Darker and Heavier

Spin-2 Dark Matter

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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

arXiv:1604.08564 in PRD

and

arXiv:1607.03497 in JCAP

See also Aoki and Mukohyama (2016)

Bimetric theory essentials Hassan and Rosen (2012) x2

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

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:

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

What's in this theory?

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

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

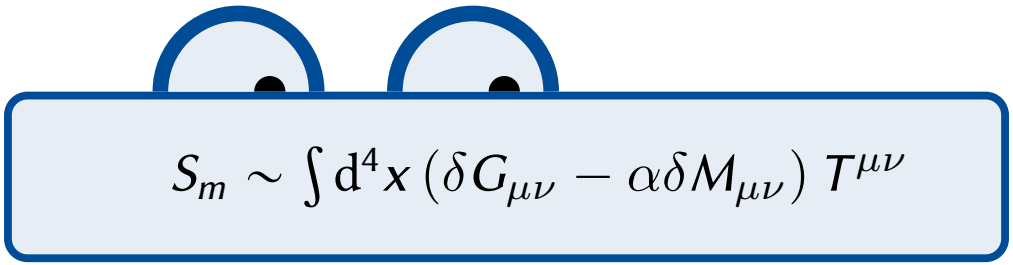
- We have one (linearised) GR for the field δG
- We have one Fierz-Pauli spin-2 field δM and mass $m_{\mathrm{FP}} \sim \sqrt{\beta}_n M_{\mathrm{Pl}}$
- These are mixtures of the interaction eigenstates with parameter α

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

PS: We have defined the physical Planck mass as $M^2_{\mathrm{Pl}} \equiv (1 + \alpha^2) m_g^2$

Matter?

Matter was coupled to $g_{\mu\nu}$ so that at tree-level...



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

Matter automatically couples to both massless δG and massive δM states.

The coupling of δM is proportional to $\alpha/M_{\rm Pl}$

By the way: $\Lambda = \frac{\alpha^2 M_{\rm Pl}^2}{1+\alpha^2}\left(\beta_0 + 3\beta_1 + 3\beta_2 + \beta_3\right) = \frac{M_{\rm Pl}^2}{1+\alpha^2}\left(\beta_4 + 3\beta_3 + 3\beta_2 + \beta_1\right)$

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

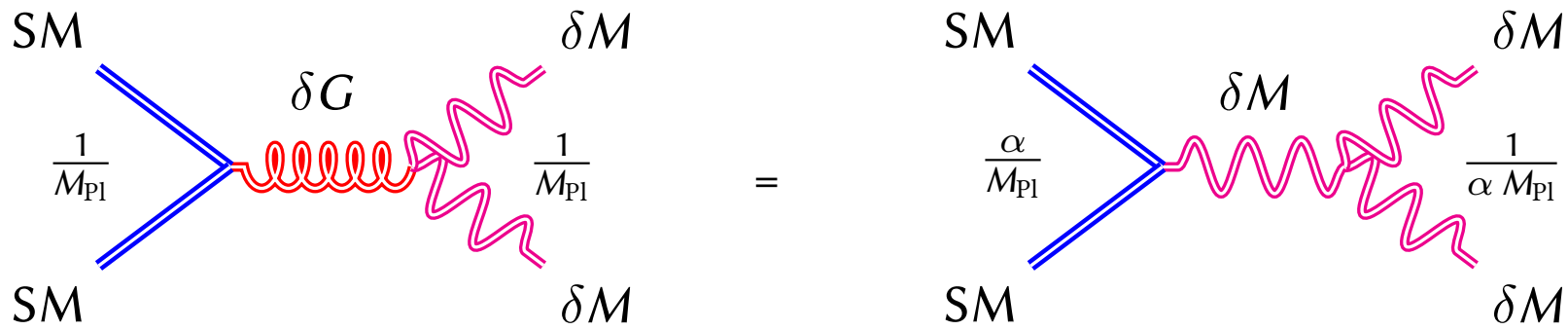
ii. There is no decay of δM into any number of δG

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:

