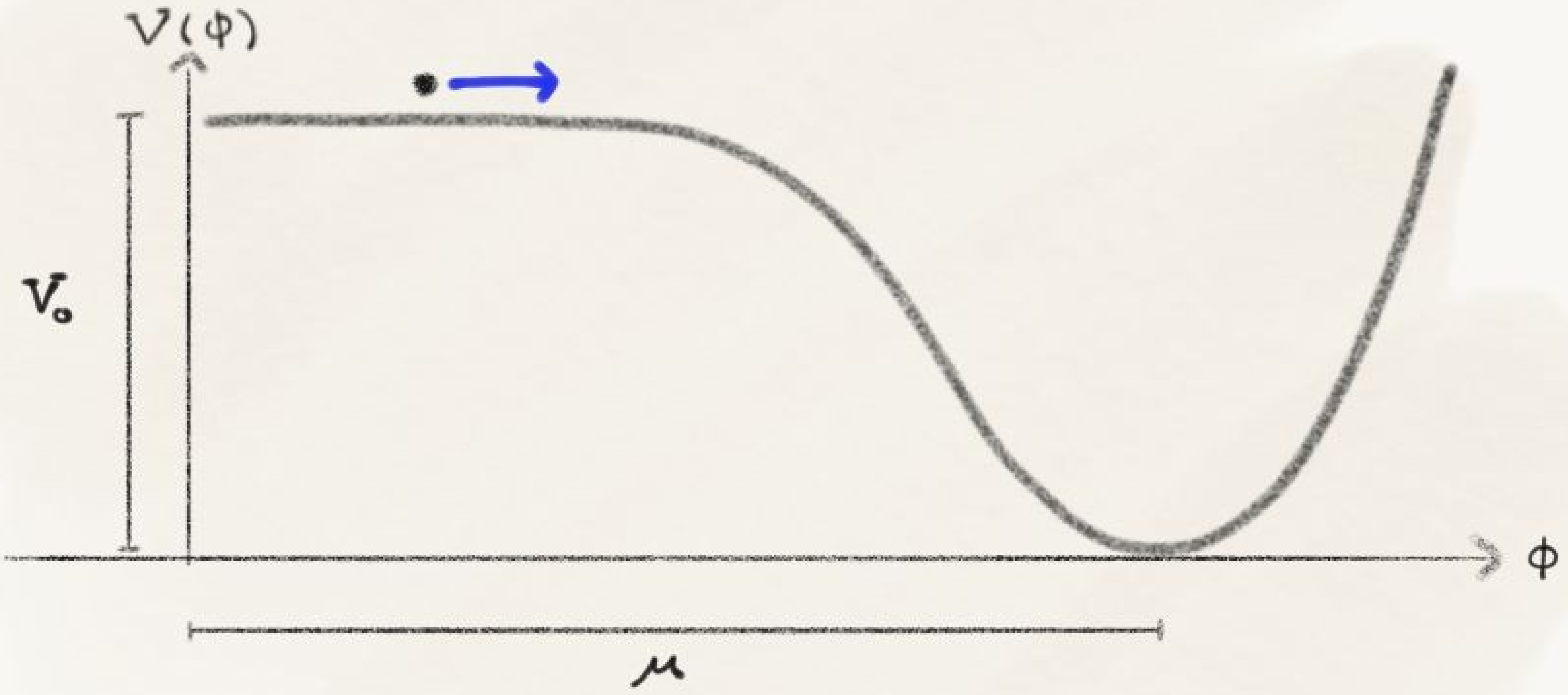
SWAMP CREATURES OF THE INFLATION LANDSCAPE

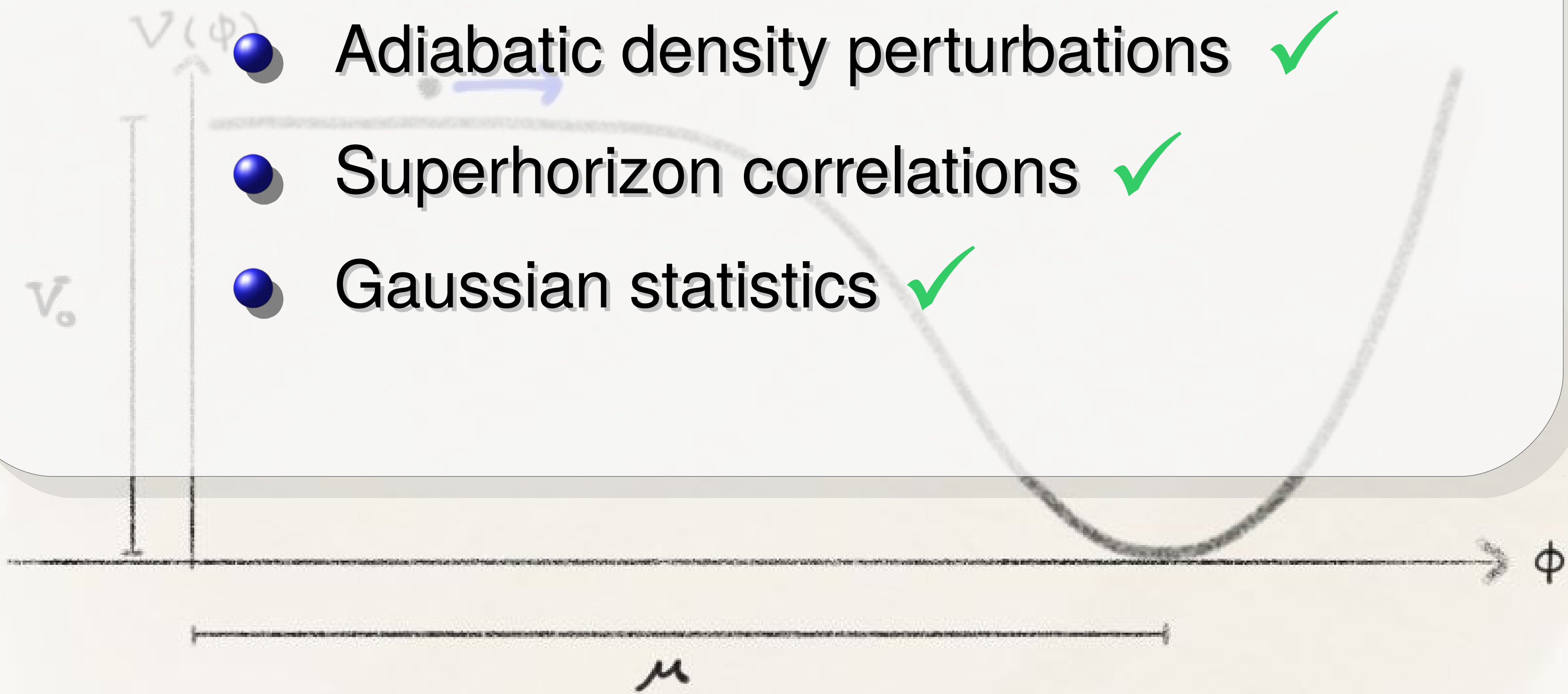
Will Kinney
COSMO19, Aachen
2 September 2019

Inflation: Basic Predictions



Inflation: Basic Predictions

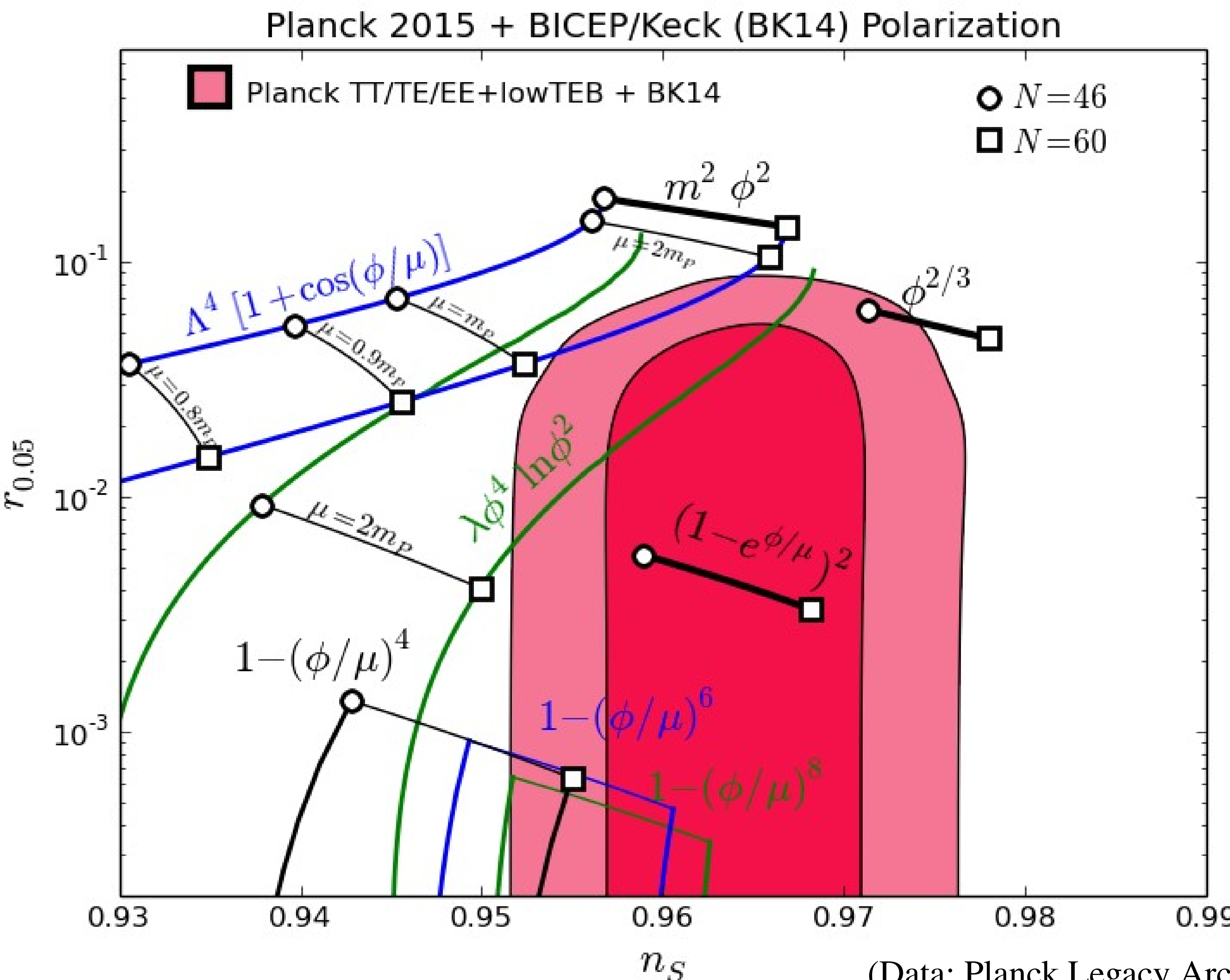
- Adiabatic density perturbations ✓
- Superhorizon correlations ✓
- Gaussian statistics ✓



$$\mathcal{L} = \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi)$$

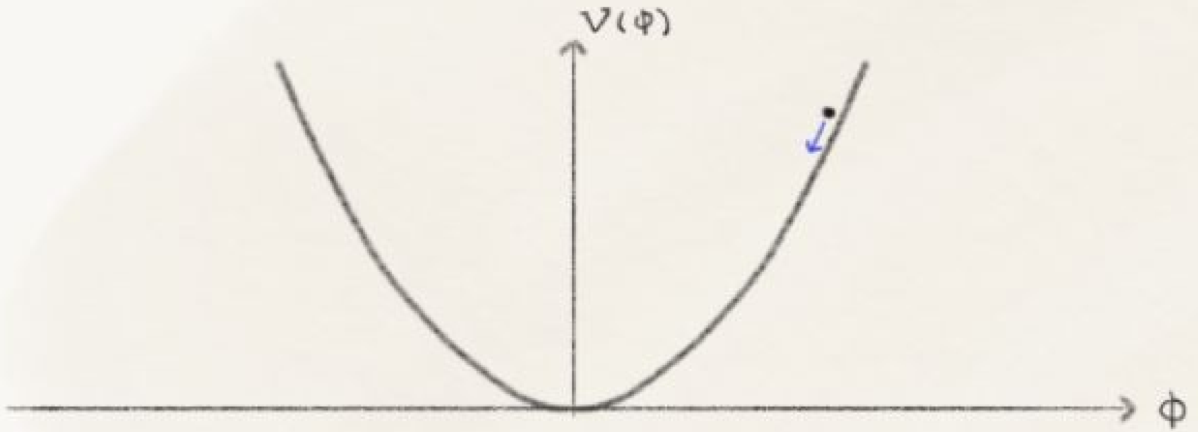
Fully consistent with data.

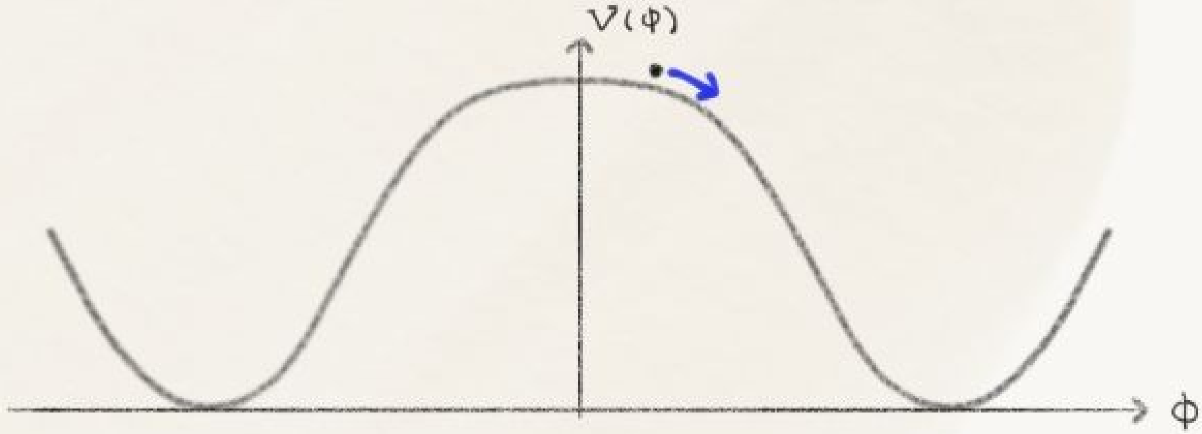
Summary: Current Constraints from Planck



