Extra-Hubble EFT, Open EFT & Inflation

Large fields,
open systems
and inflation

Cliff Burgess

Why EFTs?

- *Decoupling:* short-distance physics is largely irrelevant for long-distance physics
  - EFTs concisely express what is important at long distances

Patron Saint of All Things Natural

Why EFTs?

- *Decoupling:* short-distance physics is *largely* irrelevant for long-distance physics
  - EFTs concisely express what is important at long distances
  - *Cosmology likes the unnatural! (what UV completions hate)*

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Outline

- Natural inflation revisited
  - Trigonometric, exponential and power-law potentials *(1306.3512 and 1404.6236)*
    w Cicoli, Quevedo & Williams

- Open EFTs and EFTs w/o effective lagrangians
  - Decoherence, stochastic inflation and the EFT outside the horizon *(1408.5002)*
    w Holman, Tasinato & Williams

Part I

EFTS W/O EFF LAGRANGIANS

Open EFTs

Effective theory outside the horizon

EFTS W/O EFF LAGRANGIANS

EFTs w/o Effective Lagrangians

- Open EFTs

EFTs w/o Effective Lagrangians

- Op

Usually EFTs rely on simplicity when $E < M$ to summarize high-energy effects for low-energy observables in terms of an effective Lagrangian.

$$e^{iS_{eff}(\varphi)} = \int D\psi \; e^{iS(\varphi,\psi)}$$

S_{eff} *is simple when expanded in* ∂ / M

EFTs w/o Effective Lagrangians

- Op

Such a description is not in general possible for open systems, even when degrees of freedom may be integrated out.

eg: particle moving through a medium

courtesy Scientific American

EFTs w/o Effective Lagrangians

- O[...]

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L_{eff} need not exist since in general pure states can evolve to mixed due to ability to exchange info

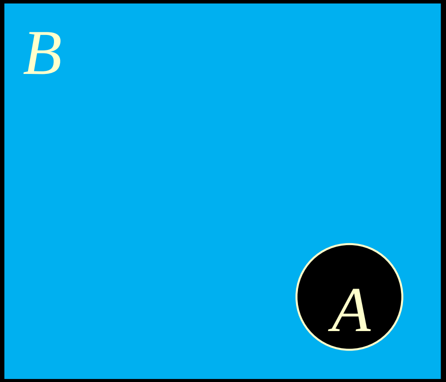
courtesy Scientific American

EFTs w/o Effective Lagrangians

• O|

EFT nonetheless can exist: *ie things can simplify given a hierarchy of scales*.

Divide system into small observed subsystem, A, in presence of a large environment, B:



$$H = H_A + H_B + V$$

then simplifications can arise when

$$t_c \ll t_p$$

Where t_c is the correlation time of V in B and t_p is the time beyond which perturbation in V fails.

EFTs w/o Effective Lagrangians

- Op

For such a system evolution over times $t \gg t_p$ can be computed by computing a coarse-grained evolution:

$$(d\rho_A/dt)_{cg} = \frac{1}{\Delta t}\, Tr_B[U(\Delta t)\rho\, U^*(\Delta t)]$$

for $t_c \ll \Delta t \ll t_p$ and integrating.

for $A \ll B$ this limit this is a Markov process

EFTs w/o Effective Lagrangians

- Op

Because $\Delta t \ll t_p$ evolution can be computed in perturbation theory: *if*

$$\langle V(t)V(t')\rangle_B - \langle V(t)\rangle_B \langle V(t')\rangle_B = \tau\, \delta(t-t')$$

$$and \;\; \bar{V} = \langle V\rangle_B \; then$$

$$(d\rho_A/dt)_{cg} = i[\bar{V}, \rho_A] + \tau\, Tr_B\{V^2\rho_A + \rho_A V^2 - 2V\rho_A V\} + \cdots$$