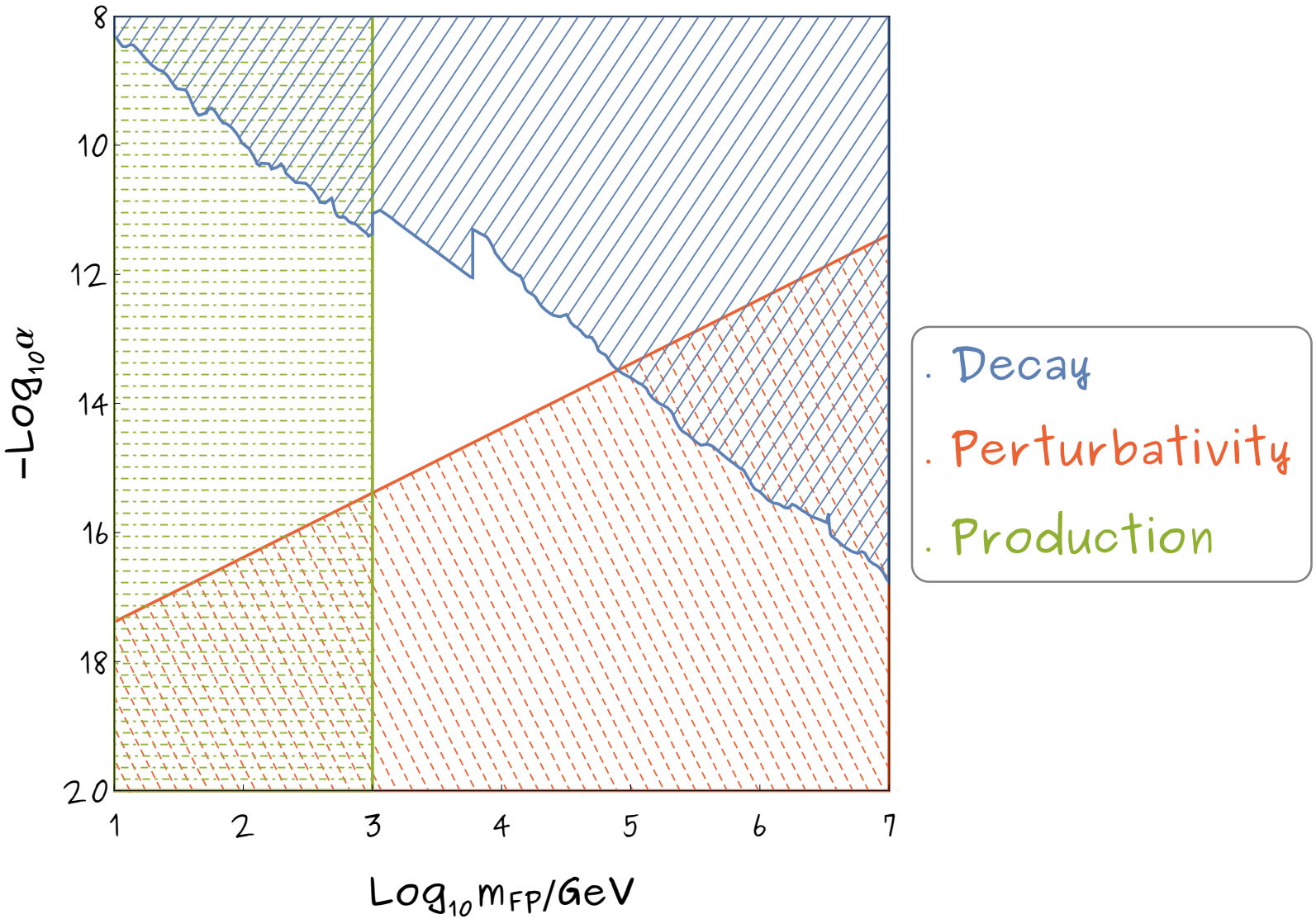


★ δM decays universally into all SM particles (but not massless gravitons):

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

★ The froze-in DM should have the right abundance and not decay too fast: this can be arranged!

The parameter space



Wrapping it up

Bimetric automatically contains a new, massive spin-2 field:

- It gravitates identically to normal matter
- It couples extremely weakly (gravitational strength) to the SM
- It can be produced with correct abundance via freeze-in
- It is heavy, 1÷66 TeV, and is stable enough

We win 😎

Thank you! — Aitäh!