Generalized Galileons for Particle Physics & Cosmology

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- Galileons and higher-derivative theories in general, are an intriguing class of scalars that *may* have a shot at addressing some of these problems, and perhaps most interestingly, are tied to attempts to modify gravity such as massive gravity!
- We'll see - too early to know if these will be useful or not - but it is turning out to be great fun trying.

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$$\pi(x) \to \pi(x) + c + b_\mu x^\mu$$

The *Galilean* symmetry!

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Computing Feynman diagrams - terms of the galilean form cannot receive new contributions! More soon.

Luty, Porrati, Ratazzi (2003); Nicolis, Rattazzi (2004)

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So forces much smaller than gravitational strength within the Vainshtein radius - hence safe from 5th force tests.

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Thus, if we canonically normalize the kinetic term of the perturbations, we raise the effective strong coupling scale, and, more importantly, heavily suppress the coupling to matter!

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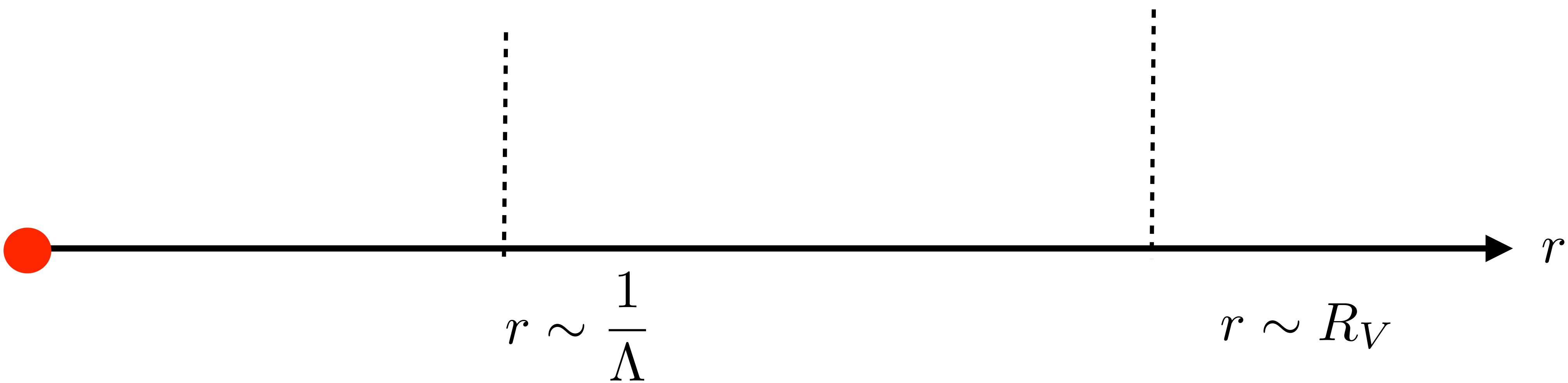

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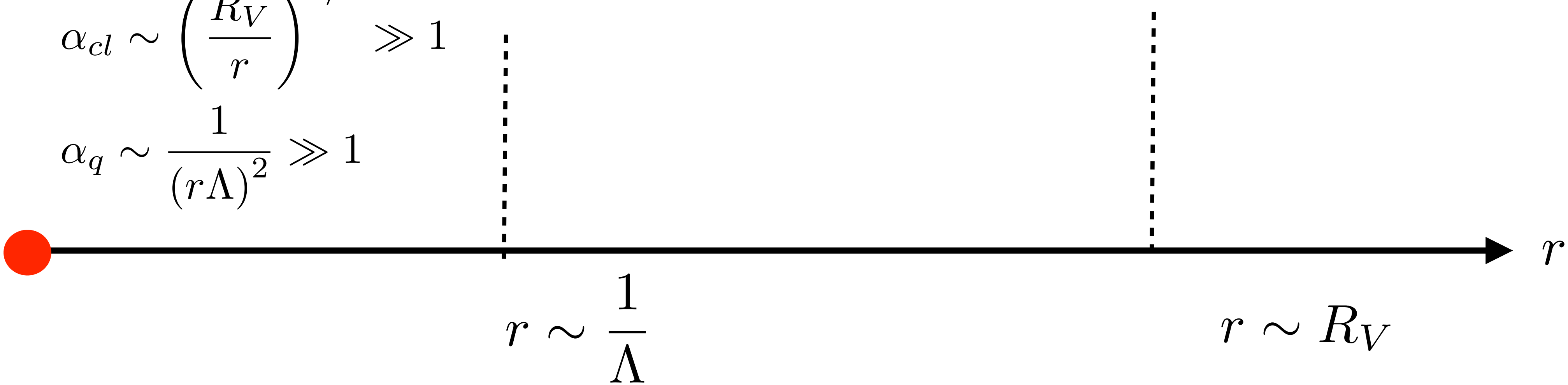

