行政院國家科學委員會補助專題研究計畫成果報告

高維理論與宇宙常數(3/3)

計畫類別：個別型計畫
計畫編號：NSC 94-2112-M-009-002
執行期間：2005 年 8 月 1 日至 2006 年 10 月 31 日

計畫主持人：高文芳
計畫參與人員： Dr. Y. Umeda、陳正彬、鍾旻峰、謝玉真、陳偉軒、王瑞仁、黃翔瑞、胡明志

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一、　中文摘要

早期宇宙空間彎曲起伏的非常劇烈,因此暴漲及量子宇宙論的機制非常值得深入研究探討.近來愛因斯坦的宇宙常數項,因爲新發現的觀察數據,引起諸多關注.另外在強磁場背景下,相關物理,如黑洞,蟲洞,中子星的形成與演化及其和高維理論的相關聯,近來皆受到相當的重視,尤其是brane universe的觀念最近不但有相當的進展也受到相當的關注.因此我們打算對宇宙常數的演化和高維重力理論、強磁場背景的關聯做全域性的探討.

關鍵詞：早期宇宙、量子宇宙、brane universe、宇宙常數、高維理論

Abstract

Quantum fluctuations are pretty violent in the early universe. Therefore the quantum effect in the inflationary universe deserves more attention. In addition, evdences indicate that the Einstein's cosmological constant, or a component of the material content of the universe, e.g. the dark energy, that varies only slowly with time and space and so acts like Einstein's cosmological constant. Detection of dark energy could

offer a resolution to an old puzzle, the gravitational effect of the zero-point energies of particles and fields. The puzzle is that the value of the dark energy density has to be tiny compared to what is suggested by dimensional analysis; the startling new evidence is that it may be different from the only other natural value, zero.

Keywords: early universe, quantum cosmology, brane universe, cosmological constant, higher dimensional theory

二、緣由與目的

背景:

早期宇宙空間彎曲起伏的非常劇烈,因此暴漲及量子宇宙論的機制非常值得深入研究探討.近來愛因斯坦的宇宙常數項,因爲新發現的觀察數據,引起諸多關注.另外在強磁場背景下,相關物理,如黑洞,蟲洞,中子星的形成與演化及其和高維理論的相關聯,近來皆受到相當的重視,尤其是 brane universe 的觀念最近不但有相當的進展也受到相當的關注.因此我們打算對宇宙常數的演化和高維重力理論、強磁場背景的關聯做全域性的探討.

目的:

我們希望結合共同的力量,一起研究量子宇宙理論,暴漲理論與高維重力理論與宇宙常數演化的關聯.其中近來一直受到重視的各類不同類型的自發對稱破缺(SSB)的矢量場(scalar field)位能模型與高維理論的相互影響.我們希望能通盤考量他們的確切相互關聯,同時也希望順道釐清黑洞及中子星形成及演化過程,強磁場所扮演的確切角色.有鑑於我們先前計劃有相當的成果也相當成功, 爲了延續我們研究群先前的研究工作, 因此提出這個計劃.

三、結果與討論

研究進度與預期大致相符. For example, we discuss the stability analysis of the Kantowski-Sachs type universe

in pure higher derivative gravity theory in details. The non-redundant generalized Friedmann equation of the system is derived by introducing a reduced one dimensional generalized KS type action. This method greatly reduces the labor in deriving field equations of any complicate models. Existence and stability of inflationary solution in the presence of higher derivative terms are also studied in details. Implications to the choice of physical theories are discussed in details in the report. We also study the effect of a modified gravity with scalar field coupled the higher derivative theory. Kaluza-Klein of anisotropic higher dimensional theory is also studied for their application in the inflationary universe. This paper was accepted by one of referees of the journal Physical Review D and is currently in the reviewing process in response to the comment from a second referee. In additon, we have been working on the dynamical structure of the spiral galaxies based on the theory of MOND. We have successfully obtained mass distribution information from the rotation curve data and provide a detailed M/L function for more practical study of spiral galaxies and the role of dark matter in the large.

四、計畫成果自評

持續我們自 2000 年起近 15 篇豐碩的研究成果，研究進行期間,已有 3 篇論文發表,另有 3 篇投稿中，還有 2 篇正在改寫中。另因爲我們展開新的研究方向探討大尺度星系重力結構與宇宙常數關聯，爲求完整寫稿進度較爲慎重，目前有 3 篇完稿中,成果不錯.

