

Disformal Extensions to the Rescue

Jack Morrice
in collab. with Carsten van de Bruck
University of Sheffield

The PARTICLE ZOO

Subatomic Particle Plush Toys FROM THE STANDARD MODEL OF PHYSICS & beyond!

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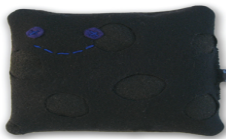
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Is DARK MATTER the key to understanding what the universe is *really* made of and if it will expand forever, remain static or eventually contract? Or is he just a piece of black Swiss cheese? Dark Matter is also part of the [Theoreticals 4-Pack](#) and [Darkness & Light 2-Pack](#). No two are exactly the same. This is the heaviest particle in the Zoo.

Approximately 24 oz/700 grams; 5.5 inches/15 cm across.
For ages 5 and up as it contains glued-on/small parts.

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SHOP ALL PARTICLES](#)

DARK MATTER



DARK MATTER is the name given to material in the Universe that does not emit or reflect light but is necessary to explain observed gravitational effects in galaxies and stars. Dark matter, along with dark energy, totals 96% of the Universe, yet it remains a mystery as to what exactly it is.

Acrylic felt, wool felt, and fleece with gravel fill for maximum mass.

Packaged in a black opaque bag designed for concealing contents.

\$10.49 PLUS SHIPPING



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NEUTRON DOWN QUARK TAU GLUON **DARK MATTER** NEUTRINO TACHYON ELECTRON UP QUARK DOWN
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The PARTICLE ZOO

Dark matter, disformally coupled

Action

$$\mathcal{S} = \int d^4x \sqrt{-g} \left[\frac{\mathcal{R}(g)}{16\pi G} + \underbrace{-\frac{1}{2}(\nabla\phi)^2 - V(\phi)}_{\mathcal{L}_{DE}} + \mathcal{L}_{SM} \right] \\ + \int d^4x \sqrt{-\tilde{g}} \tilde{\mathcal{L}}_{DM}$$

Metric transformation

$$\tilde{g}_{\mu\nu} = C(\phi)g_{\mu\nu} + D(\phi)\partial_\mu\phi\partial_\nu\phi$$

Dark matter, disformally coupled

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$$\mathcal{S} = \int d^4x \sqrt{-g} \left[\frac{\mathcal{R}(g)}{16\pi G} + \underbrace{-\frac{1}{2}(\nabla\phi)^2 - V(\phi)}_{\mathcal{L}_{DE}} + \mathcal{L}_{SM} \right] \\ + \int d^4x \sqrt{-\tilde{g}} \tilde{\mathcal{L}}_{DM}$$

Metric transformation

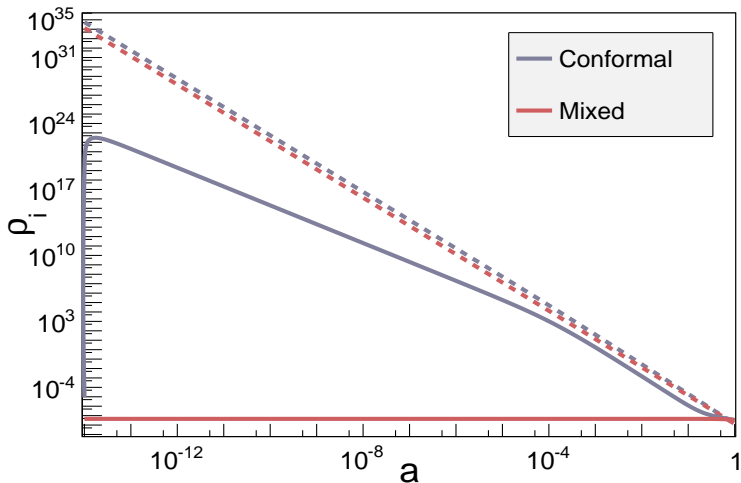
$$\tilde{g}_{\mu\nu} = \mathbf{C}(\phi)g_{\mu\nu} + \mathbf{D}(\phi)\partial_\mu\phi\partial_\nu\phi$$

→ 3 free model functions to play with

Background energy densities

Conformal: $D = 0$, $C = e^{\phi/M_p}$.