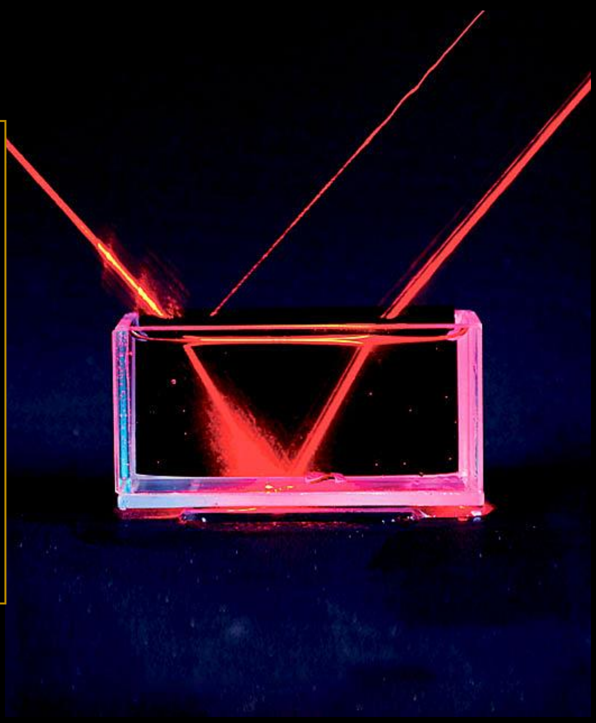
EFTs w/o Effective Lagrangians

- Op

For such a system evolution over times $t \gg t_p$ can be computed by computing a coarse-grained evolution:

This is what allows calculation of light propagation over distances for which scattering from atoms is 100% likely

for $A \ll B$ *in this limit thi*



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EFTs w/o Effective Lagrangians

- Open EFTs

- Effective theory outside the horizon

EFTs w/o Effective Lagrangians

CB, Holman, Tasinato & Williams

- O[...]
- Ef[...]

Q: What is the effective theory outside the Hubble scale during inflation?

Claim: this is described by an Open EFT

System A: extra-Hubble modes: $\frac{k}{a} \ll H$

System B: intra-Hubble modes: $\frac{k}{a} > H$

Correlation time: $t_c \approx H^{-1}$

EFTs w/o Effective Lagrangians

CB, Holman, Tasinato & Williams

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Calculation of off-diagonal matrix elements of ρ_A:

suppose $V = \int A^i B_i \, d^3x$

and $\langle \delta B_i(x) \, \delta B_j(x') \rangle = U_{ij}(x) \, \delta(t - t')$

also extra-Hubble squeezing of modes implies

$$A^i(\Phi, \Pi)\big|\varphi > \to A^i(\Phi, 0)\big|\varphi > = \alpha^i(\varphi)|\varphi >$$

so A^i is always diagonal in field eigenbasis

EFTs w/o Effective Lagrangians|

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- O
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Calculation of off-diagonal matrix elements of ρ_A:

then can integrate equation for ρ_A in field basis:

$$\langle\varphi|\rho_A|\tilde{\varphi}\rangle = \langle\varphi|\rho_{A0}|\tilde{\varphi}\rangle e^{-\Gamma}$$

where $\Gamma = \int d^3x dt\ \left[\alpha^i - \tilde{\alpha}^i\right]\left[\alpha^j - \tilde{\alpha}^j\right]U_{ij}$

implies off-diagonal elements *decohere* as with variance narrowing on Hubble times: $\sigma^{-2} \propto a^3$

EFTs w/o Effective Lagrangians

Starobsinky, Yokoyama

- Op
- Ef

What of the diagonal matrix elements of ρ_A?

For these $\Gamma = 0$ and so the probabilities are governed by initial quantum state.

$$\mathrm{P}[\varphi] = \langle \varphi | \rho_A | \varphi \rangle = |\Psi(\varphi)|^2$$

Schrodinger evolution plus tracing of sub-Hubble modes implies P satisfies $\frac{\partial P}{\partial t} = N \frac{\partial^2 P}{\partial \varphi^2}$ with $N = H^3/8\pi^2$ as in *Starobinsky stochastic inflation*

EFTs w/o Effective Lagrangians

- Op
- Ef

Summary:

Open systems provide a new type of EFT where simplicity of scale hierarchy is not captured by an effective lagrangian

Appropriate for EFT outside inflationary Hubble scale, and provides derivation of Starobinsky's stochastic inflation as well as the rapid decoherence of primordial quantum fluctuations.

Fin