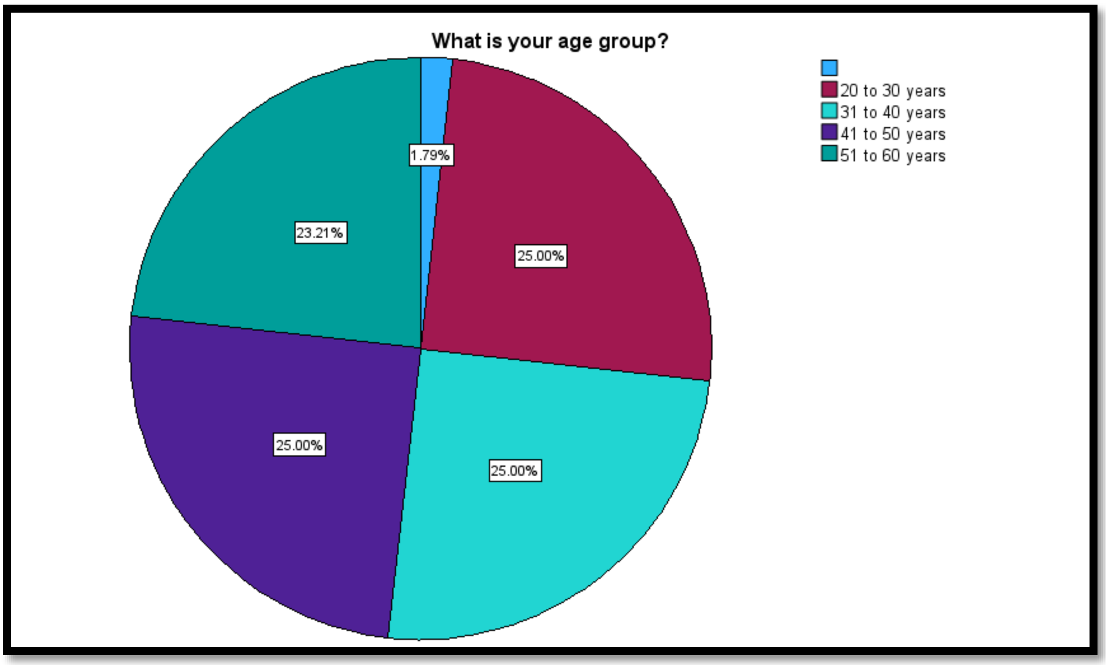

Figure 6 Age Group

(Source: SPSS)

Figure 6 helps to identify the response rate of the participants. Therefore, the maximum response rate of participants belonged between the 20-30 years age group, and their response rates were 25.0%. Thus, the lowest response rate is 31 years to 40 years of age group and their response rate is 25.0%.

4.3. Occupation

Table 3 Profession

What is your occupation?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		1	1.8	1.8	1.8
	Employee	27	48.2	48.2	50.0
	Scientists	14	25.0	25.0	75.0
	Student	14	25.0	25.0	100.0
	Total	56	100.0	100.0	

(Source: SPSS)

Table 3 is based on the response rate of the participants based on their profession. 27 numbers of employees take part in this data collection process. Therefore, 14 scientists are capable to give responses. After that, the frequency of response rate of students is 14.

