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ORIGINAL ARTICLE

Expanding universe: thermodynamical aspects from different models

Sridip Pal · Ritabrata Biswas

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Abstract The pivotal point of the paper is to discuss the behavior of temperature, pressure, energy density as a function of volume along with determination of caloric EoS from following two model: $w(z) = w_0 + w_1 \ln(1+z)$ & $w(z) = -1 + \frac{(1+z)}{3}\frac{A_1+2A_2(1+z)}{A_0+2A_1(1+z)+A_2(1+z)^2}$. The time scale of instability for this two models is discussed. In the paper we then generalize our result and arrive at general expression for energy density irrespective of the model. The thermodynamical stability for both of the model and the general case is discussed from this viewpoint. We also arrive at a condition on the limiting behavior of thermodynamic parameter to validate the third law of thermodynamics and interpret the general mathematical expression of integration constant U_0 (what we get while integrating energy conservation equation) physically relating it to number of micro states. The constraint on the allowed values of the parameters of the models is discussed which ascertains stability of universe. The validity of thermodynamical laws within apparent and event horizon is discussed.

Keywords Thermodynamic processes · Equations of state

S. Pal
Department of Physical Sciences, Indian Institute of Science Education and Research-Kolkata, Mohanpur 741252, Nadia, West Bengal, India
e-mail: sridippaliiser@gmail.com

R. Biswas (✉)
Department of Physics, Indian Institute of Science, Bangalore 560012, India
e-mail: ritabrata@physics.iisc.ernet.in

R. Biswas (✉)
e-mail: biswas.ritabrata@gmail.com

1 Introduction

To explain the cosmic acceleration predicted from the Ia type supernova observations (Perlmutter et al. 1999; Riess et al. 1998) one popular wayout is to modify the stress energy tensor part, i.e., the right hand side of the Einstein's field equation. Existence of some unknown matter termed as Dark Energy (DE hereafter) is been assumed (Riess et al. 2004; Perlmutter et al. 1998; Garnavich et al. 1998; Bachall et al. 1999; Copeland et al. 2006) which violates the strong energy condition. The simplest candidate of DE is a tiny positive cosmological constant (Λ) which obeys the equation of state (EoS hereafter), $w = -1$. But due to low energy scale than the normal scale for constant Λ, the dynamical Λ was introduced (Caldwell et al. 1998). Again at very early stage of universe the energy scale for varying Λ is not sufficient. So to avoid this problem, known as cosmic coincidence (Steinhardt et al. 1999), a new field, called tracker field (Zlatev et al. 1999) was prescribed. In similar way there are many models (Sahni and Starobinsky 2003) in Einstein gravity to best fit the data. Yet they require some modifications. From this point of view some alternative models are evolved. Most of the DE models involve one or more scalar fields with various actions and with or without a scalar field potential (Maor and Brustein 2003). Now, as the observational data permits us to have a rather time varying EoS, there are a bunch of models characterized by different scalar fields such as a slowly rolling scalar field (Quintessence) ($-1 < \omega < -1/3$, $\omega(= p/\rho)$, being the EoS parameter) (Caldwell et al. 1998), k-essence (Armendariz–Picon et al. 2000), tachyon (Sen 2002), phantom ($\omega < -1$) (Caldwell 2002), ghost condensate (Arkani-Hamed et al. 2004; Piazza and Tsujikawa 2004), quintom (Feng et al. 2005), Chaplygin gas models (Kamenshchik et al. 2001) etc. Some recent reviews on DE models are described in Copeland et al. (2006), Li et al. (2011).