Bounds on Diffusive DE-DM Scenario From SNe-Ia Data

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What I have done?

- Diffusive dark matter and dark energy scenario and $k-$essence in the context of Supernova Ia observations $\rightarrow$eprint: arXiv:1808.05259

Theme of the Poster

- An unified model of dark energy and dark matter with exchange of energy between them.
- Particles of Dark matter undergo a velocity diffusion from Dark matter to Dark energy.
- Motivation: solve coincidence probelm.
- From SNe Ia observational data we estimate the total dark fluid energy density, energy density of dark matter and bounds on diffusion parameter in the background of FLRW spacetime.

Experimental evidence of late time cosmic evolution

Hubble's observation: Expanding Universe

Dark Energy:

Observation:

■ Red shifts and luminosity distance of type Ia Supernova (SNe Ia).

$\Rightarrow$ Transition from a phase of decelerated expansion to a phase of accelerated expansion during late time phase of cosmic evolution.

Dark energy is a general label for this late time cosmic acceleration.

Dark Matter:

Observation:

■ Rotation curves of spiral galaxies.

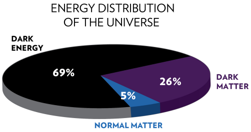
Gravitational Lensing

$\Rightarrow$ Presence of non-luminous matter (Dark matter) having only gravitational interactions.

Content of Present universe

Observation:

Wilkinson Microwave Anisotropy Probe (WMAP) & Planck satellite Experiments.



Formalism of the Interacting model

- The dynamics of cosmic evolution: Einstein's equations

$$\boxed{R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu}}$$

$R_{\mu\nu} \Rightarrow$ Ricci tensor, $R = g^{\mu\nu} R_{\mu\nu}$ and G is Newton's gravitation constant. Where $T_{\mu\nu} =$ Total energy-momentum tensor of universe $\rightarrow$ conserved. Total energy-momentum tensor($T_{\mu\nu}$) of universe is divided into 4 parts,

$$\boxed{T_{\mu\nu} = T^{R}_{\mu\nu} + T^{b}_{\mu\nu} + T^{\rm dm}_{\mu\nu} + T^{\rm de}_{\mu\nu}}$$

- When the dark sector (dark matter and dark energy) of the universe is not interacting with baryonic matter and radiation, so there contribution are neglected.
- Now for interacting dark matter and dark energy resulting in exchange of energy between them, this effect shows up as a source term in the continuity equation,

$$\boxed{\nabla_{\mu} T^{\mu\nu}_{de} = -\nabla_{\mu} T^{\mu\nu}_{dm} \equiv -\sigma J^{\nu}}$$

$\sigma \rightarrow$ Diffusion coefficient (which is a measure of average energy transferred to the particles of the dark matter fluid per unit time.) $J^{\mu} \rightarrow$ Current density of matter satisfying the conservation law, $\nabla_{\mu} J^{\mu} = 0$.

- In FLRW metric with scale factor $a(t)$, using the conservation law $\Rightarrow$ $n(t)a^3(t) = \mathrm{constant} = n_0$.
  $n_0 \rightarrow$ Number density at present epoch and value of the scale factor at present epoch normalised to unity.
- Particles of dark matter fluid undergo velocity diffusion from dark matter to dark energy, where energy density & pressure of dark matter is characterised by ρ_{dm} and $p_{\mathrm{dm}} = 0$ and for dark energy is ρ_{de} and p_{de}.
- New form of non-conservation equation for dark matter,

$$\boxed{\dot{\rho}_{\mathrm{dm}} + 3H\rho_{\mathrm{dm}} = \sigma \frac{n_0}{a^3(t)}}$$

$H = \dot{a}/a \rightarrow$ Hubble parameter & $\sigma \rightarrow$ Diffusion coefficient.
Subsequently, we can write also non-conservation equation for Dark energy fluid,

$$\boxed{\dot{\rho}_{\mathrm{de}} + 3H(\rho_{\mathrm{de}} + p_{\mathrm{de}}) = -\sigma \frac{n_0}{a^3(t)}}$$

sum of the above equations are satisfy total conservation equation.