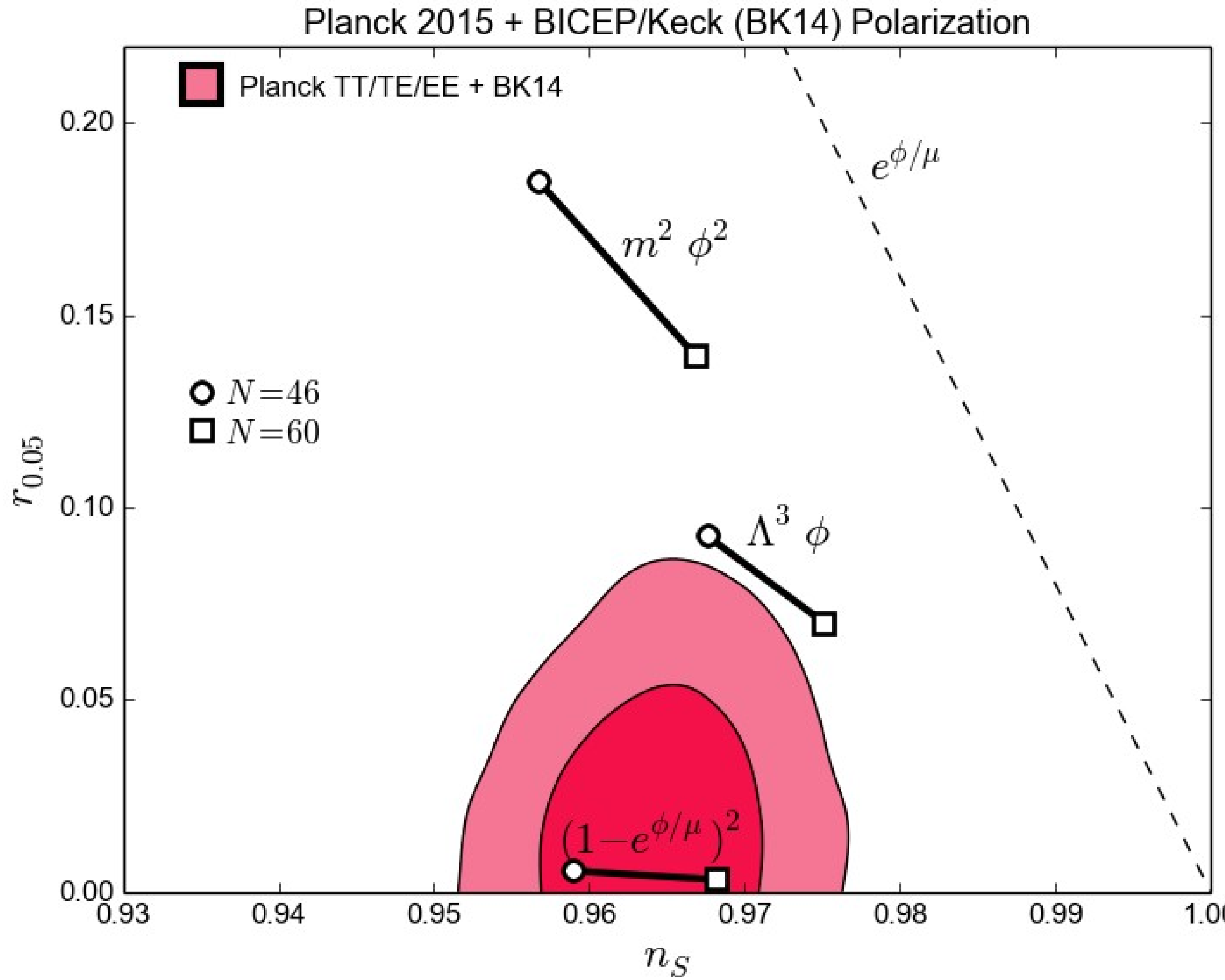
(Data: Planck Legacy Archive)

Convex or Concave?

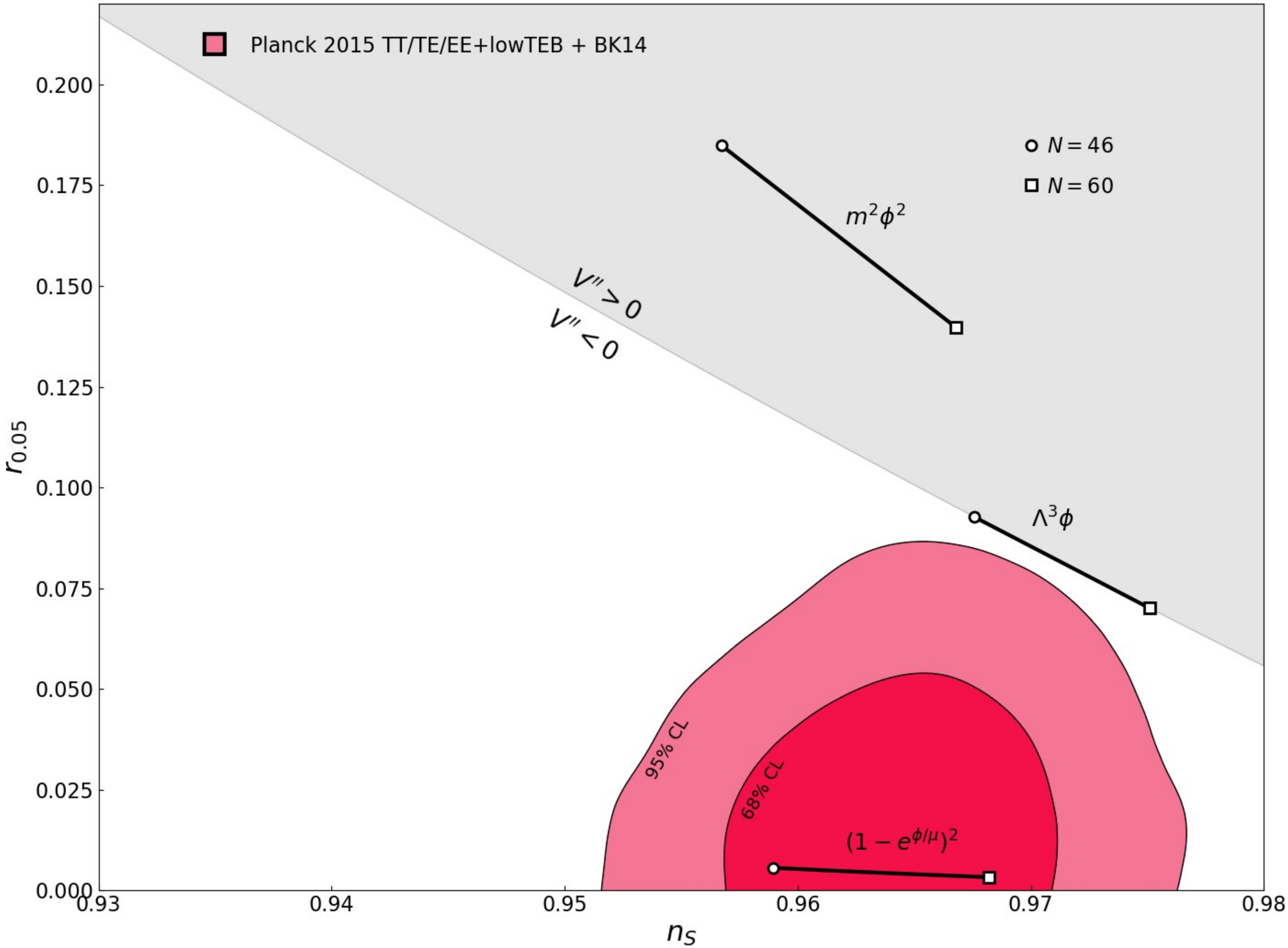




$$r = 8M_P^2 \left(\frac{V'}{V}\right)^2$$

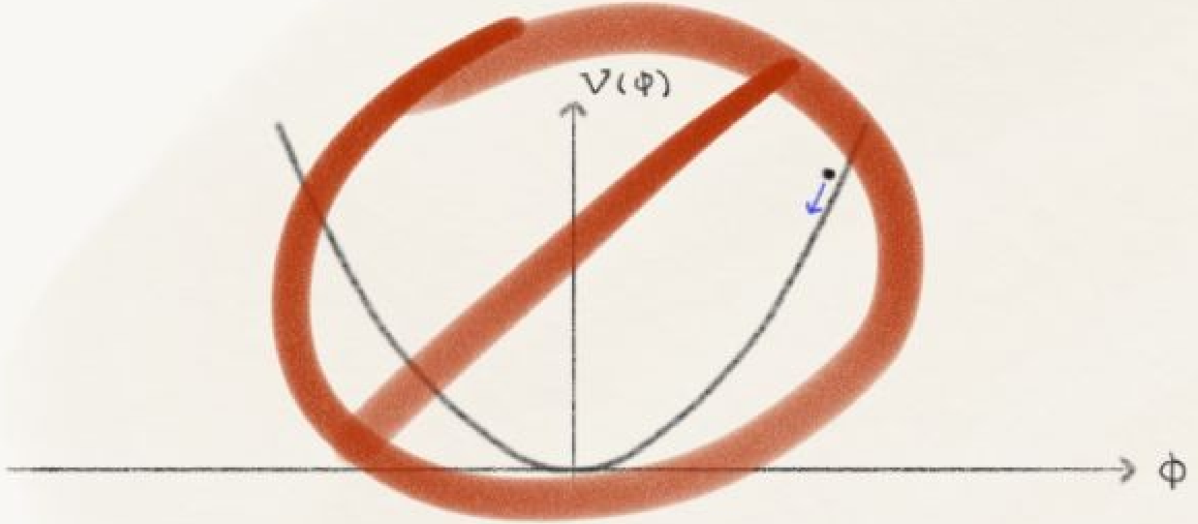


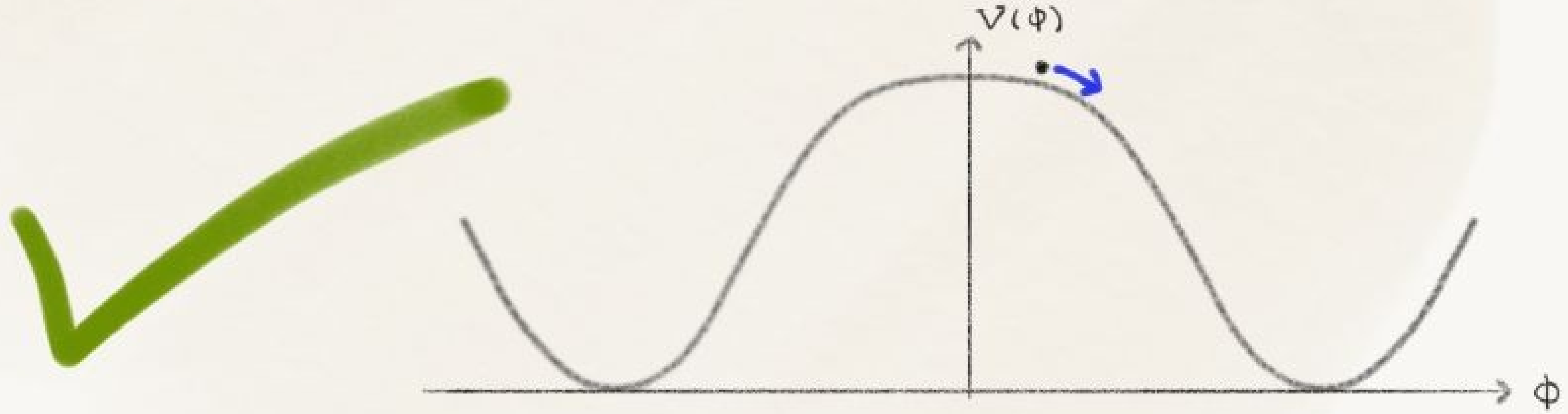
$$n_S = 1 - 3M_P^2 \left(\frac{V'}{V}\right)^2 + 2M_P^2 \frac{V''}{V}$$



Planck 2015 TT/TE/EE+lowTEB + BK14
N = 46
N = 60
$m^2\phi^2$
$V'' > 0$
$V'' < 0$
$\Lambda^3\phi$
95% CL
68% CL
$(1 - e^{\phi/\mu})^2$
$r_{0.05}$
n_S
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.93
0.94
0.95
0.96
0.97
0.98

Convex or Concave?

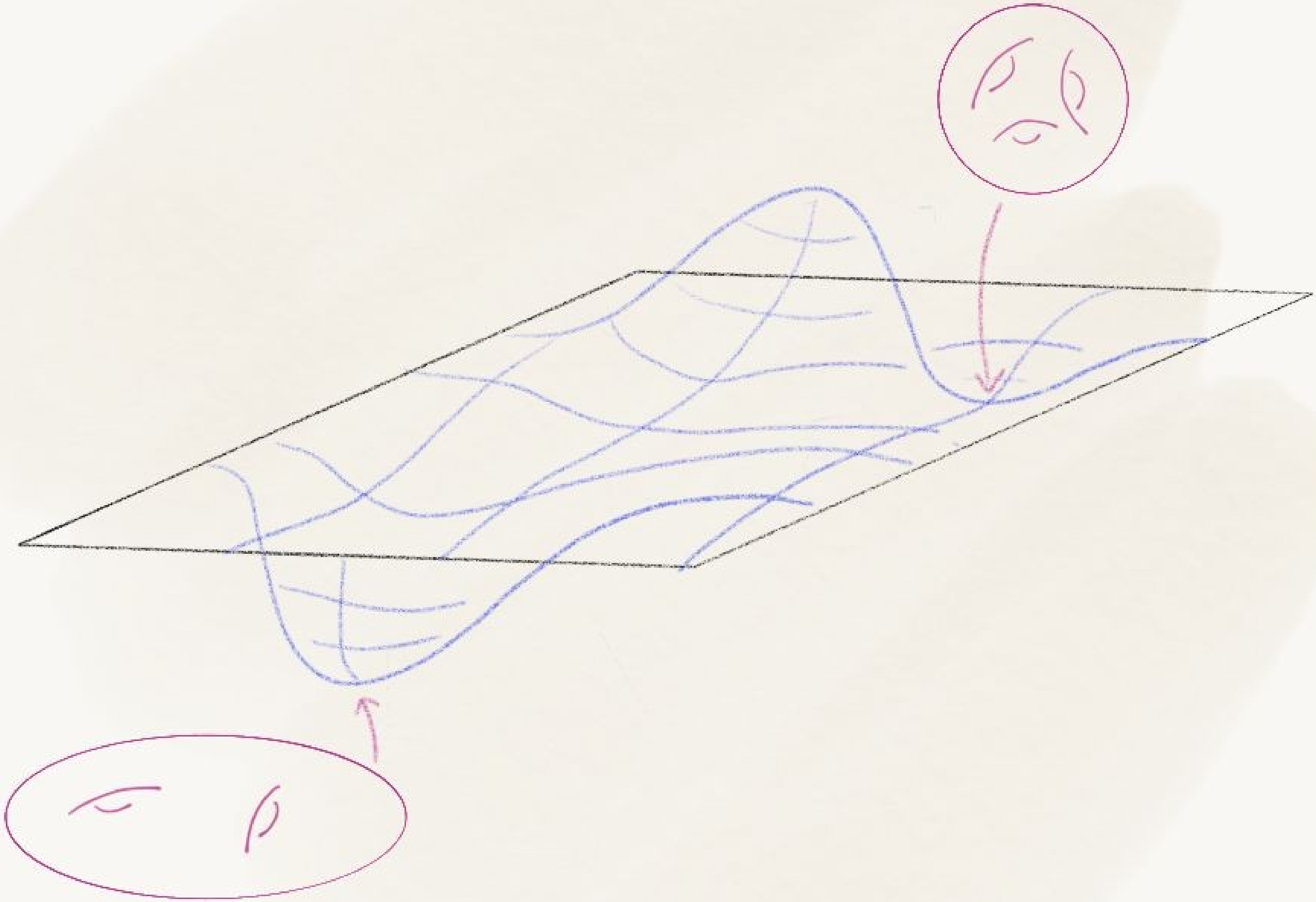




Inflation: Swampland or Landscape?