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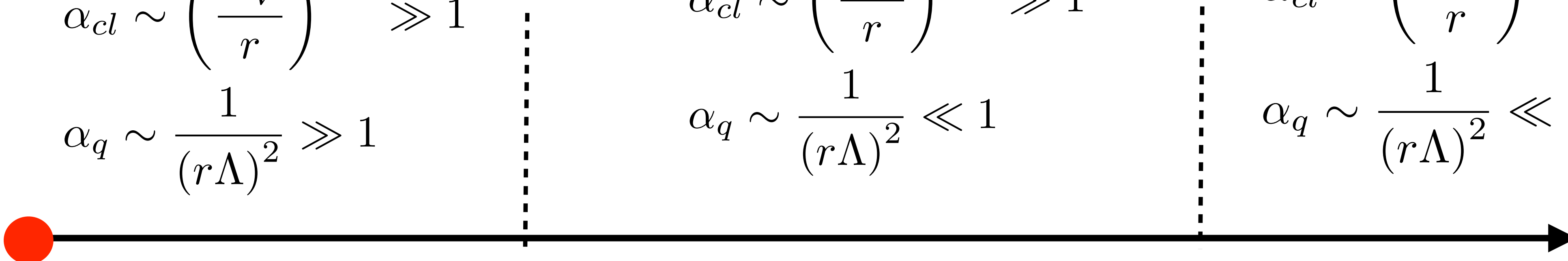

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A new classical regime, with order one nonlinearities

Multi-field Galileons and Higher co-Dimension Branes

Higher co-Dimension Probe Branes

[K. Hinterbichler, M.T., D. Wesley, *Phys. Rev.* D82 (2010) 124018.]

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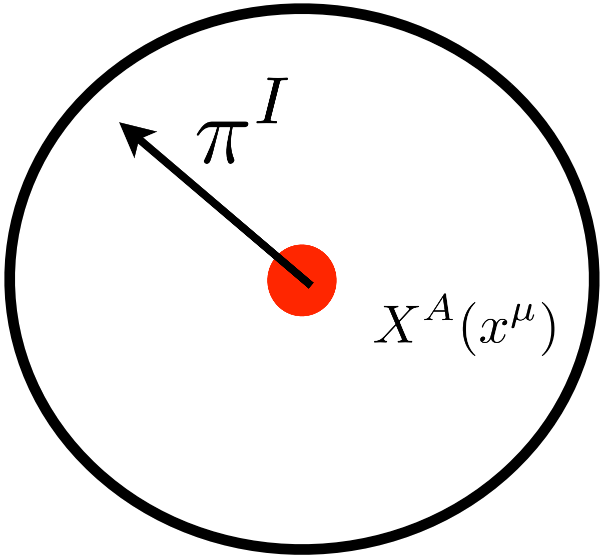

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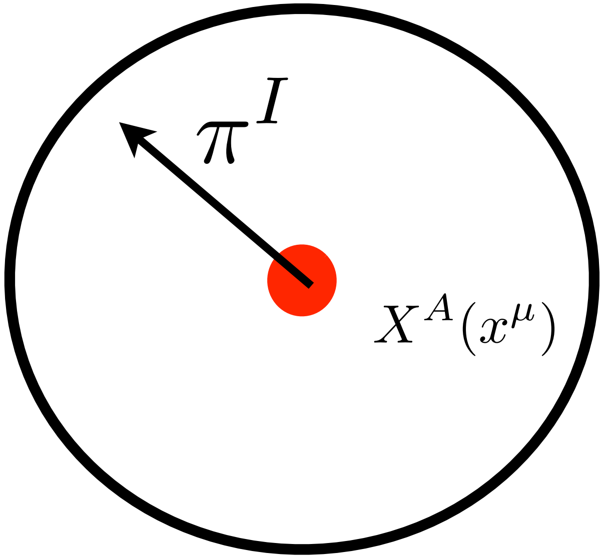