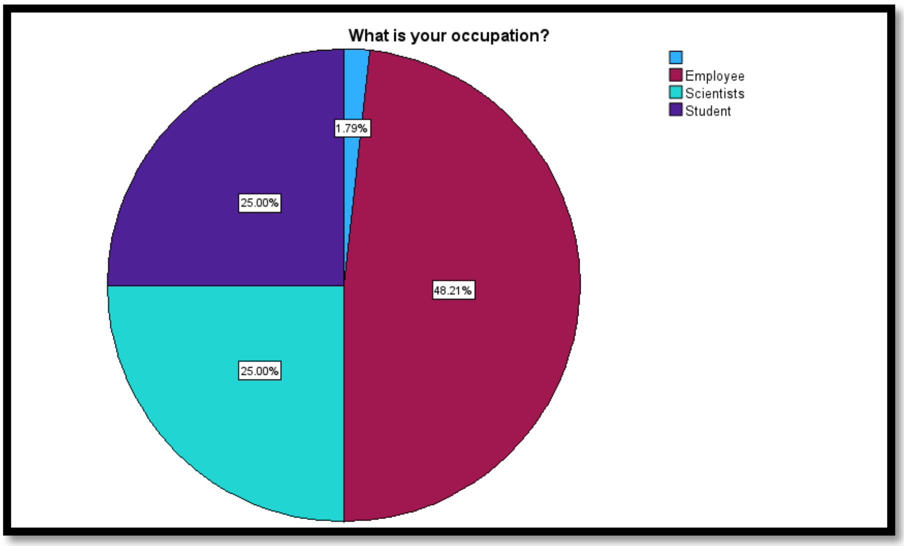

Figure 7 Profession

(Source: SPSS)

Figure 7 is based on the response rate of the participants and it shows that the maximum response rate is 48.2% and respondents belong to employee occupations. Therefore, the lowest response rates for participants are students and scientists and their response rate is 25.0%.

4.4. Statistical Analysis

4.4.1. Descriptive Analysis

Table 4 helps to identify the “mean” and “standard deviation” value of the variables. Therefore, the “mean value” of the dependent variable (DV) is 4.25 and the “standard deviation” value is .440. Therefore, the first independent variable carried out the “mean value” of 3.75 and the “standard deviation” value of .440. Therefore, the second and third variables have 4.00 and 4.25 “mean” values, and .097, and .059 “standard deviation” values respectively.

Table 4 Descriptive analysis of different variables

Descriptive Statistics

	N	Minimum	Maximum	Mean		Std. Deviation	Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error
IV 1	55	3	4	3.75	.059	.440	-.683	.634
IV 2	55	3	5	4.00	.097	.720	-1.019	.634
IV 3	55	4	5	4.25	.059	.440	-.683	.634
DV	55	4	5	4.25	.059	.440	-.683	.634
Valid N (listwise)	55							

(Source: IBM SPSS)

4.5. Hypothesis 1

Table 5 details the regression analysis of the first hypothesis. As per the “model summary” table, the significance value of the first variable is 0.011. Therefore, according to “The ANOVA” table significance value of this variable is also 0.011. Therefore, the “t value” of this variable is 2.645. Moreover, with the aid of this table, it is mentioned that there is no existing co-relation is found between these two variables.

Table 5 Linear regression analysis

Model Summary[b]

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.341[a]	.117	.100	.417	.117	6.995	1	53	.011	3.270

a. Predictors: (Constant), DV

b. Dependent Variable: IV 1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.217	1	1.217	6.995	.011[b]
	Residual	9.220	53	.174		
	Total	10.436	54			

a. Dependent Variable: IV 1

b. Predictors: (Constant), DV

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	2.293	.552		4.152	<.001
	DV	.341	.129	.341	2.645	.011

(Source: IBM SPSS)

4.6. Hypothesis 2

According to table 6, the significance value is .001, and the "t value" is 10.391. This significance value is less than 0.05, therefore, it is indicated that there is a significant relationship exists between these independent and dependent variables.

Table 6 Linear regression analysis for Hypothesis 2

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.819[a]	.671	.665	.417	.671	107.963	1	53	<.001	3.270

a. Predictors: (Constant), DV

b. Dependent Variable: IV 2

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.780	1	18.780	107.963	<.001[b]
	Residual	9.220	53	.174		
	Total	28.000	54			

a. Dependent Variable: IV 2

b. Predictors: (Constant), DV

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-1.707	.552		-3.092	.003
	DV	1.341	.129	.819	10.391	<.001

(Source: IBM SPSS)

4.7. Hypothesis 3

Table 7 Linear regression analysis for Hypothesis 3

Model Summary[c]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	1.000[a]	1.000	1.000	.000	1.000	.	1	53	.	.[b]

a. Predictors: (Constant), DV

b. Not computed because there is no residual variance.

c. Dependent Variable: IV 3

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.436	1	10.436	106.900.	<0.001.[b]
	Residual	.000	53	.000		
	Total	10.436	54			

a. Dependent Variable: IV 3

b. Predictors: (Constant), DV

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.000	.000		3.023.	.004.
	DV	1.000	.000	1.000	9.974.	<0.001

(Source: SPSS)

Table 7 helps to understand the relationship of the third hypothesis. Therefore, as per the “model summary” table, the significance value is .001 and the “t value” of this variable is 9.974. Therefore, it is noticed that there is a significant relationship is existed between these variables.