WHK, Vagnozzi, Visinelli [arXiv:1808.0624]

The String Landscape




NO UV COMPLETION
NO UV COMPLETION

High Energy Physics - Theory

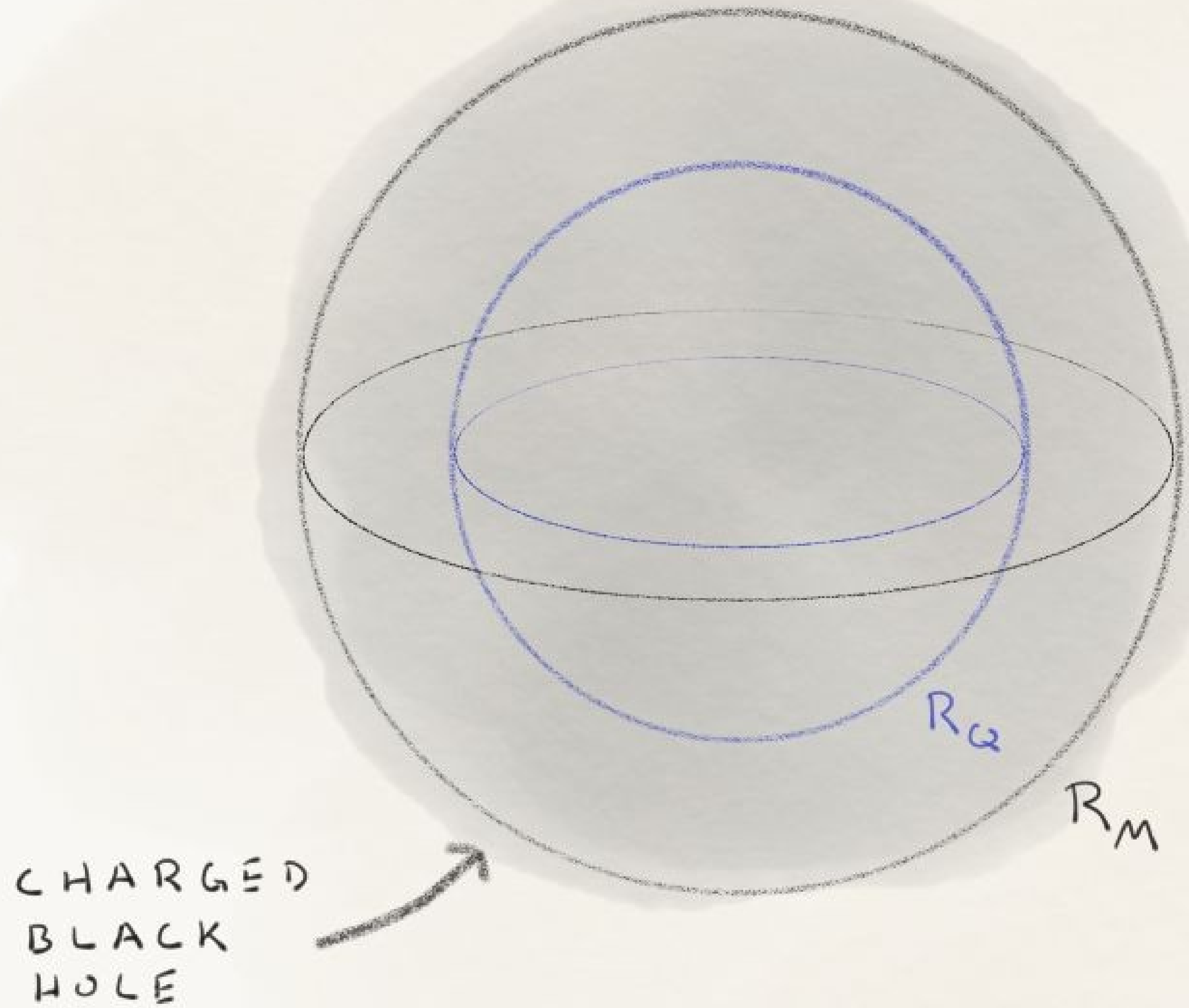
The Marshland Conjecture

David M.C. Marsh, J.E. David Marsh

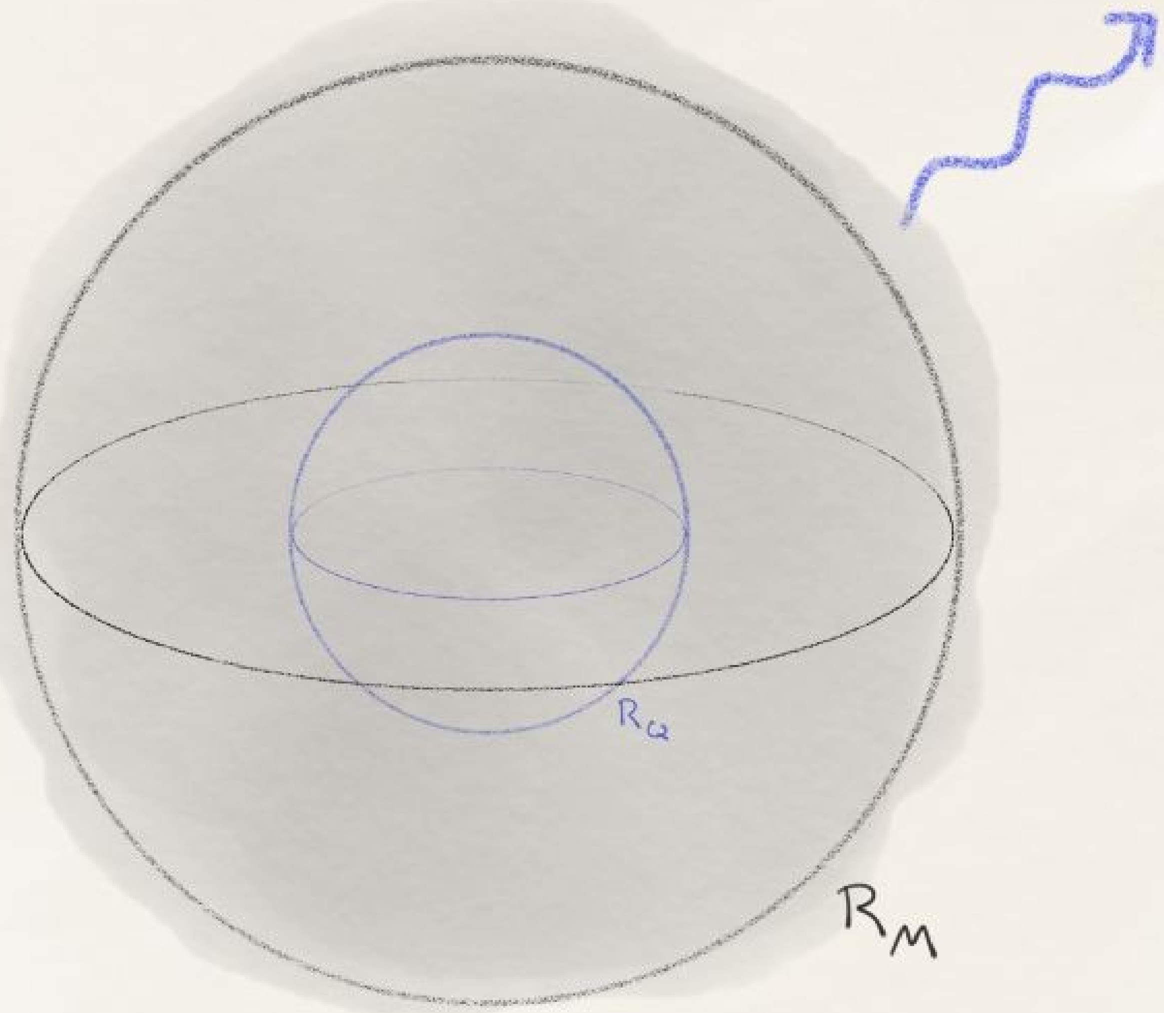
(Submitted on 29 Mar 2019)

We posit the existence of the Marshland within string theory. This region is the boundary between the landscape of consistent low-energy limits of quantum gravity, and the swampland of theories that cannot be embedded within string theory because they violate certain trendy and obviously uncontroversial conjectures. The Marshland is probably fractal, and we show some pretty pictures of fractals that will be useful in talks. We further show that the Marshland contains theories with a large number of light axions, allowing us to cite lots of our own papers. We show that the Marshland makes up most of the volume of the landscape, and admits a novel, weakly broken $\mathbb{Z}_2$ Marshymmetry that we find strong evidence for by considering a carefully crafted example.

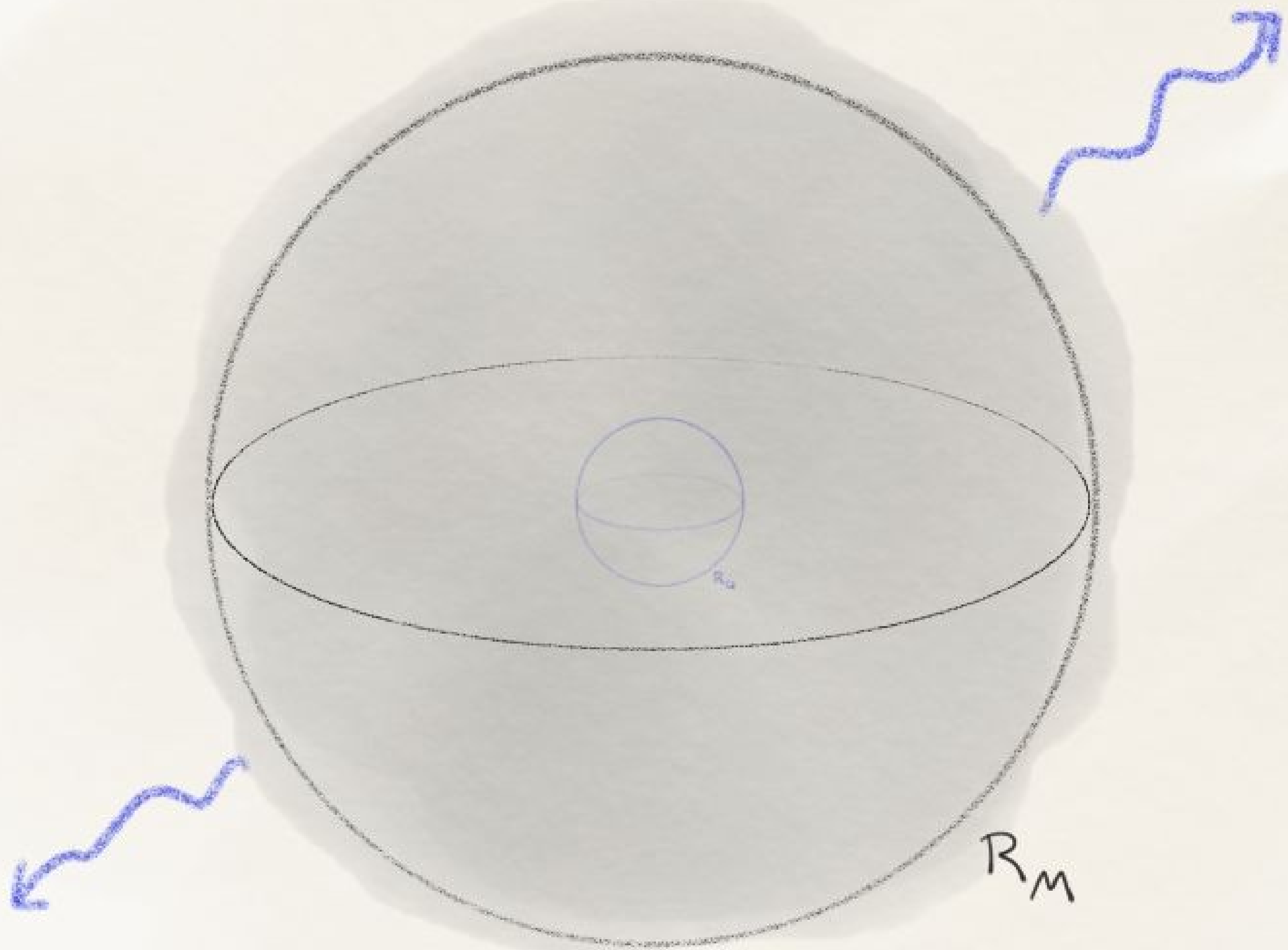
The Weak Gravity Conjecture



The Weak Gravity Conjecture



The Weak Gravity Conjecture



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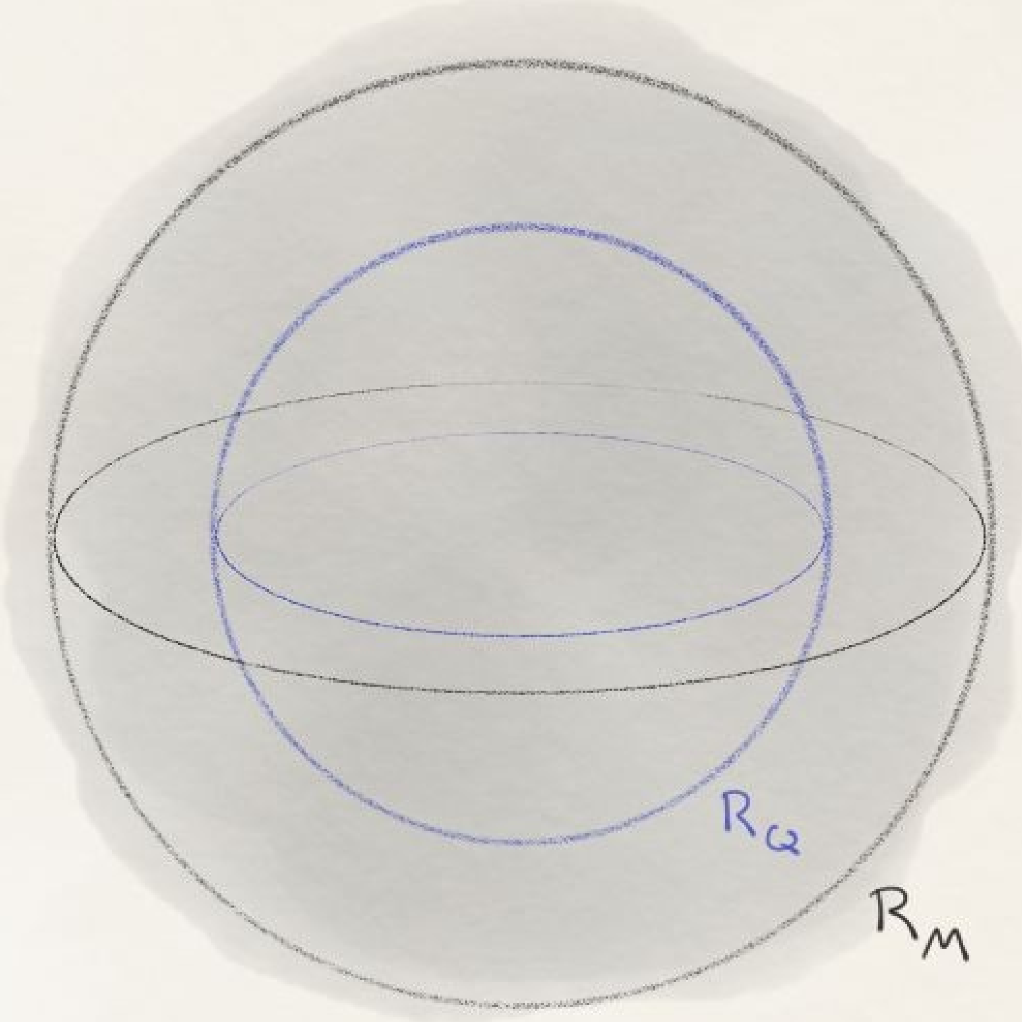

