Primordial gravitational waves & the swampland

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DESY, Hamburg

Particle Physics Challenges - DESY Theory Workshop
26th September 2018

STRINGFLATION Consolidator Grant

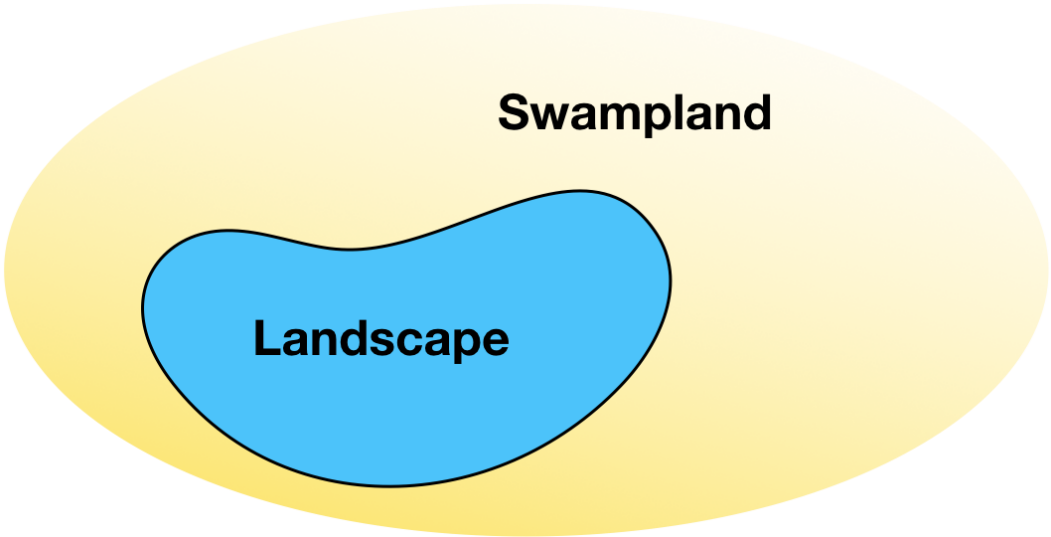
1807.06579: Mafalda Dias, Jonathan Frazer, A.R. & Alexander Westphal

Plan of the talk

1. Introduction: landscape vs. swampland
2. Some swampland conjectures & implications to inflation
3. Relaxing the conjectures & implications to inflation

Introduction: landscape vs. swampland

Q: which QFTs (without gravity) can be consistently coupled to gravity?



Multiple conjectures exist motivated by e.g.

- Black hole physics [Arkani-Hamed,Motl,Nicolis,Vafa '06]
- String theory [Ooguri,Vafa '06; Obied,Ooguri,Spodyneiko,Vafa '18]
- ...

Some swampland conjectures ...

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  EFT lagrangians arising at different points are different.
  Large displacements in $\mathcal{M}$ lead to invalidating an EFT via the appearance of an infinite tower of states s.t.

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- **C2: Swampland de Sitter Conjecture.** [Obied,Ooguri,Spodyneiko,Vafa '18]
  Lots of trouble to find de Sitter in string theory. [Maldacena,Nunez '00; Bena,Grana,Kuperstein,Massai '14; Kutasov,Maxfield,Melnikov,Sethi '15; Junghans,Zagermann '16; Andriot,Blaback '16; Moritz,AR,Westphal '17; Danielsson,Van Riet '18; Brennan,Carta,Vafa '18; Dvali,Gomez '14; ...]

  De Sitter is in the swampland. $m' \sim \exp\left(-\frac{cV(\phi)}{M_P|\nabla V(\phi)|}\right)$, $c = \mathcal{O}(1)$

Some swampland conjectures & implications to inflation

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Recall in single field slow-roll inflation $\epsilon = \frac{M_P^2}{2}\left(\frac{\nabla V}{V}\right)^2$ & $r = 16\epsilon$

And the Lyth bound is [Lyth '97] $N_e\sqrt{2\epsilon} \lesssim \frac{\Delta\phi}{M_P}$

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Putting everything together: safe if [Agrawal,Obied,Steinhardt,Vafa '18]

$$8c^2 < r \lesssim 8\frac{\mathcal{D}^2}{N_e^2}$$

If $c, \mathcal{D} = \mathcal{O}(1)$ and $N_e \simeq 60$, inequalities cannot hold and it would imply

trouble for single field slow-roll inflation!!!

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Alternatives: - multi-field slow-roll inflation [Achucarro,Palma '18]
- relax conditions $c, \mathcal{D} = \mathcal{O}(1)$ [Dias,Frazer,AR,Westphal '18]

Relaxing the conjectures ...

