Disformal Theories of Gravity: Screening from the Solar System to Cosmology

Jeremy Sakstein
Institute of Gravitation and Cosmology
University of Portsmouth

Dark Energy Interactions

Nordita
Stockholm
1^{st} October 2014
JS: 1409.1734 & 1409.7296

Outline

Disformal Gravity

$$S = \int \mathrm{d}^4x\sqrt{-g}M_{\mathrm{pl}}^2\left[\frac{R}{2} - \frac{1}{2}(\nabla_\mu\phi)^2 - V(\phi)\right] + S_{\mathrm{m}}[\tilde{g}_{\mu\nu};\Psi_{\mathrm{i}}]$$

$$\tilde{g}_{\mu\nu} = \underbrace{A^2(\phi)}_{\text{conformal}}\left(g_{\mu\nu} + \underbrace{\frac{B^2(\phi)}{\Lambda^2}\partial_\mu\phi\partial_\nu\phi}_{\text{disformal}}\right)$$

Define:

$$\alpha \equiv \frac{\mathrm{d}\ln A}{\mathrm{d}\phi} \qquad \gamma \equiv \frac{\mathrm{d}\ln B}{\mathrm{d}\phi}$$

This Talk

- Local behaviour not well understood
- No universal paradigm
- Lack of viable models

Local Behaviour

Recall GR:

$$\nabla^2\Phi_{\rm N} = 4\pi G\rho \quad F_{\rm N} = -\nabla\Phi_{\rm N}$$

Disformal: No fifth-force in Minkowski but in FRW get

$$\nabla^2\phi = 8\pi Q G\rho \quad F_5 = -Q\nabla\phi$$

$$\Rightarrow \frac{F_5}{F_{\rm N}} = 2Q^2$$

$$Q = \underbrace{\alpha}_{\rm conformal} + \underbrace{\frac{B^2}{\Lambda^2}\left(\ddot{\phi}_\infty + \dot{\phi}_\infty^2\left[\gamma - \alpha\right]\right)}_{\rm disformal}$$

$$\phi_\infty = \text{ cosmological scalar}$$

Screening?

Can screen locally if cosmological dynamics are such that $Q \ll 1$.

$$\text{Simple Example:} \quad B(\phi) = A(\phi) = 1 \Rightarrow \gamma = \alpha = 0$$

Model studied by Brax, van de Bruck, Burrage, Davis... et al.

$$Q = \frac{\ddot{\phi}_\infty}{\Lambda^2}$$

Want slowly-rolling fields!

$$V(\phi) = H_0^2(1 + \phi^2)$$

Cosmology

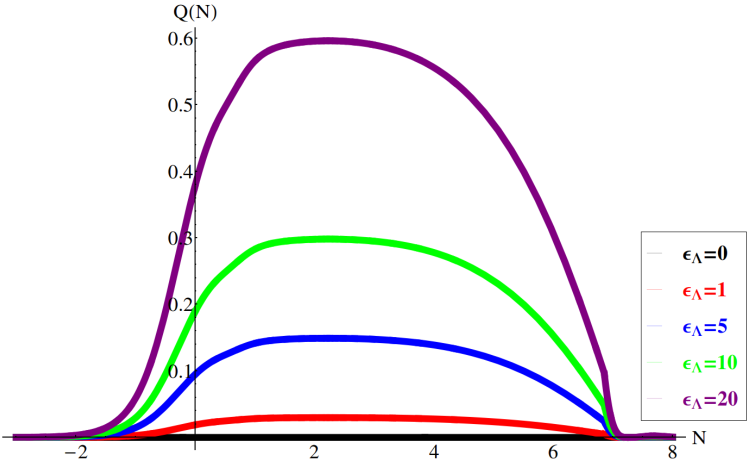
Friedmann equations are same as GR.

$$\ddot{\phi}_\infty + 3H\dot{\phi}_\infty + V(\phi_\infty)_{,\phi} = -Q_0$$
$$\dot{\rho}_{\mathrm{m}} + 3H\rho_{\mathrm{m}} = Q_0\dot{\phi}_\infty$$

$$Q_0 = Q_0\left(\rho_{\mathrm{m}}, \alpha, \frac{BH}{\Lambda}, \gamma\right)$$

Field/matter EOM encodes MG effects.

Local Scalar Charge



Solar System Tests

Best constraint: Cassini

$$|\gamma_{\mathrm{PPN}} - 1| < 2.1 \times 10^{-5}$$

Use measurements of H_0, Ω_{DE}, w_0 and w_a to find

$$\frac{\Lambda}{H_0} \gtrsim 5.6 \times 10^5 \quad (\mathcal{M} \gtrsim \mathrm{eV})$$

What does this mean?

$$\frac{\Delta G}{G} < 10^{-24}!!!$$

Background cosmology indistinguishable from quintessence!