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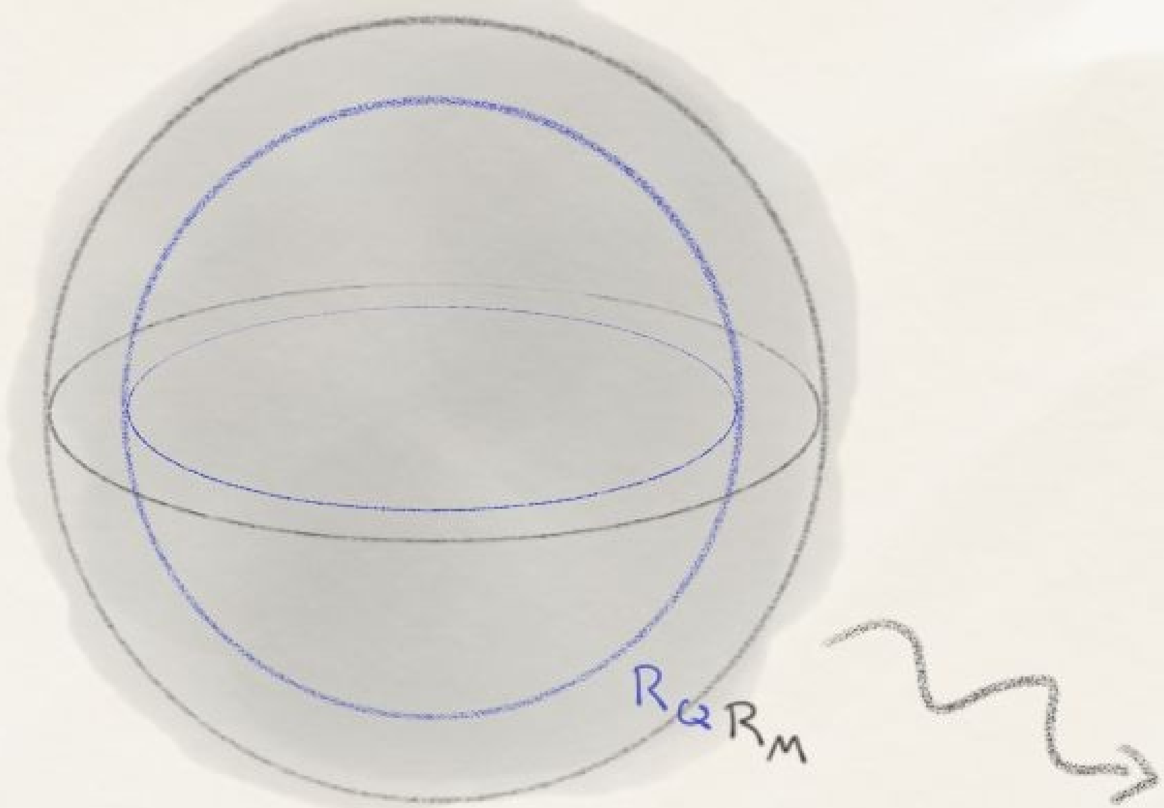

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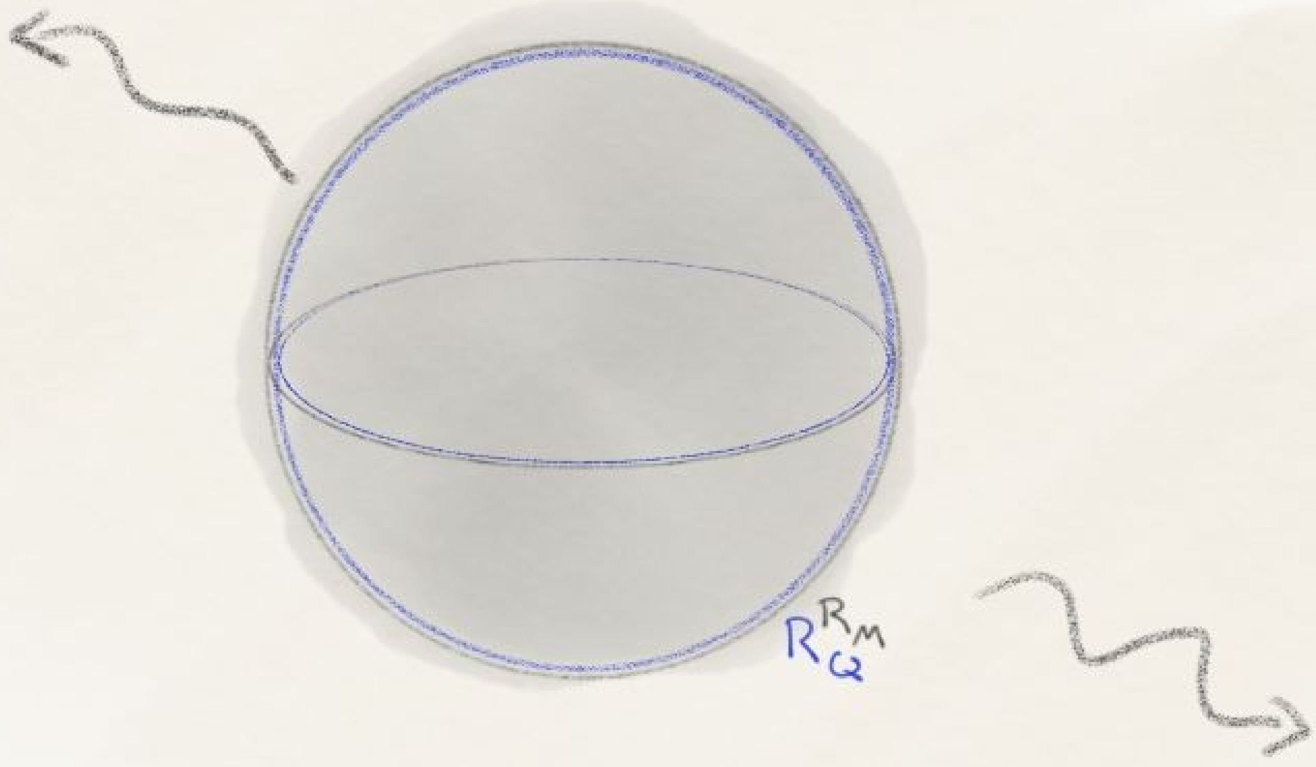

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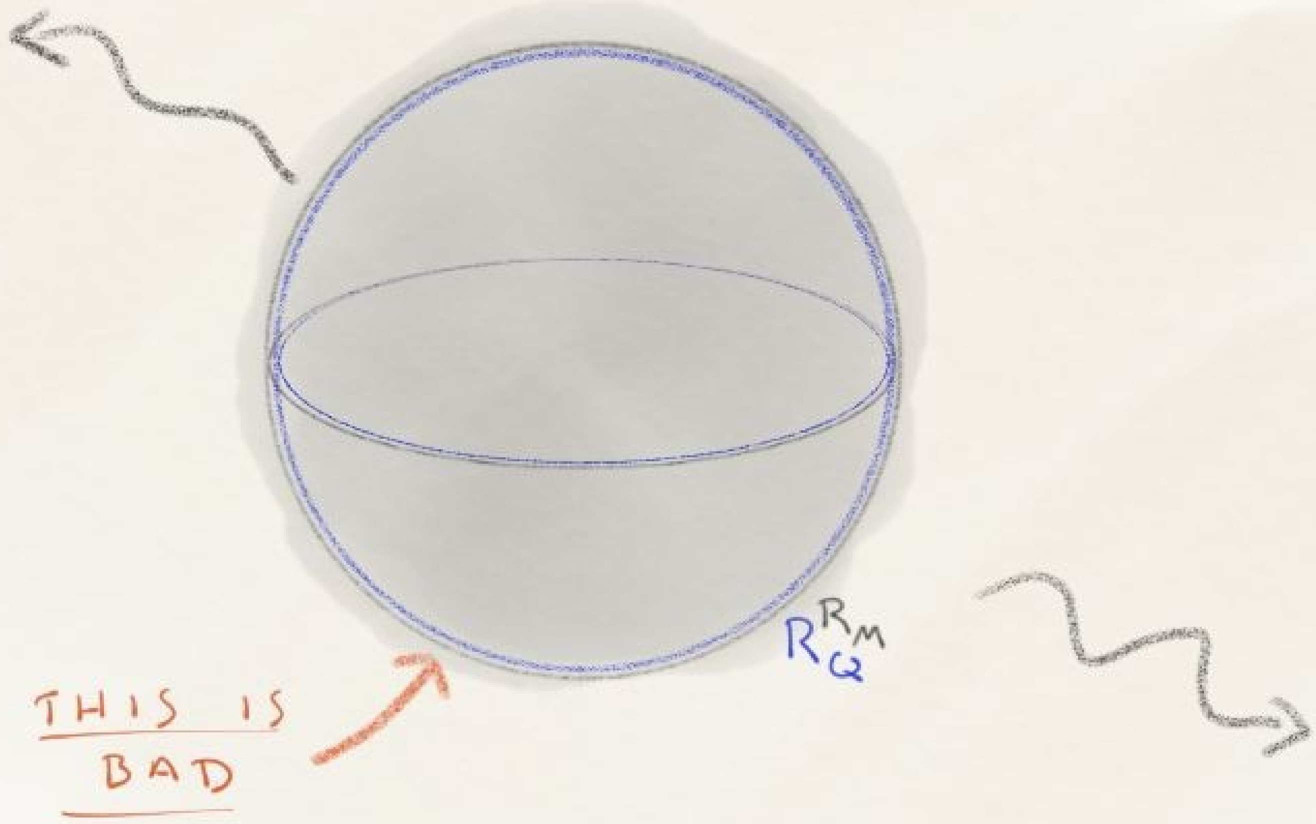

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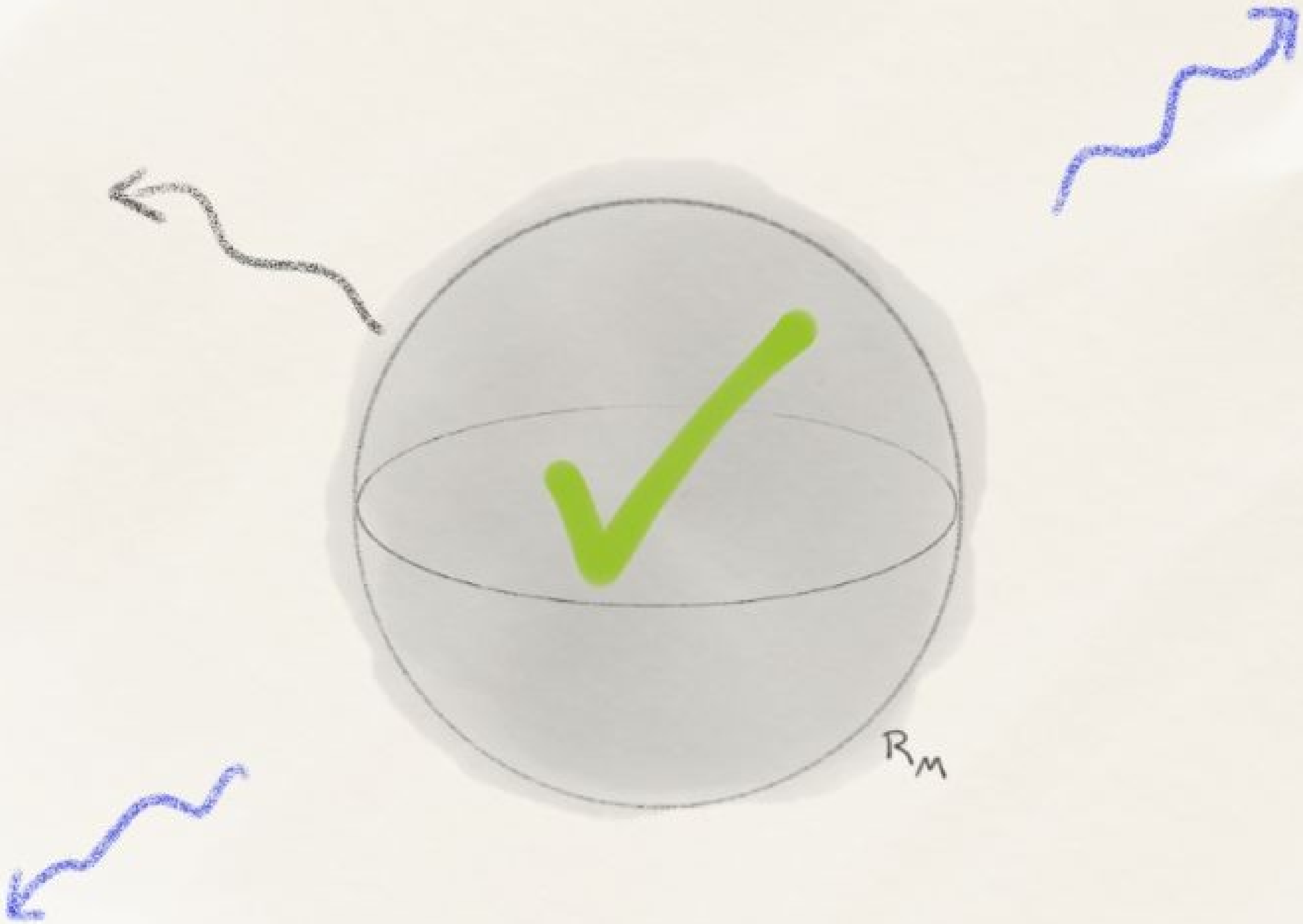
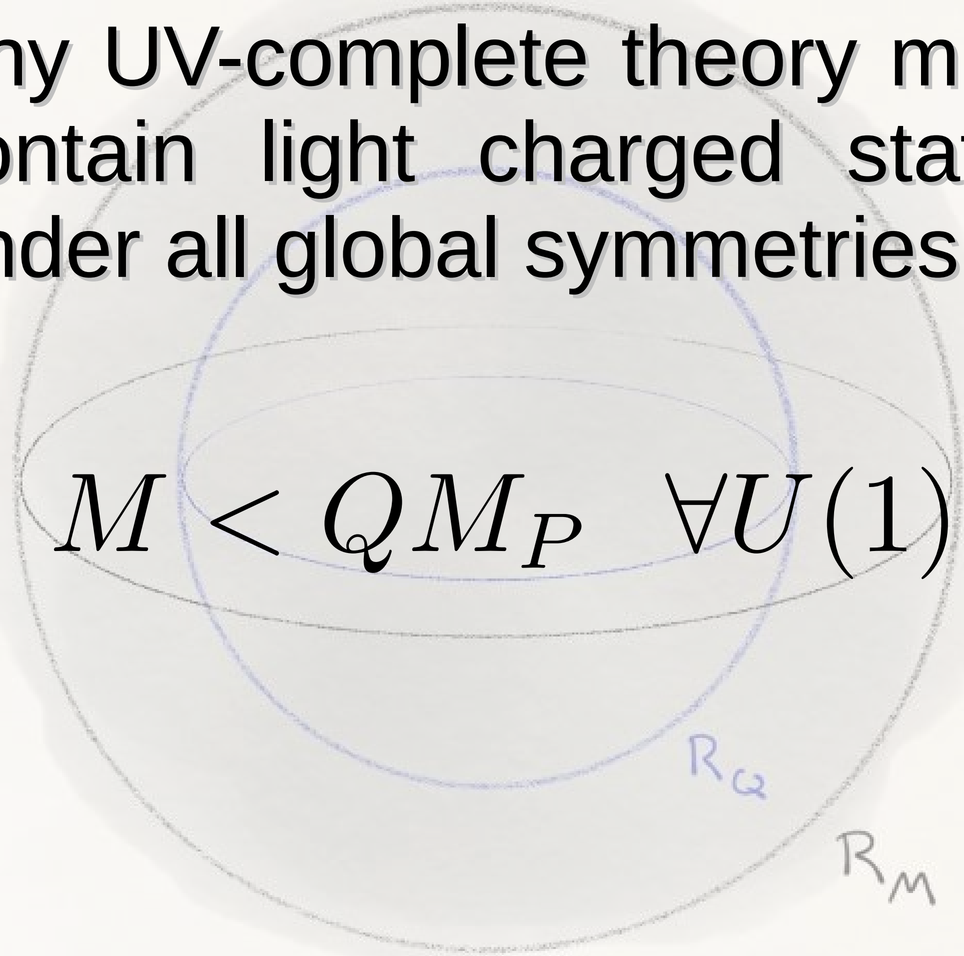


