

Title Page

The Submission Title: What are the basic substances of the universe? Current research and future predictions

Author Name: Y Liu

Author Affiliation: Hebei International Studies University

Postal Code: 051132

Corresponding Author: Y Liu

Country: China

Address: Shijiazhuang City, Hebei Province, China

Email address: dhqy202@163.com

ORCID ID: <https://orcid.org/0009-0003-1436-4972>

What are the basic substances of the universe? Current research and future predictions

Abstract

Exploring the fundamental components of the universe remains one of the most profound challenges in science. Although significant progress has been made in terms of particles and forces, the composition of the universe is far from being solved. This article explores the hypothesis that the most basic matter in the universe is composed of four interrelated elements: matter, energy, time and space. We believe that these components are not only the basis of physical phenomena, but also the basic components of atoms and the universe. This article describes the advantages and limitations of established theories such as Standard Model and General Relativity, and draws evidence from cosmology, quantum mechanics, and particle physics, and conducts in-depth research on the complex relationships of matter, energy, time and space on different scales. By proposing the overall framework for the interaction of these four elements, we raise the need for future physics research to unify the microscopic and macroscopic worlds and explore other long-standing major issues in physics.

Keywords: Theoretical Physics, Atomic Physics, Elementary Particles, Universe, Quantum Physics

1. Introduction

From ancient times to the present, human beings have been trying to explore the basic essence of the universe. This pursuit has developed from philosophical thinking to a

rigorous framework of modern physics. The current scientific paradigm is mainly to analyze the material composition of the universe, break them down into elementary particles and study their interactions. This simplified approach was very successful, leading to the development of the Standard Model for Particle Physics, which describes known particles and their forces with incredible accuracy. However, this model is incomplete. It cannot explain the nature of gravity, dark matter and dark energy, nor the asymmetry between matter and antimatter observed in the universe. ¹

We know that the universe is composed of matter, energy, time and space, and we also know that there is matter, energy, time and space inside atoms. So, are the basic matter of the universe composed of matter, energy, time and space? Is there a connection between the macroscopic scale of the universe and the microscopic scale of matter and phenomena? Current physics research focuses on studying units of matter within atoms. So, does physicists need to study the composition of matter, energy, time and space within the universe and atoms and their relationships? Therefore, it is necessary for us to change the current research paradigm, and we must conduct a more comprehensive analysis of matter, energy, time and space as a unified system. This article will explore these issues by combining existing knowledge and predicting future research directions.

2. Current research on the composition of the universe

Our current cosmological framework is in a paradoxical state: we know a lot, but we know almost nothing. Popular models, known as Lambda Cold Dark Matter (Λ CDM), provide a phenomenological description of the fine constraints of the universe. It

assumes that the universe is flat in space, expanding at an accelerated rate, consisting of about 5% of ordinary matter, 27% of dark matter and 68% of dark energy. While observations from cosmic microwave backgrounds, galaxy surveys and supernova strongly support this model, the fundamental properties of its two largest components, dark matter and dark energy, remain an unsolved mystery.²

The Standard Model (SM) of Particle Physics describes the composition of ordinary matter well. SM is a successful theory that classifies all known fundamental particles (quarks, leptons and bosons) and describes three of the four fundamental forces (electromagnetic, weak, and strong). However, its success is obscured by serious limitations. SM does not include gravity, and the mass of neutrinos cannot be explained without correction, nor does it provide candidate particles for dark matter. Therefore, finding physics beyond the Standard Model (BSM) is a major focus of modern particle physics, and through experiments, it is possible to find phenomena such as dark photons, axion and other weakly interacting particles that may constitute dark sectors.^{1,3}

Dark matter is inferred from its gravitational action on galaxies and clusters, and it does not interact with light and is therefore invisible. Regarding its composition, many hypotheses have been proposed, ranging from weakly interacting large-mass particles (wimps) to ultralight axion. A series of complex experiments are underway to detect dark matter, either directly through its faint interaction with ordinary matter, indirectly through its annihilation product, or in a particle collider.^{4,5} Some new detection mechanisms, such as finding oscillations of fundamental constants caused

by ultralight dark matter fields or detecting the generation of dark matter internal pairs, are being explored to detect previously unreachable parameters.^{6,7}

The concepts of time and space also present unresolved challenges. In general theory of relativity, space-time is a dynamic four-dimensional manifold, whose curvature is determined by the distribution of matter and energy. However, in quantum mechanics, time is regarded as a universal, absolute parameter rather than a dynamic variable. This fundamental conflict between the two theories is a major obstacle to the development of quantum gravity theory, which is necessary to describe phenomena such as the Big Bang singularity or the inside of a black hole. These two views cannot be reconciled, highlighting that our understanding of space and time as physical entities is incomplete.