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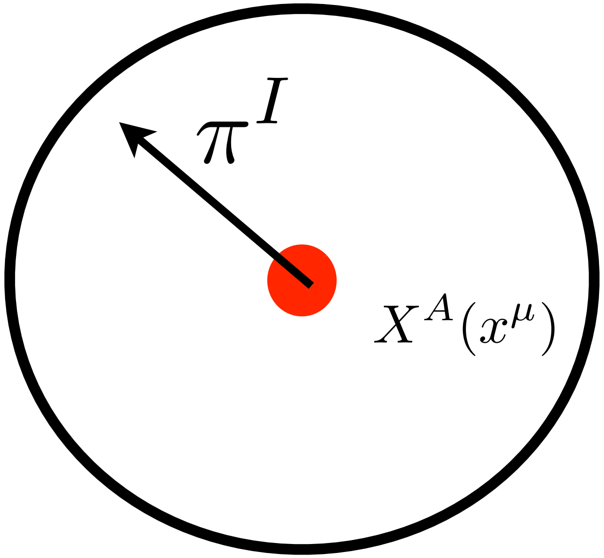

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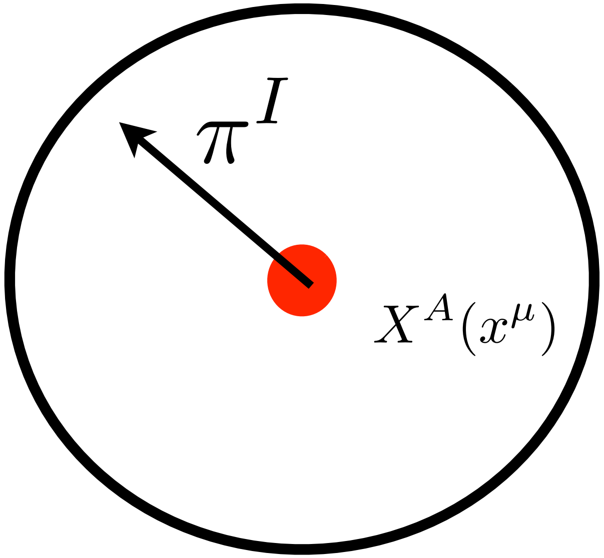

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$$S = \int d^4x \, \sqrt{-g} F\left(g_{\mu\nu}, \nabla_\mu, R^i{}_{j\mu\nu}, R^\rho{}_{\sigma\mu\nu}, K^i_{\mu\nu}\right)\Big|_{g_{\mu\nu}=\eta_{\mu\nu}+\partial_\mu\pi^I\partial_\nu\pi_I}$$

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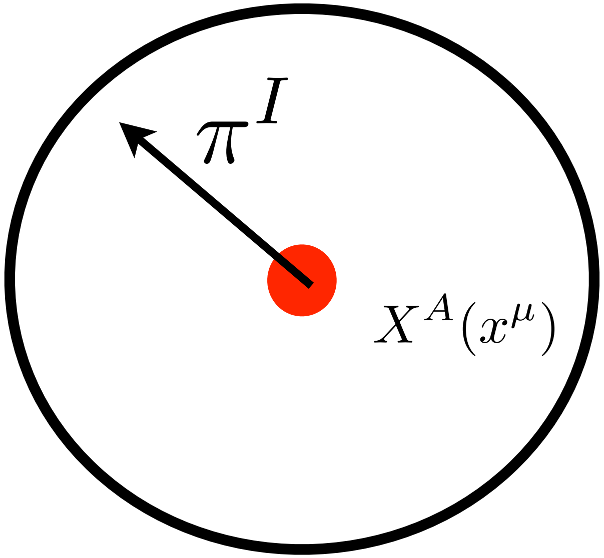

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More general version of action de Rham & Tolley wrote

Covariant Derivative

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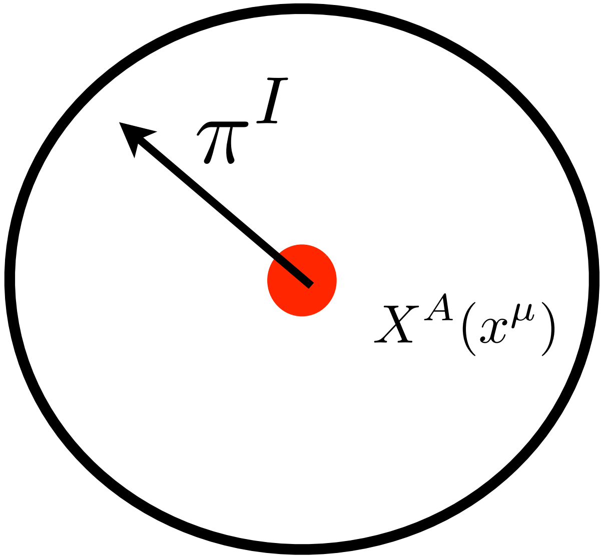
Higher co-Dimension Probe Branes

[K. Hinterbichler, M.T., D.Wesley, *Phys. Rev.* D82 (2010) 124018.]



