Effective Thoughts about Inflation

Power-counting, Openness and the Swampland

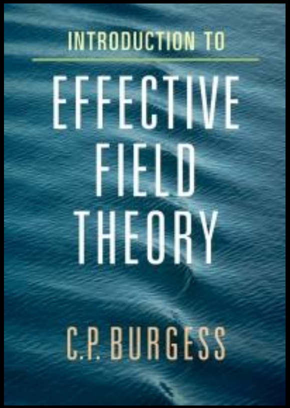
CPB @

McMaster University

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Effective Thoughts about Inflation

Power-counting, Openness and the Swampland



CPB @
McMaster University
PI
PERIMETER INSTITUTE

Power-counting

w Adshead, Babic, Geshnizjani, Holman, Lee, Shandera, Trott: gr-qc/0311082, 0902.4465, 1708.07443, 1910.05277

Openness & Late-time Resummation

w Holman, LeBlond, Shandera, Tasinato, Williams: 0912.1608, 1005.3551, 1408.5002, 1512.00169

w Kaplanek, Rummel: 1806.11415, 1912.12951, 1912.12955, 2007.05984

Symmetries vs Swampland

w Cicoli, Ciupke, de Alwis, Krippendorf, Quevedo: 1603.06789, 2006.06694, 2011.03069

Outline

EFTs Underlie Everything

The Power of Counting

Outline

EFTs Underlie Everything

The Power of Counting

Open Systems and Inflationary EFTs

Late times, Decoherence, IR effects

Outline

EFTs Underlie Everything

The Power of Counting

Open Systems and Inflationary EFTs

Late times, Decoherence, IR effects

Swamping the Inflationary Boat

What UV physics says about inflation

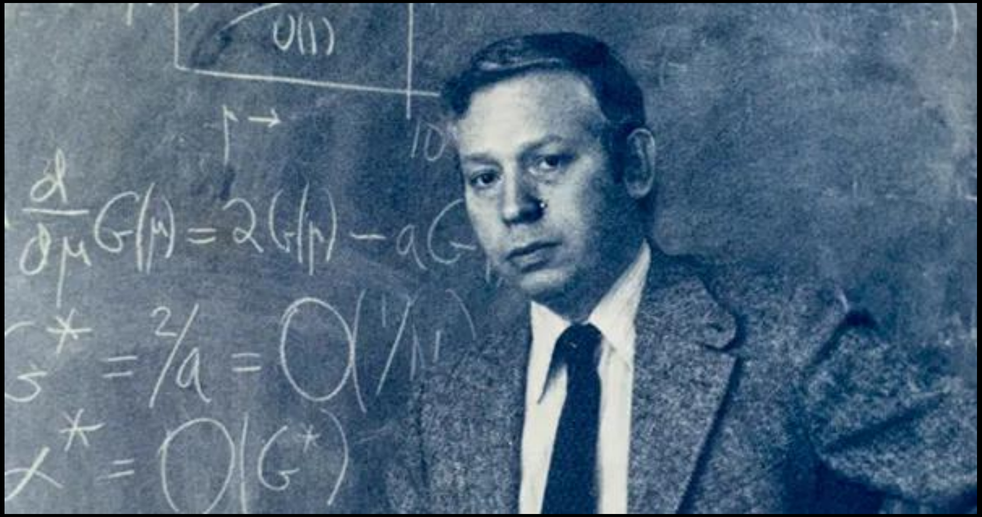
https://www.goodreads.com/book/show/35504431-turtles-all-the-way-down

