UNIVERSITI PUTRA MALAYSIA

TWO FLUID SCENARIO FOR DARK ENERGY MODELS IN A BIANCHI TYPE I UNIVERSE

SYED NASRULLAH ALI QAZI

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By

SYED NASRULLAH ALI QAZI

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Chair: Associate Professor Hishamuddin B. Zainuddin, Ph.D.

Faculty: Institute for Mathematical Research

The current observations reveal the fact that the universe is expanding at an accelerating rate. The observations indicate that the driving force behind the accelerating expansion is the mysterious component known as dark energy. The only known information about dark energy is that it constitutes 73% of the total mass energy density of universe, its pressure is negative which acts as anti-gravitational force and it dominates at late times. However its nature still remains mysterious and it poses a challenge to the theoretical and observational cosmologists. Besides dark energy another mystery component in the universe that occupy large portion of universe after dark energy is dark matter. Since the nature of these dark components are relatively unknown to us, we could assume some sort of interaction between these components. The aim of this research is to study the nature of the dark energy by considering its physical quantity known as equation of state parameter $\omega_D = \frac{p_D}{\rho_D}$ that specifies the model for dark energy. The general theory of relativity has the important role in explaining the dynamics of the universe as gravity governs the largest scale structure of the universe. Considering the fact that at present times that the universe to be in the form of perfect fluid, the equation of state describes the type of matter energy present in universe. The measurements from cosmic microwave background reveals the anisotropies in the temperature and almost spatially flat universe. Therefore in this research, I study the dark energy models in the framework of the anisotropic Bianchi I spacetime. The cosmological models studied here are mainly concerned with the recent epoch of universe. The behavior of the ω_D is considered for two scenarios. First is the non-interacting scenario where the dark energy and dark matter are minimally coupled to each other. Second is the interacting scenario where there exists an interaction between the dark components and this is connected by an interaction term Q. I investigate the behavior of the ω_D parameter by considering the function of universe scale factor of two types. First is the scale factor in the form of power function law and it is found that ω_D parameter for both non-interacting and interacting cases varies in the phantom region $\omega_D < -1$. Second is using the solutions of the Einstein field equation where I derive the general form of the ω_D parameter for Bianchi I spacetime. Then I use the scale factor in terms of hyperbolic function with general ω_D parameter. It is shown that in non-interacting case, depending on the value of the anisotropy parameter K, the dark energy EoS parameter is varying from phantom $\omega_D < -1$ to quintessence $\omega_D > -1$ whereas in interacting case EoS parameter vary in quintessence region. However, eventually all of these models tend to reach $\omega_D = -1$. Generally it is found that the behavior of the EoS parameter from all these models is that the dark energy model behaves like scalar field models such as quintessence, phantom and quintom.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SENARIO DUA-BENDALIR BAGI MODEL TENAGA GELAP DALAM ALAM SEMESTA JENIS BIANCHI-I

Oleh

SYED NASRULLAH ALI QAZI

Oktober 2014

Pengerusi: Profesor Madya Hishamuddin Zainuddin, Ph.D.