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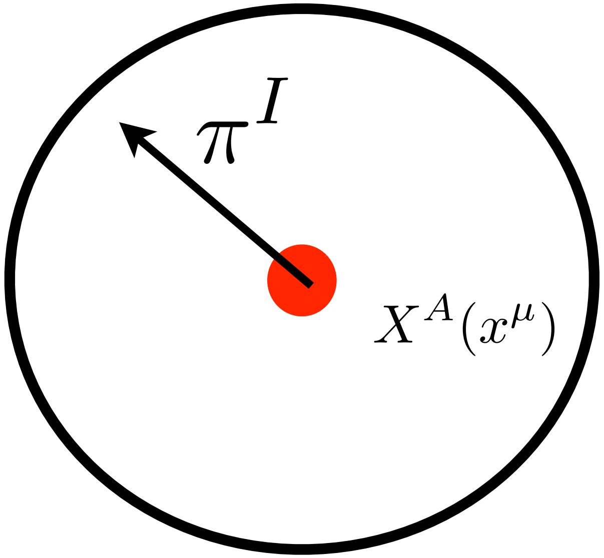

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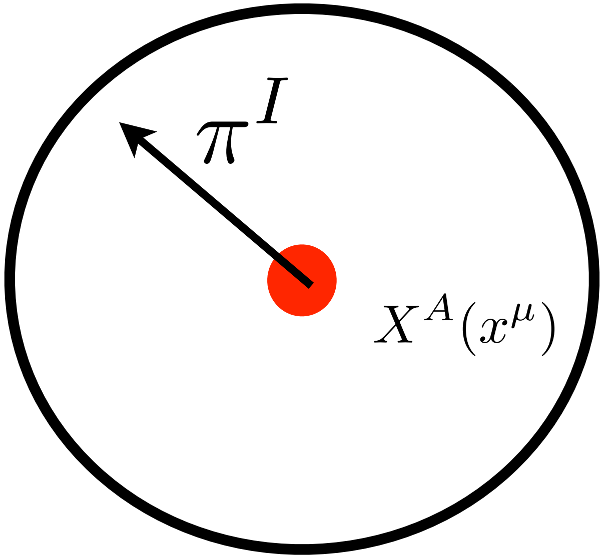

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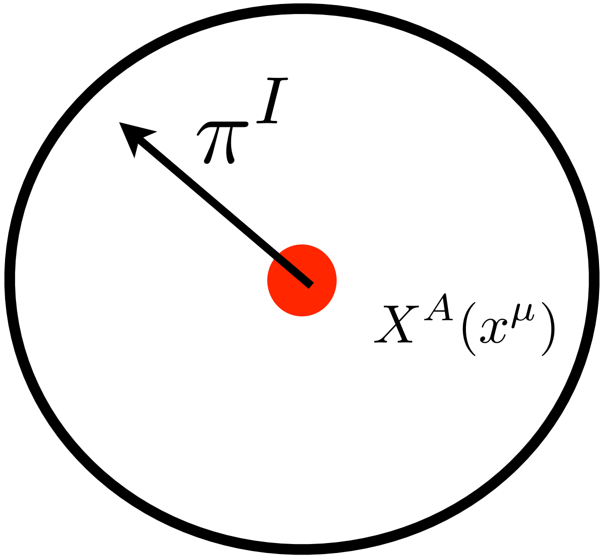

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Extrinsic curvature
Normal Bundle Curvature

In co-dimension1, for 2nd order equations, use Lovelock terms and associated boundary terms. Here, for 4d brane, prescription *depends on co-dimension*

If N = 2, boundary terms include only brane cosmological constant, and

$$\mathcal{L}_{N=2} = \sqrt{-g}\left(R[g] - (K^i)^2 + K^i_{\mu\nu}K_i^{\mu\nu}\right)$$