EFTs are Everywhere

The many virtues of power-counting

The Backstory: GR is GREFT

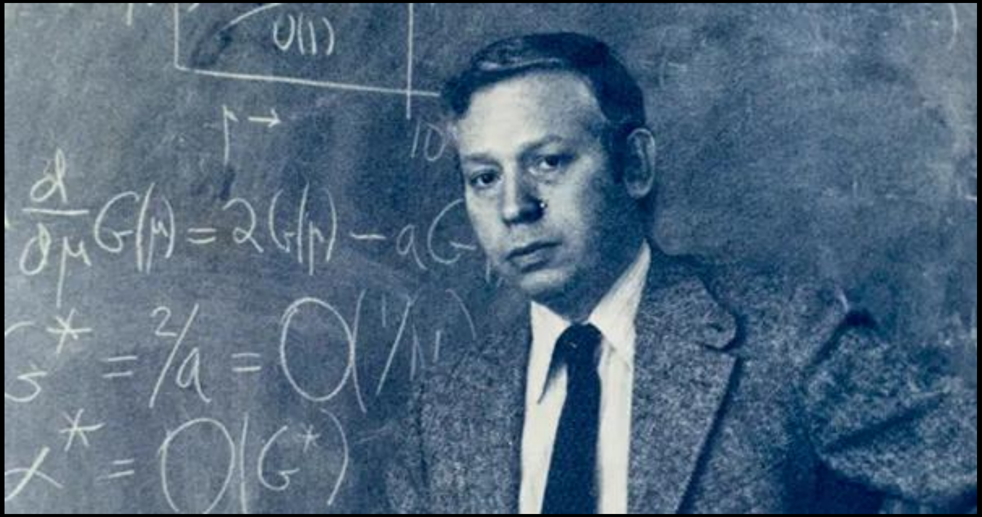
S. Weinberg



EFT reasoning underpins ***all*** quantitative applications of QFT, but especially for GR

The Backstory: GR is GREFT

S. Weinberg



Weinberg 79; Donoghue 94; gr-qc/0311082

$$\mathscr{L} \sim \sqrt{-g}\left[M_p^2 R + c_1 R^2 + \frac{c_2}{m^2} R^3 + \cdots\right]$$

$$\mathscr{A}_E(Q) \sim \left(\frac{Q^2}{M_p^{E-2}}\right)\left(\frac{Q}{4\pi M_p}\right)^{2L} \prod_{n,d>2}\left[\frac{Q^2}{M_p^2}\left(\frac{Q}{m}\right)^{d-4}\right]^{V_{nd}}$$

The Backstory: GR is GREFT

Similar power-counting for inflation shows classical approximation justified by the derivative expansion

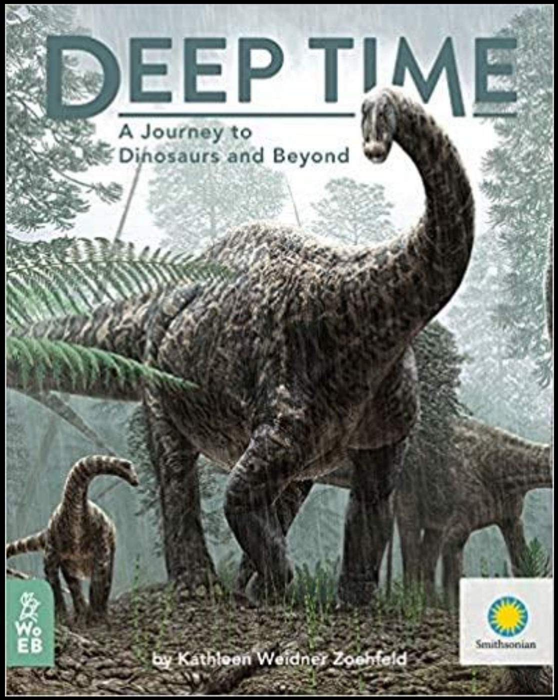
$$\mathscr{L} \sim \sqrt{-g}\left[M_p^2[R + (\partial\phi)^2] + \boxed{v^4 U(\phi)} + c_1 R^2 + c_2(\partial\phi)^4 + \frac{c_3}{m^2}R^3 + \cdots\right]$$

$$\mathscr{B}_E(Q) \sim \frac{M_p^2}{H^2}\left(\frac{H^2}{M_p}\right)^E \left(\frac{H}{4\pi M_p}\right)^{2L} \boxed{\prod_{n,d=0}\left(\frac{v^4}{H^2 M_p^2}\right)^{V_{n0}}} \prod_{n,d>2}\left(\frac{H}{M_p}\right)^{2V_{nd}} \left(\frac{H}{m}\right)^{(d-4)V_{nd}}$$

Does classical treatment of P(X) models make sense?

For DBI: justified by powers of $c_s << 1$. Not clear if similar arguments work for other models.

