Effective Field Theories

in Cosmology

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credit: Quentin Blake

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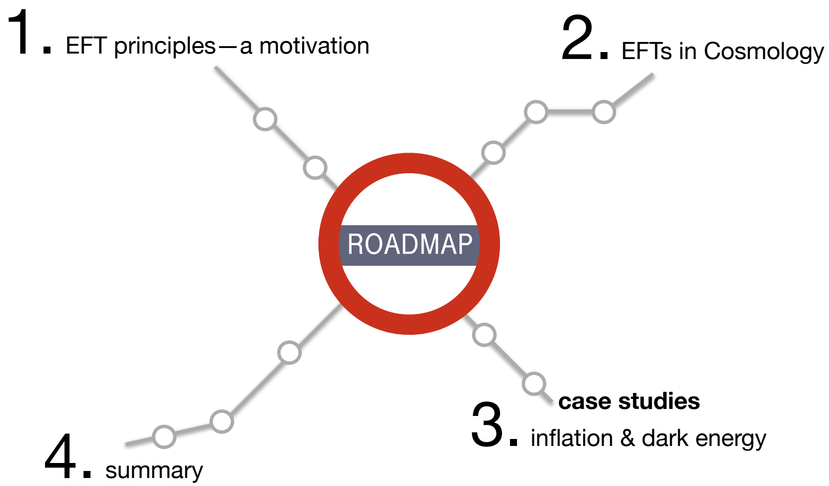

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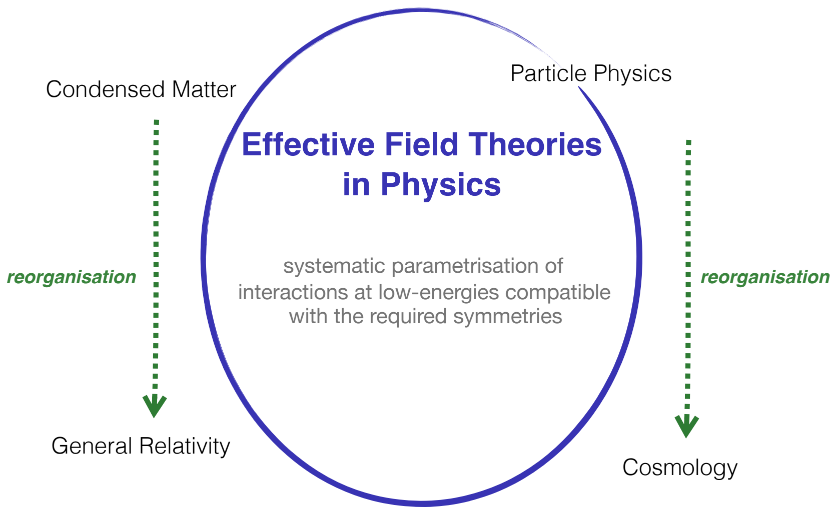
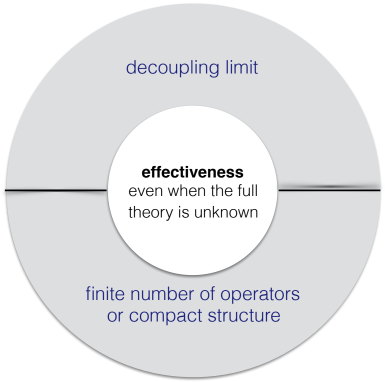
1 EFT principles

"effective"
=successful in producing a desired or intended result

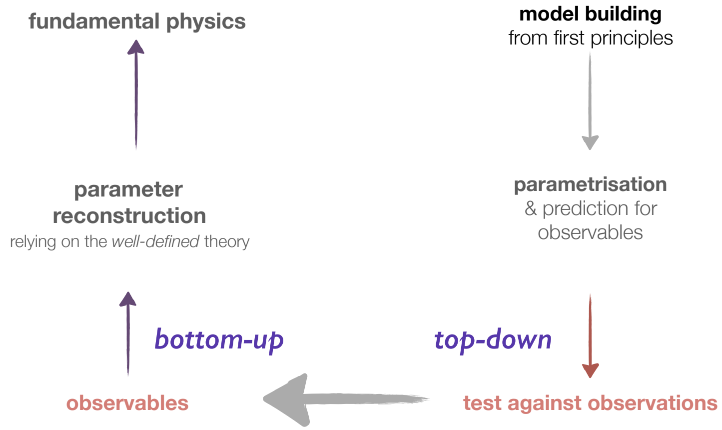


traditional principles of EFTs

- why are they **effective**?