More General Models?

Important next step: Find viable models

What we want: Dark energy dominated solutions with $Q = 0$.

Do this using a phase-plane analysis - classify all solutions and find fixed points with these properties.

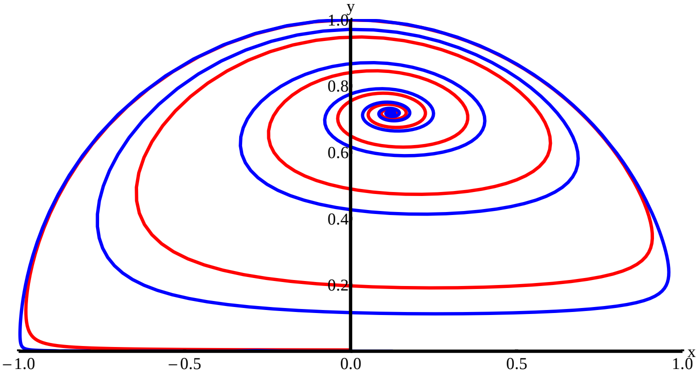
$$A(\phi) = e^{\alpha\phi} \quad B(\phi) = e^{\gamma\phi} \quad V(\phi) = m_0^2 e^{-\lambda\phi}$$

Model of Koivisto, Mota & Zumalacarregui.

Phase-plane analysis

C.f. Coupled dark energy (conformal but no disformal).

Phase space is 2D.



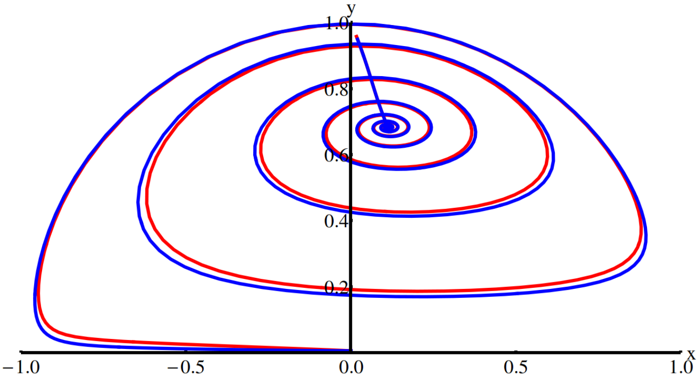
Phase-Plane

3D phase space because Q_0 depends on $B(\phi)$ and γ — c.f. conformal has $Q_0 = \alpha \Rightarrow$ 2D.

General Case:

- No DE $Q = 0$ fixed points $\Rightarrow$ dark energy but large fifth-forces
- Old fixed points unstable - system evolves towards dark energy domination and $Q \to \infty$

General Case



Special Case

$$\gamma = \lambda/2$$

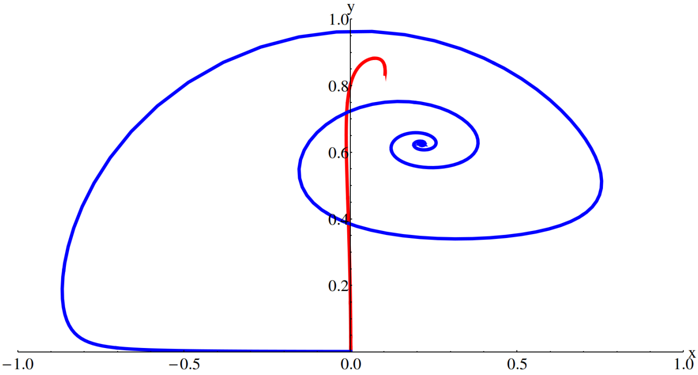
Reduces the phase space to 2D and gives a new fixed point with

- $Q = 0 \Rightarrow$ no fifth-forces
- $w_{\rm DE}(\lambda, \Lambda/m_0)$ and $\Omega_{\rm DE}(\lambda, \Lambda/m_0)$

Can always reproduce any value of $w_{\rm DE}$ and $\Omega_{\rm DE}$ e.g. $\lambda = 3.77953$, $\Lambda/m_0 = 0.174519$ gives WMAP9 results exactly.

Special Case

$$\gamma = \lambda/2$$



Red = disformal dark energy, Blue = conformal dark energy

Open Questions

$$\gamma = \lambda/2 \quad \text{good candidate model for disformal dark energy}$$

Open problems:

- Proper fit to expansion history
- What about linear perturbations?

Need to find a good candidate model before doing more complicated things!