1910.05277



Open Systems

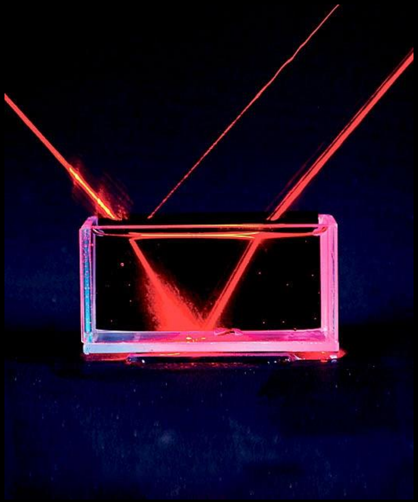
Late times, Decoherence and IR effects

Open EFTs

Derivative expansion generically necessary for theoretical control, but is it sufficient?

No! *Generic* breakdown at late times in presence of environment (eg gravitational fields) revealed by phenomenon of 'secular growth'

$$O(g,t) = O_0(t)\Big[1 + c\,g^2 t + \cdots\Big]$$



Open EFTs

Late-time behaviour can often be resummed: work to all orders in g^2 t (neglecting terms of order g^4 t).

$$1 + c\,g^2 t + \cdots = \exp(-c\,g^2 t)\Big[1 + \mathcal{O}(g^4 t)\Big]$$

0912.1608, 1512.00169, 1912.12955

In inflation WKB approx. for super-Hubble modes allows leading contributions to be captured by stochastic methods.

Starobinsky 86; Starobinsky & Yokoyama 94; Sasaki et.al. 93; Kiefer & Polarsky 98; Tsamis & Woodard 05; Senatore et.al. 09 & 14; Tanaka & Urakawa 09 & 13; Baumann et.al. 12; Boyanovsky 15, Cohen & Green 20 and many more

Open EFTs

Open EFTs: express this in terms of evolution of reduced density matrix for super-Hubble modes

$$\varrho_A(t) = \mathrm{Tr}_B\left[\rho(t)\right]$$

Evolution of diagonal elements reproduce stochastic arguments (plus corrections), while off-diagonal elements capture decoherence effects (which prove to be very efficient for super-Hubble modes during inflation)

$$\langle\varphi|\varrho_A(t)|\varphi\rangle = P(\varphi, t)$$

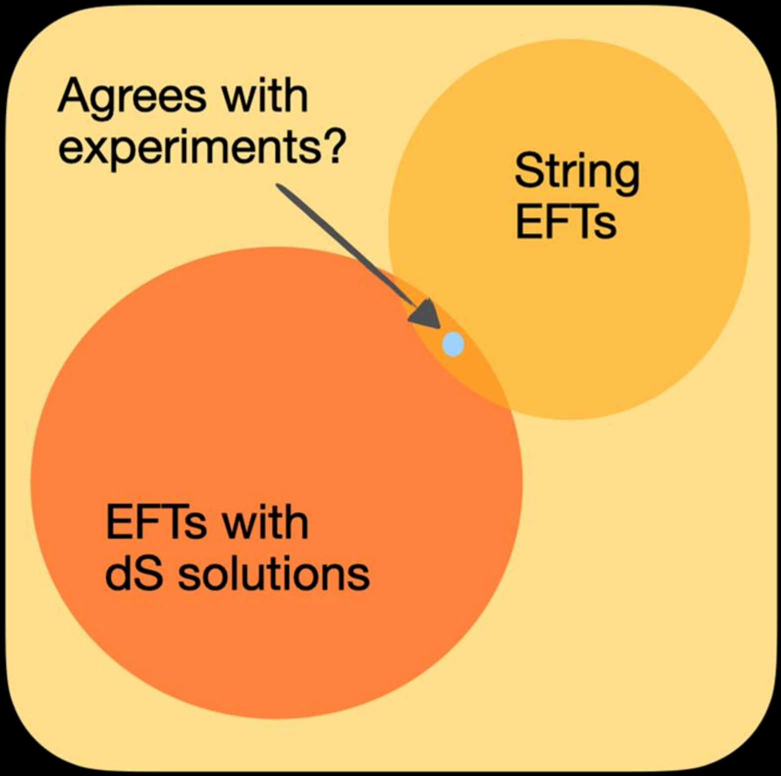
$$\langle\varphi|\varrho(t)|\varphi'\rangle$$

