Dilatonic couplings and the late time universe

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Based on: Amendola, Bettoni, GD & Gomez, arXiv: 1803.06368
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Late time universe

- Dark energy (looks like Λ very much)
- (To be sure it's Λ) Test against other models
- Strong local constraints (Screenings?)
- What do we do?
  - Fundamental model?
  - **Study most general set up?**

Propagation of GWs

- Interesting signatures: modification of c_{gw} ! Horndeski '74 Deffayet +11

$$G_4 R + G_{4,X}\left(\left(\Box\phi\right)^2 - \left(\nabla\nabla\phi\right)^2\right)$$

- In ADM…

$$G_4 R^{(3)} + \left(G_4 - 2XG_{4,X}\right)\left(K_{ij}K^{ij} - K^2\right) \qquad X = -\frac{1}{2}(\partial\phi)^2$$

- Late Universe (up to z~0.08): $c_{gw} \approx 1 \pm 10^{-15}$! **GW170817** LIGO '17

Ezquiaga+17, Creminelli +17, Sakstein +17, ...

(no X dependence in G_4)

- Early Universe: $c_{gw} \neq 1$? (B-modes)

Higher-derivatives out?

- More precisely

Kobayashi +11

$$c_{gw}^2 = \frac{G_4 - \ddot{\phi} X G_{5,X}}{G_4 - 2XG_{4,X} - 2X\dot{\phi}HG_{5,X}}$$

Background dependent!

- Fine tuning? Easily spoiled! ($\Omega_{DM} \sim 27\,\%$!)
- Ways out?
  - Bg independent tuning (in DHOST) — Langlois +17
  - **Interacting dark sector?** — Amendola +99, Miranda +17

Interacting dark sector

- (Not to mess with SM) Non-universal coupling $\bar{g}_{\mu\nu} = e^{\beta\phi} g_{\mu\nu}$

$$\mathscr{L} \sim \mathscr{L}_{\rm Horn}(\phi, g) + \mathscr{L}_{DM}(\bar{g}(\phi)) + \mathscr{L}_{SM}(g)$$

- Non-conservation of DM energy density **(two interacting fluids)**

$$\dot{\rho}_{DM} + 3H\rho_{DM} = -Q(\phi)\rho_{DM} \qquad \dot{\rho}_{DE} + 3H(1 + w_{DE})\rho_{DE} = Q(\phi)\rho_{DE}$$

$$Q \equiv \frac{d(\beta\phi)}{dt}$$

- Interesting cosmology? $\Omega_b/\Omega_{DM} \neq \text{constant}$
  - Alleviate H_0 or $f\sigma_8$ tensions (CMB and local exp). Valentino +17 Miranda +17
  - Baryogenesis Sakstein +17
  - Effects to 21 cm line (z~17 ; dark ages). Costa +17
  - At z<0.3 $\Omega_{DM}/\Omega_{DE} = \text{constant}$? Amendola + 99

Doppelgänger DE

- Quite messy in general but:

- Like Jordan ⟷ Einstein frame $d\bar{\rho}_{DM}/d\bar{t} + 3\bar{H}\bar{\rho}_{DM} = 0$

  $\bar{g}_{\mu\nu} = \mathrm{e}^{\beta\phi} g_{\mu\nu}$

- We have Matter ⟷ Dark Matter frame

$$1 + \bar{w}_{\rm eff} = \frac{1}{1-\alpha}\left(1 + w_{\rm eff} - \frac{2}{3}\alpha - \frac{2}{3}\frac{d\ln(1-\alpha)}{Hdt}\right) \qquad \alpha \equiv \frac{d(\beta\phi)}{Hdt} = \frac{Q}{H}$$

- Now they are decoupled $3H^2 G_4 = \rho_\phi + \rho_{DM}$

- E.g. Canonical: $V \propto \mathrm{e}^{-\lambda\phi}$ $\rho_\phi \propto a^{-\lambda^2}$ λ=√3 → $\rho_\phi \propto \rho_{DM}$

  $G_4 = 1$

- In general: $Y = X\mathrm{e}^{-\lambda\phi} = \text{constant}$ → $G_i = \mathrm{e}^{p_i\phi} a_i(Y)$

Tuning c_{gw}=1

- **Fix point, attractor** with accelerated expansion

$$c_{gw}^{-2} = \frac{a_4 - 2Y a_{4,Y}}{a_4} \rightarrow a_{4,Y}\Big|_{Y=Y_*} = 0$$

Zero at the fix point

- A simple non-trivial choice is

$$a_4 = 1 + c_4 (1 - Y/Y_*)^n$$

- The background dependence is now hidden in Y_*

- Is this choice still okay? What effects do we have?

Effect of baryons

- We should not forget that: $3H^2 G_4 = \rho_\phi + \rho_{DM} + \rho_b(\phi)$
- Take us out of fix point by: $\Omega_b / \Omega_{DM} \approx 4\,\%$
- You can see how sensitive it is:

$$\delta c_{gw}^2 \propto \frac{2Y^2 a_{4,YY}}{a_4}\Big|_* \frac{\Omega_b}{\Omega_{DM}} \sim 10^{-1} \frac{Y^2 a_{4,YY}}{a_4}\Big|_* < 10^{-15}$$

- The Lagrangian is highly constrained: **n>16!**

$$\delta c_{gw}^2 \propto \sim 10^{-n} \frac{Y^n a_{4,Y^n}}{a_4}\Big|_* < 10^{-15}$$

Note: This value is only at the fix point nowadays. In the past

$$a_4 = 1 + c_4 (1 - Y/Y_*)^n \neq 1$$

Summary

- Modified gravity may need a more fundamental approach
- Modifications to $c_{gw} = 1$ seem unlikely (or at least hard to conceive) if due to DE field
- Interacting dark sector might provide ways out but Lagrangian very much constrained
- Possible effects in the early universe
- Origin of non-universal coupling?