4.8. Correlation Test

Table 8 Correlation test between a dependent variable and independent variables

Correlations

		IV 1	IV 2	IV 3	DV
IV 1	Pearson Correlation	1	.819**	.341*	.341*
	Sig. (2-tailed)		<.001	.011	.011
	N	55	55	55	55
IV 2	Pearson Correlation	.819**	1	.819**	.819**
	Sig. (2-tailed)	<.001		<.001	<.001
	N	55	55	55	55
IV 3	Pearson Correlation	.341*	.819**	1	1.000**
	Sig. (2-tailed)	.011	<.001		<.001
	N	55	55	55	55
DV	Pearson Correlation	.341*	.819**	1.000**	1
	Sig. (2-tailed)	.011	<.001	<.001	
	N	55	55	55	55

(Source: SPSS)

As per Table 8, the significance value of the first variable is .011, therefore, these two variables do not co-related to each other. The significance value of the second and the third variables are both .001. Therefore, these variables also have highly correlated relationships with their dependent variables.

5. Discussion

Based on the above study objectives and questions, literature review, primary quantitative data collection and SPSS analysis, the below discussion has been undertaken.

Topological defects in the early universe have impacted the cosmos' large-scale structure and expansion. These captivating and complicated structures, initiated during phase transitions, have shaped the disbandment of matter and energy, impacted different aspects of cosmology and presented valuable understandings of the basic physics of the early cosmos. As per the view of Angelescu, Goertz & Tada (2022), one of the most notable results of topological defects is the cosmic microwave background (CMB) radiation, the afterglow of the Big Bang. The existence of these flaws has impressed different patterns on the CMB, assembling temperature fluctuations and polarisation ways that are perceptible in modern CMB experimentations. As commented by Dvali, Funcke& Vachaspati, 2023), cosmic strings have contributed to the shape of anisotropies in the CMB temperature disbandment. These anisotropies have been exemplified as hot and cold spots in the CMB map, and their distinctive patterns rely on the characteristics of the cosmic strings, such as their viscosity and tension. Adherence to the CMB has permitted to place bounds on the number of cosmic strings and other topological defects, thus authorising experimenters to experiment with different cosmological scenarios.

Topological defects are not only applicable in cosmology but also discover intriguing applications in the domain of active nematics, a class of non-equilibrium systems consisting of self-propelled components that align with their neighbours. As per the statement of Digal &Mamale (2022), in active nematics, the relations between the self-propelled components and their alignment choices can provide advancement to topological defects in the coordinated motion of the system. These defects are equivalent to those monitored in cosmology during the early universe's phase transitions. However, the underlying physics in active nematics and cosmology are intrinsically different. According to Amiri, Mueller &Doostmohammadi (2022), in cosmology, topological defects are assembled during symmetry-breaking phase transitions as the universe cools down, resulting in structures like cosmic strings, monopoles, and domain walls. In contrast, as asserted by Miyashita & Yamaguchi (2022), in active nematics, topological defects have occurred due to the interplay between active motion and alignment relations among the components, leading to the appearance of whirlpools and disclinations in the exposure field of the system.

The gravitational theory, particularly General Relativity, has owned enormous significance in physics and the acquaintance of the basic laws controlling the universe. As stated by Zeng et al. (2021), this theory is of principal significance in physics. It has exemplified the force of gravity in phrases of spacetime curvature, foreshadows a spectrum of gravitational phenomena, and assembles the basis for modern cosmology. Its prosperous projections and continued exploration have played a crucial position in increasing the knowledge of the universe and its basic laws. However, a lot of issues have been associated with the topological aspects.

