Study of non-canonical scalar field model using CPL parametrization

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Plan of the talk

- Motivation
- Introduction
  - Dark Energy (DE)
- Brief description of the model
- Results
- Conclusions

Motivation

- We live in an expanding universe. Everything is getting further apart.
- The expansion was believed to be decelerated (as gravity is attractive).
- In 1998, observations reveal something completely different scenario $\rightarrow$ **SCP** and **HSST** independently reported the late-time cosmic acceleration by observing distant type SN Ia.

The universe is accelerating today!!

- Assume the Universe is homogeneous and isotropic on large scale and is governed by the spatially flat FRW metric:

$$ds^2 = dt^2 - a^2(t)[dr^2 + r^2 d\theta^2 + r^2 sin^2\theta d\phi^2] \quad (1)$$

- In FRW background, the dynamics of the Universe is described by Einsteins equations (EE):

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\Pi G T_{\mu\nu} \quad (2)$$

- In FRW background the modified EE gives

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) \quad (3)$$

- Observation from the above equation:

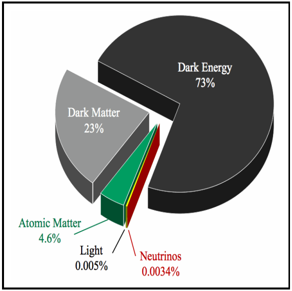
  A large negative pressure from an unknown source can accelerate ($\ddot{a} > 0$) the Universe.

Motivation

- Logically there are two possible way to explain the current acceleration!

  1. We need modification in the geometry part of the Einstein's equations.
  2. Inclusion of Dark Energy: An unknown form of energy that seems to be the source of a repulsive force causing the expansion of the universe to accelerate.

  We shall concentrate only on the second possibility.



- **Composition of our Universe:**
  Recent Cosmological experiments have revealed that our universe is made up of nearly **73% DE**, **23% DM** and **4% normal matter**.

Motivation

- **Popular dark energy candidates are**
  - Cosmological constant
  - Quintessence scalar fields (Canonical scalar field)
  - **Non-canonical scalar fields**
  - $f(R)$ gravity models
  - and many others...............

Toy Model

- Let us consider the theory described by the following action

$$S = \int \sqrt{-g} dx^4 \left[\frac{R}{2} + \mathcal{L}(\phi, X) \right] + S_m \quad (4)$$

(We have chosen the unit where $8\pi G = c = 1$.)

where,

$$\mathcal{L}(\phi, X) = X^2 - V(\phi) \quad \text{and} \quad X = \tfrac{1}{2}\partial_\mu \phi \partial^\mu \phi$$

Toy Model

- For a spatially flat FRW universe the field equations take the following form

$$3H^2 = \rho_m + \frac{3}{4}\dot{\phi}^2 + V(\phi) \tag{5}$$

$$2\dot{H} + 3H^2 = -\left(\frac{1}{4}\dot{\phi}^2 - V(\phi)\right) \tag{6}$$

$$\ddot{\phi} + H\dot{\phi} + \frac{1}{3\dot{\phi}^2}\frac{dV}{d\phi} = 0 \tag{7}$$

$$\dot{\rho}_m + 3H\rho_m = 0 \tag{8}$$

We define

$$\rho_\phi = \tfrac{3}{4}\dot{\phi}^2 + V(\phi), \qquad p_\phi = \tfrac{1}{4}\dot{\phi}^2 - V(\phi)$$

- We made an ansatz for **EoS** of the scalar field:

$$\omega_\phi(a) = \frac{p_\phi}{\rho_\phi} = \omega_0 + \omega_1(1-a), \qquad \textbf{[CPL parametrization]}$$

- The deceleration parameter q is defined as

$$q = -\frac{\ddot{a}}{aH^2} = -\left(1 + \frac{\dot{H}}{H^2}\right).$$

For this model, one can solve for q (in terms of redshift $z = \frac{1}{a} - 1$) as

$$q(z) = \frac{1}{2} + \frac{3}{2}\left[\frac{\omega_0 + \omega_1\left(\frac{z}{1+z}\right)}{1 + \kappa(1+z)^{(3-3\alpha)} e^{\left(-\frac{3\omega_1}{1+z}\right)}}\right]$$

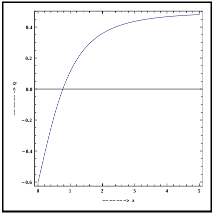


Figure: *Plot of q vs. z. This is for $\kappa = \frac{\Omega_{m0}}{\Omega_{\phi 0}} = \frac{0.27}{0.73}$, $\omega_0 = -1$ and $\omega_1 = 0.01$. Here, $\alpha = (1 + \omega_0 + \omega_1)$.*

Toy Model: Results

- Also the density parameters for the matter and scalar field comes out respectively as

$$\Omega_m(z) = \frac{1}{1+\frac{1}{\kappa}(1+z)^{3\alpha-3}e^{\frac{3\omega_1}{(1+z)}}}$$

$$\Omega_\phi(z) = \frac{1}{1+\kappa(1+z)^{3-3\alpha}e^{-\frac{3\omega_1}{(1+z)}}}$$

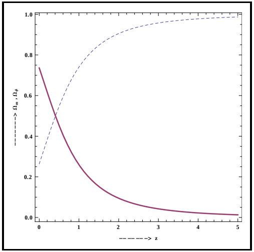


Figure: *Plot of Ω_m (dashed curve) and Ω_ϕ (solid curve) as a function of z. This is for $\kappa = \frac{0.27}{0.73}$, $\omega_0 = -1$, $\omega_1 = 0.01$. Here, $\alpha = (1 + \omega_0 + \omega_1)$.*

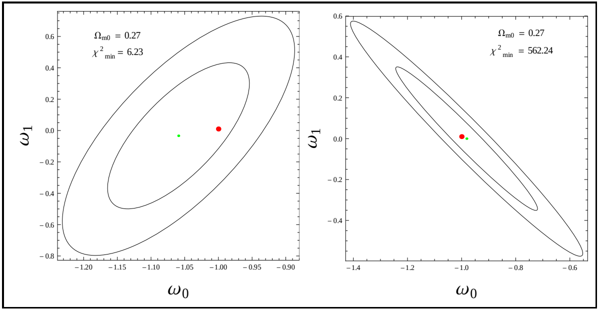


Figure: *Plot of 1σ and 2σ confidence contours on $\boldsymbol{\omega_0 - \omega_1}$ parameter space for the* **Hubble data** *(left panel) and the* **Supernova data** *(right panel) respectively. In this graph, χ^2_{min} indicates the minimum value of χ^2 corresponding to the best fit values of ω_0 and ω_1 for both the datasets respectively, as indicated in the frames. This is for $\Omega_{m0} = 0.27$.*

Conclusions

- We have considered CPL parametrization for the EoS of the non-canonical scalar field with a Lagrangian density of the form $\mathcal{L}(\phi, X) = X^2 - V(\phi)$.
- We have shown that the deceleration parameter q has a smooth transition from early deceleration to late time acceleration of the universe $\longrightarrow$ consistent with the recent observations.
- We have also compared our model with the observational data from the Hubble and SNIa datasets $\longrightarrow$ values of the model parameters which were chosen for analytical results are well fitted in the 1σ and 2σ confidence contours.
- Dark energy models of the universe are still in an early stage of development and much work is still needed to be done in this new field of Cosmology.

Thank You