1408.5002, 1512.00169
Collins et.al. 17; Nelson 17

Boating Safety Magazine

Swamping the boat

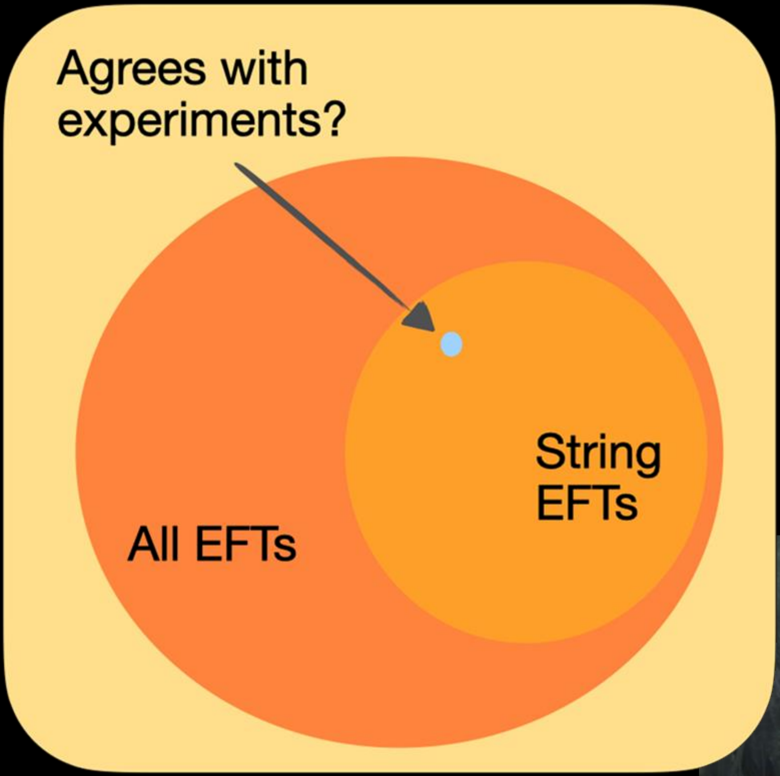
What UV physics says about inflation



UV Robustness

Strategies

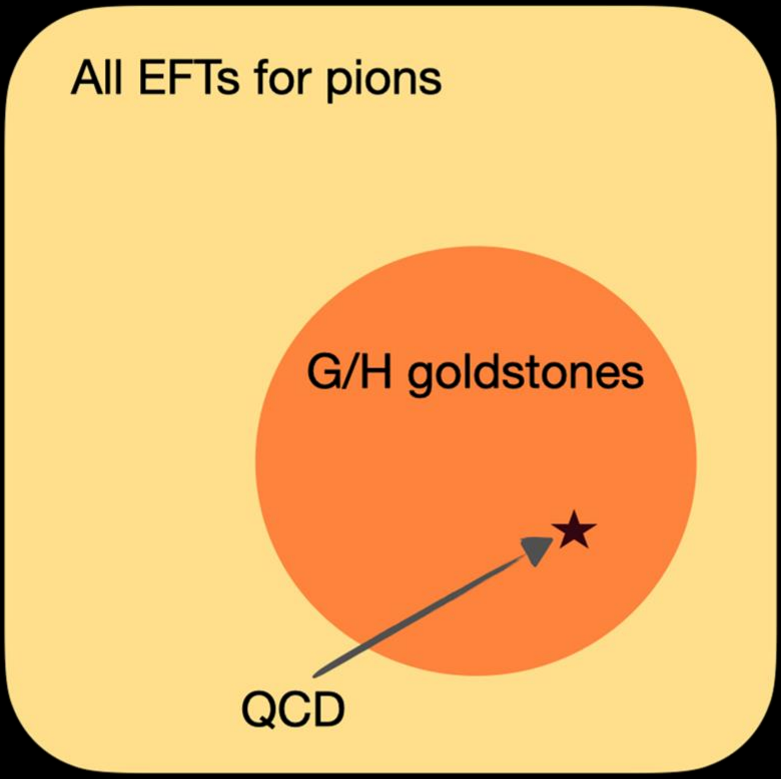
- What do we learn from UV completions at the Planck scale?
  - Examples exist! for concreteness' sake use string theory
  - Some things seem rare: Standard Model, de Sitter phases of the universe,…



UV Robustness

Strategies

- Swampland hypothesis:
  - Many EFTs have no UV completion (which ones?)