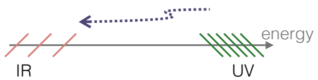


to top-down and to bottom-up

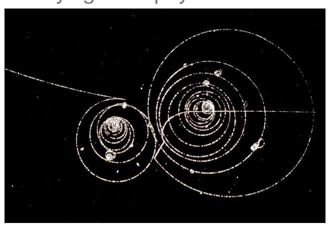


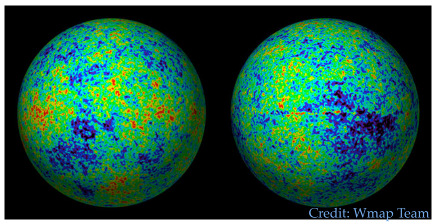
advantages of an EFT approach

- systematic approach to parametrise our ignorance about fundamental physics, without commitment to a specific model
- provides a clear notion of separation of scales



- need not know the complete theory, but can look for hidden signatures of the underlying microphysics



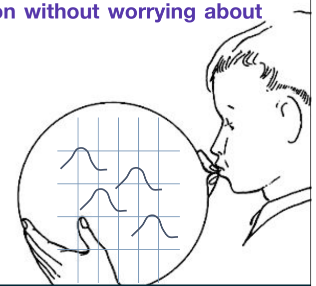


2 EFTs in Cosmology

inflationland

- can we devise theory tests which are complementary to observational constraints?
- **can we have a self-consistent theory for inflation without worrying about quantum gravity?**

Every inflation model necessarily needs to address the issue of quantum corrections.



what is the physics of dark energy?

- what is the scalar field theory that describes dark energy?
- **is there an EFT of cosmic acceleration that is consistent with GR at small scales?**

traditional EFTs in flat spacetime

- write a tower of interactions which are categorised by power counting

$$\mathscr{L}_{tEFT}(\phi) = \int \mathrm{d}^4 x \left\{ \mathscr{L}_{\text{low-energy}} + \sum_i c_i \frac{\mathcal{O}_\beta(\phi)}{\Lambda^\beta} \Lambda^4 \right\}$$

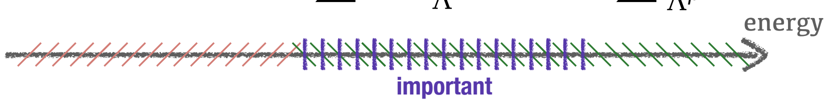
- study the organisation of the EFT—e.g. which operators are important?
- the accuracy of the computed observables becomes crucial in truncating the operator expansion

EFTs in a gravitational context

Relevant for inflation models that predict large equilateral non-gaussianity and screening mechanisms

relevant | irrelevant

$$\mathscr{L}_{\text{EFT}} = \mathscr{L}_{\text{low-energy}} + \sum \frac{f_\alpha(\partial\phi, \partial^2\phi)}{\Lambda^\alpha} \Lambda^4 + \sum \frac{\mathcal{O}_\beta}{\Lambda^\beta} \Lambda^4$$



reorganised EFT built on a hierarchy between (different orders in) derivatives

3 EFT lessons on **inflation** and **modified gravity**

how can UV physics come in?

Suppose the theory is

$$\mathscr{L}_{\text{classical}} = c_1 \mathrm{O}_1 + c_2 \mathrm{O}_2$$

1. are the c_n coefficients corrected by high energy physics? $\mathscr{L}_{\text{classical}} = \tilde{c}_1 \mathrm{O}_1 + \tilde{c}_2 \mathrm{O}_2$
2. does high energy physics introduce extra operators? $\mathscr{L}_{\text{classical}} = \tilde{c}_1 \mathrm{O}_1 + \tilde{c}_2 \mathrm{O}_2 + c_3 \mathrm{O}_3$

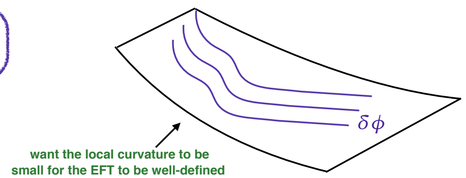
Pick up a theory. We can determine its **regime of validity** by requiring

$$|\mathscr{L}_{\text{classical}}| \gg |\mathscr{L}_{\text{one-loop}}|$$

geometrical intuition

- when are these UV effects small?

$$\sqrt{g_{\text{eff}}}\, |R^2[g_{\text{eff}}]| \ll \Lambda^4 \, P(X)$$

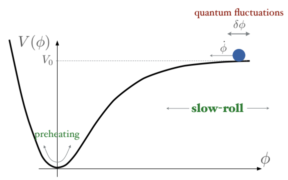


Barvinsky & Vilkovisky Phys.Rept. 119 (1985) & Nucl.Phys. B333 (1990)

Avramidi arXiv:math-ph/0107018

early universe

single-field inflation



As the field rolls down the potential, it quantum-mechanically fluctuates.

Consider a homogeneous scalar field.

Silverstein & Tong hep-th/0310221

Consider a specific class of P(X) models: Dirac—Born—Infeld [DBI] theories

$$\mathscr{L}_{\text{DBI}} = -\Lambda^4 \sqrt{1 - X} + \Lambda^4 \qquad X = \frac{\dot{\phi}^2}{\Lambda^4}$$

In the strongly coupled regime, we have $|X| \lesssim 1$ and $\gamma \equiv \frac{1}{\sqrt{1-X}} \gtrsim 1$

DBI inflation: theory **and** data constraints

$$\mathscr{L}_{\rm DBI} = -\Lambda^4\sqrt{1-X} + \Lambda^4 \simeq \frac{1}{2}\dot\phi^2 + \frac{1}{8}\frac{\dot\phi^4}{\Lambda^4} + \cdots$$ while $\dot\phi_0 \sim \Lambda^2$

What controls the EFT of DBI operators?