3. The relationship between matter, energy, time and space

Matter, energy, time and space are fundamental components of the universe, and this proposition requires the study of their profound interconnections that manifest differently on macroscopic and microscopic scales.

On the macroscopic cosmic scale, Albert Einstein's general theory of relativity describes this relationship. The field equations of this theory establish a direct connection between space-time geometry and the distribution of matter and energy in it. In essence, matter and energy affect the bending of space and time, while the curvature of space and time affects the movement of matter. This dynamic interaction suggests that space and time are not passive, but are important components of the universe.

At the microscopic quantum scale, these associations become more complex and counterintuitive. The most famous link is Einstein's mass-energy equivalent, $E=mc^2$, which reveals two aspects of matter and energy being the same entity. This principle is the basis of nuclear physics and particle physics. Quantum field theory further develops this concept, assuming that particles are only local excitations of the underlying fields that penetrate into all space-time. In this view, vacuum is not empty, but an ocean of fluctuating energy, from which virtual particles can instantly appear, blurring the difference between matter and vacuum.

4. Future development direction and forecast

In order to transcend the limitations of current physical theories and achieve a more basic understanding of the universe, future research must integrate the research of matter, energy, time and space into one framework. This effort requires progress at the theoretical, experimental and interdisciplinary frontiers.

The most important challenge, theoretically speaking, is to develop a unified new theory of physics that coordinates relativity with quantum mechanics.

Experimentally, the development of next-generation particle colliders and observation facilities is crucial to testing new theories and exploring unknown areas.

Furthermore, the increasing complexity of physical systems and the huge data sets generated by modern experiments require an interdisciplinary approach. For example, using machine learning and artificial intelligence to analyze complex and chaotic experimental data.

5. Conclusion

Although the Standard Model and General Relativity provide a powerful framework for describing the universe at the particle and cosmic levels, respectively, they are still incomplete and interconnected. Research on dark matter, dark energy, and space-time suggests that our current particle-centric paradigm may not be enough. This paper proposes a hypothesis that a deeper understanding and exploration of the universe and atoms can be achieved by considering matter, energy, time and space as the four main, interrelated components of reality. The future progress of physics will depend on our ability to establish a unified theoretical framework to view these elements as a whole and supported by the next generation of experimental instruments that can detect them. By exploring and studying the relationship between atoms and the universe's matter, energy, time and space, I believe we will have a better understanding of the origin, composition and development of the universe.

Reference

1. Chen, Shenjian, and Stephen Lars Olsen. "New physics searches at the BESIII experiment." *National Science Review* 8.11 (2021): nwab189.
2. Lawrence, Andy. "Invisible matter, invisible brains?." *Science* 387.6737 (2025): eadw0099.
3. Fiorillo, Damiano FG, Tetyana Pitik, and Edoardo Vitagliano. "Energy transfer by feebly interacting particles in supernovae: the trapping regime." *Physical Review Letters* 135.7 (2025): 071005.
4. Lin, Yen-Hsun, and Meng-Ru Wu. "Supernova-Neutrino-Boosted Dark Matter from All Galaxies." *Physical Review Letters* 133.11 (2024): 111004.
5. Aad, Georges, et al. "Search for Dark Matter Produced in Association with a Dark Higgs Boson in the $b\bar{b}$ Final State Using pp Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector." *Physical review letters* 134.12 (2025): 121801.
6. Oswald, R., et al. "Search for dark-matter-induced oscillations of fundamental constants using molecular spectroscopy." *Physical review letters* 129.3 (2022): 031302.
7. Dutta, Bhaskar, et al. "Dark Matter Internal Pair Production: A Novel Direct Detection Mechanism." *Physical Review Letters* 135.1 (2025): 011804.