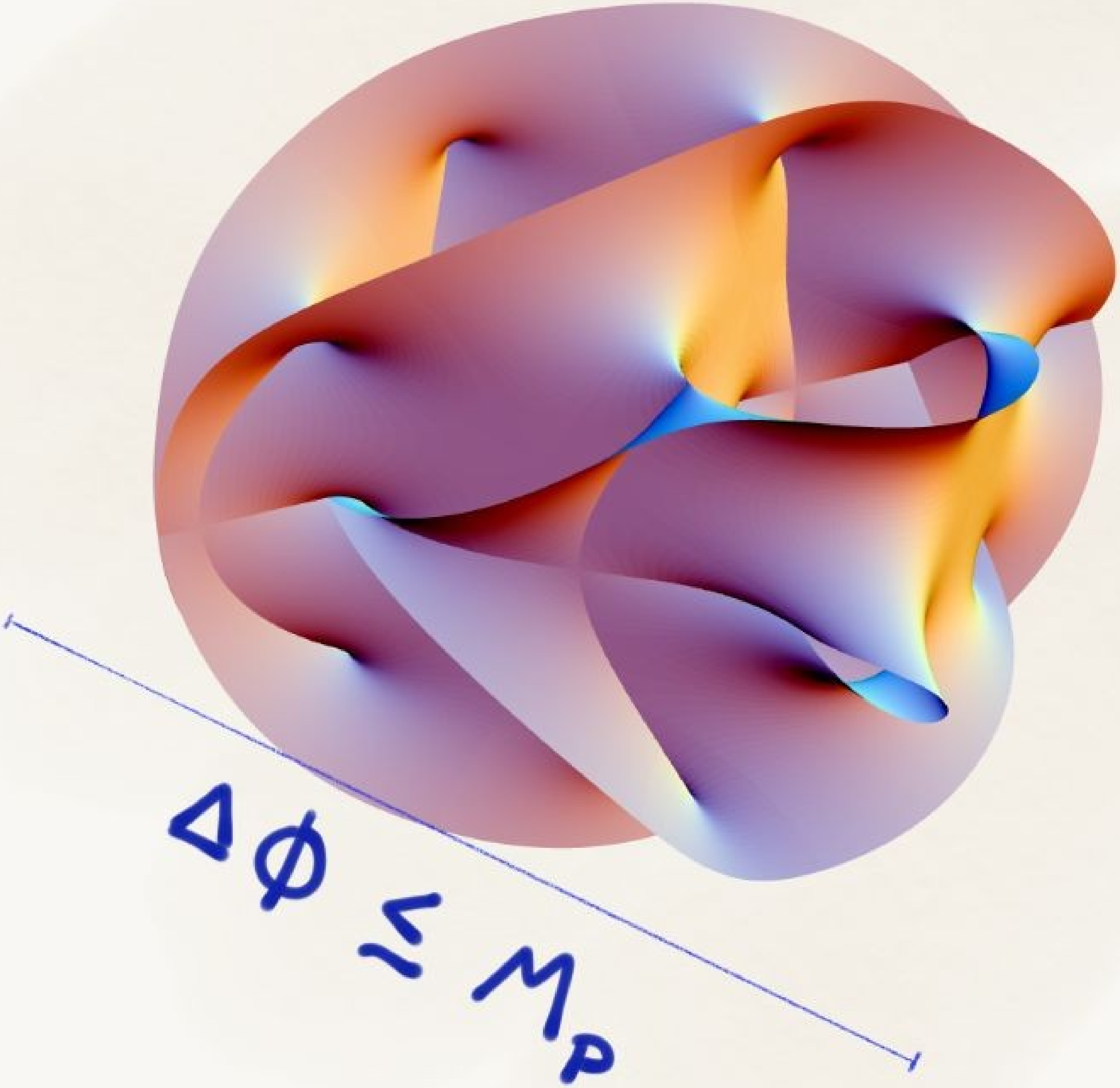
The Weak Gravity Conjecture

Any UV-complete theory must contain light charged states under all global symmetries.

$$M < QM_P \quad \forall U(1)$$



The deSitter Swampland Conjecture



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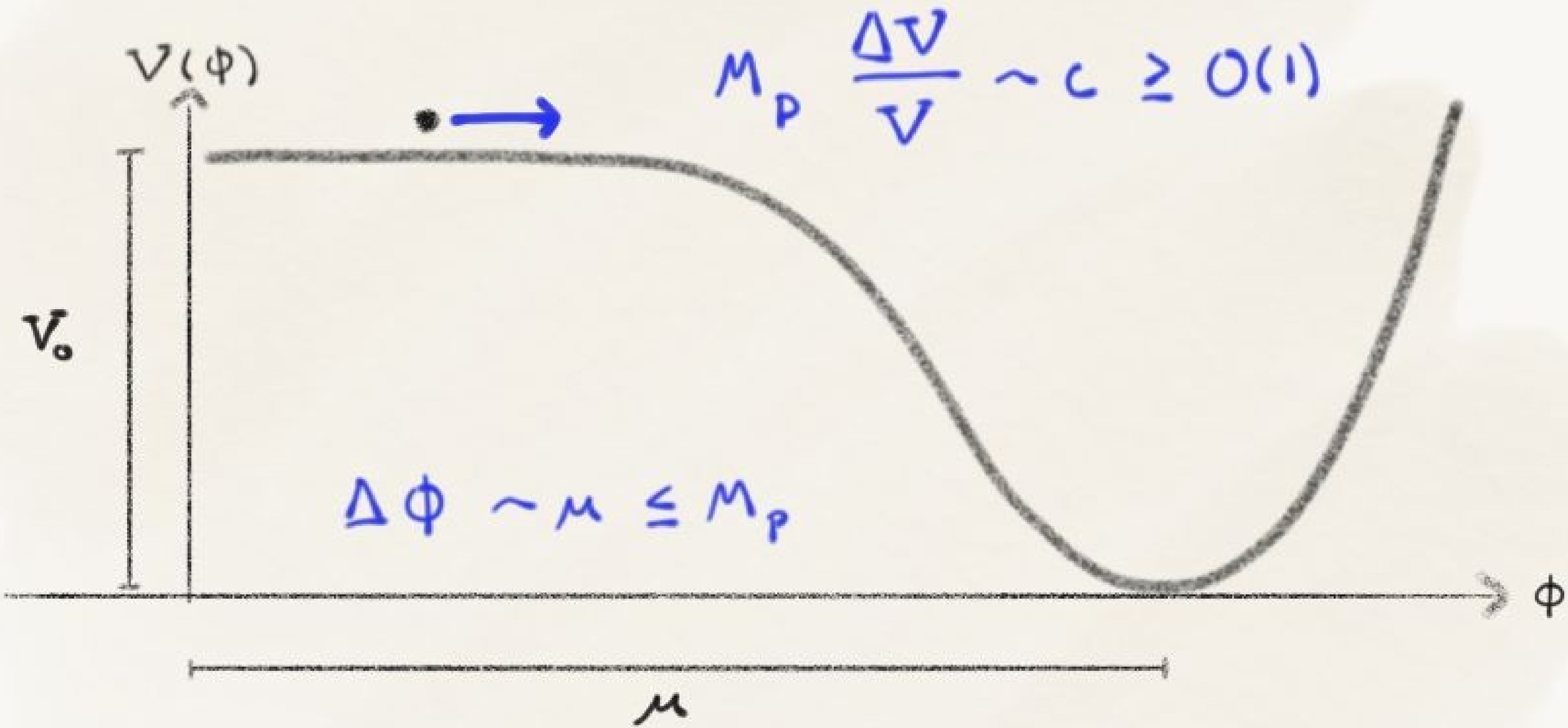
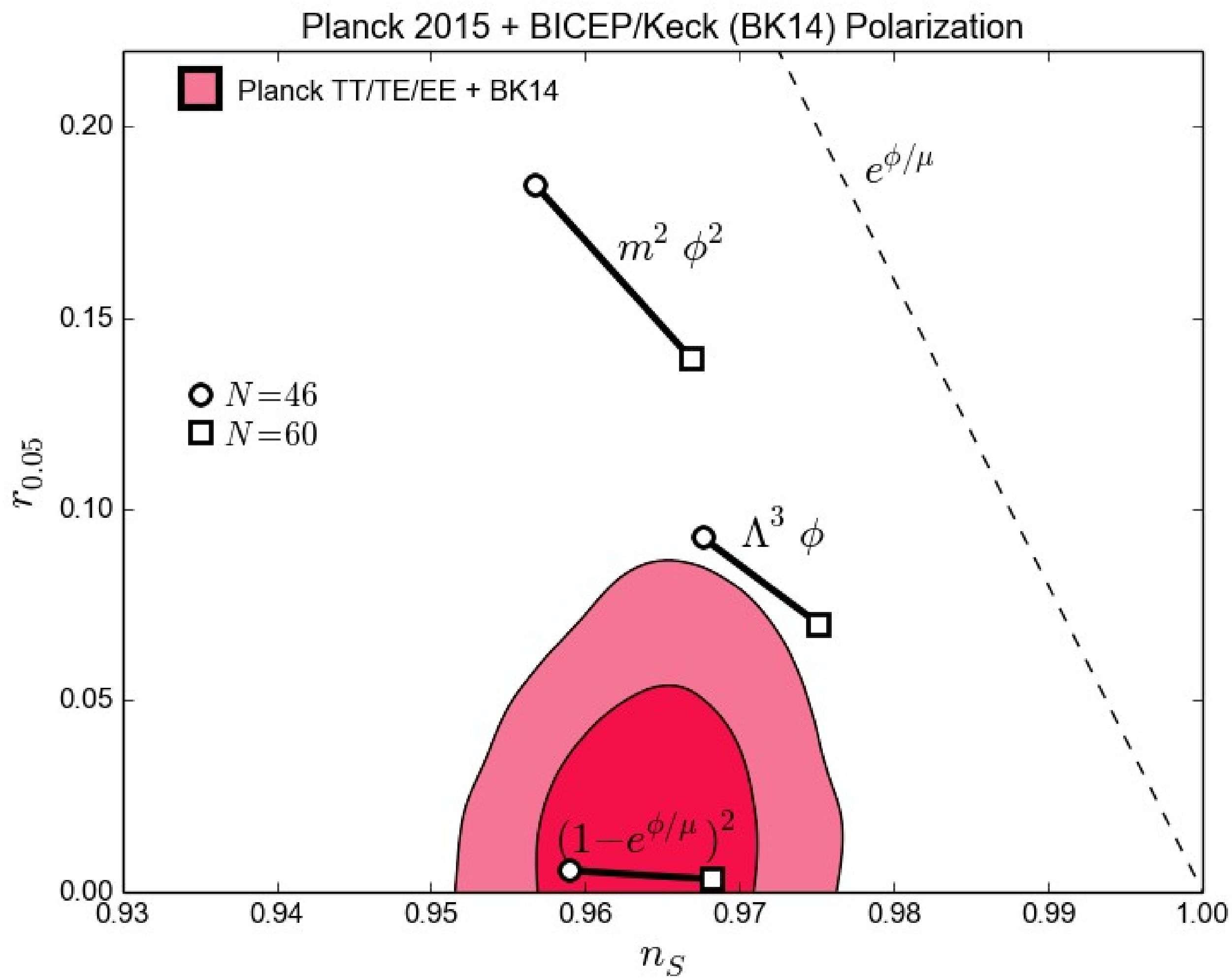
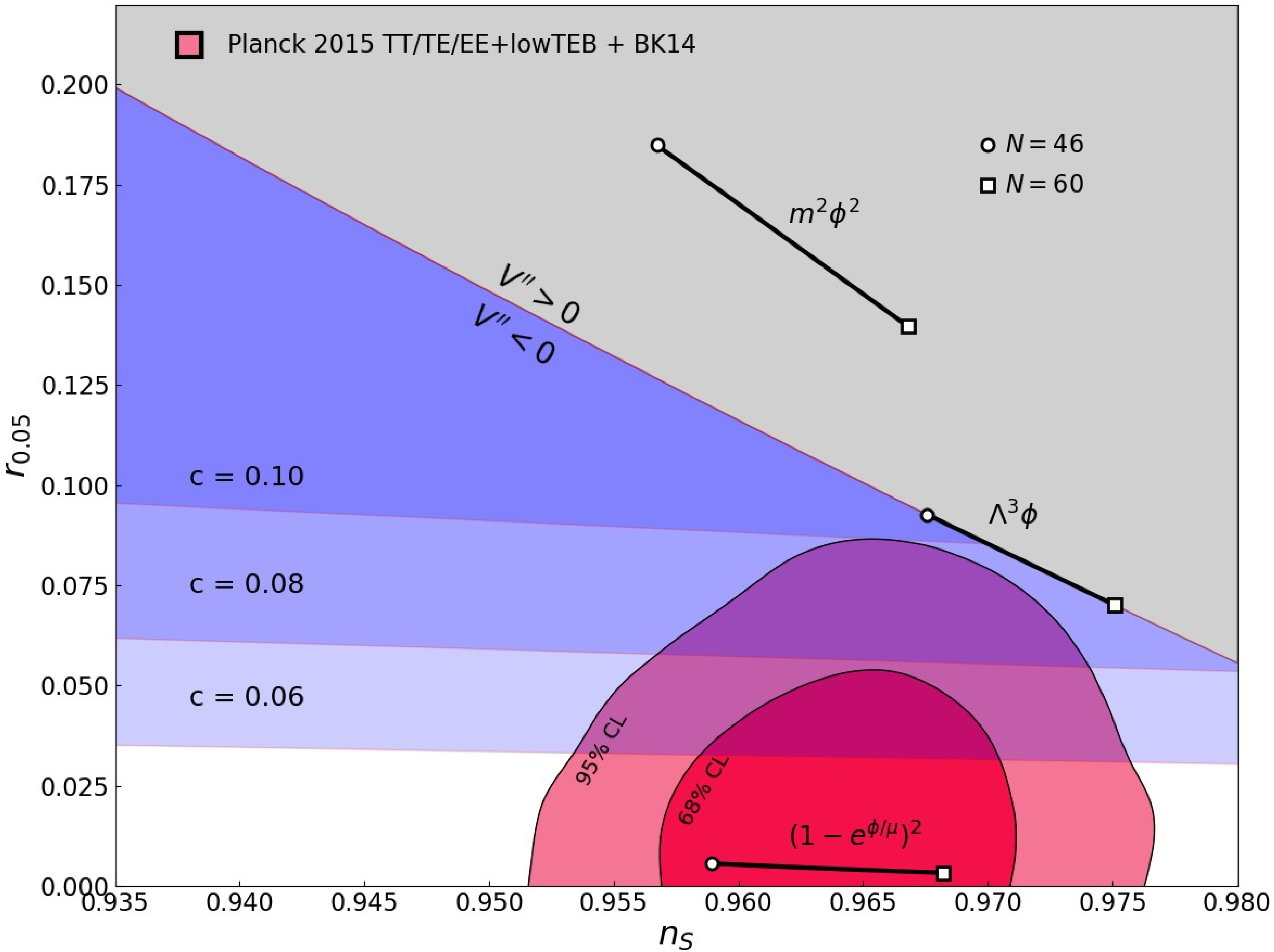


$$r = 8M_P^2\left(\frac{V'}{V}\right)^2$$



$$n_S = 1 - 3M_P^2\left(\frac{V'}{V}\right)^2 + 2M_P^2\frac{V''}{V}$$

Single-Field Inflation and the Swampland



WHK, Vagnozzi, Visinelli [arXiv:1808.0624]