Analysis from SNe Ia data

- The temporal behaviour of the FRW scale factor $a(t)$, energy density and pressure of the dark fluid during the late time phase of evolution are known from the analysis of SNe-Ia data.
- The luminosity distance(d_L) and redshift(z) relationship for redshift values up to $z \sim 1$ obtained from SNe-Ia observations is instrumental in revealing features of late time phase of cosmic evolution.
- In an FRW spacetime relation between Hubble's parameter(H_z) and redshift(z) through luminosity distance(D_L)expressed as,

$$\boxed{E(z) \equiv \frac{H(z)}{H_0} = \left[\frac{d}{dz}\left(\frac{D_L(z)}{1+z}\right)\right]^{-1}}$$

  $H(z)$ & H_0 respectively represent the value of Hubble parameter at an instant corresponding to redshift value z and present epoch respectively.

- As we know, $H = \frac{\dot{a}}{a}$ & $\frac{a_0}{a} = 1 + z$.
  we get, the realtion between t_0 & z as,

$$\boxed{\frac{t(z)}{t_0} = 1 - \frac{1}{H_0 t_0}\int_z^0 \frac{dz'}{(1+z')E(z')}}$$

  where t_0 is the time corresponding to present epoch.
- The function $E(z)$ as obtained from analysis of JLA data in [1].

- From the $z - t(z)$ relationship thus obtained and the equation $a_0/a = 1 + z$ we eliminate z to obtain the scale factor a as a function of t.

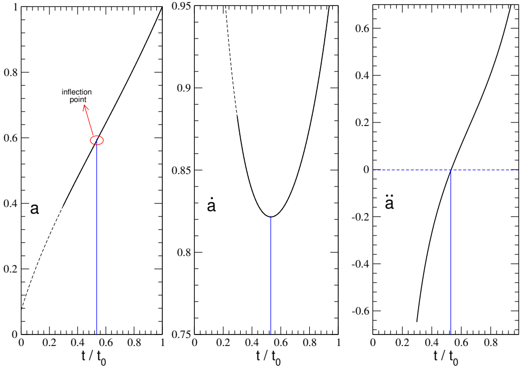


Figure: Left panel: Plot of a vs t/t_0 as obtained from analysis of observational data; Middle panel: Plot of $\dot{a}$ vs t/t_0 as obtained from analysis of observational data; Right panel: Behaviour of $\ddot{a}$ vs t/t_0

Results and Discussion

- In FRW spacetime background, the equations governing dynamics of late time cosmic evolution are the following two independent Friedmann equations,
$H^2 = \frac{8\pi G}{3}(\rho_{\rm de} + \rho_{dm})$ & $\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}[(\rho_{\rm dm} + \rho_{\rm de}) + 3p_{\rm de}]$
- Equation of state of total dark fluid expressed in terms of scale factor and its derivatives from above two equations as,

$$\boxed{\omega = \frac{p_{\rm de}}{\rho_{\rm de}+\rho_{\rm dm}} = -\frac{2}{3}\frac{\ddot{a}a}{\dot{a}^2} - \frac{1}{3}}$$

- Equation of state ω of the dark fluid can be expressed as a function of time by using SNe Ia data. Dependence of equation of state ω as a function of dimensionless time parameter τ ($\tau = \ln a(t)$) may be fitted with a polynomial of the form, $\omega(\tau) = -1 + \sum_{i=0} B_i \tau^i$ with coefficients known coefficients of B_i's.

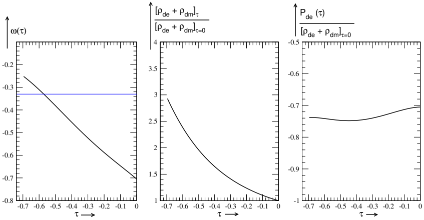


Figure: Left panel: Plot of $\omega(\tau)$ vs τ as obtained from analysis of observational data. The horizontal line represent the value $\omega = -1/3$ ($\ddot{a}$ =0), Middle panel: Plot of $\frac{[\rho_{\rm de}+\rho_{\rm dm}]_\tau}{[\rho_{\rm de}+\rho_{\rm dm}]_0}$ vs τ as obtained from analysis of observational data; Right panel: Behaviour of p_{de} vs τ