Fakulti: Institut Penyelidikan Matematik

Cerapan terkini menunjukkan kenyataan bahawa alam semesta mengembang dengan kadar memecut. Pencerapan mendapati bahawa daya di sebalik pengembangan memecut ini adalah suatu komponen bermisteri yang dipanggil sebagai tenaga gelap. Maklumat yang diketahui mengenai tenaga gelap hanyalah tenaga ini memenuhi 73% daripada jumlah ketumpaan jirimtenaga alam semesta, tekanannya yang negatif berperanan sebagai daya anti-graviti dan tenaga ini kini mendominasi alam. Walau bagaimanapun sifat tenaga ini masih tidak diketahui dan kekal menjadi cabaran bagi komuniti teoris dan pencerap. Selain tenaga gelap, satu lagi komponen bermisteri yang diketahui memenuhi sebahagian besar alam ini adalah jirim gelap. Oleh sebab, sifat komponen-komponen gelap ini tidak diketahui, kita boleh mengandaikan adanya sejenis saling tindakan antara komponen-komponen ini. Tujuan penyelidikan ini adalah untuk mengkaji sifat tenaga gelap dengan pertimbangan kuantiti fizikal yang dikenali sebagai parameter persamaan keadaan $\omega_D = \frac{p_D}{\rho_D}$ yang menentukan model tenaga gelap. Teori kerelatifan umum mempunyai peranan penting dalam menjelaskan dinamik alam semesta kerana graviti menguasai struktur skala besar alam ini. Dengan pertimbangan pada masa kini bahawa alam semesta berada dalam bentuk bendalir sempurna, persamaan keadaan akan menjelaskan jenis jirim-tenaga yang akan wujud dalam alam semesta. Pengukuran dari latar belakang mikrogelombang kosmik menunjukkan anisotropi dalam suhu dan alam semesta yang hampir datar. Dengan itu, kajian ini menyelidiki model tenaga gelap dalam kerangka ruang-masa anisotropi Bianchi-I. Model kosmologi yang dikaji di sini adalah lebih tertumpu pada zaman semasa. Sifat ω_D dipertimbang dalam dua senario. Pertama adalah senario tak bersaling tindak yang mana tenaga gelap dan jirim gelap hanya terganding antara satu sama lain secara minimal. Kedua adalah senario bersaling tindak yang mana wujud saling tindakan antara komponen-komponen gelap ini dan dihubungkan melalui sebutan saling tindakan Q. Pertama adalah faktor skala dalam bentuk fungsi kuasa dan didapati bahawa parameter ω_D bagi kedua-dua kes

tiada saling tindakan dan bersaling tindak, parameter berubah dalam rantau fantom $\omega_D < -1$. Kedua, menggunakan penyelesaian persamaan medan Einstein, bentuk umum parameter ω_D diterbitkan untuk ruangmasa Bianchi I dan seterusnya faktor skala dalam bentuk fungsi hiperbolik. Dalam kes tanpa saling tindakan, ditunjukkan bahawa, bergantung pada parameter anisotropi K, parameter persamaan keadaan tenaga gelap berubahan dari fantom $\omega_D < -1$ ke kuintesens $\omega_D > -1$. Manakala untuk kes bersaling tindak, parameter persamaan keadaan hanya berubah dalam rantau kuintesens. Walau bagaimanapun kesemua model ini sampai ke had $\omega_D = -1$. Secara umumnya didapai bahawa perlakuan parameter persamaan keadaan bagi semua model tenaga gelap menyamai model medan skalar kuintesens, fantom dan kuintom.

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Approval Sheet 1

I certify that a Thesis Examination Committee has met on (**insert the date of viva voce**) to conduct the final examination of (**insert the student's name**) on his (or her) thesis entitled "**Title of thesis**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (**insert the name of relevant degree**).

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Professor
Faculty of Science
Universiti Putra Malaysia
(Chairperson)

Anvarjon Ahmedov, Ph.D.
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Zaidan Abdul Wahab, Ph.D.
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Name of External Examiner, Ph.D.
Title (e.g. Professor/Associate Professor/Ir) – Omit if not relevant
Name of Department and/or Faculty
Name of Organisation (University/Institute)
Country
(External Examiner)

ZULKARNAIN ZAINAL, Ph.D.
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science.

The members of the Supervisory Committee were as follows:

Hishamuddin B. Zainuddin, Ph.D.
Associate Professor
Institute of Mathematical Research
Universiti Putra Malaysia
(Chairperson)

M. Mahmudur Rahman, Ph.D.
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

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LIST OF ABBREVIATIONS

EoS	Equation of state parameter
SNIa	Type Ia supernova
CMB	Cosmic microwave background
BAO	Baryon acoustic oscillation
WMAP	Wilkinson Mcrowave Anistropy Probe
WEC	Weak energy conditions
DEC	Dominant energy conditions
SEC	Strong energy conditions
Λ	Cosmological constant
ω_D	Equation of state parameter
Ω_D	Dark energy density
Ω_m	Dark matter density
Q	Interaction term
σ	constant coupling
σ^2	shear scalar