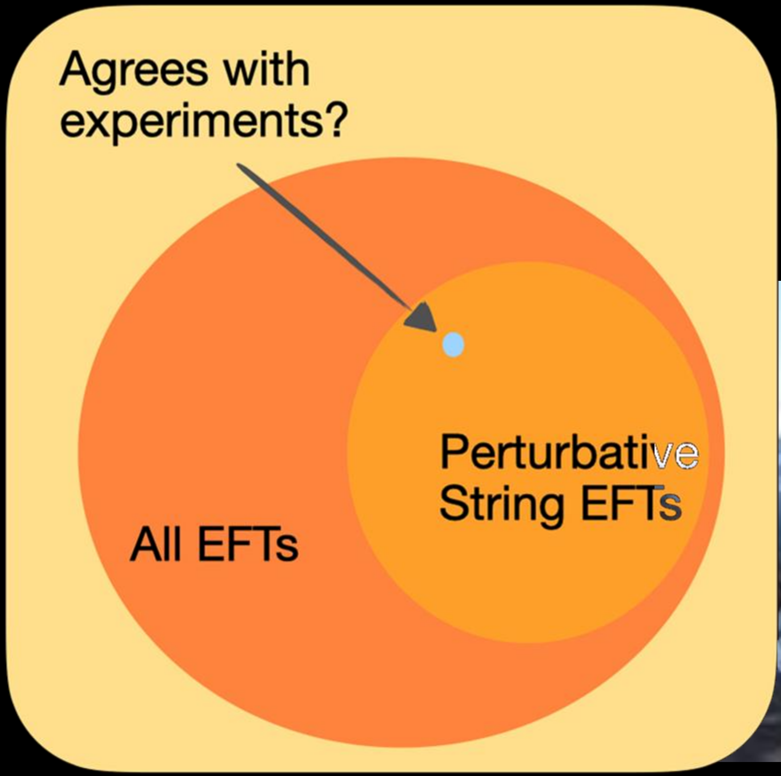


UV Robustness

Reliable vs UV informative

- Decoupling implies some low-energy predictions are robust, while others are not
  - Robust: e.g. soft-pion theorems are true for any goldstone bosons for $SU_L(2) \times SU_R(2) / SU_V(2)$
  - UV sensitive: e.g. value of pion or proton mass more sensitive to QCD details

Robust scaling symmetries of perturbative string vacua are why dS hard to get from string theory. Interplay between scaling and supersymmetry responsible for much of string 'magic'. More effective to exploit consequences of this.



$$g_{\mu\nu} \to \lambda\, g_{\mu\nu} \qquad S \to \lambda^p\, S$$

2006.06694, 2011.03069

Practical consequences for inflationary models

Two kinds of low-energy pseudo-Goldstone bosons with which to build technically natural inflationary string potentials, one class of which arises due to approximate scale invariances

