Einstein Yang-Mills Higgs dark energy revisited

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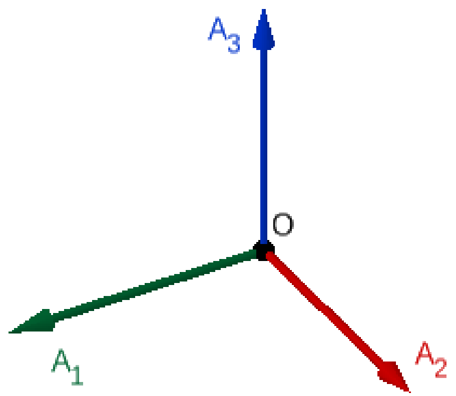
Introduction



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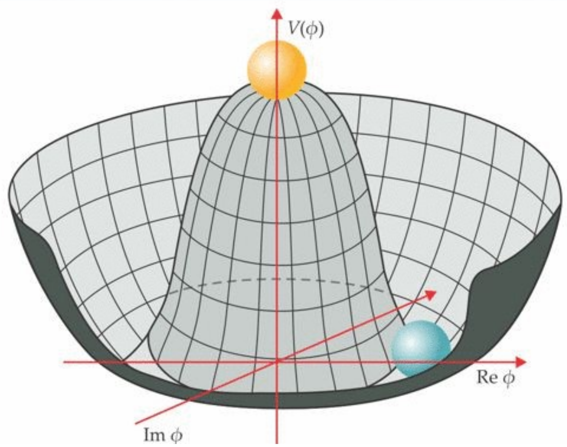

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The Model

$$S = \int d^4x\sqrt{-g}\left[\frac{m_P^2}{2}R - \frac{1}{4}F_a^{\mu\nu}F_{\mu\nu}^a - \left(D^\mu\Phi\right)^\dagger\left(D_\mu\Phi\right)\right.$$

$$\left. - V\left(\Phi^2\right) + \mathcal{L}_r + \mathcal{L}_m\right],$$

Stress tensor

$$F_{\mu\nu}^a \equiv \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + \gamma\epsilon_{bc}^a A_\mu^b A_\nu^c, \quad a = 1, 2, 3, \quad \mu = 0, 1, 2, 3,$$

Higgs potential

$$V\left(\Phi^2\right) \equiv \frac{\lambda}{4}\left(\Phi^2 - \Phi_0^2\right)^2,$$

Covariant derivative

$$D_\mu \equiv \nabla_\mu - i\gamma\frac{\sigma_c}{2}A_\mu^c.$$

Homogeneity and Isotropy

FLRW

$$ds^2 = -dt^2 + a^2(t)d\vec{x}^2,$$

Cosmic triad

$$A^a_\mu = f(t)\delta^a_\mu,$$

Higgs field

$$\Phi \equiv \begin{pmatrix} \Phi_1 \\ \Phi_2 \end{pmatrix} = \begin{pmatrix} \phi_1 + i\psi_1 \\ \phi_2 + i\psi_2 \end{pmatrix}$$

Everything was going well, except...

$$2\left.\frac{\partial \mathcal{L}_{\,\mathrm{mat}}}{\partial g^{\mu\nu}}\right|_{\mu\nu=0i} = -\frac{1}{4}\gamma f \,\mathrm{Im}\left(\dot{\Phi}^\dagger \sigma_i \Phi\right),$$

Unitary representation

$$\Phi(t) \equiv \begin{pmatrix} \phi(t) \\ 0 \end{pmatrix}.$$

Field equations

$$H^2 = \frac{1}{3m_P^2}\left[\frac{3}{2}\frac{\dot{f}^2}{a^2} + \dot{\phi}^2 + \frac{3}{2}\frac{\gamma^2 f^4}{a^4} + \frac{3}{4}\frac{\gamma^2\phi^2 f^2}{a^2} + V\left(\phi^2\right) + \rho_r + \rho_m\right]$$

$$\dot{H} = -\frac{1}{2m_P^2}\left[2\frac{\dot{f}^2}{a^2} + 2\dot{\phi}^2 + 2\frac{\gamma^2 f^4}{a^4} + \frac{\gamma^2\phi^2 f^2}{2a^2} + \frac{4}{3}\rho_r + \rho_m\right] \quad ,$$

$$\ddot{f} + H\dot{f} + 2\frac{\gamma^2 f^3}{a^2} + \frac{\gamma^2 f\phi^2}{2} = 0$$

$$\ddot{\phi} + 3H\dot{\phi} + \frac{3}{4}\frac{\gamma^2 f^2\phi}{a^2} + \frac{dV(\phi)}{d\phi} = 0$$

