Heavier and Darker

Spin-2 Dark Matter

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Take home message

This model can be falsified!

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- Bimetric contains a new, massive spin-2 field
- It naturally behaves as DM (see below)
- As it's a manifestation of gravity, its coupling to matter is universal
- The detection in one channel automatically tells you what you should see in all other channels
- A factor of 100 improvement in the DM lifetime constraint will close the parameter space

Outline

What is bigravity?!?

A new heavy spin-2 field

Spin-2 Dark Matter

Phenomenology

Based on work with the *FatGR-DM monster collaboration*:
Babichev, Marzola, Raidal, Schmidt-May, FU, Veermäe, von Strauss

PRD94, (2016) no.8, 084055

and

JCAP 1609 (2016) no.09, 016

See also Aoki and Mukohyama (2016), and Marzola, Raidal, FU (in preparation)

Bimetric theory essentials Hassan and Rosen (2012) x2

$$S = \int d^4x \left[\sqrt{|g|} m_g^2 R(g) + \sqrt{|f|} m_f^2 R(f) - 2m^4 \sqrt{|g|}\, V(g, f; \beta_n) \right]$$

1. $R(g)$ is GR for the metric $g_{\mu\nu}$, with strength m_g
2. $R(f)$ is GR for the metric $f_{\mu\nu}$, with strength $m_f \equiv \alpha\, m_g$
3. The interaction potential is $V(g, f)$ and it depends on 5 parameters β_n
4. This action contains **no ghosts**! It took about 100 yrs to get it right

The ghost-free coupling to matter breaks the symmetry:

$$S_m = \int d^4x \sqrt{|g|}\, \mathcal{L}_m(g, \Phi)$$

What's in this theory?

Expand around proportional backgrounds $f_{\mu\nu} = c\, g_{\mu\nu}$ (for technical reasons)

$$S^{(2)} = \int \mathrm{d}^4x \sqrt{|\bar{g}|} \left[\mathcal{L}^{(2)}_{\mathrm{GR}}(\delta G) + \mathcal{L}^{(2)}_{\mathrm{FP}}(\delta M) \right]$$

- $\mathcal{L}_{\mathrm{GR}}$ is the (linearised) GR for δG
- $\mathcal{L}_{\mathrm{FP}}$ is the Fierz-Pauli spin-2 field δM with $m_{\mathrm{FP}} \sim \sqrt{\beta}_n M_{\mathrm{Pl}}$
- These fields are mixtures of the interaction eigenstates with parameter α

$$\delta g_{\mu\nu} \simeq (\delta G_{\mu\nu} - \alpha \delta M_{\mu\nu}) \,, \quad \delta f_{\mu\nu} \simeq \left(\delta G_{\mu\nu} + \alpha^{-1} \delta M_{\mu\nu}\right)$$

MATTER

$$S_m \sim \int \mathrm{d}^4x \, (\delta G_{\mu\nu} - \alpha \delta M_{\mu\nu}) \, T^{\mu\nu}$$

How does δM gravitate?

δG^3	$\delta G^2 \delta M$	$\delta G \delta M^2$	δM^3
1	**0**	**1**	$1/\alpha$

δG^4	$\delta G^3 \delta M$	$\delta G^2 \delta M^2$	$\delta G \delta M^3$	δM^4
1	**0**	**1**	$1/\alpha$	$1/\alpha^2$

i. All δG vertices have the same strength as in GR

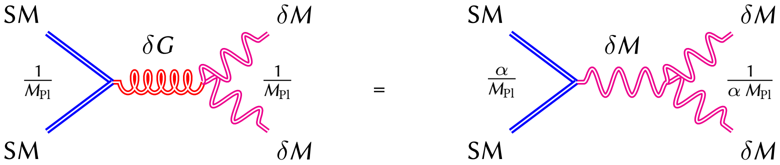
ii. There is no decay of δM into any number of δG

iii. $\delta G \delta M^2$ is 1: the response to δG is the same as SM matter

iv. δM self-interactions are enhanced compared to GR

Production and decay

- The massive spin-2 can be produced via freeze-in:



★ δM decays universally into all SM particles (but not massless gravitons):

$$\Gamma(\delta M \to XX) \simeq \alpha^2 m_{\rm FP}^3/M_{\rm Pl}^2$$

★ The froze-in DM should have the right abundance and not decay too fast: this can be arranged (see next slide).

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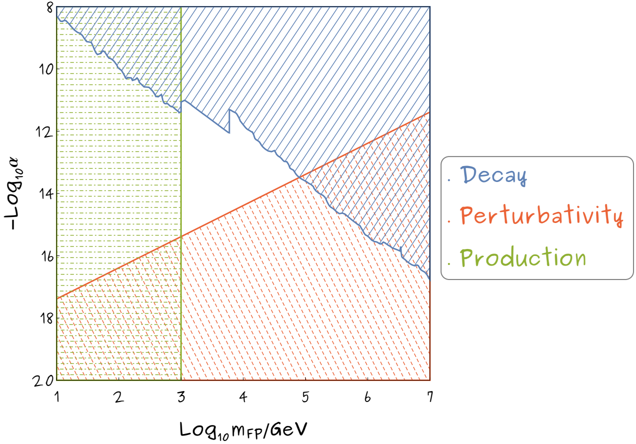

$1\ \text{TeV} \lesssim m_{\text{FP}} \lesssim 66.6\ \text{TeV} \qquad 10^{-12} \lesssim \alpha \lesssim 10^{-16}$