Axions	Dilatons

Practical consequences for inflationary models

Axions Dilatons

Axionic inflationary models

- axions are ubiquitous
- axions have protected masses

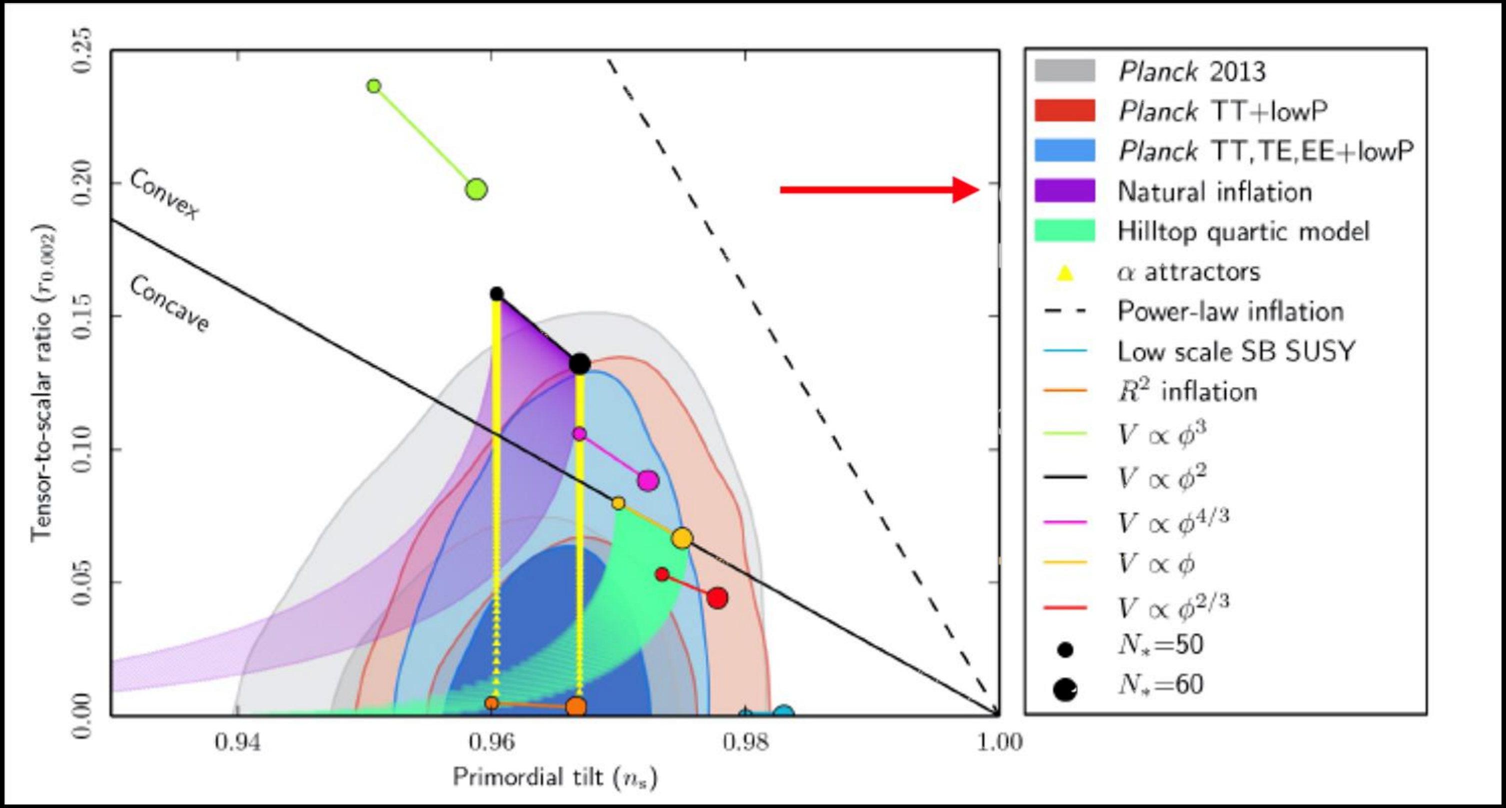
$$V(a) = A + B\cos\left(\frac{a}{f}\right)$$