CHAPTER 1

INTRODUCTION

Before the end of twentieth century,we believed that our universe comprised of mostly matter and its gravitational influence is causing universe's expansion rate to slow down. However, this perception was changed in 1998 when the observation from the Supernovae Type Ia data from two independent teams, High-redshift Supernovae Search Team (Riess et al., 1998) and Supernovae Cosmology Team Project (Perlmutter et al., 1999) showed the universe is expanding at an accelerating rate which is caused by unknown energy. Since this kind of energy does not have interaction with the ordinary matter (energy) its nature still remains enigma for us and for this reason cosmologists call it 'dark energy'. Furthermore, numerous observation such as Cosmic Microwave Background, Baryon Acoustic Oscillation, and etc. show that the dark energy occupies 73%, dark matter 23% and matter only 4% in the total energy density of universe. These observations indicate that our universe is mostly dominated by dark components. Thus this opens a new perspective about our understanding of our universe and also gives some fundamental unsolved problem in cosmology about the nature of dark energy and dark matter and the possibility of detecting them.

From 1998 many observational as well as theoretical attempts (Zlatev et al., 1999; Caldwell, 2002; Alam et al., 2004; Feng et al., 2005; Astier et al., 2006; Copeland et al., 2006; Kowalski et al., 2008; Zhao et al., 2012) have been made in order to investigate the nature and properties of dark energy. Until now, there are so many candidates available to explain the model of dark energy. The first and simplest candidate for dark energy is the cosmological constant Λ which is constant vacuum energy in empty space and acts as a repulsive force opposing the gravitational force with having constant negative pressure. However it suffers from many problems among them are the fine-tuning and cosmic coincidence (Weinberg, 1989; Perlmutter et al., 1999; Carroll, 2001). The other models for dark energy are the dynamical models (Ratra and Peebles, 1988; Caldwell et al., 1998; Caldwell, 2002; Feng et al., 2005; Copeland et al., 2006; Singh, 2008; Tiwari and Singh, 2012) that could resolve to address the issues posed by cosmological constant. Such dynamical models include scalar field models (quintessence, phantom, quintom, k-essence), varying cosmological term models, and chaplygin gas. So far the dark energy models have been studied mainly in the framework of homogeneous and isotropic universe described by FRW (Friedmann-Robertson-Walker) metric. However the FRW model is not suited to describe at certain epoch in universe such as the moments after the Big Bang or satisfactorily explain the anisotropic radiation background in the universe observed at present times. Therefore, it is possible to consider to study models of universe with different background such as anisotropic Bianchi models, inhomogeneous models which are less symmetric than FRW and alternate to standard cosmology. There are also theoretical argument to explain the phase from anisotropic to isotropic phase (Misner, 1968). This is further supported from the observations of the cosmic microwave background radiation which reveals anisotropy in background radiation (Spergel et al., 2003). Since theoretical and experimental supports the universe to have anisotropic background phase, this motivate us to study the dark energy models in universe with anisotropic background. The Bianchi models are such models that describe the universe having anisotropic and homogeneous property and also generalization of FRW models. The simplest model is the Bianchi I spacetime which is generalization of flat spacetime, is suitable to provide the description of the universe from the early anisotropic phase to isotropic.

Another possible way to understand the nature of dark energy is to allow the possibility of its interaction with the rest of the matter energy content in universe. In fact the detection of dark energy and dark matter by their gravitational effects, implies that there could be some sort of interaction between them. The study of the interaction models could possibly alleviate the 'Coincidence problem. In this research the evolution of dark energy is studied within the framework of homogeneous Bianchi I model. The behavior of the evolution of the dark energy parameter is investigated in two circumstances i) absence of interaction between dark energy and barotropic fluid ii) presence of interaction between dark energy and barotropic fluid. Therefore, the objectives set in this research are:

1.1 Objectives of the Research

1. To study the dark energy models in Bianchi I universe by considering the behavior of scale factor as power law.
2. To study the dark energy models in Bianchi I universe by considering the behavior of scale factor as hyperbolic function that is applied in the exact solutions of the metric.
3. To interpret the solutions of these models and discuss their physical behavior with respect to cosmological evolution.

I start off with Chapter 2 summarizing the on the observational evidence and status of dark energy as well as reviewing the various models of dark energy. In Chapter 3, I review the some basics in cosmology and general relativity which would be relevant for this research. In Chapters 4 and 5 I solve for the dark energy models in non-interacting and interacting case for different scale factors respectively. Chapter 6 summarize the results for this research and suggest future problems.

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