Dark Matter with genuine spin-2 fields

Forget Dark Energy, let's modify Gravity for Dark Matter!

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Babichev, Marzola, Raidal, Schmidt-May, FU, Veermäe, von Strauss PRD, JCAP (2017)

Marzola, Raidal, FU PRD (2018)

López Nacir, FU arXiv 18xx.soon; Marzo, Marzola, FU arXiv 18not.so.soon

Bimetric theory essentials   Hassan and Rosen (2012) x2

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

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:

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

What's in this theory?

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

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

- $\mathcal{L}_{\mathrm{GR}}$ 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 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

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

How does δM gravitate?

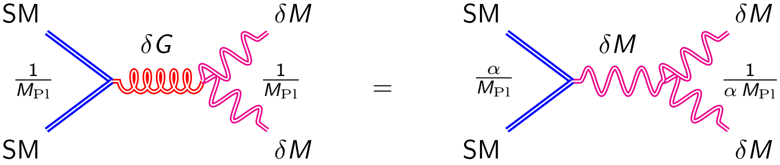
δG^3	$\delta G^2 \delta M$	$\delta G \delta M^2$	δM^3
1	**0**	**1**	$1/\alpha$

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

Phenomenology 1: heavy

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

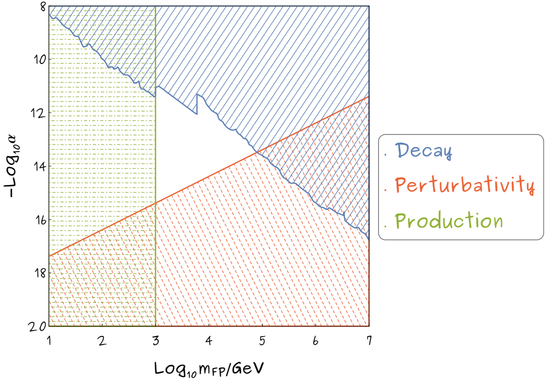


⁎ δM decays universally into all SM particles (but not massless gravitons):

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

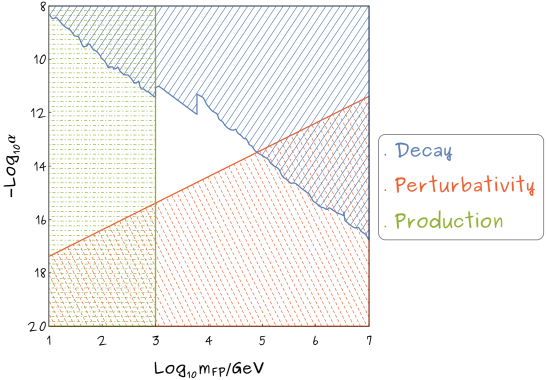
⊛ The froze-in DM should have the right abundance and not decay too fast: this can be arranged (see next slide).

Heavier and darker



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

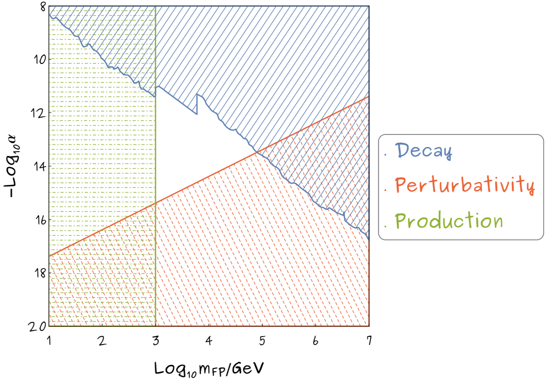
Heavier and darker



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

This range can be extended up to the $\alpha \simeq 1$ region with multiple spin-2 fields González Albornoz, Schmidt-May, von Strauss (2017)

Heavier and darker



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

This range can be extended down to the MeV to GeV region with dark freeze-out via 3-to-2 interactions Chu, Garcia-Cely (2018)

Phenomenology 2: light

A. Fuzzy DM is a very (very) light DM field, usually with $m_{\rm FP} \ll 1$ eV

B. All we need is a potential dominated by the mass term

This is the typical situation for axions and ALP models

C. Late Universe dynamics: $\ddot{M}_{ij} + 3H\dot{M}_{ij} + m^2_{\rm FP} M_{ij} = 0$

- a This means $M_{ij} \sim a(t)^{-3/2} \cos(m_{\rm FP} t)$
- b This means $T_{00} \sim a^{-3}$, and the rest is stuff $\times \cos(m_{\rm FP} t)$
- c This means, averaging over Hubble, $T^{\mu}{}_{\nu} = (\varrho, 0, 0, 0)$ with $\varrho = a^{-3}$
- d This means Dark Matter!

D. The working mass range is roughly 10^{-23}eV$\lesssim m_{\rm FP} \lesssim \mathcal{O}(0.1)$eV

Testing this scenario

1. Fifth force experiments: $\alpha < 10^{-2}$ for $m_{\rm FP} \lesssim \mathcal{O}(0.1)$eV
2. Lab tests: the electric charge oscillates
   - A. Atomic clocks experiments
   - B. Atomic spectroscopy
   - C. Resonant mass detectors
   - D. But: $E_i E_j \pm B_i B_j$ and $E_j B_j \pm B_i E_j$ vs $E^2 - B^2$ and $E \cdot B$
3. Secular change in binary systems orbital parameters
   - I : DM generates an oscillating environment for the binary
   - II : $F^i = R^i{}_{0j0} x^j$
   - III : When oscillations and binary resound we have secular variations
   - IV : $\dot{P} \simeq 10^{-17} (P/100\mathrm{d})^2$ F(Ne)
   - V : In principle detectable with next generation timing data

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Thank You, and...

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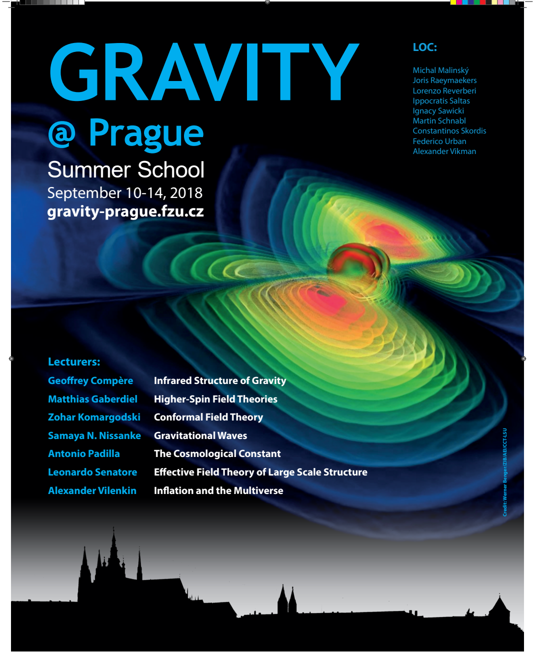

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