Since these conjectures are based on evidence from string theory compactifications, take a deeper look at evidence.

[Blumenhagen,Valenzuela,Wolf '17] show $\mathcal{D} \sim \left(\frac{m_h}{m_\ell}\right)^p > 1 \quad , \quad p = 1, 2, ...$

Expected behaviour from general rules of decoupling in QFT.

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Similar reasoning can be used to relax $c = \mathcal{O}(1)$.
Illustrate using toy model for inflation in [Dong,Horn,Silverstein,Westphal '10]

$$V(\phi, \chi) = g^2 \phi^2 \chi^2 + m_h^2 (\chi - \chi_0)^2 \quad \Rightarrow \quad V_{eff}(\phi) = m_\ell^2 \phi^2 \frac{1}{1 + \frac{\phi^2}{M_P^2 \mathcal{D}^2}}$$

where $\chi_0 \sim M_P/2$ so that $m_h/H > 3/2$ and $\mathcal{D} = \frac{\chi_0}{M_P} \frac{m_h}{m_\ell} > 1$ ✓

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Now compute

$$M_P \frac{|V'_{eff}|}{V_{eff}} = \frac{2M_P}{\phi} - \frac{2\phi}{M_P \mathcal{D}^2} + \ldots \gtrsim \frac{1}{\mathcal{D}} \qquad \Rightarrow \qquad c \sim \frac{1}{\mathcal{D}} \sim \left(\frac{m_\ell}{m_h}\right)^{p'} < 1$$

Relaxing the conjectures & implications to inflation

- In single field inflation: m_ℓ is the inflaton mass, and m_h the lightest field integrated out.
- In string theory $\quad m_\ell \lesssim H < m_h \lesssim m_{\rm KK}\ ,\ m_{\rm W} < M_{\rm s} < M_P$
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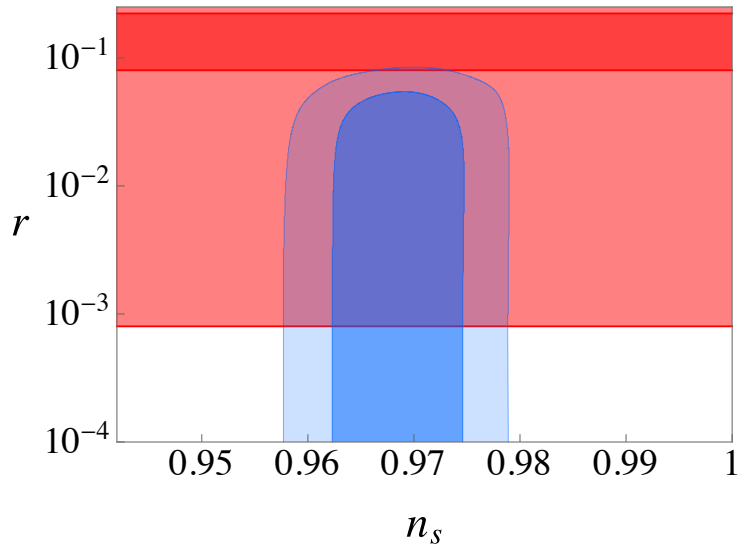
- Lower bound is within reach of future surveys!!!



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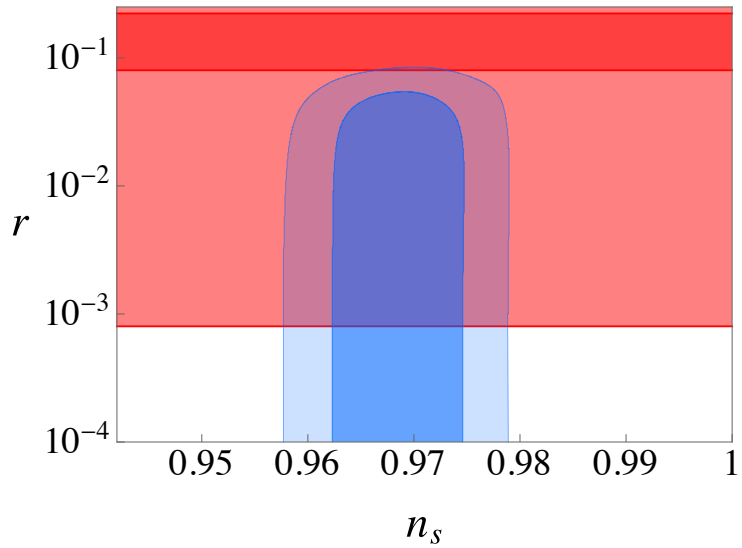

Thank you