Cosmology meets Quantum Gravity ?

Sergey Sibiryakov

Benasque, 08/08/14

plethora of inflationary models

vs.

limited experimental information

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bottom-up

Effective theory of inflation

Cheung et al. (2008)

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Effective theory of inflation

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Postulate theoretical requirements to restrict the inflationary sector

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- As minimal as possible / falsifiable
- Connected to particle physics
- Embedded into a UV complete theory including gravity

Examples of minimal models

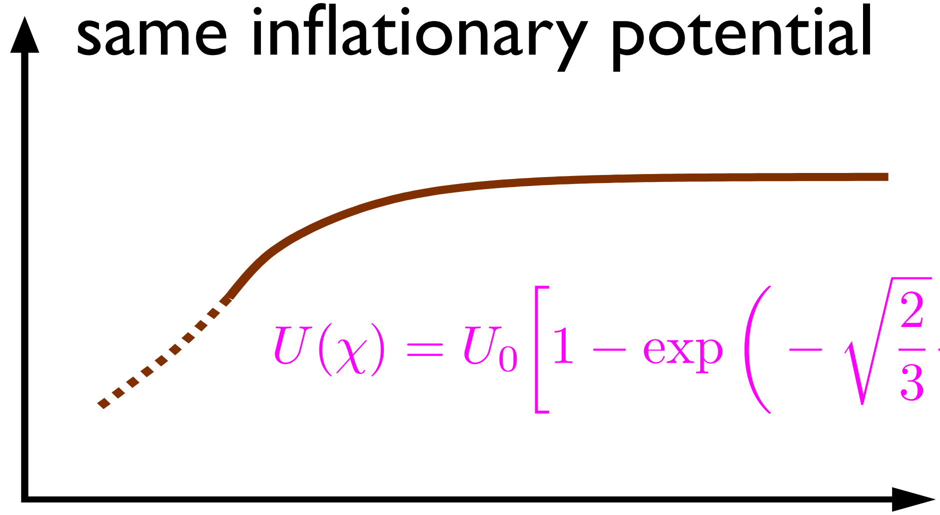
Starobinsky

$$-\frac{M_P^2 R}{2} + \frac{R^2}{6f_0^2} + \mathcal{L}_{SM}$$

Higgs

$$-\frac{M_P^2 R}{2} - \xi H^\dagger H R + \mathcal{L}_{SM}$$

same inflationary potential



$$U(\chi) = U_0\left[1 - \exp\left(-\sqrt{\frac{2}{3}}\frac{\chi}{M_P}\right)\right]^2$$

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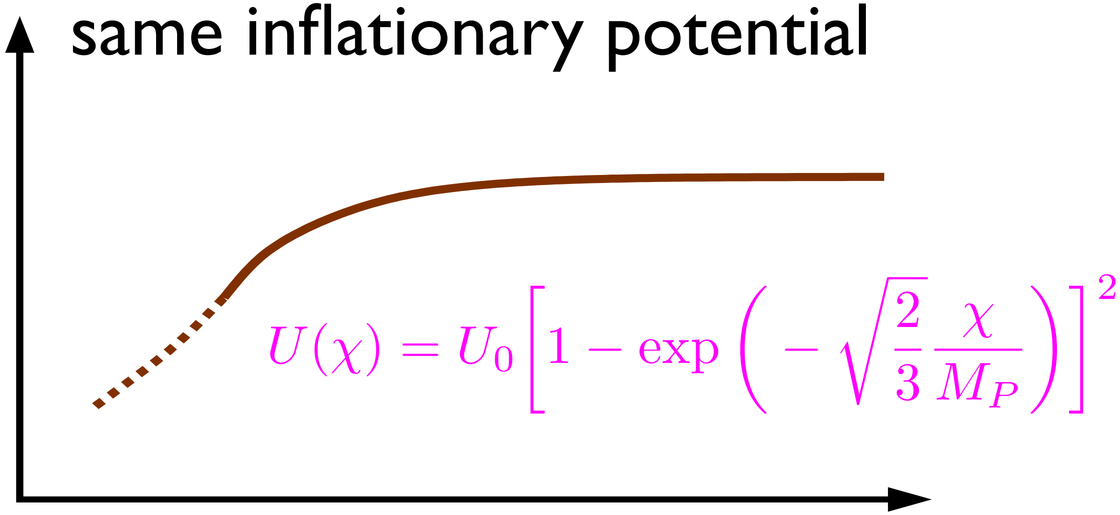


but (slightly) different predictions because of different reheating

Bezrukov & Gorbunov (2011)