The de Sitter Swampland Conjecture

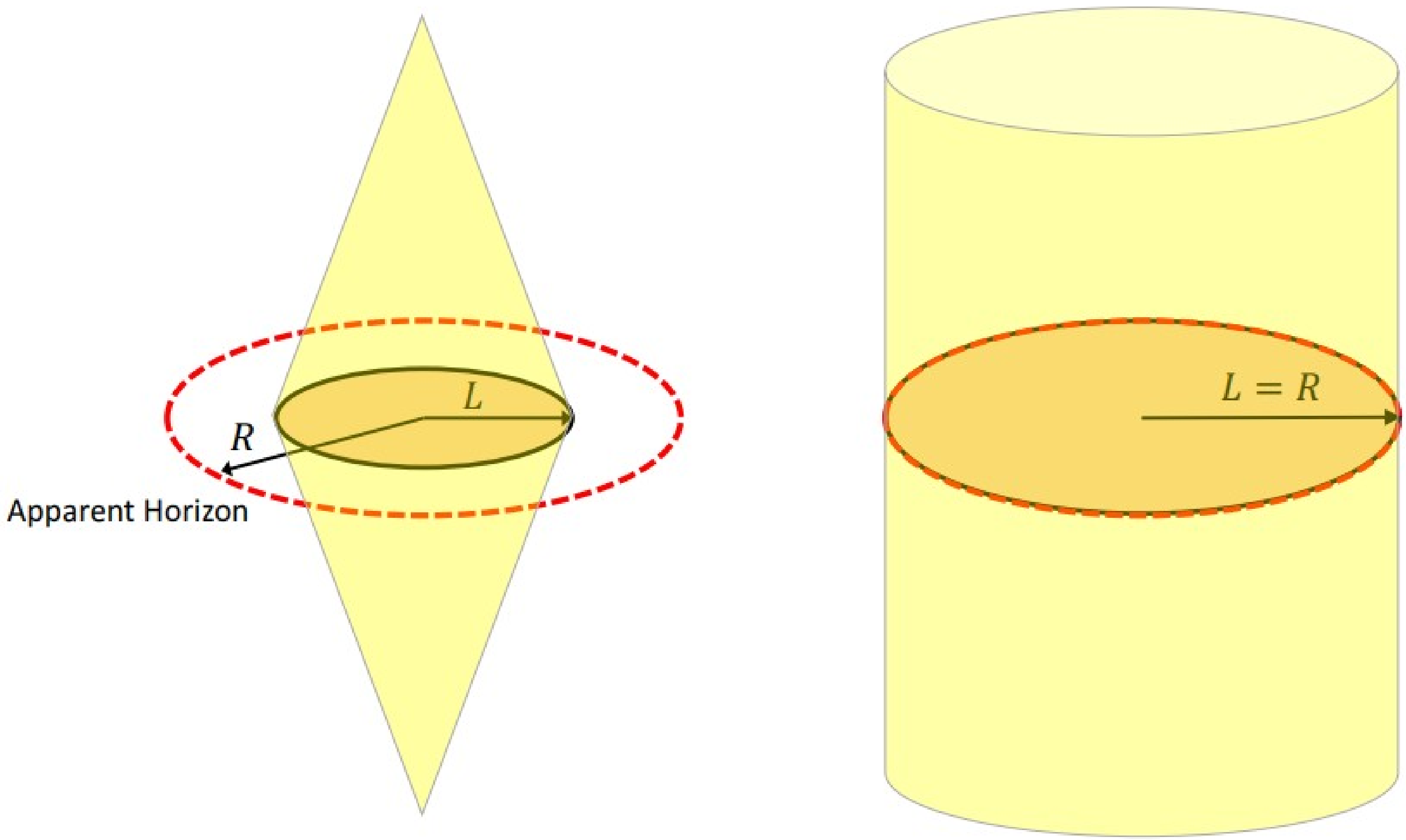
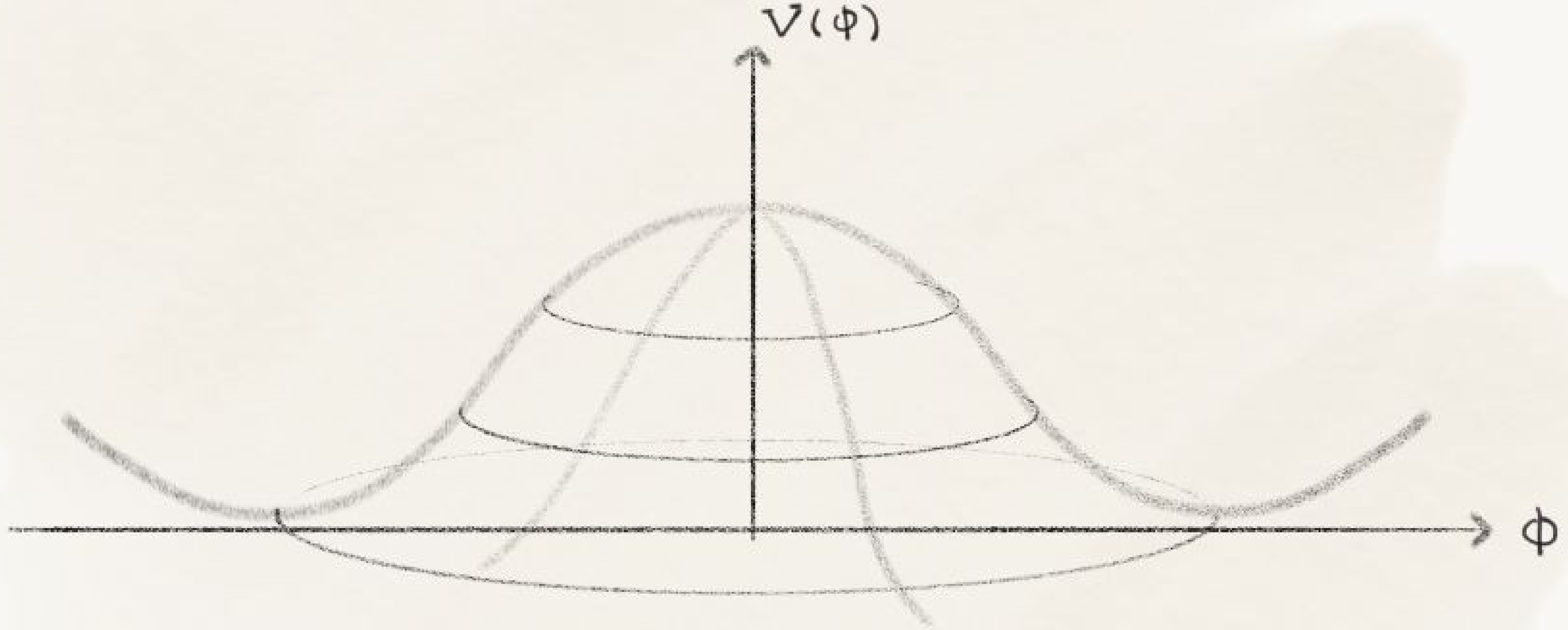


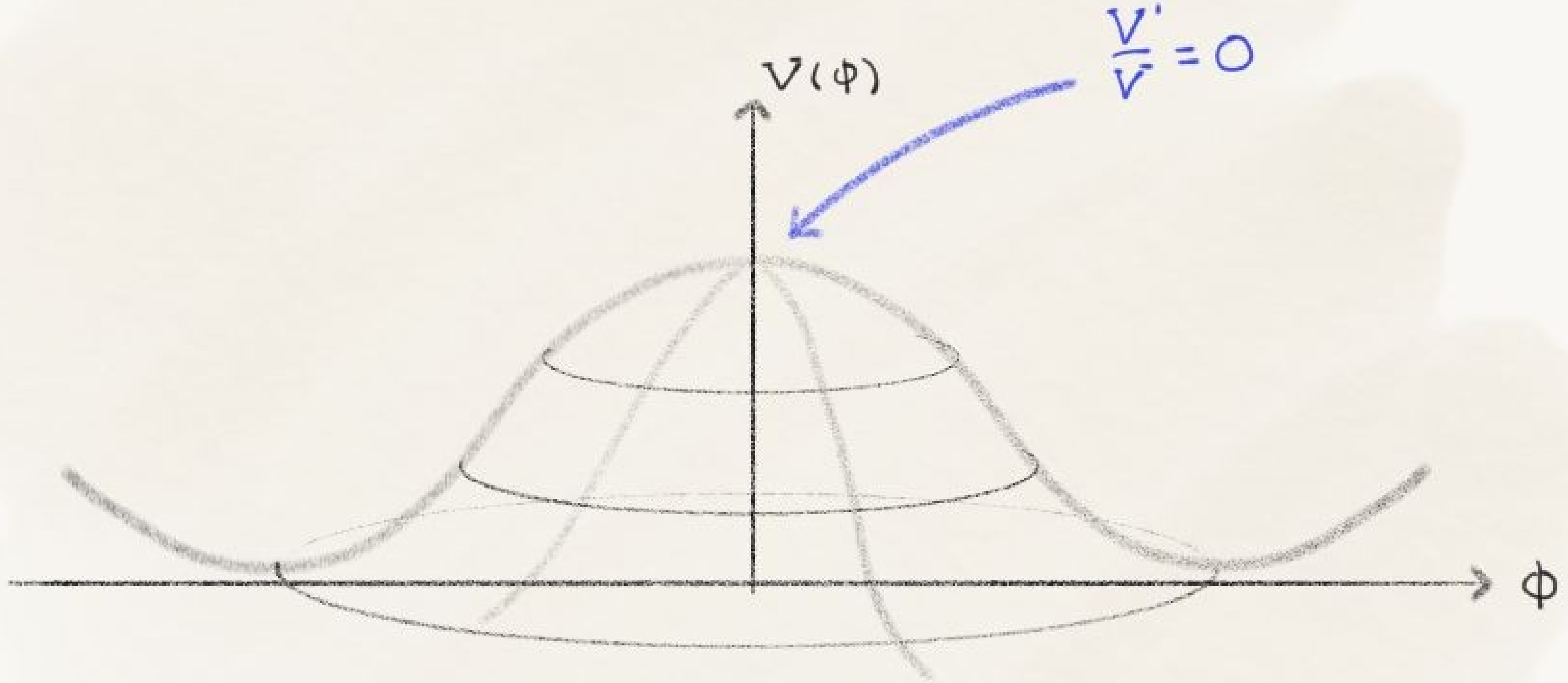
Figure 37: Figure illustrating the light sheets associated to spheres with radii L smaller than, or equal to, the apparent horizon of an accelerating universe of radius R. The sheets converge to a caustic at finite distance for $L < R$. The covariant entropy bound relates to the entropy of states on the light sheets, thereby naturally associating a maximum entropy to the apparent horizon.

Palti [arXiv:1903.06239]

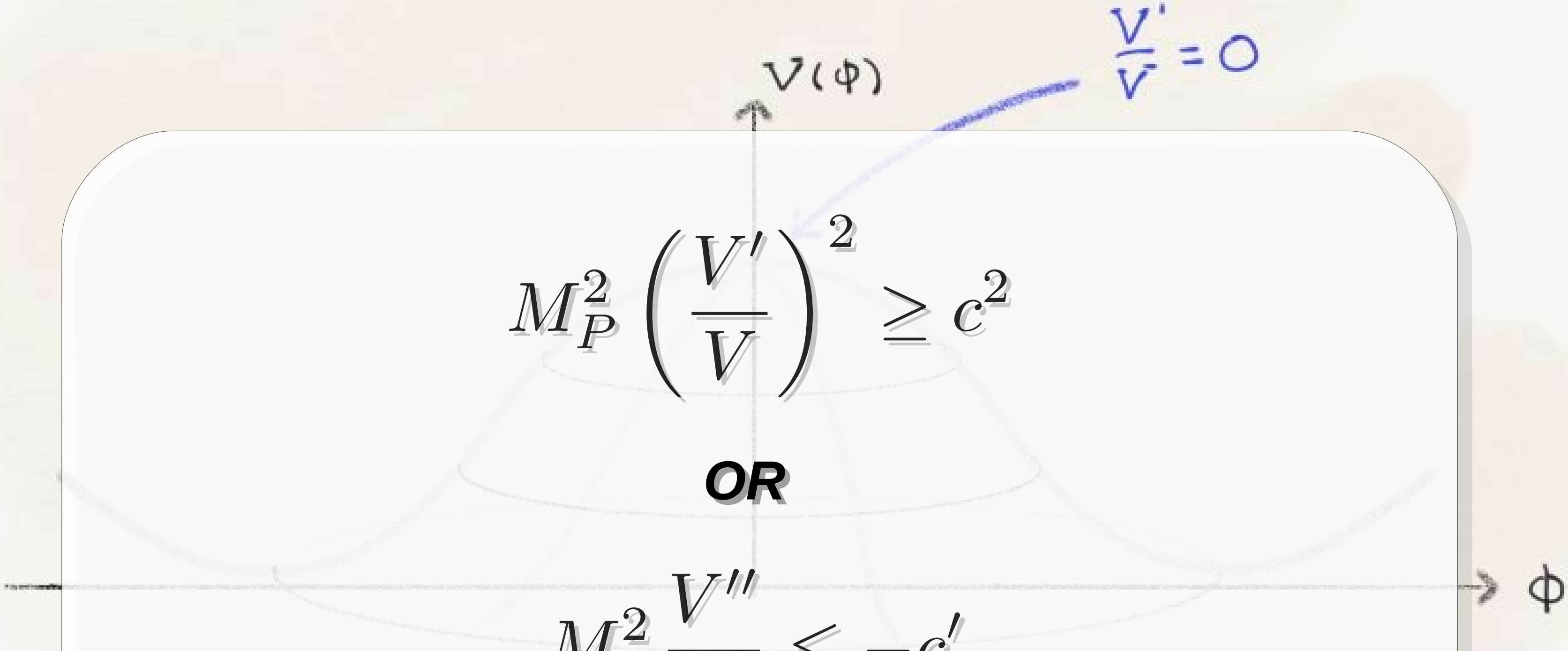
What about symmetry breaking?



What about symmetry breaking?



