Is dark matter really different from modified gravity?[1]

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[1] based on X. Calmet, I. K. [arXiv:1702.03832]

Seminar structure

1. Classification of theories
2. Dark matter
3. Conclusions

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- Fields are dummy variables

$$\mathcal{A} = \int \mathcal{D}\phi e^{iS[\phi]}$$

- Physics doesn't depend on the parametrization
- Classification?

- Mathematically a theory is parametrized by $\mathcal{T} = (\phi^1_{\alpha_1}, \ldots, \phi^n_{\alpha_n}, S)$
- $\mathcal{T}_1 \sim \mathcal{T}_2$ iff there is a frame (choice of variables) where
  1) they have the same #(degrees of freedom)
  2) and the same action
- The theories might look different at first sight
- The set of theories is divided into equivalence classes
- Algorithm
  - Identify all degrees of freedom
  - Verify how they couple to each other

- Degrees of freedom can be found by linearizing the EOM $g_{\mu\nu} = g^{(0)}_{\mu\nu} + h_{\mu\nu}$

$$\mathcal{D}_{\alpha\beta\mu\nu} h^{\mu\nu} = T_{\alpha\beta} \implies \mathcal{P}_{\alpha\beta\mu\nu} = \mathcal{D}^{-1}_{\alpha\beta\mu\nu}$$

- The position of the poles reveals the degrees of freedom

- The dynamics can be compared in two ways:
  - Lagrangian level: suitable transformations that map one theory to the other (e.g. field redefinitions)
  - EOM level: checking if EOMs can be matched

- Example: $f(R)$

$$S = \int d^4x\sqrt{-g}\left(\frac{1}{16\pi G}f(R) + \mathcal{L}_M\right)$$

- Conformal transformation $\tilde{g}_{\mu\nu} = f'(R)g_{\mu\nu}$

$$S = \int d^4x\sqrt{-\tilde{g}}\left(\frac{1}{16\pi G}\tilde{R} - \frac{1}{2}\tilde{g}^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right) + \int d^4x\sqrt{-\tilde{g}}F^{-2}(\phi)\mathcal{L}_M(F^{-1}(\phi)\tilde{g}_{\mu\nu}, \psi_M),$$

where

$$\phi \equiv \sqrt{\frac{3}{16\pi G}}\log F,$$
$$F(\phi) \equiv f'(R(\phi)).$$

- More generally, $f(R, R_{\mu\nu}R^{\mu\nu}, R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma})$ is equivalent to GR plus a scalar χ and a non-physical massive spin-2 field $\tilde{\pi}_{\mu\nu}$
- Generalized Pauli-Fierz conditions

$$\tilde{\nabla}^{\mu}\left(\tilde{\pi}_{\mu\nu} - g_{\mu\nu}\tilde{\pi}\right) = 0,$$
$$\tilde{\pi} - {m_2}^{-2}\left[\left(\tilde{\nabla}\chi\right)^2 + 2{m_0}^2\left(1 - e^{-\chi}\right)^2\right] = 0.$$

- Does that mean that *ANY* physical theory is equivalent to GR? NO!
- But conservative theories are
- This doesn't cover theories that:
  - has different symmetries than GR
  - has different spacetime structure

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- One-to-one map between modified gravity and modifications in the matter sector
- Is it possible to differentiate between modified gravity and particle dark matter?
- Different interpretations of the same phenomenon

Seminar structure

- We proposed a classification framework for the gravitational dynamics
- Assuming Diff invariance, we showed modified gravity = GR + new fields
- Corollary: particle dark matter = modified gravity dark matter
- Other applications might include GWs, dark energy and so on
- Note: this doesn't explain dark matter, just show the equivalence between the two approaches