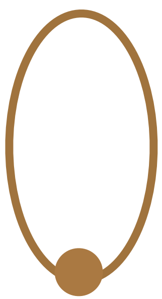
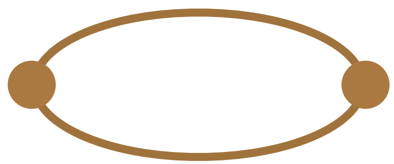
n_s	0.965	0.967
r	0.0036	0.0032

cf. CMBPol target $\delta n_s \approx 0.0016$, $\delta r \approx 0.5 \times 10^{-3}$

Beyond tree level ?

Bezrukov, Manin, Shaposhnikov, S.S. (2010)
George, Mooji, Postma (2014)

$$U(\bar{\chi}+\delta\chi) = U(\bar{\chi}) + \sum_{n=2}^{\infty} \frac{U^{(n)}(\bar{\chi})}{n!}(\delta\chi)^n$$

 $+$  $+ \ldots = \bar{U}''\Lambda^2 + (\bar{U}'')^2 \log\Lambda + \ldots$

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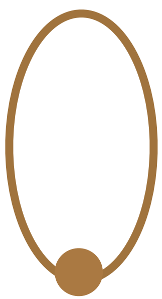
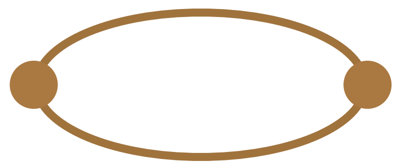
 $+$  $+ \ldots = \bar{U}''\Lambda^2 + (\bar{U}'')^2 \log\Lambda + \ldots$

At large χ the divergences are absorbed in an EFT-like expansion

$$U(\chi) = U_0\left[1 + \sum_{n=1}^{\infty} u_n \exp\left(-n\sqrt{\frac{2}{3}}\frac{\chi}{M_P}\right)\right]$$

Physical principle: asymptotic shift symmetry at $\chi \to \infty$

Losses: no unique determination of slow-roll parameters

$\eta \propto u_1$, $\varepsilon \propto u_1^2$

uncertainty of order 1 in $n_s - 1$

still robust prediction $\varepsilon = \frac{3}{4}\eta^2 + O(\eta^3)$

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e.g. the cutoff can be due to integration of a heavy field

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Seemingly, UV completion must involve gravity

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field theory in 4d based on general covariance

Quantum mechanics

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String theory

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– very non-minimal

- proliferation of extra fields
- moduli stabilization
- poorly understood in curved space-time
- poorly understood with broken SUSY
- no direct relation between inflation and low energies

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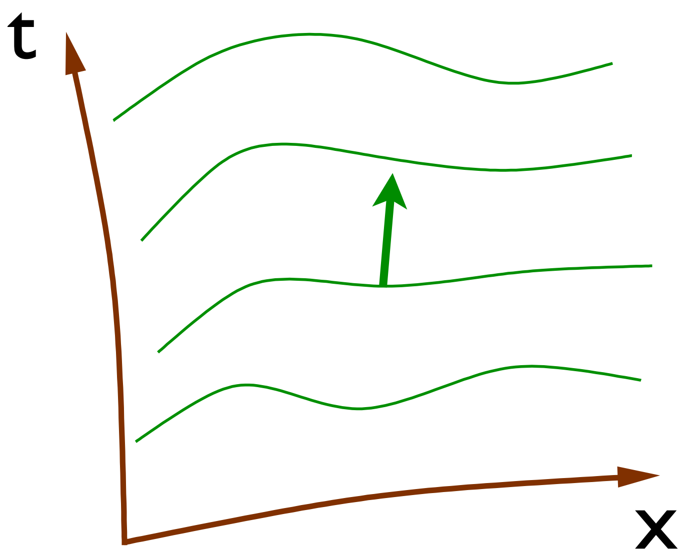
$$\langle g_{\mu\nu} g_{\lambda\rho} \rangle \propto \frac{1}{\omega^2 - k^6}$$

loop integrals with gravitons are better behaved, the theory is "power counting renormalizable"



