様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費
KAKENHI

科学研究費助成事業　　研究成果報告書

令和　元 年　 ６ 月 １８ 日現在

機関番号：２２６０４
研究種目：基盤研究(C)（一般）
研究期間：2014～2018
課題番号：２６４００２５２

研究課題名（和文）Modified Supergravity Models of Cosmological Inflation and Particle Production in Early Universe

研究課題名（英文）Modified Supergravity Models of Cosmological Inflation and Particle Production in Early Universe

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交付決定額（研究期間全体）：（直接経費）　　3,600,000円

研究成果の概要（和文）：我々の研究の目的は宇宙の進化及び素粒子の起源を理解することである。これに関連した具体的な問題は、宇宙の加速膨張を引き起こしているものは何か、銀河を繋ぎとめている原因は何か、初期宇宙における構造形成の機構はどのようなものか、である。これらの問題はそれぞれ暗黒エネルギー、暗黒物質、インフレーションと呼ばれる。我々のアプローチは超重力理論（重力と他の力を統一し、異なるスピンと統計を持つ粒子同士を関連付ける理論）に基づいており、その結果我々はすべての観測結果と一致し、特有のインフレーション機構と暗黒エネルギー、そして暗黒物質に適した素粒子をもつ超重力の新しいモデルを構築することに成功した。

研究成果の学術的意義や社会的意義
Our research results brought better understanding of dark energy, dark matter and cosmological inflation in the supergravity theory, which is non-trivial. This further strengthened the supergravity itself as the viable candidate for new physics beyond the Standard Model of elementary particles.

研究成果の概要（英文）：The purpose of our research is to understand the evolution of the Universe, and the origin of elementary particles. This is related to the more specific problems such as (i) what causes the accelerated expansion of the Universe?, (ii) what is the reason for keeping the galaxies together?, and (iii) what is the mechanism of the structure formation in the early Universe? These problems are called dark energy, dark matter, and inflation, respectively. The current scientific knowledge about gravity and elementary particles is not enough to address these problems, so that more advanced theories should be developed. Our approach is based on the supergravity theory that unifies gravity with other forces and relates particles of different spin and statistics. We succeeded in constructing the new models of supergravity, which are consistent with all observations and have the specific mechanisms of inflation and dark energy, together with a suitable elementary particle for dark matter.

研究分野：particles and fields

キーワード：supergravity　inflation　dark energy　dark matter　supersymmetry breaking

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９、ＣＫ－１９（共通）

１．研究開始当初の背景

High-energy physics of the very early Universe (cosmological inflation), origin of elementary particles (reheating), and dark energy (cosmological constant) are the big mysteries in physics. The recent measurements of the cosmic microwave background radiation by Planck satellite mission put severe constraints on theoretical models of inflation and reheating. Dark energy is the subject of intensive research.

２．研究の目的

The purpose of our research is to construct new theoretical models of inflation, reheating and dark energy, which are consistent with all cosmological observations.

３．研究の方法

Modified supergravity theory and string theory, spontaneous supersymmetry breaking.

４．研究成果

The main research objectives of the project were achieved due to devoted efforts of PI and his research collaborators, and also in part due to significant advances of our research made in the previous years. All this allowed us to construct new viable models of cosmological ination in the early Universe, by using most economic theoretical models in four-dimensional N=1 supergravity. This area of theoretical research is very competitive both in Japan and worldwide. We explicitly calculated the inverse transformation from a scalar-tensor gravity to the dual f(R) gravity theory and applied it for studying quantum (matter) corrections in Starobinsky inationary model [1]. We extended the Starobinsky ination to N=2 extended supergravity for the first time [2]. It represents the important step towards a construction of inationary models in string theory with extra dimensions.

To get progress in the theoretical description of inflation in string theory, we conducted joint research with our colleagues in Montpellier (France) and derived the non-perturbative scalar potential in type IIA strings compactified on rigid Calabi-Yau manifolds [7]. Later we applied these results to inflation [12].

