

Anisotropic Solid Dark Energy

J. Motoa-Manzano, J. B. Orjuela-Quintana, T. Pereira & C. A. Valenzuela-Toledo,

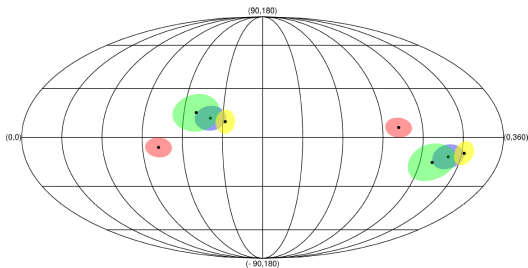
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Motivations

- CMB and LSS observations allow the existence of anomalies.
- Anomalies in the peculiar velocities, LQG, anisotropy in the cosmic expansion rate.
- Nature of Dark energy.



arXiv:1401.5044

The solid like model

The standard homogeneous scalar field

$$\langle \phi \rangle \equiv \phi(t)$$

The broken symmetry

$$\phi'(t') \rightarrow \phi(t) + \tau$$

The solid like model

$$\langle \phi^I \rangle \equiv c_I x^I.$$

The broken symmetries

$$\begin{aligned} \phi'^I &\rightarrow \phi^I + a^I, \\ \phi'^I &\rightarrow \sum_J O_J^I \phi^J. \end{aligned}$$

arXiv:0705.1167, arXiv:1210.0569

The model

The action

$$S = \int d^4x \sqrt{-g} \left[\frac{m_{\text{P}}^2}{2} R - \sum_I F^I(\Phi^I) + \mathcal{L}_r + \mathcal{L}_m \right], \quad I = 1, 2, 3.$$

The Bianchi-I metric

$$ds^2 = -dt^2 + a^2(t) \left(e^{2\beta_1(t)} dx^2 + e^{2\beta_2(t)} dy^2 + e^{2\beta_3(t)} dz^2 \right),$$

The building blocks

$$\Phi^I = g^{\mu\nu} \nabla_\mu \phi^I \nabla_\nu \phi^I = g^{II},$$

The restriction

$$\sum_I \beta_I(t) = 0,$$

The axi-symmetric Bianchi-I metric

The anisotropy parameters

$$\begin{aligned}\beta_1(t) &\equiv -2\sigma(t), \\ \beta_2(t) &= \beta_3(t) = \sigma(t),\end{aligned}$$

The solid lagrangian

$$\sum_I F^I (\Phi^I) = F^1 (\Phi^1) + 2F^2 (\Phi^2),$$

The field equations

$$\begin{aligned}3 m_{\text{P}}^2 H^2 &= F^1 + 2F^2 + \rho_m + \rho_r + 3 m_{\text{P}}^2 \dot{\sigma}^2, \\ -2 m_{\text{P}}^2 \dot{H} &= \frac{2}{3} \Phi^1 F_{\Phi}^1 + \frac{4}{3} \Phi^2 F_{\Phi}^2 + \rho_m + \frac{4}{3} \rho_r + 6 m_{\text{P}}^2 \dot{\sigma}^2, \\ m_{\text{P}}^2 \ddot{\sigma} + 3 m_{\text{P}}^2 H \dot{\sigma} &= \frac{2}{3} (\Phi^2 F_{\Phi}^2 - \Phi^1 F_{\Phi}^1).\end{aligned}$$

The autonomous system

The variables of the system

$$f_1^2 \equiv \frac{F^1}{3m_p^2 H^2}, \quad f_2^2 \equiv \frac{F^2}{3m_p^2 H^2}, \quad \Sigma \equiv \frac{\dot{\sigma}}{H}, \quad \Omega_m \equiv \frac{\rho_m}{3m_p^2 H^2}, \quad \Omega_r \equiv \frac{\rho_r}{3m_p^2 H^2}.$$

The constraint in the variables

$$f_1^2 + 2f_2^2 + \Sigma^2 + \Omega_r + \Omega_m = 1.$$

The model assumed

$$F^1 \propto (\Phi^1)^n, \quad F^2 \propto (\Phi^2)^m.$$

The EoS of DE

$$w_{\text{DE}} = -1 + \frac{2}{3} \frac{n f_1^2 + 2m f_2^2 + 3\Sigma^2}{(f_1^2 + 2f_2^2 + \Sigma^2)}.$$

