

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

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

- In ADM...

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

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

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

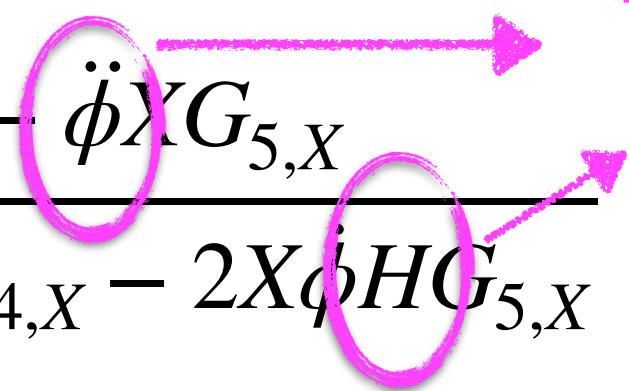
(no X dependence in G_4)

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

Higher-derivatives out?

- More precisely

Kobayashi +11

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


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

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

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

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

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

- Interesting cosmology? $\Omega_b/\Omega_{DM} \neq \text{constant}$

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

- Alleviate H_0 or $f\sigma_8$ tensions (CMB and local exp).

Valentino +17

- Baryogenesis Sakstein +17

Miranda +17

- Effects to 21 cm line ($z \sim 17$; 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 \longleftrightarrow Einstein frame $d\bar{\rho}_{DM}/d\bar{t} + 3\bar{H}\bar{\rho}_{DM} = 0$

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

- We have Matter \longleftrightarrow Dark Matter frame

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

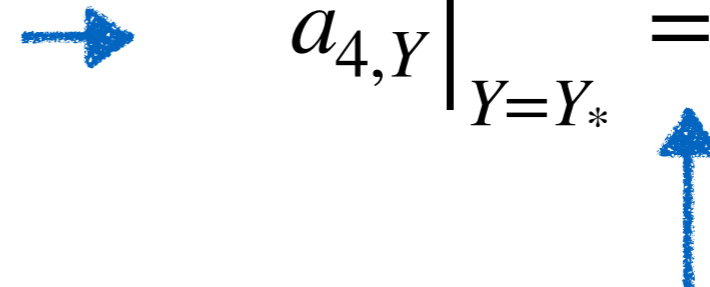
- Now they are decoupled $3H^2 G_4 = \rho_\phi + \rho_{DM}$

- E.g. Canonical: $V \propto e^{-\lambda\phi}$ $\rho_\phi \propto a^{-\lambda^2}$ $\lambda = \sqrt{3} \rightarrow \rho_\phi \propto \rho_{DM}$
 $G_4 = 1$

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

Tuning $c_{gw}=1$

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

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


- A simple non-trivial choice is

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

Zero at the fix point

- 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: $3H^2G_4 = \rho_\phi + \rho_{DM} + \rho_b(\phi)$
- 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?