Regime of predictability of the EFT:

$$|\mathscr{L}_{\rm classical}| \gg |\mathscr{L}_{\rm 1-loop}| \longrightarrow \frac{\ddot\phi_0}{\Lambda^3} \ll \gamma^{-3} \sim {\rm O}(10^{-3})$$

using Planck's constraints

we learn about the background field dynamics

with Rham
arXiv:1405.5213

EFT and standard perturbation theory

Two complementary constructions which can be used to learn more about the background theory of inflation.

EFT rules tell us how perturbation theory is organised.

Example: consider the theory of the primordial fluctuation.

$$S[\zeta] = S^{(2)} + S^{(3)} + \cdots$$

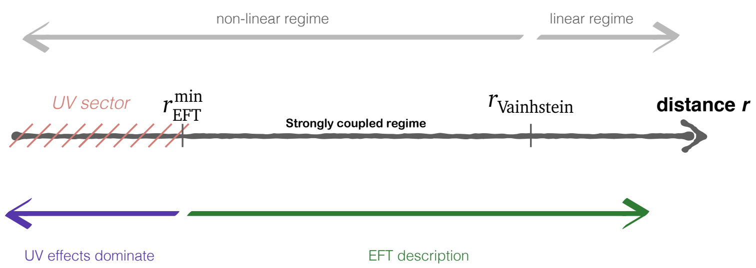
$$h_{ij} = a^2(t)e^{2\zeta(t,\vec x)}\delta_{ij}$$

can do the perturbation theory analysis assuming smallness of the fluctuation

and/or can use EFT rules
with Kenton, Mulryne & Thomas

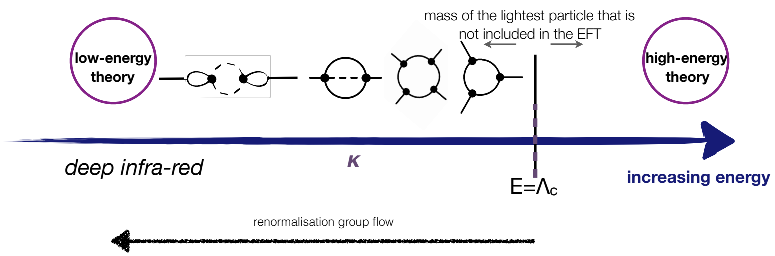
Class of dark energy theories

Vainshtein PLB39 (1972)
Babichev & Deffayet arXiv:1304.7240
Babichev et al. arXiv: 0905.2943



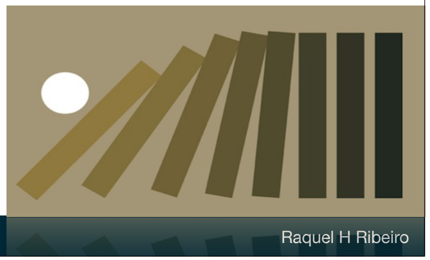
e.g. smallest scale for dark energy EFTs

tells you how the Lagrangian runs with scale

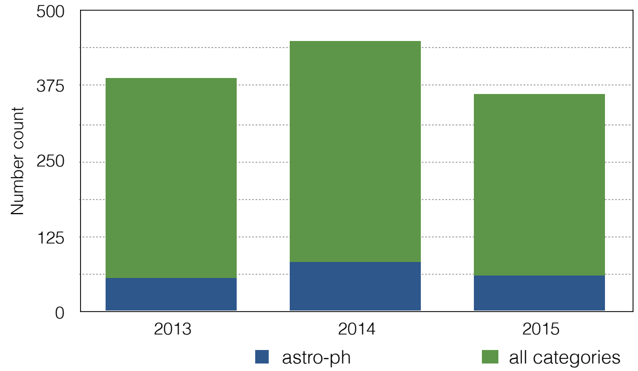


sheds light into the range of screening mechanisms

4 summary



trending 'EFT' in the Arxiv

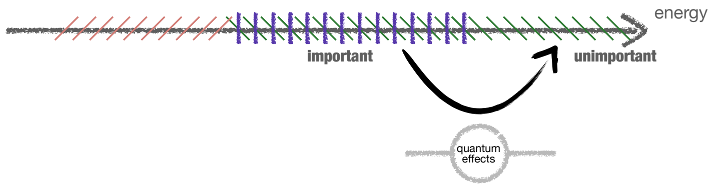


EFTs as a toolkit

with Rham
arXiv:1405.5213

relevant | irrelevant

$$\mathscr{L}_{\text{EFT}} = \mathscr{L}_{\text{low-energy}} + \sum \frac{f_\alpha(\partial\phi, \partial^2\phi)}{\Lambda^\alpha}\Lambda^4 + \sum \frac{\mathcal{O}_\beta}{\Lambda^\beta}\Lambda^4$$



- notion of theory error becomes clearer
- **the range of scales of the EFT is defined**
- **learn about the background from the theory itself**