Dark matter from Dark Energy-Baryonic Matter Couplings

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Outline

- Motivations
- Interactions with the Trace of the Energy Momentum Tensor
- Background Cosmology
- Cosmological Perturbations
- Summary and Conclusions
Motivations

- **Dark Degeneracy** [M. Kunz PRD 80, 123001 (2009)]: Dark components in the Universe are defined through

\[ 8\pi G T_{\mu\nu}^{\text{dark}} = G_{\mu\nu} - 8\pi G T_{\mu\nu}^{\text{obs}} \]

- Interacting models between dark energy and matter fields have been proposed in order to ameliorate the Coincidence Problem.
  - But, this interactions give rise to long range undetected new forces.
  - Some screening mechanism have been proposed in order to evade fifth forces and equivalence principle tests.[Khoury and Weltman PRD 69, 044026 (2004)]

- In some interactions the continuity equation of baryonic matter is preserved.
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Interactions with the trace of the energy momentum tensor

\[ S = S_\phi + S_m + S_{\text{int}} \]

\[ T = g^{\mu\nu} T_{\mu\nu} , \]

\[ S_{\text{int}} = \int d^4x \, A(\phi) \, T \sqrt{-g} . \]

\[ T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta(S_m + S_{\text{int}})}{\delta g^{\mu\nu}} . \]

- **Fermionic Field**

\[ L = -\sqrt{-g} \bar{\psi} (i \gamma^\mu \partial_\mu - m) \psi + A(\phi) \, T \sqrt{-g} \]

\[ \rightarrow \quad -\sqrt{-g} \bar{\psi} (i \gamma^\mu \partial_\mu - e^{\alpha(\phi)} m) \psi \]

\[ e^{\alpha(\phi)} = \frac{1}{1 - A(\phi)} \]

- **Electromagnetic Field**

\[ L = -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} \sqrt{-g} + A(\phi) \, T \sqrt{-g} \]

\[ \rightarrow \quad -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} \sqrt{-g} \]

- **Perfect Fluid**

\[ L = -\rho \sqrt{-g} + A(\phi) \, T \sqrt{-g} \]

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Interactions with the trace of the energy momentum tensor 1

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Interactions with the trace of the energy momentum tensor

**Action**

\[ S = \int d^4x \sqrt{-g} \left[ \frac{R}{16\pi G} - \frac{1}{2} \phi^{,\alpha} \phi_{,\alpha} - V(\phi) - A(\phi) T - \rho \right], \]

**Field Equations**

\[ G_{\mu\nu} = 8\pi G (T^\phi_{\mu\nu} + e^{\alpha(\phi)} T^b_{\mu\nu}), \]

\[ \Box \phi - V'(\phi) = \alpha'(\phi) e^{\alpha(\phi)} \rho, \]

\[ V_{ef}(\phi) = V(\phi) + e^{\alpha(\phi)} \rho. \]

**Conservation Equations:**

1. **Continuity Equation**

\[ \nabla^\mu (\rho u_\mu) = 0, \]

2. **Geodesic Equation**

\[ u^\mu \nabla_\mu u^\nu = -\alpha'(\phi) (g^\mu\nu + u^\mu u^\nu) \partial_\mu \phi. \]

**Newtonian Limit**

\[ \frac{d^2 \tilde{X}}{dt^2} = -\nabla \Phi_N - \nabla \alpha(\phi) \]
Interactions with the trace of the energy momentum tensor 2

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Background Cosmology 1

\[ H^2 = \frac{8\pi G}{3} \left( \frac{1}{2} \dot{\phi}^2 + V(\phi) + (e^{\alpha(\phi)} - 1) \rho + \rho \right) \]

\[ \ddot{\phi} + 3H \dot{\phi} + V'(\phi) + \alpha'(\phi)e^{\alpha(\phi)}\rho = 0 \]

\[ \dot{\rho} + 3H \rho = 0 \]

\[ \rho_{\text{dark}} = \rho_{\phi} + (e^{\alpha(\phi)} - 1) \rho \]

\[ \dot{\rho}_{\text{dark}} + 3H(1 + w_{\text{dark}}) \rho_{\text{dark}} = 0, \]

\[ w_{\text{dark}} \approx -\frac{1}{1 + \frac{e^{\alpha(\phi)} - 1}{V(\phi)} \rho_0 a^{-3}}. \]

\[ V(\phi) = \frac{M_{n+4}}{\phi^n} \]

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\[ \beta = 0.04 \Rightarrow \frac{\beta}{M_p^2} \sim G \]
Supernovae Ia Fit

UNION 2  [R. Amanullah et al. (SCP), Astrophys. J. 716, 712 (2010).]

\[ z = \frac{1}{a} - 1 \]

\[ \mu = 5 \log_{10} \left( \frac{d_L}{\text{Mpc}} \right) + 25 \]

\[ d_L(z) = (1 + z) \int_0^z \frac{dz'}{H(z')} \]

\[ C_1 = e^{\alpha(\phi)} - 1 \bigg|_{\text{today}} \rho \]

\[ C_2 = e^{\alpha(\phi)} - 1 \bigg|_{\text{today}} \]
Cosmological Perturbations

- Scalar perturbations on longitudinal gauge

\[ ds^2 = -(1 + 2\Psi)dt^2 + a^2(t)(1 - 2\Phi)\delta_{ij}dx^i dx^j \]

- Perturbed variables

\[
\begin{align*}
\rho(\vec{x}, t) &= \rho_0(t)(1 + \delta(\vec{x}, t)) \\
\phi(\vec{x}, t) &= \phi_0(t) + \delta\phi(\vec{x}, t) \\
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Cosmological Perturbations 2

\[ \beta = 0.01 \]

\[ \beta = 0.04 \]
Conclusions

- Interactions between dark energy and baryonic matter could be an alternative to some of the dark matter in the Universe.

- Couplings to the trace of the energy momentum tensor are suitable for this purpose:
  - The interaction to the electromagnetic field and to relativistic matter become zero.
  - The continuity equation of matter is preserved.

- The numerical analysis shows that these models are capable of reproducing the observed background cosmology. Also, that linear perturbations have an acceptable behavior.
Thank you

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arXiv: 1012.3203