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六、本計畫支助之論文成果、研究進行期間期刊論文：

- **Anisotropic higher derivative gravity and inflationary universe, W.F. Kao, hep-th/0605208: Phys. Rev. D 74, 043522 (2006)**
- **Stability of the Anisotropic Brane Cosmology, Chiang-Mei Chen, W.F. Kao; hep-th/0201188, CJP, 42 (2004) 45;**
- **Rotational perturbations of high density matter in the brane cosmology, Chiang-Mei Chen, T. Harko, W. F. Kao and M. K. Mak, Journal of Cosmology and Astroparticle Physics, 0311 (2003) 005, hep-th/0208033,**

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1. W.F. Kao; Inflaton in anisotropic higher derivative gravity; hep-th/0612257
2. W.F. Kao, Anisotropic induced gravity and inflationary universe, hep-th/0612082
3. W.F. Kao, Kaluza-Klein Higher Derivative Induced Gravity, hep-th/0605078;

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Anisotropic higher derivative gravity and inflationary universe

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Stability analysis of the Kantowski-Sachs type universe in pure higher derivative gravity theory is studied in detail. The nonredundant generalized Friedmann equation of the system is derived by introducing a reduced one-dimensional generalized Kantowski-Sachs type action. Existence and stability of inflationary solution in the presence of higher derivative terms are also studied in detail. Implications to the choice of physical theories are discussed in detail in this paper.

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I. INTRODUCTION

Inflationary theory is a nice resolution for the flatness, monopole, and horizon problems of our present universe described by the standard big bang cosmology [1]. In particular, our universe is homogeneous and isotropic to a very high degree of precision [2,3]. Such a universe can be described by the well-known Friedmann-Robertson-Walker (FRW) metric [4].

One expects that gravitational physics could be different from the standard Einstein models near the Planck scale [5,6]. For example, quantum gravity or string corrections could lead to interesting cosmological applicastions [5]. Indeed, some investigations have already addressed the possibility of deriving inflation from higher order gravitational corrections [7–10].

For example, a general analysis of the stability condition for a variety of pure higher derivative gravity theories could be useful choosing physical models. In particular, it has been shown that a stability condition should hold for any potential candidate of inflationary universe in the flat FRW space [10].

In addition, there is no particular reason for our universe to be initially isotropic to such a high degree of precision. Even if anisotropy can be smoothed out by the proposed inflationary process, it is also interesting to study the stability of the FRW space during the post-inflationary epoch. Nonetheless, it is interesting to study the cases where our universe starts out from an initially anisotropic universe. As a result, our universe is expected to evolve from certain anisotropic universe to a stable and isotropic universe. Indeed, it has been shown that there exists such kind of anisotropic solution for a NS-NS model with a metric, a dilaton, and an axion field [11]. Such inflationary solution is also shown to be stable against small field perturbations [12]. Note also that similar stability analysis has also been studied in various fields of interest [13,14].

Higher derivative terms should also be important for the Planck scale physics [10,13]. For example, higher order corrections from quantum gravity or string theory have been considered as the inflationary models [15]. In addition, higher derivative terms also arise as the quantum corrections to the matter fields [15]. The stability analysis of the pure higher derivative gravity models has hence been shown in Ref. [10]. Therefore, it is interesting to study the implication of this stability analysis in different models.

Recently, there are also growing interests in the study of Kantowski-Sachs (KS) type anisotropic universes [16–18]. Hence we will try to study the existence and stability conditions of an inflationary de Sitter final state in the presence of higher derivative theory in Kantowski-Sachs spaces. In particular, it will be applied to study a large class of pure gravity models with inflationary KS/FRW solutions in this paper. Any KS type solution that leads itself to an asymptotic FRW metric at time infinity will be referred to as the KS/FRW solution in this paper for convenience.

It will be shown that the existence of a stable de Sitter background is closely related to the choices of the coupling constants. We will try to generalize the work in Refs. [19,20] in order to obtain a model-independent formula for the nonredundant field equations in the Kantowski-Sachs (KS) type anisotropic space.

We will first derive a stability equation which turns out to be identical to the stability equation for the existence of the inflationary de Sitter solution discussed in Refs. [10,20]. Note that an inflationary de Sitter solution in pure gravity models is expected to have one stable mode and one unstable mode for the system to undergo inflation with the help of the stable mode. Later on, the inflationary era will come to an end once the unstable mode takes over after a brief period of inflationary expansion. The method developed in Refs. [10,20] was shown to be a helpful way in choosing physically acceptable model for our universe. Our result indicates, however, that the unstable mode will also tamper the stability of the isotropic space. To be more specific, if the model has an unstable mode for the de Sitter background perturbation with respect to isotropic perturbation, this unstable mode will also be unstable with respect to any anisotropic perturbations.

In particular, we will show in this paper that the roles played by the higher derivative terms are dramatically different in the inflationary phase of our physical universe. First of all, third order terms will be shown to determine the expansion rate H_0 for the inflationary de Sitter space. The quadratic terms will be shown to have nothing to do with