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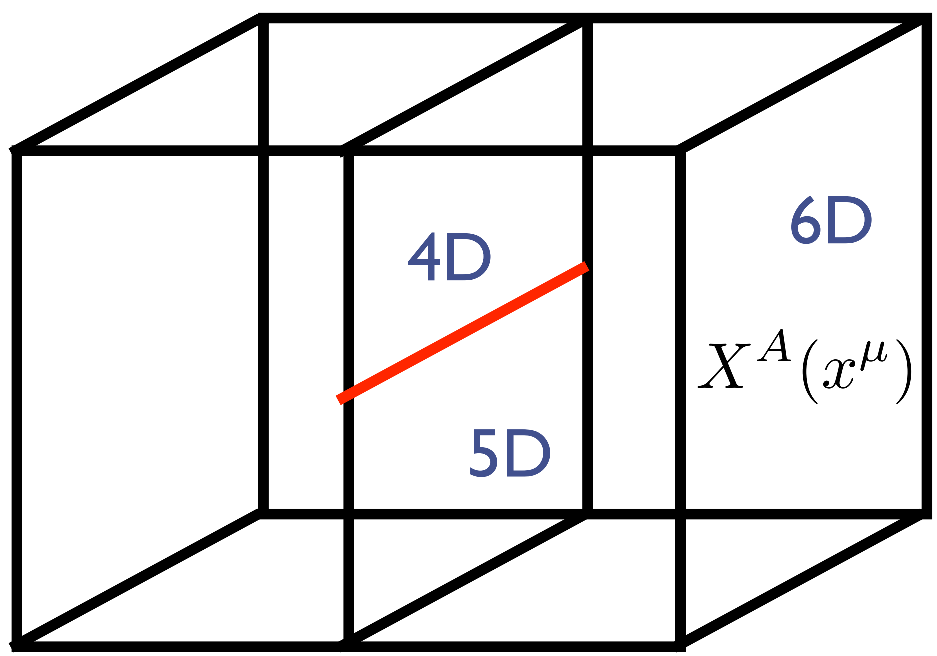

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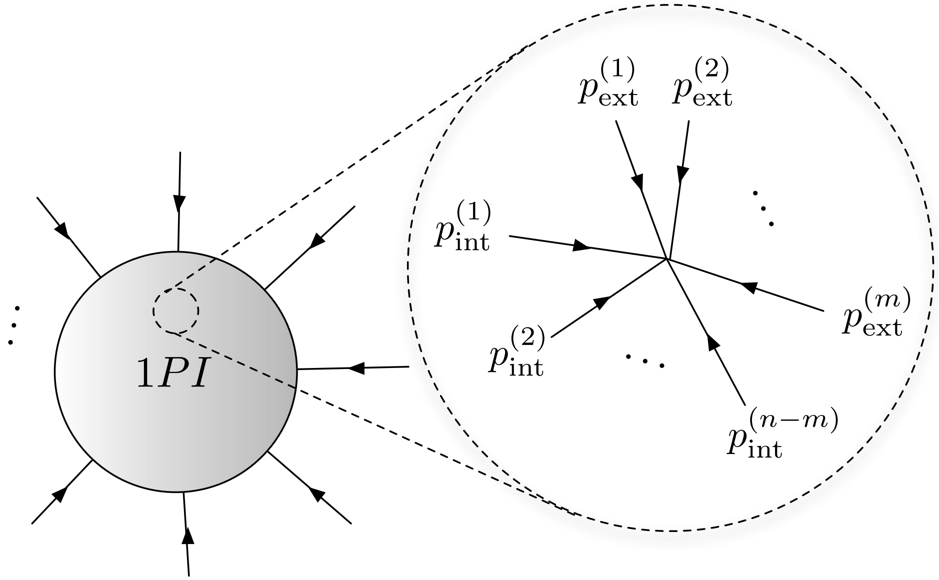