Topological aspects in different fields of science, containing cosmology and condensed matter physics, can propose a lot of challenges. Managing these issues is essential to enhance the knowledge of complicated systems and promote scientific study. As per the opinion of Dunsky et al. (2022), studying topological aspects in large-scale systems can be computationally intensive and challenging. The calculation of topological invariants or the dynamics of topological defects may require significant computational resources and time. In order to diminish this issue, experimenters can study the consequence of more efficacious algorithms and employ parallel computing approaches to accelerate analyses. On constraints, as asserted by Ahmed et al. (2023), topological aspects have usually required expertise from various fields, such as physics, computer science and mathematics. Providing effective interdisciplinary cooperation is necessary to manage the challenges and capitalise on the synergies of different fields.

6. Conclusion

It has concluded that topological aspects have played a key function in diverse scientific fields, from cosmology to concentrated matter physics. These intriguing phenomena, such as topological deficiencies, invariants, and whirlpools, deliver practical understandings of the basic nature of the universe and the demeanour of complicated systems. However, the study of topological aspects has arrived with its share of issues, and managing these impediments is necessary to completely leverage their possibility in increasing scientific study.

The effect of topological defects in the early universe is deep and multifaceted. These defects have affected the disbandment of matter and energy, played a key function in the shape of cosmic structures such as galaxies and galaxy clusters, and left marks on CMB radiation. The reflection of topological defects has furnished worthwhile insights into the physical operations that emerged during the early phases of the universe's development and proposed a unique window into high-energy ideas such as grand unified theories and string theory. The significance of gravitational theory in physics cannot be exaggerated. General Relativity, as one of the considerably successful and essential theories in modern physics, has revolutionised the knowledge of gravity. It has defined gravity as the curvature of spacetime generated by mass and energy, unifying the notion of gravity with the geometry of the universe. It has initiated the basis for modern cosmology and has played a critical position in illustrating the large-scale structure and development of the universe. Furthermore, the study of topological defects in active nematics has extended thrilling opportunities for studying emergent phenomena in non-equilibrium systems.

However, studying topological aspects can raise several issues. Computational sophistication, experimental detection, theoretical intricacies, interdisciplinary cooperation, and validation and reproducibility issues have been faced by the experimenters when examining topological defects. In order to manage these issues, experimenters must design efficient algorithms and use advanced computational methods to overcome computational sophistication. Moreover, supporting cultivated experimental instruments and cooperating with experts in experimental physics can sweeten the detection and compliance of topological defects in physical systems. Additionally, it has been concluded that the study of topological defects in the early universe and their connections to gravitational theories has far-reaching importance in physics as well as cosmology. The gravitational theory has included the bedrock of the insight of gravity and its position in shaping cosmic structures. Comprehending topological defects in active nematics has offered an understanding of emergent phenomena in out-of-equilibrium systems.

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Appendices

Appendix 1: Questionnaires

Survey Link: https://forms.gle/QUwMafQEJ4sthrgx9

- What is your age group?
- 20 to 30 years
- 31 to 40 years
- 41 to 50 years
- 51 to 60 years
- What is your gender
- Male
- Female
- Prefer not to say
- What is your occupation?
- Student

- Employee
- Scientists
    - The notion of topological defects in cosmology and their applicability to the Early Universe is familiar to everyone
    - Gravitational theories have played a crucial role in understanding the formation of topological defects in the Early Universe
    - Cosmic strings are fascinating topological shortcomings in the context of the Early Universe
    - The study of topological defects can deliver valuable understandings of the essential physics of the Early Universe
    - Inflation theory is deemed a plausible gravitational theory describing the building of topological defects in the Early Universe
    - The existence of topological defects can have noticeable effects on the large-scale structure of the Universe nowadays
    - Knowledge of topological defects is fundamental for advancing the understanding of the Early Universe's evolution
    - Adherence to cosmic microwave background radiation is pledging for detecting topological defects
    - There are practical implications emerging from the analysis of topological defects and gravitational theories
    - Examining the relationships between topological defects and gravitational theories in the Early Universe is of interest to many experimenters