The Refined Swampland Conjecture



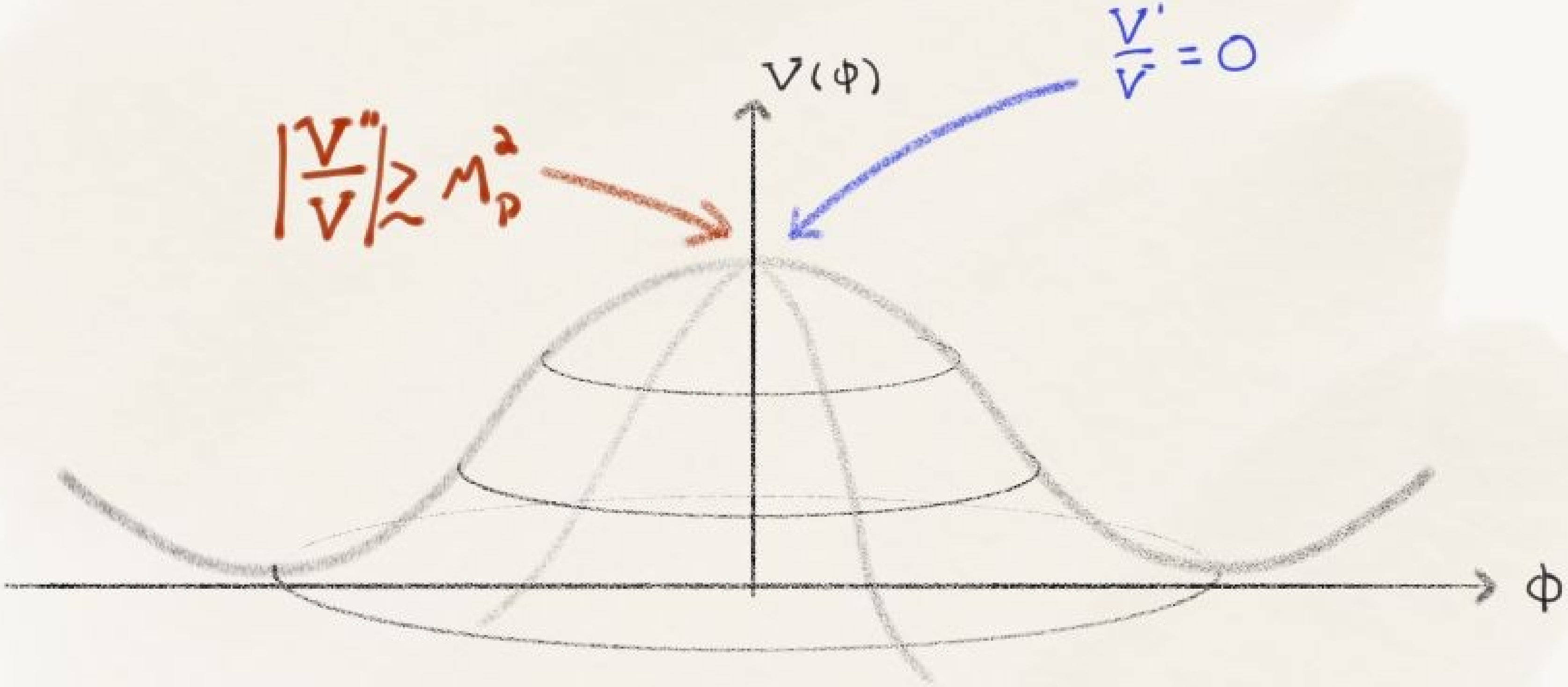
$$M_P^2 \left(\frac{V'}{V}\right)^2 \geq c^2$$

OR

$$M_P^2 \frac{V''}{V} \leq -c'$$

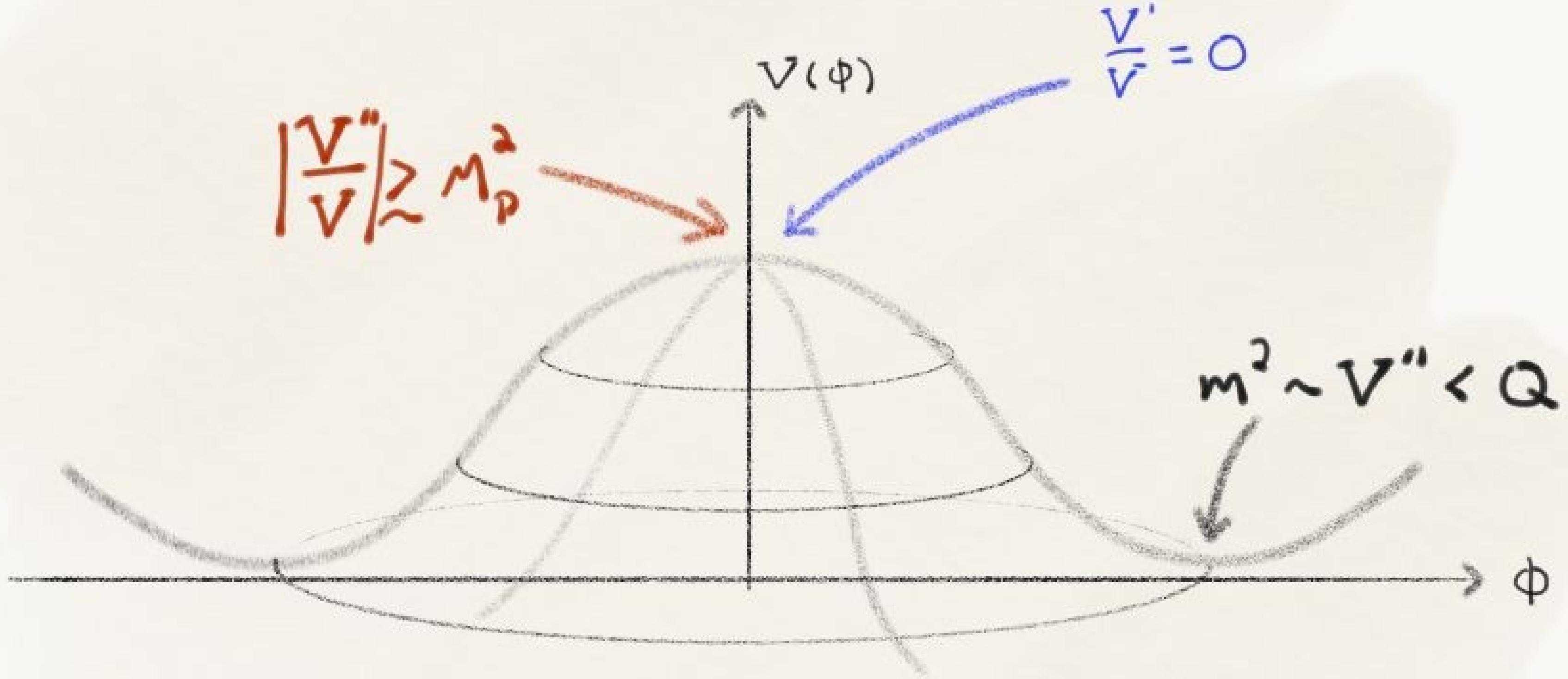
Ooguri, Palti, Shiu, Vafa [arXiv:1810.05506]

The *Refined* Swampland Conjecture



Ooguri, Palti, Shiu, Vafa [arXiv:1810.05506]

The *Refined* Swampland Conjecture



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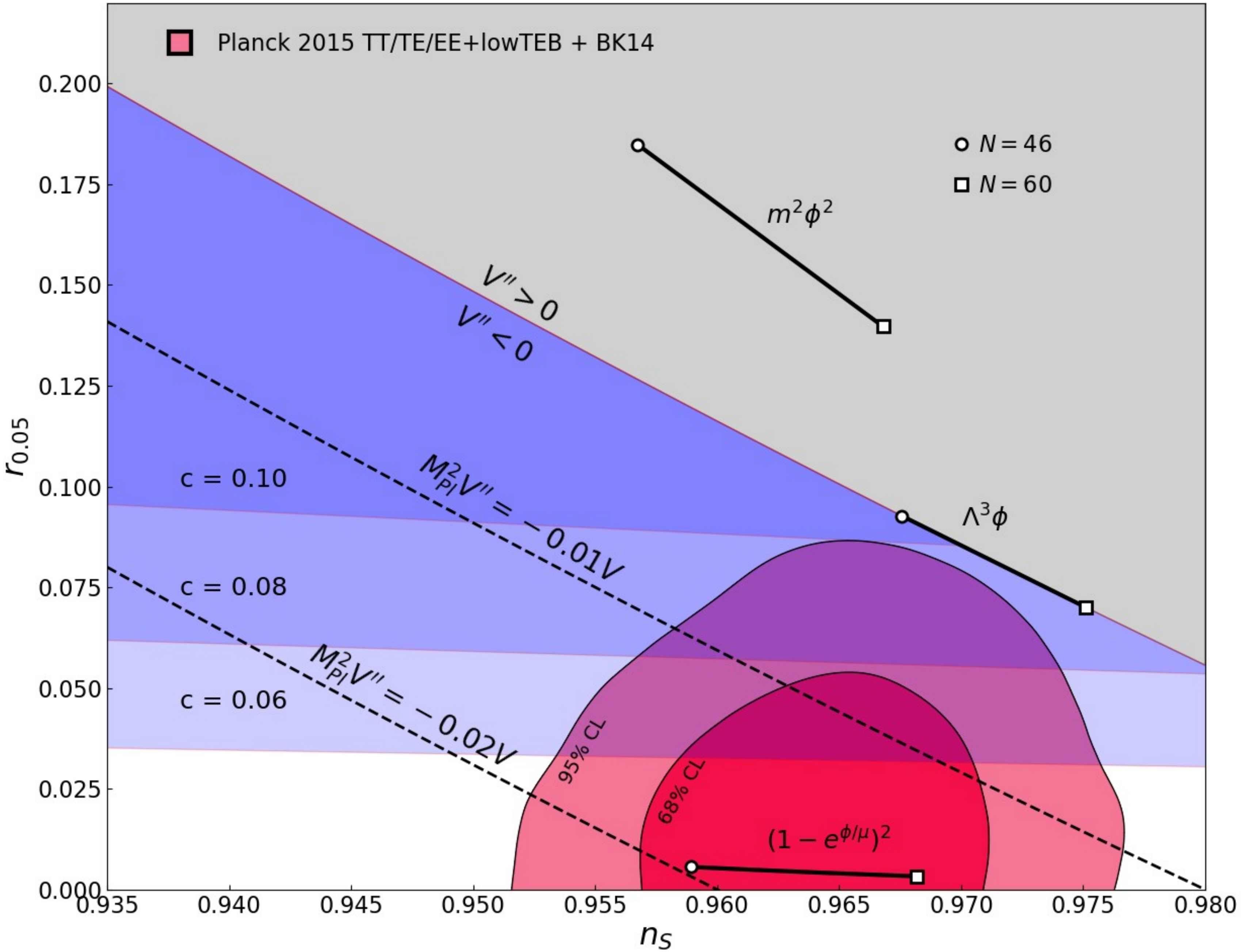
Single-Field Inflation and the Swampland



WHK, Vagnozzi, Visinelli [arXiv:1808.0624]

Ways Out

- Multi-Field Inflation

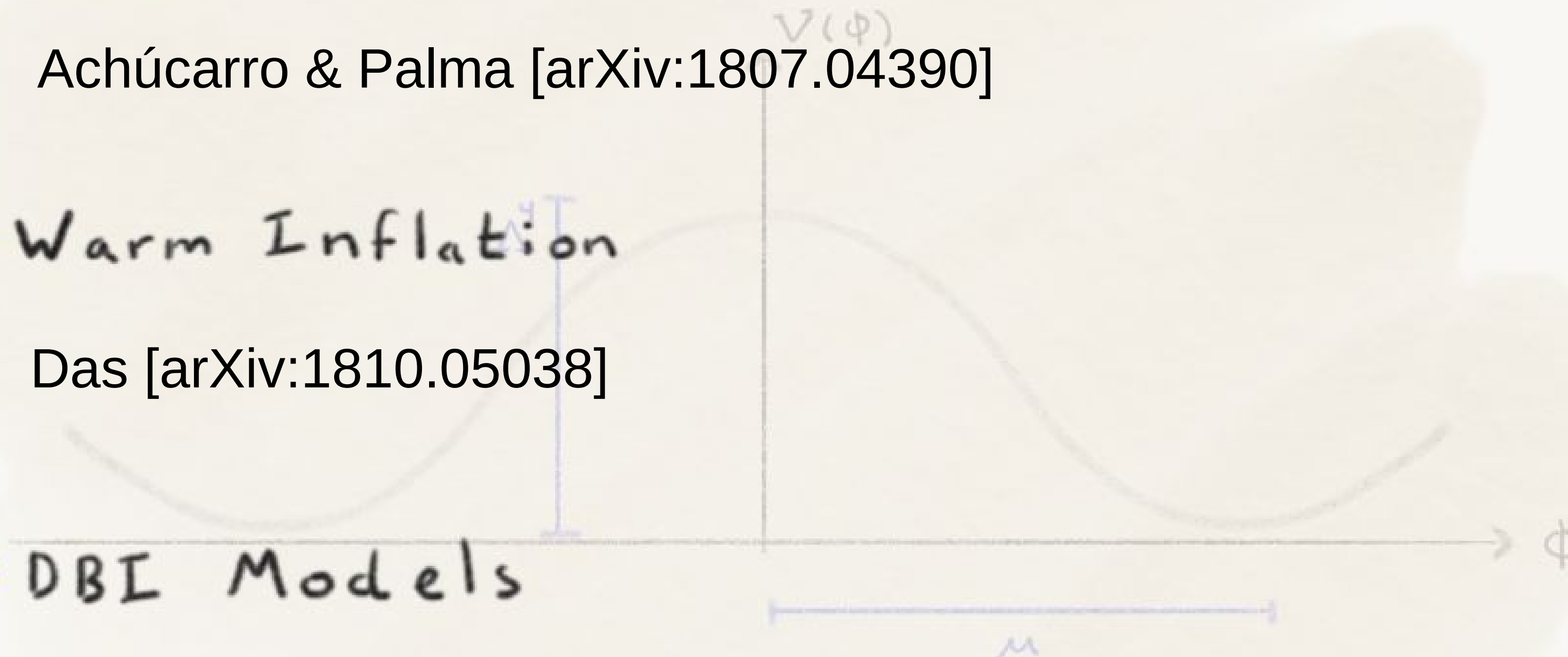
  Achúcarro & Palma [arXiv:1807.04390]

- Warm Inflation

  Das [arXiv:1810.05038]

- DBI Models

  Planck: $c_S > 0.0627 \rightarrow M_P(V'/V) < 0.37$



Tensor-Scalar Ratio, Sound Speed and Non-Gaussianity

Planck Limits on Non-Canonical Generalizations of Large-Field Inflation Models

Nina K. Stein and William H. Kinney

University at Buffalo
The State University of New York

Introduction

By generalizing to a Lagrangian with a non-canonical kinetic term, reducing the sound speed ameliorates the generic overproduction of tensors in large-field inflation, as the tensor-scalar ratio becomes

$$r = 16\epsilon c_S.$$

However, you cannot reduce the sound speed arbitrarily, since

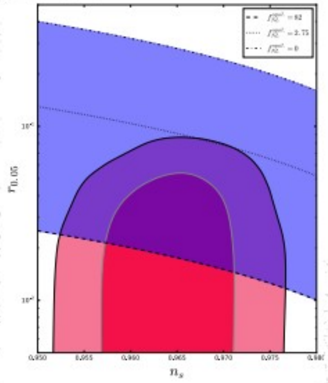
$$f_{NL}^{equil.} = \frac{35}{108}\left(\frac{1}{c_S^2} - 1\right).$$

Thus, the current Planck+ BICEP/KECK results limit the potential tensor mode suppression.

Planck + BICEP/KECK
$r \lesssim 0.066$
$n_S = 0.9644 \pm 0.0048$
$f_{NL}^{equil.} = -4 \pm 43$

Power Law Inflation Models
Constant Sound Speed

If the speed of sound is constant, this just represents a rescaling of the canonical Power-Law inflation case, with no additional degrees of freedom, as shown below.

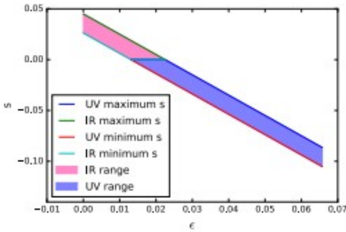


Power Law Inflation Models
Varying Sound Speed

For varying sound speed, we introduce an extra slow-roll parameter s, related to the derivative of the sound speed, such that

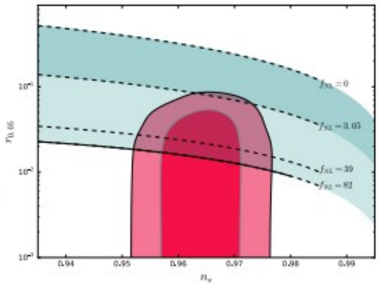
- $s > 0$ implies increasing sound speed (IR case),
- $s < 0$ implies decreasing sound speed (UV case).

For both UV and IR, there is now a permitted region of ϵ and s combinations allowed by the 2σ range of n_S, as shown below:



Note that the IR region for ϵ continues all the way to $\epsilon = 0$: This indicates that IR Power-Law DBI inflation sidesteps the overproduction of tensors issue we started with by having ϵ go arbitrarily small; consequently, we cannot place any constraints on this model via sound speed.