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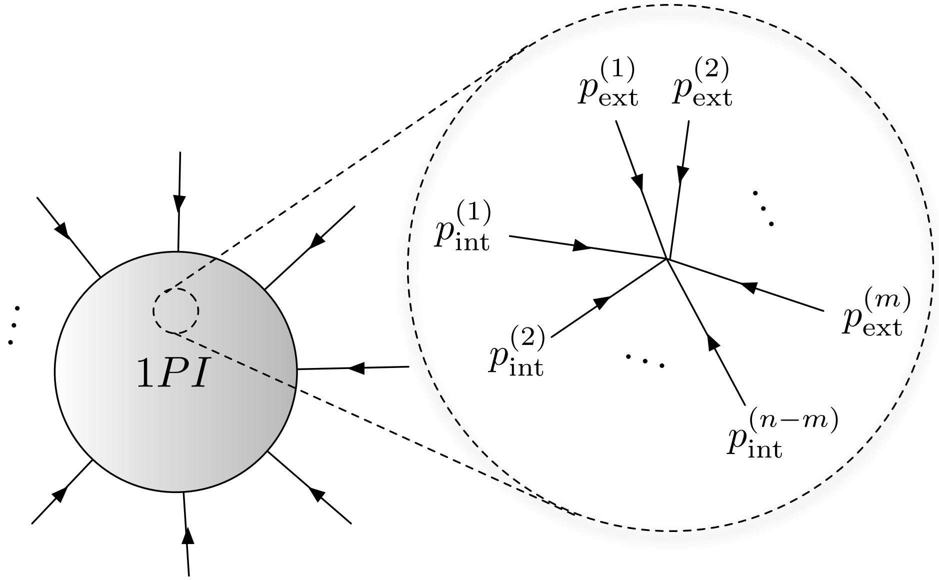

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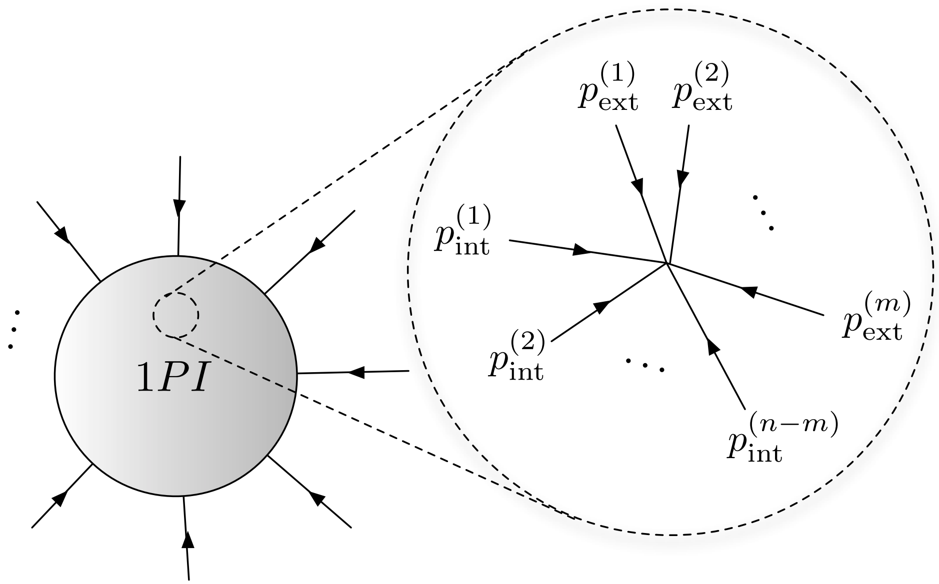

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Can even add a mass term and remains technically natural

Generalized Galileons on Curved Geometries

Galileons on General Backgrounds

[Goon, Hinterbichler, M.T., *Phys. Rev.Lett.* 106, 231102 (2011).
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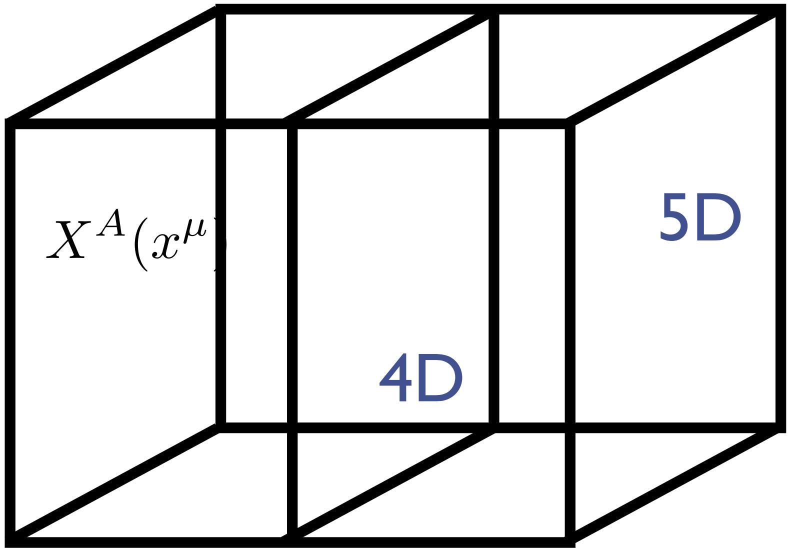