Freese et.al. 90; Kachru et.al. 03;
Silverstein & Westphal 08 and more

Practical consequences for inflationary models

But: need $f \gg M_p$
disfavoured by data

Axions Dilatons



Planck collaboration

Practical consequences for inflationary models

Axions *Dilatons*

Scaling inflationary models

- Fibre moduli are ubiquitous
- F. mod have protected masses

$$V(a) = A - B\, e^{-a/f}$$

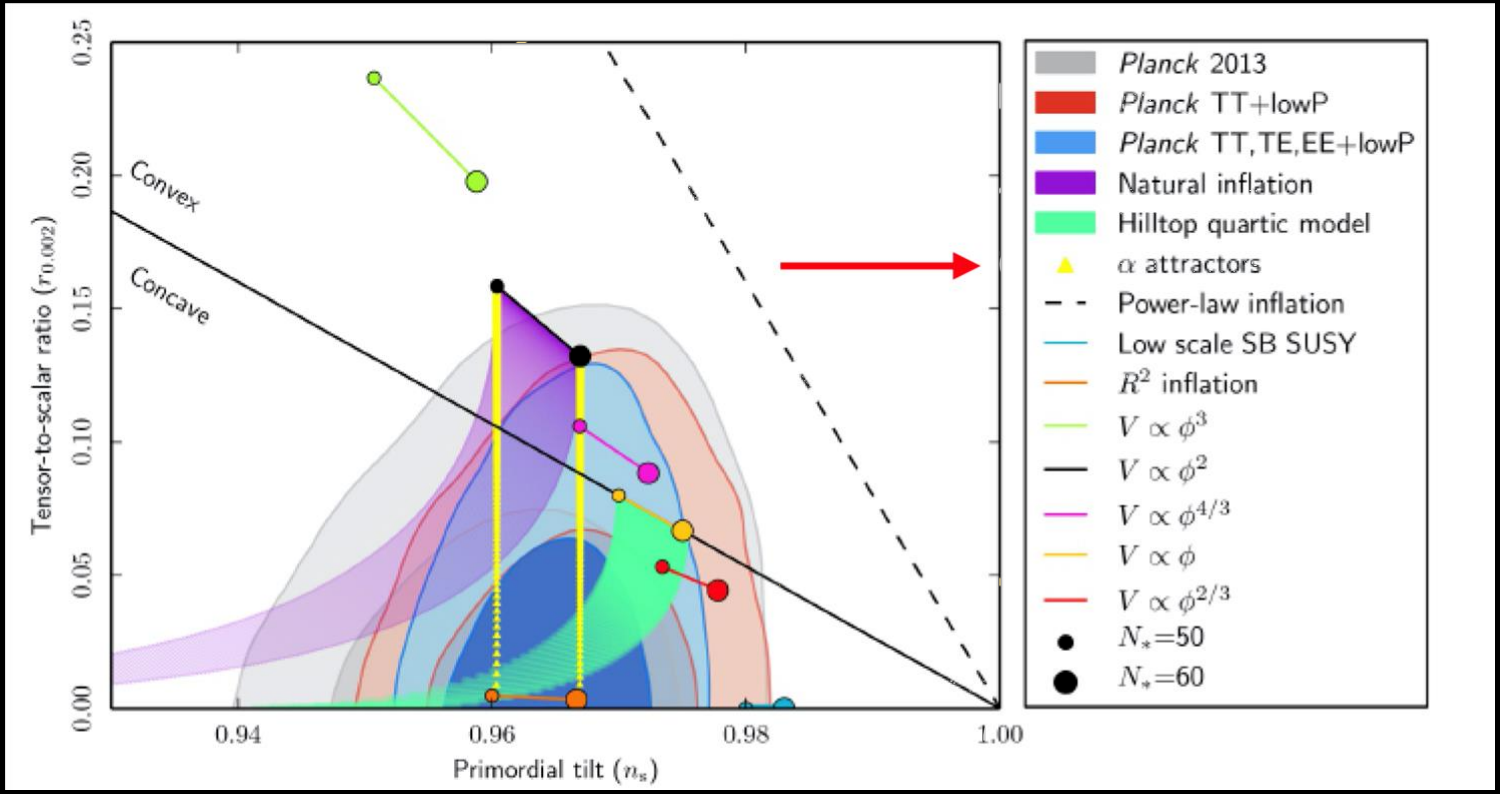
Goncharov & Linde 84; Kallosh & Linde 13 & 15

hep-th/0111025; 0808.0691; 1603.06789

need $f \simeq M_p$
loved by data
predicts $r \simeq (n_s - 1)^2$

Practical consequences for inflationary models

Axions *Dilatons*



Planck collaboration

Conclusions

EFTs Underlie Everything, especially for gravity

Generally requires sensible derivative expansion, though some controlled exceptions exist (eg DBI)

Conclusions

EFTs Underlie Everything, especially for gravity

Generally requires sensible derivative expansion, though some controlled exceptions exist (eg DBI)

EFTs with gravity more Open than Wilsonian systems

Generic phenomena like late-time perturbative failure and decoherence, which Open EFTs can help resum reliably

Conclusions

EFTs Underlie Everything, especially for gravity

Generally requires sensible derivative expansion, though some controlled exceptions exist (eg DBI)

EFTs with gravity more Open than Wilsonian systems

Generic phenomena like late-time perturbative failure and decoherence, which Open EFTs can help resum reliably

UV completions can be informative

Accidental scaling symmetries likely much more informative than swampland conjectures

Thanks for your time!