Isotropic and Anisotropic Dark Energy Models

Bijan Saha
Laboratory of Information Technologies Joint Institute for Nuclear Research Dubna, Moscow region, 141980 Russia
e-mail: bijan@jinr.ru; http://bijansaha.narod.ru

Abstract — In this review we discuss the evolution of the universe filled with dark energy with or without perfect fluid. In doing so we consider a number of cosmological models, namely Bianchi type I, III, V, VI, VI and FRW ones. For the anisotropic cosmological models we have used proportionality condition as an additional constrain. The exact solutions to the field equations in quadrature are found in case of a BVI model. It was found that the proportionality condition used here imposed severe restriction on the energy-momentum tensor, namely it leads to isotropic distribution of matter.

Anisotropic BVI, BV, BIII and BIDE models with variable EoS parameter $\omega$ have been investigated by using a law of variation for the Hubble parameter. In this case the matter distribution remains anisotropic, though depending on the concrete model there appear different restrictions on the components of energy-momentum tensor. That is why we need an extra assumption such as variational a law for the Hubble parameter. It is observed that, at the early stage, the EoS parameter $\omega$ is positive i.e. the universe was matter dominated at the early stage but at later time, the universe is evolving with negative values, i.e., the present epoch. DE model presents the dynamics of EoS parameter $\omega$ whose range is in good agreement with the acceptable range by the recent observations.

A spatially homogeneous and anisotropic locally rotationally symmetric Bianchi-I space time filled with perfect fluid and anisotropic DE possessing dynamical energy density is studied. In the derived model, the EoS parameter of DE ($\omega^{(de)}$) is obtained as time varying and it is evolving with negative sign which may be attributed to the current accelerated expansion of Universe. The distance modulus curve of derived model is in good agreement with SNLS type Ia supernovae for high redshift value which in turn implies that the derived model is physically realistic.

A system of two fluids within the scope of a spatially flat and isotropic FRW model is studied. The role of the two fluids, either minimally or directly coupled in the evolution of the dark energy parameter, has been investigated. In doing so we have used three different ansatzs regarding the scale factor that gives rise to a variable decelerating parameter. It is observed that, in the non-interacting case, both the open and flat universes can cross the phantom region whereas in the interacting case only the open universe can cross the phantom region. The stability and acceptability of the obtained solution are also investigated.

Keywords: Homogeneous cosmological models, perfect fluid, dark energy, EoS parameter

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1. INTRODUCTION

Cosmology is a discipline to understand the nature of origin, evolution, large scale structure, and ultimate fate of the Universe. Being that it is perhaps the oldest discipline of the world. From the very beginning of mankind, looking at the sky people were eager to know, where do they come from and who is behind these all. Many leaves it with God, while a few goes forward to get a logical answer. In their quest for knowledge they modeled the Universe in accord with the information they have at hand.

The start of scientific cosmology took place as early as 1543 with Nicholas Copernicus suggesting the heliocentric model of the Universe. Further development of scientific cosmology is connected with the scientists like Galilio Galilei and Johannes Kepler, who provided both observational and theoretical support to this cause. The Isaac Newton took this mission forward. But the biggest boost for cosmology came in 1920’s with the theoretical works by A. Einstein, A. Friedmann, W. de Sitter and observations by E. Hubble.

Nevertheless, only after World War Two ended, it moved from a speculative science to the much firmer ground of prediction, observation and verification. And it is because only then astronomers and astrophysicists took advantage of a powerful array of new tools and technologies. For the first time, astronomers began to make comprehensive studies of the sky at wavelengths other than the visible. At the same time, they began to use rockets to lift their instruments far above the Earth’s surface. Eventually, they succeeded in placing instruments in space that brought dramatic confirmation of the Big Bang hypothesis—and pointed to yet stranger features of the universe. And

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each new findings, every single discovery of astrophysics poses an even greater challenge to the cosmologists to give theoretical explanation of these observations.

In this review we plan to discuss the problem of late time acceleration and its possible solutions within the scope of both isotropic and anisotropic cosmological models.

The review is organized as follows: in section II, we give a brief review of dark energy; in section III, dark energy models are discussed; in section IV, a short description of cosmological models is given; in section V, we study the Bianchi type-VI cosmological model; in section VI, Bianchi type-VI₀ cosmological model filled with dark energy is investigated; in section VII, we study the Bianchi type-III dark energy model; in section VIII, a Bianchi type-I cosmological models are studied; in section IX we consider the isotropic and homogeneous FRW models and in section X, we give conclusion remarks of the results obtained.

2. DARK ENERGY

In the early 20th century the common world-view held that the universe is static—more or less the same throughout eternity. Even Albert Einstein supported this long standing idea and in order to get the steady state Universe he introduced cosmological constant in his famous system. So when in 1922 the Russian meteorologist and mathematician Alexander Friedmann had published a set of possible mathematical solutions that gave a non-static universe [68, 69], Einstein rejected it noting that this model was indeed a mathematically possible solution to the field equations. This model has gained big popularity only after the works of Robertson and Walker and became known as FRW model. This model describes a homogeneous and isotropic Universe. By homogeneity we mean that space has the same metric properties (measures) in all points, whereas by isotropy we mean that the space has the same measures in all directions. This idea of expanding Universe suggested the presence of an initial singularity, which means the finiteness of time.

Though the idea of an expanding Universe was supported both theoretically and experimentally, it was strongly believed that the Universe is expanding with deceleration. So in 1998 when it was found that the Universe is expanding with acceleration, it comes like a bolt from the blue. The observations of Type Ia supernova (SNeIa) in 1998 established that our universe is currently accelerating [112, 113, 120] and recent observations of SNeIa of high confidence level [43, 121, 189] have further confirmed this. In addition, measurements of the cosmic microwave background (CMB) [16] and large scale structure (LSS) [185] strongly indicate that our universe is dominated by a component with negative pressure, dubbed as dark energy. In Fig. 1 the expansion of the universe in presence of a dark energy is shown.

Dark energy is a form of matter (energy) is not observable in laboratory and it does not interact with electromagnetic radiation. These facts played decisive role in naming this object. In contrast to dark matter

---dark energy is uniformly distributed over the space;
---it does not intertwine under the influence of gravity in all scales; it has a strong negative pressure of the order of energy density.

Based on these properties, cosmologists have suggested a number of dark energy models, those are able to explain the current accelerated phase of expansion of the Universe.

What Dark Energy is? More is unknown than is known. We know how much dark energy there is because we know how it affects the Universe’s expa-