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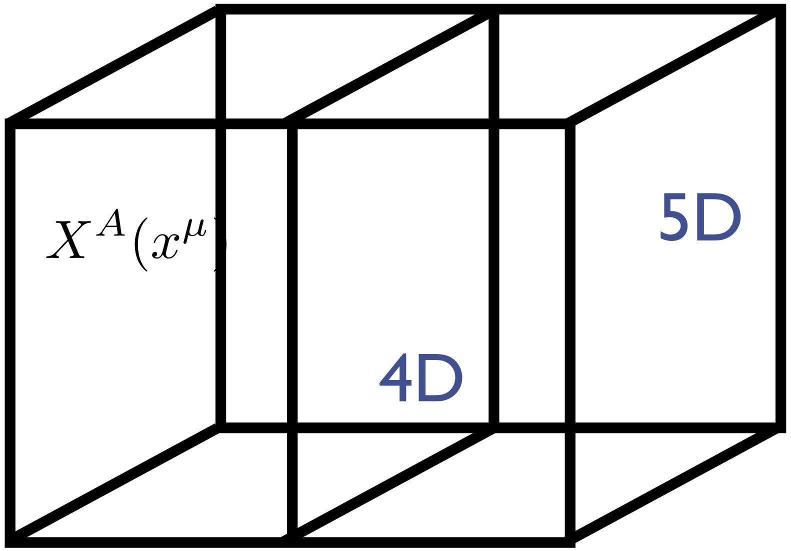

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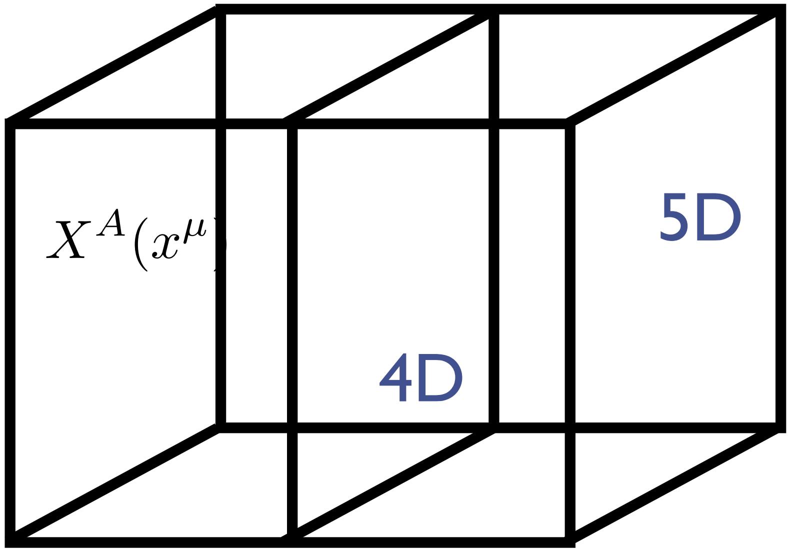

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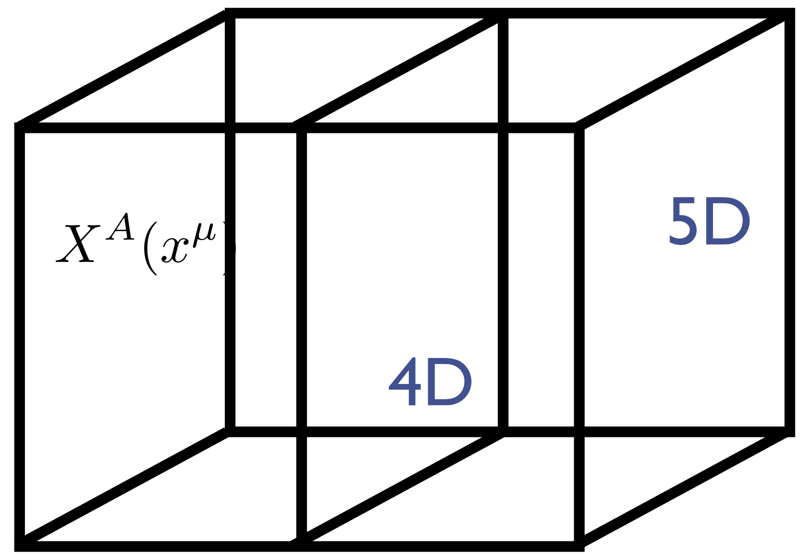