As a simplified approach to realizing inflation in string theory we proposed and studied in detail the inflationary models with two coupled scalars, by using the non-minimal couplings of the scalar fields to the Starobinsky gravity [5]. Our main research achievements in the two-feld inflation were the realization of the phenomenologically viable scenarios of inflation, such as Starobinsky modified gravity and the so-called helical-phase models where inflaton is identified with a phase of a complex scalar field [6]. Starobinsky inflation is based on the R + R^2 (modified) gravity, and is consistent with the observational (Planck) data, while its inflaton is spin-0 part of space-time metric (the so-called scalaron). The scalaron is expected to mix with other scalars (such as Higgs), so that it is important to study stability of Starobinsky inflation against scalaron couplings to other (scalar) particles. Given one extra scalar coupled to scalaron, it leads to two-field inflationary models that are much more complicated than single-field inflationary models. Any two-field inflationary model implies the existence of the so-called primordial isocurvature perturbations that may be observed in a future. Our findings support robustness of Starobinsky two-field inflation for a certain range of its parameters characterized by low tensor-to-scalar ratio (less than 0.06) and the small running of the scalar index (less than 0.05) [5]. We found for the first time several new helical-phase inflationary models in N=1 supergravity by using a more economical (single-superfield) framework versus the earlier literature [6]. Reheating after inflation in those models is not very different from that in the original Starobinsky model, so that this part of research was successful. As regards helical-phase inflation in supergravity, we got viable inflationary dynamics consistent with observations, but still had a problem of restoration of supersymmetry after inflation [10].

In the third year of our research project we effectively used our knowledge and experience in dealing with the inflationary cosmology based on supergravity theory, accumulated during the first two years. It has become clear to us how to spontaneously break supersymmetry, and how to stabilize non-inflaton scalars. We also made theoretical advances to superstring cosmology of the early Universe. These achievements were possible due to extensive international cooperation of the PI with his colleagues in USA, Germany, France, Italy, Russia, China, Thailand and Canada, as well as his collaboration with Japanese researchers at Tokyo Metropolitan University, Waseda University and the University of Tokyo [3,4,9,10].

We derived the inflationary scalar potential in four spacetime dimensions from the eight-dimensional modified gravity model in the presence of the four-form filed F^4, with the (modified gravity) coupling constant and the cosmological constant, by using the flux compactification of four extra dimensions on a 4-sphere with the non-vanishing warp factor [11,14]. The scalar potential depends upon two scalar fields given by the scalaron and the 4-sphere volume modulus. We found that this gives rise to a viable description of cosmological inflation in the early Universe, with the scalaron playing the role of inflaton and the volume modulus that is (almost) stabilized at its minimum [11]. We also studied a possibility of embedding our model in eight dimensions into a modified eight-dimensional supergavity that, in its turn, arises from the modified (and unique) eleven-dimensional supergravity [11].

We continued our efforts towards unified theoretical description of cosmological inflation, dark energy and dark matter in the early Universe, and their connection/relation to high-energy physics beyond the Standard Model of elementary particles, in the context of supergravity theory. Though this high goal was only partially achieved, we reached the main objectives of our research project as regards (i) viable description of cosmological inflation in supergravity theory, (ii) unification of cosmological inflation and dark energy (represented by a de Sitter vacuum) in supergravity, (iii) spontaneous supersymmetry breaking after inflation, in the context of high-scale (broken)supersymmetry, (iv) derivation of Starobinsky-like cosmological inflation from higher dimensions, and (v) exploring realisations of inflation and dark energy in type-IIA superstrings compactified on rigid Calabi-Yau three-folds [7,13,15,16,19,20].

During the final (5th) year of our project we strengthened our basic proposal of the viable phenomenological description of inflation, dark energy and dark matter in modified supergravity theory, by getting new models that simultaneously describe Starobinsky inflation and the dark energy as a de Sitter vacuum after inflation. We also proposed and studied our new model of the dark matter composed of heavy gravitino particles in the context of our supergravity models with high-scale supersymmetry breaking [17,18]. The specific mechanisms of supersymmetry breaking turned out to be the key to the viable phenomenological description. The main problems we encountered were mixing of the inflaton (scalaron) with other physical scalars that can easily destabilize single field inflation, and the need to disentangle the F-type and D-type supersymmetry breaking terms, in order to solve the hierarchy problem between the inflationary scale and the dark energy scale. To achieve this, we employed two new supergravity tools: the supersymmetric Born-Infeld non-linear electrodynamics and the alternative Fayet-Iliopoulos terms that do not require gauging the R-symmetry [21,22,23].

Altogether, our original research results appeared as 24 refereed research publications in the high-ranking international scientiic journals of physics (with the Q1/Q2 ranking in the classification of the Web of Science), and as 11 invited talks by PI at the international scientific conferences. The selected (most significant) publications are [3,7,11,18,21] below.

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〔図書〕（計　0　件）

〔産業財産権〕
○出願状況（計　0　件）

名称：
発明者：
権利者：
種類：
番号：
出願年：
国内外の別：

○取得状況（計　0　件）

名称：
発明者：
権利者：
種類：
番号：
取得年：
国内外の別：

〔その他〕
ホームページ等 なし

６．研究組織

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