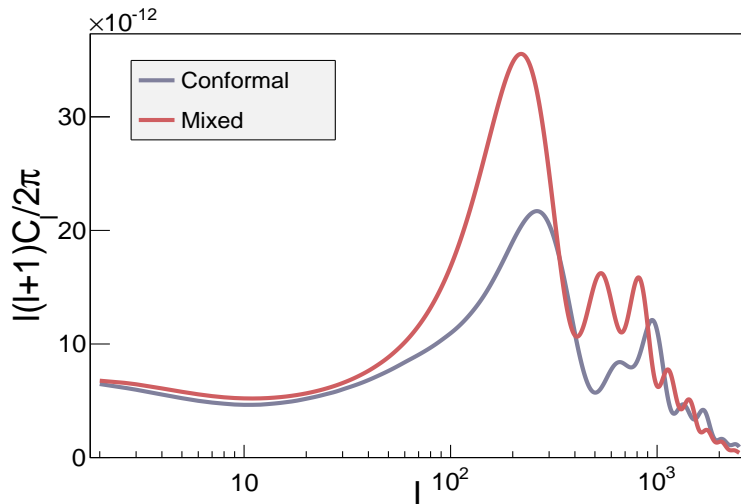
Mixed: add $M_D \sim meV$.



Angular power spectrum

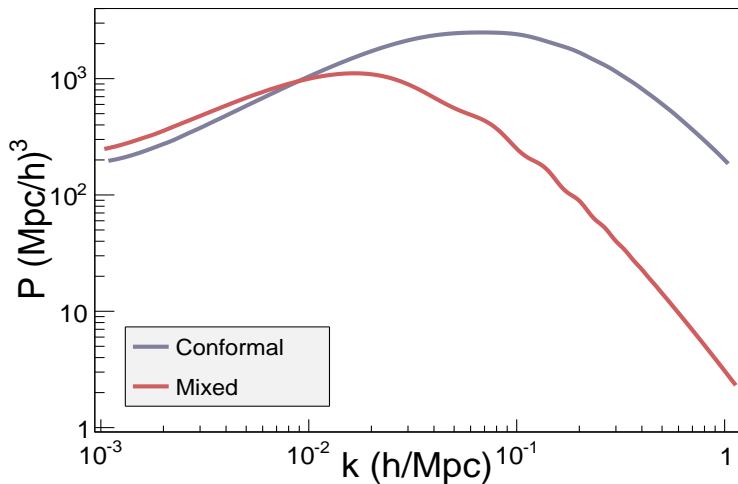
Conformal: $D = 0$, $C = e^{\phi/M_p}$.

Mixed: add $M_D \sim meV$.



Matter power spectrum

Conformal: $D = 0$, $C = e^{\phi/M_p}$. Mixed: add $M_D \sim \text{meV}$.



See also:

- ▶ V. Salvatelli, N. Said, M. Bruni, A. Melchiorri and D. Wands, **“Indications of a late-time interaction in the dark sector,”** Phys. Rev. Lett. **113** (2014) 18, 181301 [arXiv:1406.7297 [astro-ph.CO]].
- ▶ E. Abdalla, E. G. M. Ferreira, J. Quintin and B. Wang, **“New Evidence for Interacting Dark Energy from BOSS,”** arXiv:1412.2777 [astro-ph.CO].
- ▶ C. van de Bruck and J. Morrice, **“Disformal couplings and the dark sector of the universe,”** arXiv:1501.03073 [gr-qc].
- ▶ D. Blas, J. Lesgourgues and T. Tram, **“The Cosmic Linear Anisotropy Solving System (CLASS) II: Approximation schemes,”** JCAP **1107** (2011) 034 [arXiv:1104.2933 [astro-ph.CO]].

TWENTY QUESTIONS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20



DICK

HERB

VAN

FLORENCE

ALDO RAY