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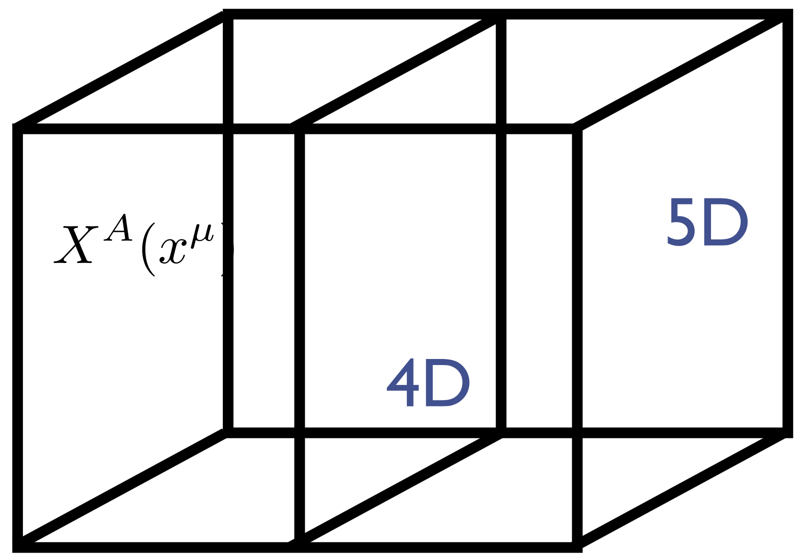

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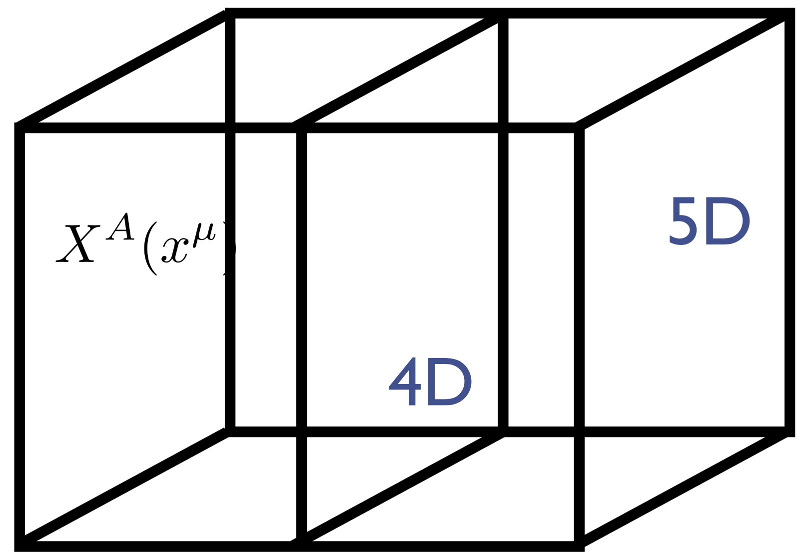

Galileons with symmetry

$$(\delta_K + \delta_{g,\text{comp}})\pi = -a^i k_i^\mu(x)\partial_\mu \pi + a^I K_I^5(x,\pi) - a^I K_I^\mu(x,\pi)\partial_\mu \pi$$

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Brane metric (columns) / Ambient metric (rows)

	AdS_4	M_4	dS_4
AdS_5	AdS DBI galileons $so(4,2) \to so(3,2)$ $f(\pi) = \mathcal{R}\cosh^2(\rho/\mathcal{R})$	Conformal DBI galileons $so(4,2) \to p(3,1)$ $f(\pi) = e^{-\pi/\mathcal{R}}$	type III dS DBI galileons $so(4,2) \to so(4,1)$ $f(\pi) = \mathcal{R}\sinh^2(\rho/\mathcal{R})$
M_5	×	DBI galileons $p(4,1) \to p(3,1)$ $f(\pi) = 1$	type II dS DBI galileons $p(4,1) \to so(4,1)$ $f(\pi) = \pi$
dS_5	×	×	type I dS DBI galileons $so(5,1) \to so(4,1)$ $f(\pi) = \mathcal{R}\sin^2(\rho/\mathcal{R})$

Small field limit ↓

AdS galileons	normal galileons	dS galileons

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  - Supersymmetrization
  - An appearance in the decoupling limit of some massive gravity theories (I'll mention a little more in my plenary)

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- Have also shown how to extend the probe brane construction to higher co-dimension branes, yielding multi-Galileon theories.
- Couplings to matter and stability still need investigating in generality - some simple couplings display instabilities.

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Thank You!

Acknowledgements & References

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