Darker and Heavier
Spin-2 Dark Matter

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Outline

😊 What is bigravity?!?
ν A new heavy spin-2 field
ν Spin-2 Dark Matter
ν 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

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

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 \(\beta_n\)
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)

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

✧ We have one (linearised) GR for the field $\delta G$

✧ We have one Fierz-Pauli spin-2 field $\delta M$ and mass $m_{\mathrm{FP}} \sim \sqrt{\beta_n} M_{\mathrm{Pl}}$

✧ These are mixtures of the interaction eigenstates with parameter $\alpha$

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

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

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

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

Matter automatically couples to both massless $\delta G$ and massive $\delta M$ states.

The coupling of $\delta M$ is proportional to $\alpha/M_{Pl}$

By the way: $\Lambda = \frac{\alpha^2 M_{Pl}^2}{1+\alpha^2} (\beta_0 + 3\beta_1 + 3\beta_2 + \beta_3) = \frac{M_{Pl}^2}{1+\alpha^2} (\beta_4 + 3\beta_3 + 3\beta_2 + \beta_1)$
How does $\delta M$ gravitate?

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i. All $\delta G$ vertices have the same strength as in GR

ii. There is no decay of $\delta M$ into any number of $\delta G$

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

iv. $\delta M$ self-interactions are enhanced compared to GR
Production and decay

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

\[
\frac{\delta G}{M_{Pl}} = \frac{\alpha}{M_{Pl}} \frac{1}{\alpha M_{Pl}}
\]

- \(\delta M\) decays universally into all SM particles (but not massless gravitons):

\[
\Gamma(\delta M \rightarrow XX) \approx \alpha^2 m_{FP}^3 / M_{Pl}^2
\]

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

- Log$_{10} \alpha$
- Log$_{10} m_{FP}/\text{GeV}$

- Decay
- Perturbativity
- Production
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

Thank you! — Aitäh!