Meanwhile, while we can use Planck's non-gaussianity measurement to limit tensor suppression in the UV case, a far stricter bound on these models comes from perturbative unitarity, which requires $f_{NL}^{equil.} < 3.05$, as indicated by the darker shaded region in the figure below.

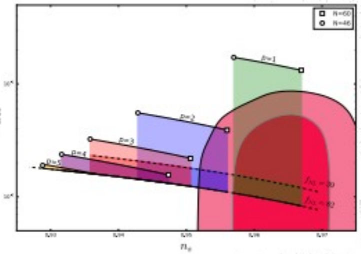


References

1. N. K. Stein and W. H. Kinney, JCAP 1704 (2017) no.04, 006 doi: 10.1088/1475- 7516/2017/04/006 [arXiv:1609.08959 [astro-ph.CO]].
2. Planck collaboration, P. A. R. Ade et al., Planck 2015 results. XVII. Constraints on primordial non-Gaussianity, 1502.01592.
3. W. H. Kinney, Inflation: Flow, fixed points and observables to arbitrary order in slow roll, Phys. Rev. D66 (2002) 083508, [astro-ph/0206032].

buffalo.edu

Isokinetic Inflation Models



Isokinetic Inflation represents a generalization of the classic $V(\phi) = m^2\phi^2$ potential to

$$H(\phi) = C\mu^{(1-p)}\phi^p$$

Where p is an arbitrary positive integer. By requiring that the speed of sound increase monotonically (there is no decreasing sound speed option here) and remain less than 1 (for causality), we find an upper bound on r independent of the Planck measurements:

$$r \leq 16\left(1 + \frac{p+1}{p}N\right)^{-2p/(p+1)}$$

So that the upper line in the top figure indicates, not $f_{NL}=0$, but that upper bound; this is why the p=5 line does not continue to N=60, and p=6 has no physically viable region.

Conclusions

In this work, we considered non-canonical generalizations to large-field inflation models, which generically overproduce tensors inconsistent with CMB constraints. We found that, while reducing the speed of sound does suppress the tensor/scalar ratio, the models which overproduce tensors generically cannot be brought into agreement with values of r below approximately 0.01, which value is within range of near-future CMB experiments, so that any measurement of

$$r \lesssim 0.01$$

would rule out broad classes of non-canonical generalizations of large-field potentia.

What are the choices?

To generate perturbations consistent with observation, must have one of:

(1) Accelerated Expansion

(2) Superluminal Sound Speed

(3) Violation of the Null Energy Condition

(4) Super-Planckian Energy Density

Geshnizjani, WHK, Moradinezhad Dizgah, [arXiv:1107.1241]
Geshnizjani, Ahmadi [arXiv:1309.4782]
Geshnizjani, WHK [arXiv:1404.4614]

Astrophysics > Cosmology and Nongalactic Astrophysics

Consistency of Tachyacoustic Cosmology with de Sitter Swampland Conjectures

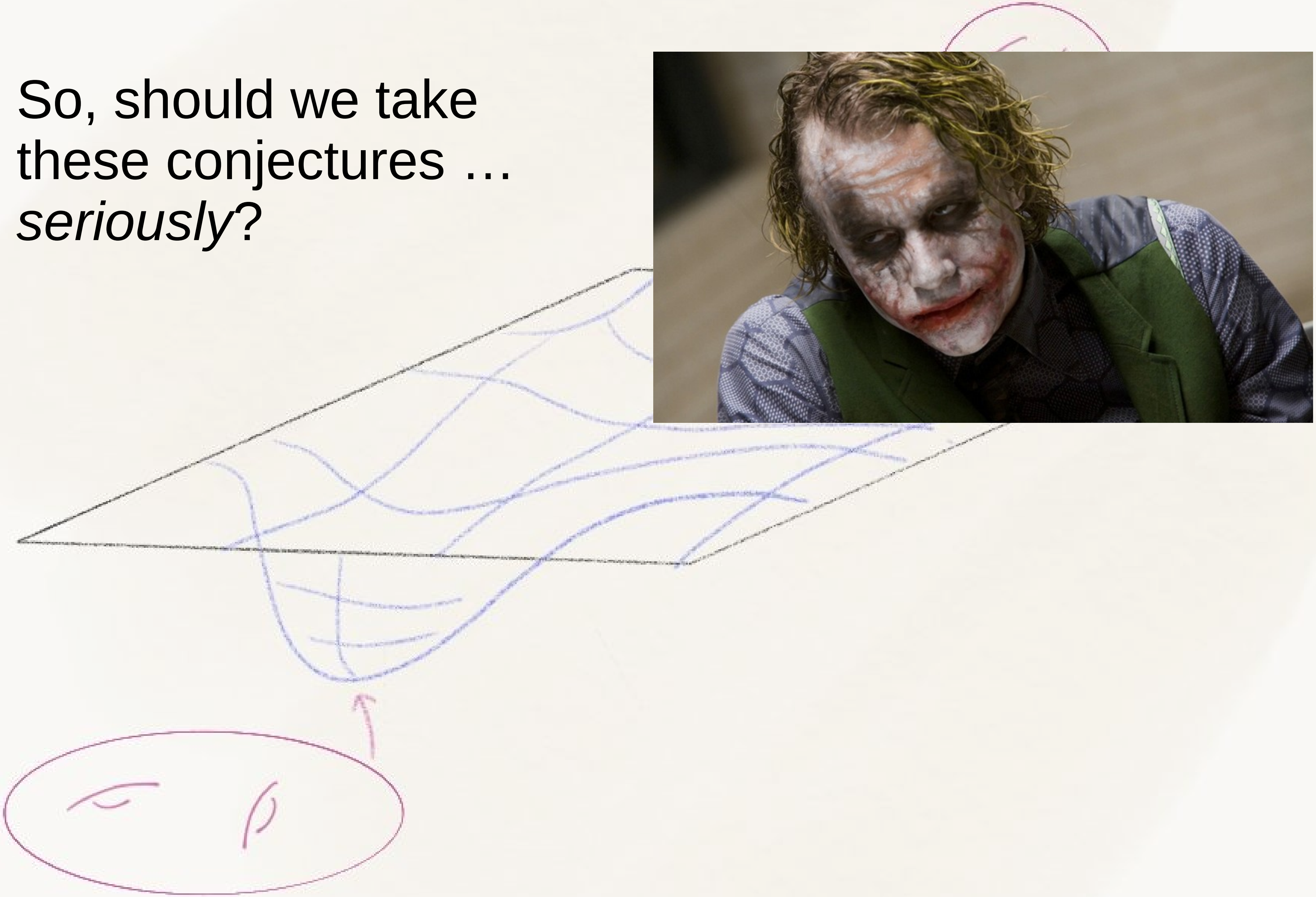
Wei-Chen Lin, William H. Kinney

(Submitted on 11 Dec 2018 (v1), last revised 10 Jan 2019 (this version, v2))

Recent studies show that there is tension between the de Sitter swampland conjectures proposed by Obeid, et al. and inflationary cosmology. In this paper, we consider an alternative to inflation, `tachyacoustic' cosmology, in light of swampland conjectures. In tachyacoustic models, primordial perturbations are generated by a period of superluminal sound speed instead of accelerating expansion. We show that realizations of tachyacoustic Lagrangians can be consistent with the de Sitter swampland conjectures, and therefore can in principle be consistent with a UV-complete theory. We derive a general condition for models with $c_S > 1$ to be consistent with swampland conjectures.

Conjecture, Smonjecture…

So, should we take these conjectures … *seriously*?



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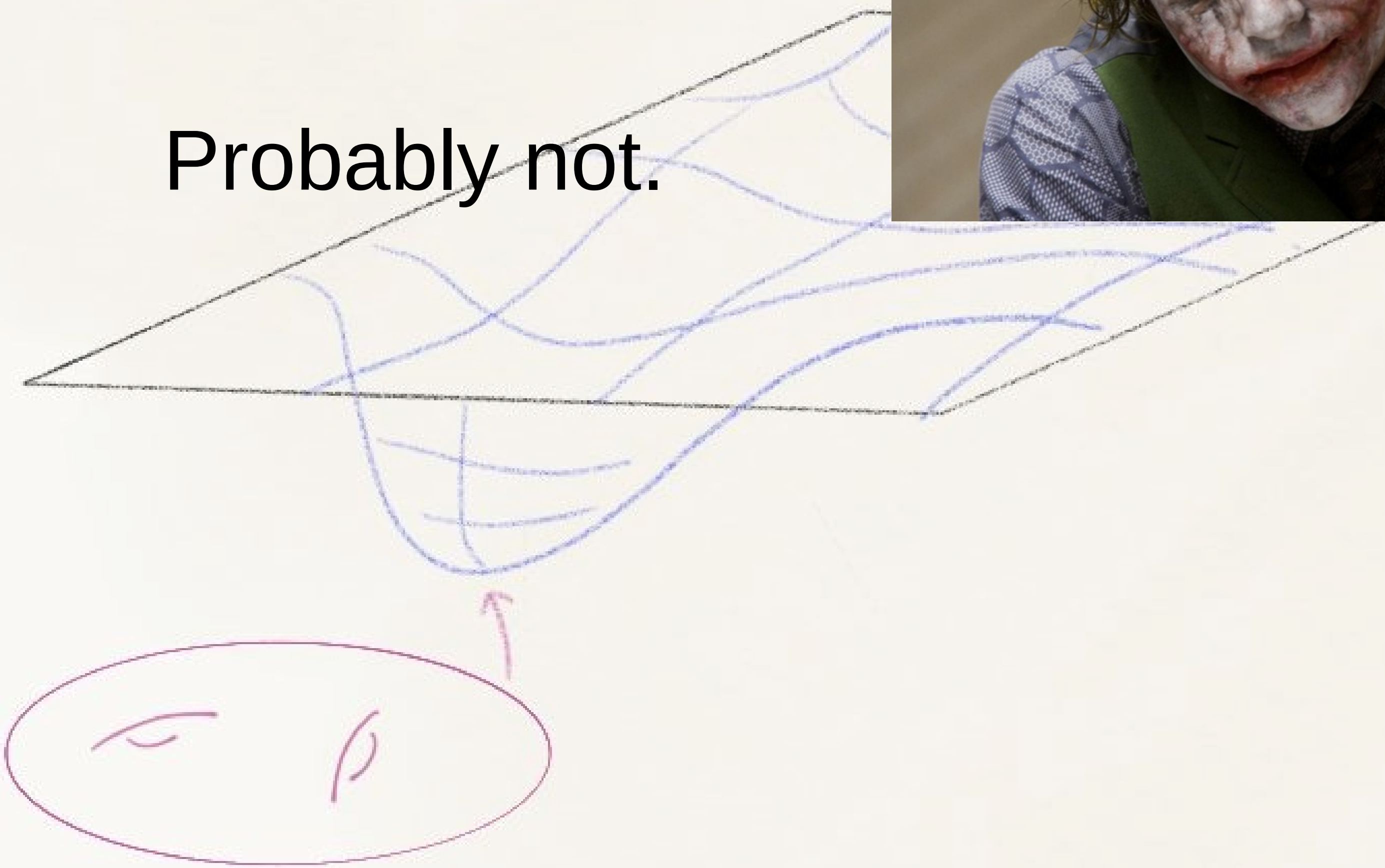
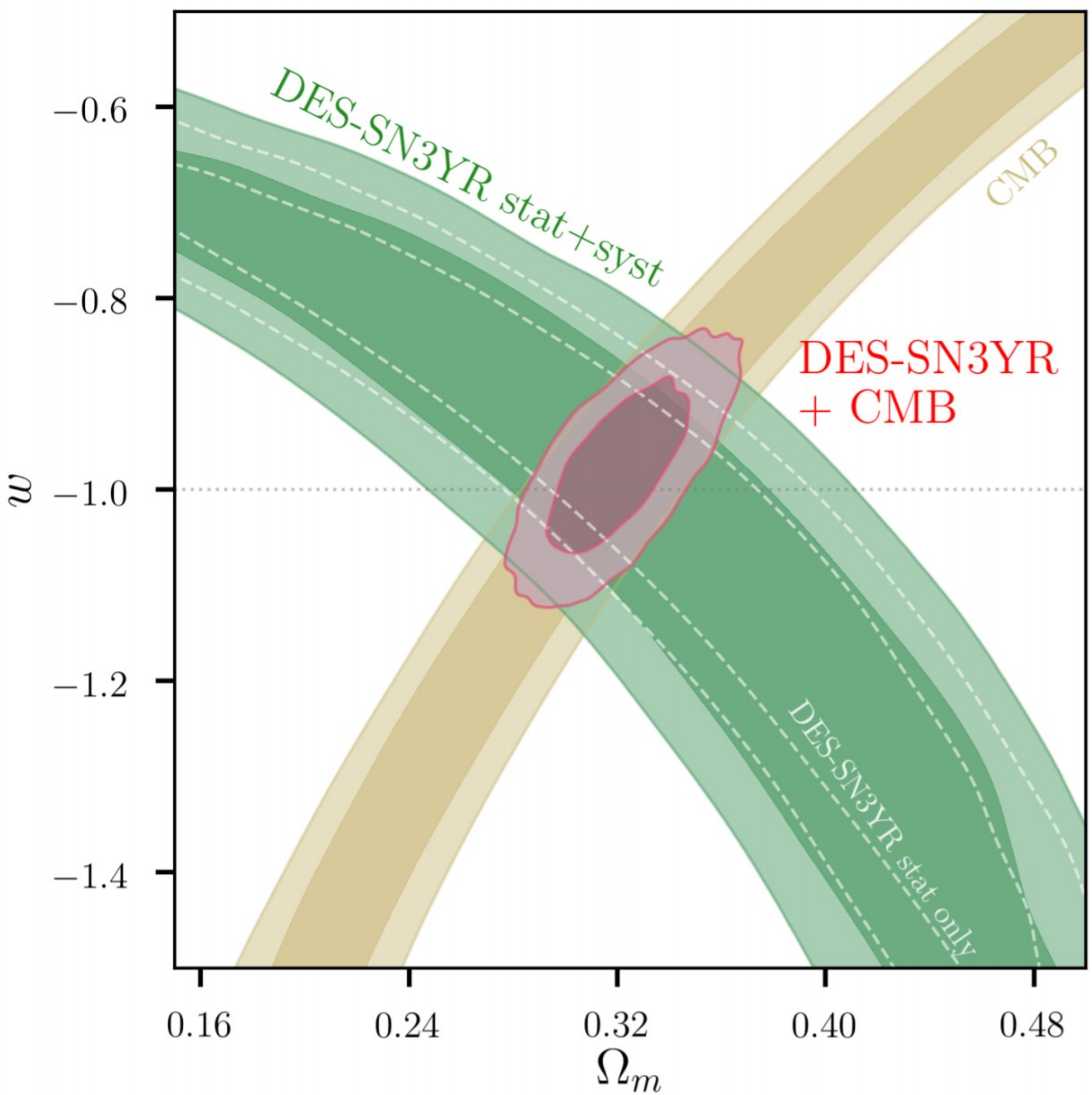


DES-SN + CMB Constraints



Flat wCDM:

$$w = -0.978 \pm 0.059$$

Flat w_0/w_a CDM:

$$w_0 = -0.885 \pm 0.114$$

$$w_a = -0.387 \pm 0.430$$

[Abbott, *et al.* ArXiv:1811.02374]

Conjecture, Smonjecture…

So, should we take these conjectures … *seriously*?

Probably not.

If string theory doesn't support de Sitter solutions, so what?

Danielsson & Van Riet, [arXiv:1804.01120]