- The total continuity equation for dark fluid expressed in newly defined time parameter τ.
- We find that from observation this time dependence may be expressed in terms of a fitted polynomial of the form,
  $\left[\rho_{\rm de} + \rho_{\rm dm}\right]_{\tau} = \left[\rho_{\rm de} + \rho_{\rm dm}\right]_0 \sum_{i=0} C_i \tau^i$; with known coefficients of C_i's.
- Subsequently we also expressed time evolution of the dark matter energy density $\rho_{\rm dm}$ in this model in terms of time parameter τ.
- From observation we can estimate time dependence of this quantity $\frac{1}{a^3 H}$ and expressed in terms of a fitted polynomial. $\left(\frac{1}{a^3(\tau)H(\tau)} \to \sum_{i=0}^{5} D_i \tau^i\right)$; with known coefficients of D_i's.
- Using power series solution for estimate energy density of dark matter density as, $\rho_{\rm dm} \to \left[\rho_{\rm de} + \rho_{\rm dm}\right]_0 \sum_{i=0}^{\infty} \alpha_i \tau^i$.
- We obtain a constrain on the value of diffusion parameter K with fraction of the dark matter density α_0 in present situation. Where, $K \to \frac{\sigma n_0}{[\rho_{\rm de}+\rho_{\rm dm}]_0} \to$ diffusion parameter and we get the relation between diffusion parameter with dark matter energy density is $\alpha_{i+1} = \frac{K D_i - 3\alpha_i}{i+1}$.

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- $K(>0)$ represents a diffusion parameter as it is linearly related to diffusion coefficient σ and $\alpha_0 \rightarrow$ Value of the fraction $\frac{\rho_{\rm dm}}{[\rho_{\rm de}+\rho_{\rm dm}]_0}$ at $\tau = 0$ (present epoch).
- For a given set of values for α_0 and K, we find α_i's ($i > 0$) using the recursion relation, Since D_i's are zero for $i > 5$ and also compute $\rho_{\rm dm}$ at all values of τ.
- From the analysis of SNe Ia data,total dark fluid energy density $\Big[\rho_{\rm dm} + \rho_{\rm de}\Big]_\tau$ at any instant of time τ has been obtained and also the value of dark matter density $\rho_{\rm dm}(\tau; \alpha_0, K)$ computed at any τ, for a given (α_0, K) is subject to the constraint,

$$\boxed{0 < \rho_{\rm dm}(\tau; \alpha_0, K) < \Big[\rho_{\rm dm} + \rho_{\rm de}\Big]_\tau}$$

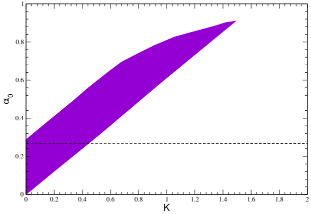
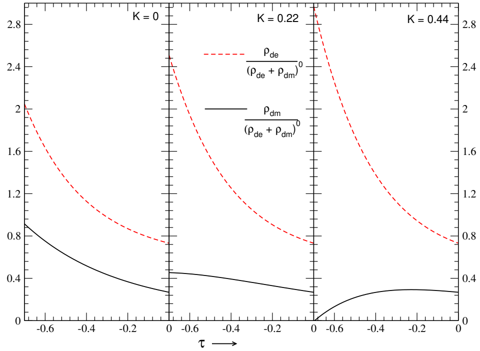


Figure: Region of $\alpha_0 - K$ parameter space

- From SNe Ia observations τ is accessible in the range $(-0.7 < \tau < 0)$. Impositing of the constraint limits the range of allowed values of α_0 and K. The shaded region in above fig. depicts the allowed domain in $\alpha_0 - K$ parameter space for which the constraint in calculating Dark matter density is realised.
- We use measured value of fractional contribution of dark matter to the total energy density(α_0) to be ~ 0.27. This has been depicted by a horizontal line. This value of α_0 corresponds to an allowed range of diffusion parameter K as $\boxed{0 \leqslant K < 0.44}$.



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THANK YOU