Dynamical System

Autonomous System

$$x = \frac{\dot{f}}{\sqrt{2} a m_P H}, \qquad y = \frac{\gamma f^2}{\sqrt{2} a^2 m_P H},$$
$$w = \frac{\gamma f \phi}{2 a m_P H}, \qquad z = \frac{\dot{\phi}}{\sqrt{3} m_P H},$$
$$v = \frac{1}{m_P H}\sqrt{\frac{V(\phi)}{3}}, \qquad r = \frac{1}{m_P H}\sqrt{\frac{\rho_r}{3}},$$
$$m = \frac{1}{m_P H}\sqrt{\frac{\rho_m}{3}}, \qquad l = \frac{\sqrt{2} a m_P}{f},$$

Friedmann Constrain

$$x^2 + y^2 + w^2 + z^2 + v^2 + r^2 + m^2 = 1,$$

Deceleration Parameter Equation

$$q = \frac{1}{2}\left(1 + x^2 + y^2 - w^2 + 3z^2 - 3v^2 + r^2\right),$$

System of equations

$$x' = x(q-1) - l\left(2y^2 + w^2\right),$$
$$y' = y(2xl + q - 1),$$
$$w' = w(xl + q) + \frac{\sqrt{3}}{2} lyz,$$
$$z' = z(q-2) - wl\left(2\alpha v + \frac{\sqrt{3}}{2} y\right),$$
$$v' = v(q+1) + \alpha l w z,$$
$$r' = r(q-1),$$
$$l' = l(1 - lx),$$

Critical Points and Critical Manifolds

- Dark Energy Critical Point $(q=-1)$

  $v=1, w=0, x=0, y=0, z=0, r=0, m=0, l=0$

- Transition Critical Point $(q=0)$

  $w=1, x=0, y=0, z=0, v=0, r=0, m=0, l=0,$

- Matter Critical Point $(q=\frac{1}{2})$

  $m=1, x=0, y=0, w=0, z=0, v=0, r=0, l=0$

- Radiation Critical Manifolds $(q=1)$

  $r=\sqrt{1-x^2-y^2}, l=0, w=0, z=0, v=0, m=0$

  $r=\sqrt{1-x^2}, l=1/x, y=0, w=0, z=0, v=0, m=0,$

- Kination Critical Point $(q=2)$

  $z=1, x=0, y=0, w=0, v=0, r=0, m=0, l=0$

Numerical Solutions

$$\Omega_{r_0} \simeq 10^{-4} \Rightarrow r_0 = 10^{-2},$$

$$\Omega_{m_0} \simeq 0.31 \Rightarrow m_0 = 0.557,$$

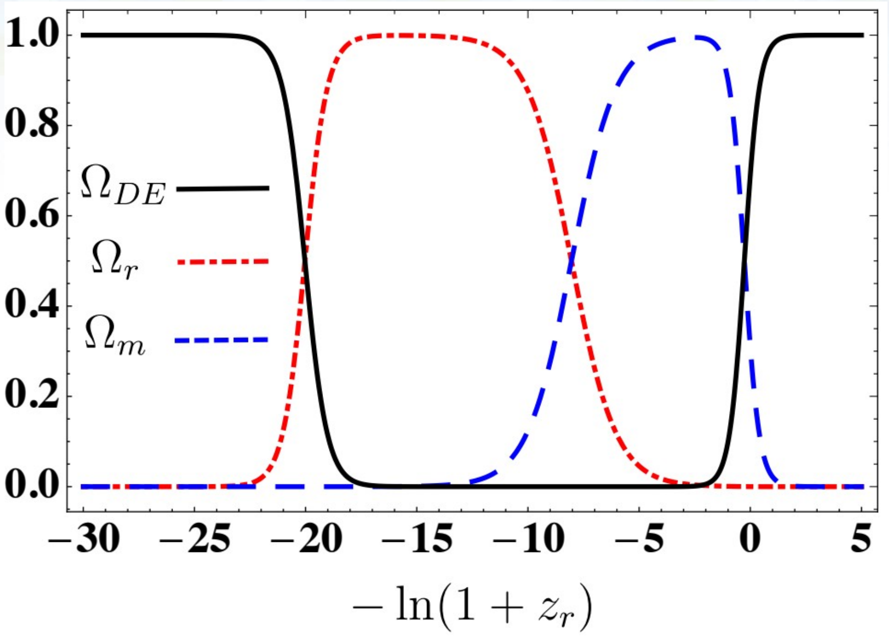
$$x_0 = 10^{-18}, \qquad y_0 = 10^{-18}$$