The autonomous system

The deceleration parameter

$$q \equiv -\ddot{a}a/\dot{a}^2 = \frac{1}{2} [1 + (2n - 3)f_1^2 + 2(2m - 3)f_2^2 + \Omega_r + 3\Sigma^2] ,$$

The autonomous system

$$f_1' = f_1 [q + 1 - n(1 - 2\Sigma)] ,$$

$$f_2' = f_2 [q + 1 - m(1 + \Sigma)] ,$$

$$\Sigma' = \Sigma(q - 2) + 2(mf_2^2 - nf_1^2) ,$$

$$\Omega_r' = 2\Omega_r(q - 1) ,$$

The fixed points

The relevant radiation and matter fixed points

- $(R - 1)$ isotropic radiation domination: $\Omega_r = 1, w_{eff} = \frac{1}{3}$.
- $(M - 1)$ isotropic matter domination: $\Omega_m = 1, w_{eff} = 0$.

The fixed points

The relevant DE fixed points

- $(DE - 1)$ anisotropic DE sourced by f^1 :

$$f_1 = \frac{\sqrt{3(n+3)(1-n)}}{3-n}, \Sigma = \frac{2n}{n-3}, w_{eff} = -1 + \frac{2n(3+n)(1-n)+8n^2}{(3-n)^2}.$$

- $(DE - 2)$ anisotropic DE sourced by f^2 :

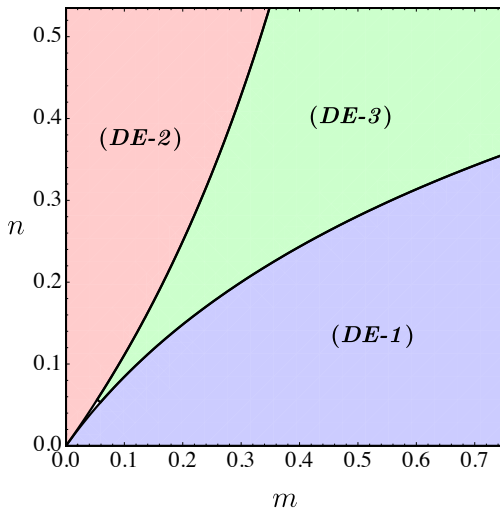
$$f_2 = \frac{\sqrt{3(3/2-m)}}{3-m}, \Sigma = \frac{m}{m-3}, w_{eff} = -1 + \frac{2m}{3-m}.$$

- $(DE - 3)$ anisotropic DE sourced by f^1 and f^2 :

$$f_1 = \frac{\sqrt{3(m-n+mn)}}{m+2n}, f_2 = \frac{\sqrt{3(n^2+mn-m+n)}}{\sqrt{2}(m+2n)}, \Sigma = \frac{n-m}{m+2n},$$

$$w_{eff} = -1 + \frac{2mn}{m+2n}.$$

Existence and stability conditions

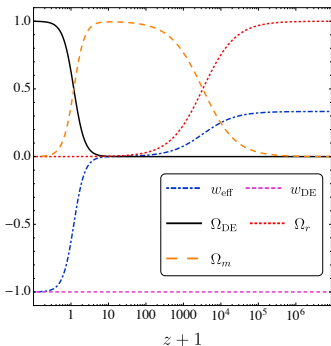


The numerical evolution

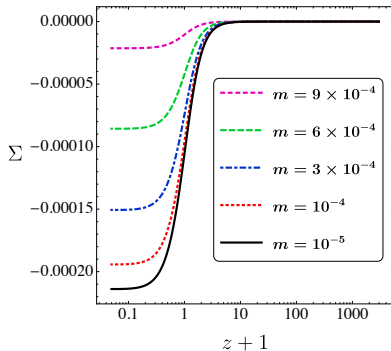
The initial conditions

$$\Omega_{r_i} = 0.99995, \quad f_{1_i} = 10^{-14}, \quad f_{2_i} = 10^{-14}, \quad \Sigma_i = 0,$$

The abundance evolution



The shear evolution



Conclusions

- The late-time cosmic acceleration can be successfully supported by the solid DE model.
- Anisotropic DE is an attractor.
- The solid DE model can reproduce the right evolution of the universe: radiation (isotropic) \rightarrow matter (isotropic) \rightarrow DE (anisotropic).
- The EoS of the DE is almost constant throughout the whole evolution.