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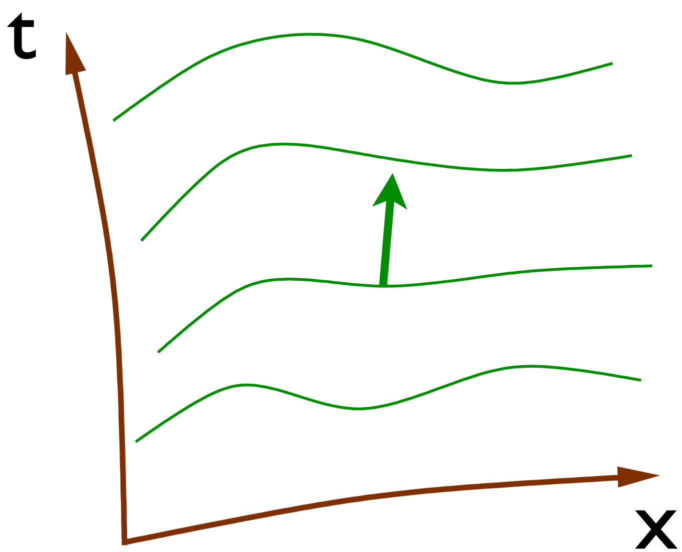

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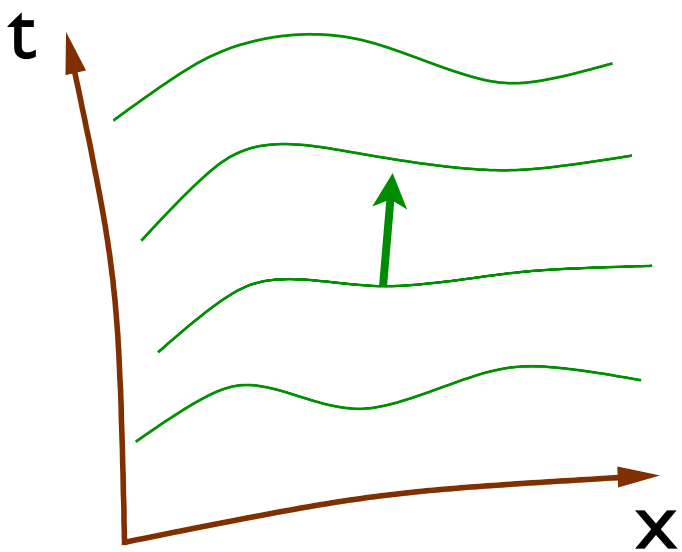

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More constraints from pulsars, CMB, LSS etc.

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Any $U(\chi)$ is renormalizable (divergences removed by normal ordering ?)

Naturally incorporates setups with asymptotic shift symmetry (the "Einstein-frame language")

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Donnelly, Jacobson (2010)
Solomon, Barrow (2014)
Ivanov, S.S. (2014)

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N.B. With $m \sim \mathrm{eV}$ can serve as a model for DE

Blas, S.S. (2011)

Challenges

- Proof of renormalizability

  gauge symmetry, instantaneous modes, technical complexity

- Emergence of Lorentz invariance in Standard Model

  $E^2 = m_i^2 + c_i^2 p^2$ $\qquad$ $|\delta c_p| \lesssim 10^{-22}$

  - Accidental symmetry due to 3d SUSY

    Groot Nibbelink, Pospelov (2005)

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  - Attraction towards Lorentz invariant fixed point

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New particle physics nearby

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New particle physics nearby

Your theory is crazy, the question is whether it's crazy enough to be true.

Bohr to Pauli

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– Ghosts ➡ loss of unitarity

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Unification with the Standard Model and dark matter

Salvio, Strumia (2014)

Challenges

- Semiclassical interpretation

  higher time-derivatives ➡ spurious run-away solutions

  Proposal:

  remove them by imposing boundary conditions in future

  Maldacena (2011)

  introduces a-causality; implications ?

- Good UV properties for $f_0^2 < 0$

  $m^2_{scalaron} \propto f_0^2 M_P^2$ ➡ tachyonic instability

  - stabilize by adding more fields ?
  - accept run-away ?

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  - to embed inflation in a broader context of particle physics
  - because observational precision approaches the level of quantum corrections
- UV completion involves QG; some standard principles must be dropped
- String theory seems too non-minimal to connect high and low-energy physics
- Alternatives to ST drop either general covariance (and Lorentz invariance) or unitarity; many conceptual and technical challenges

potential gain: direct bridge between inflation and colliders