$$w_0 = 10^{-18}, \qquad z_0 = 10^{-18}$$

$$v_0 = 0.831, \qquad l_0 = 10^2$$

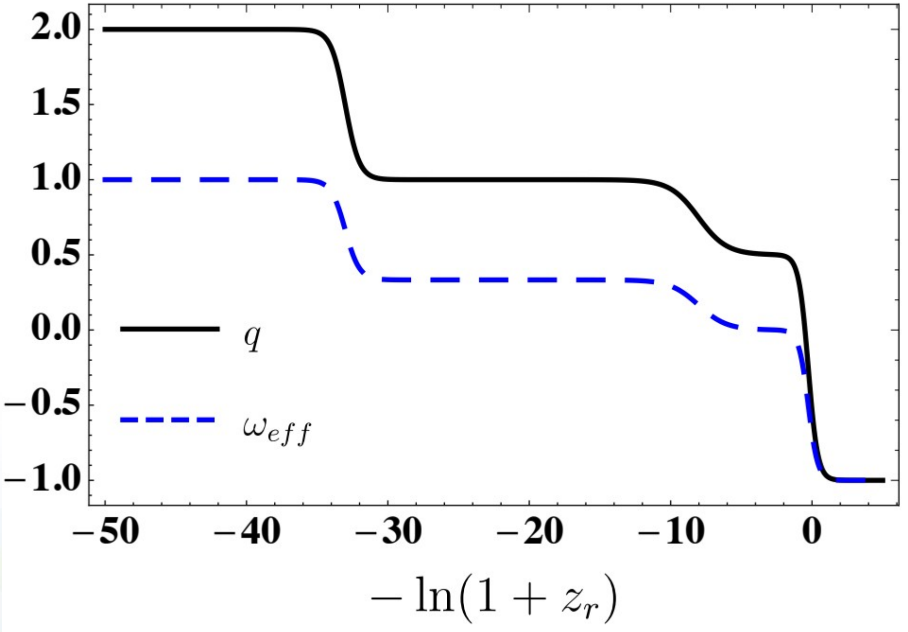
$$\alpha = 1.$$

Evolution of the System



Densities Plot of the Dark Energy(DE), non-relativistic matter(m) and relativistic matter(r).

Deceleration parameter and state parameter



Particle Physics Implications

EYMH Model

Standard Model masses

$$m_\phi \sim \sqrt{\lambda}\phi_0 \sim \alpha\gamma\phi_0$$
$$m_{A_\mu} \sim \gamma\phi_0$$

$$m_\phi \sim \gamma\sqrt{\alpha^2{\phi^2}_{\rm asymp} + \frac{3}{8}\frac{f_0^2}{a_0^2}}$$

$$m_{A_\mu} \sim \gamma\sqrt{{\phi^2}_{\rm asymp} + 4\frac{f_0^2}{a_0^2}}$$

$$m_{A_\mu} \sim m_\phi \sim 10^{-74} m_P \sim 10^{-47}\mathrm{eV}$$

$$\phi_{\rm asymp} \approx 30 m_P$$

$$\gamma \sim 10^{-75}$$

$$\frac{f_0}{a_0} \approx 10^{-2} m_P$$

Conclusions

- The model reproduces successfully the thermal post-inflationary history of the universe.
- The model requires modifications to remove the kination epoch.
- The fields used in the model mimic the Standard Model of Particles fields.
- There can be no rotation around the axis of the Mexican potential.

Thank you,
Questions?