TransPlanckian Censorship And The Swampland

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Navigating the Swampland
IFT, Madrid

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Based on 2 papers

Trans-Planckian Censorship and the Swampland

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ABSTRACT: In this paper, we propose a new swampland condition, the Trans-Planckian Censorship Conjecture (TCC), based on the idea that in a consistent quantum theory of gravity sub-Planckian fluctuations should never become larger than the horizon and freeze in an expanding universe. Applied to the case of scalar fields, it leads to conditions that are similar, but generally weaker than the refined dS swampland conjecture. For large field values, we find a bound $|V'| > \frac{2}{\sqrt{(d-1)(d-2)}}V$, which is consistent with all known cases in string theory. Like the dS conjecture, the TCC forbids long-lived meta-stable dS spaces, but it does allow sufficiently short-lived dS spaces.

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Trans-Planckian Censorship and Inflationary Cosmology

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We study the implications of the recently proposed *Trans-Planckian Censorship Conjecture* (TCC) for early universe cosmology and in particular inflationary cosmology. The TCC leads to the conclusion that if we want inflationary cosmology to provide a successful scenario for cosmological structure formation, the energy scale of inflation has to be lower than $10^9 GeV$. Demanding the correct amplitude of the cosmological perturbations then forces the generalized slow-roll parameter ϵ of the model to be very small ($< 10^{-31}$). This leads to the prediction of a negligible amplitude of primordial gravitational waves. For slow-roll inflation models, it also leads to severe fine tuning of initial conditions.

The plan for this talk is:

-Difficulties with constructing dS motivates:

1-Refined dS conjecture $|\nabla V| \geq cV$ for c>0

Strong evidence at weak couplings

2-Transplanckian Censorship Conjecture $a_f / a_i < \frac{1}{H_f}$

-Cosmological Implication of the proposed swampland criteria for past, present and future.

dS Swampland Conjecture

One can consider a bound:

$$|\nabla V| > f(\varphi)$$

And a natural choice for f is:

$$f(\varphi) = cV(\varphi)$$

Where c>0 and order 1 in Planck units. In other words for a universal c

$$|\nabla V| \geq cV$$

(Or V is too unstable with V’’ <-c’V)

One can consider M-theory in supergravity limit:

$$2\kappa_{11}^2 S = \int d^{11}x \sqrt{-g^{(11)}} \left(\mathcal{R} - \frac{1}{2}|G|^2 \right)$$

and consider compactifying to d dimensions on an arbitrary 7 manifolds with arbitrary flux. We get an effective potential $V(\varphi^i)$ which is a function of infinitely many scalars (which parameterize all possible internal metrics and fluxes on the 7-manifold). It is hard to believe but its true that for arbitrary metric and flux there is no critical point of V with V>0, as M-N no-go theorem shows (in supergravity approximation).

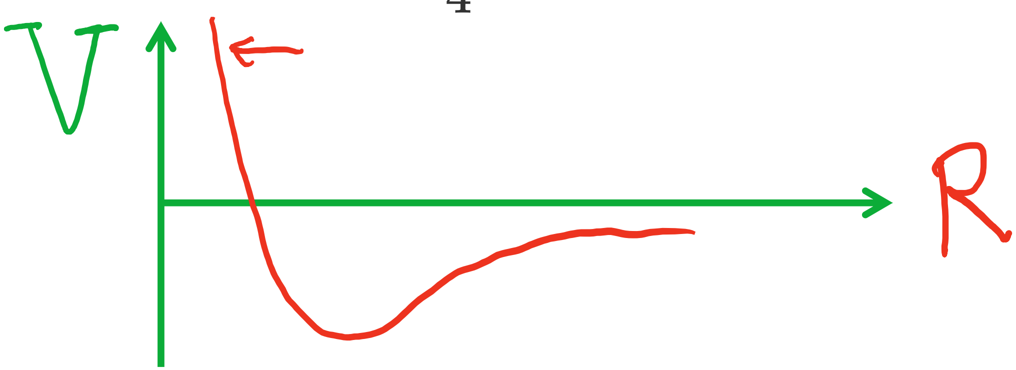
The M-N no-go theorem can be strengthened:

If we compactify M-theory to d dimensions, one can easily show, using volume rescaling, that in supergravity limit

$$\frac{|\nabla V|}{V} \geq \frac{6}{\sqrt{(d-2)(11-d)}}.$$

$$d = 4, \text{ this yields } 6/\sqrt{14} \sim 1.6$$

which is realized for $AdS_4 \times S^7$.



If we assume the Strong Energy Condition (SEC), or more precisely for compactifications respecting that,

$$\frac{|\nabla V|}{V} \geq \lambda_{SEC} \equiv 2\sqrt{\frac{D-2}{(D-d)(d-2)}}.$$

And for compactifications respecting Null Energy Condition (NEC) with zero or negative average scalar curvature

$$\frac{|\nabla V|}{V} \geq \lambda_{NEC} \equiv 2\sqrt{\frac{D-d}{(D-2)(d-2)}}$$

Where D=11,10 and d is the dimension we compactify to. For example D=10, d=4:

$$\lambda_{NEC} = \sqrt{\frac{3}{2}} \simeq 1.2$$

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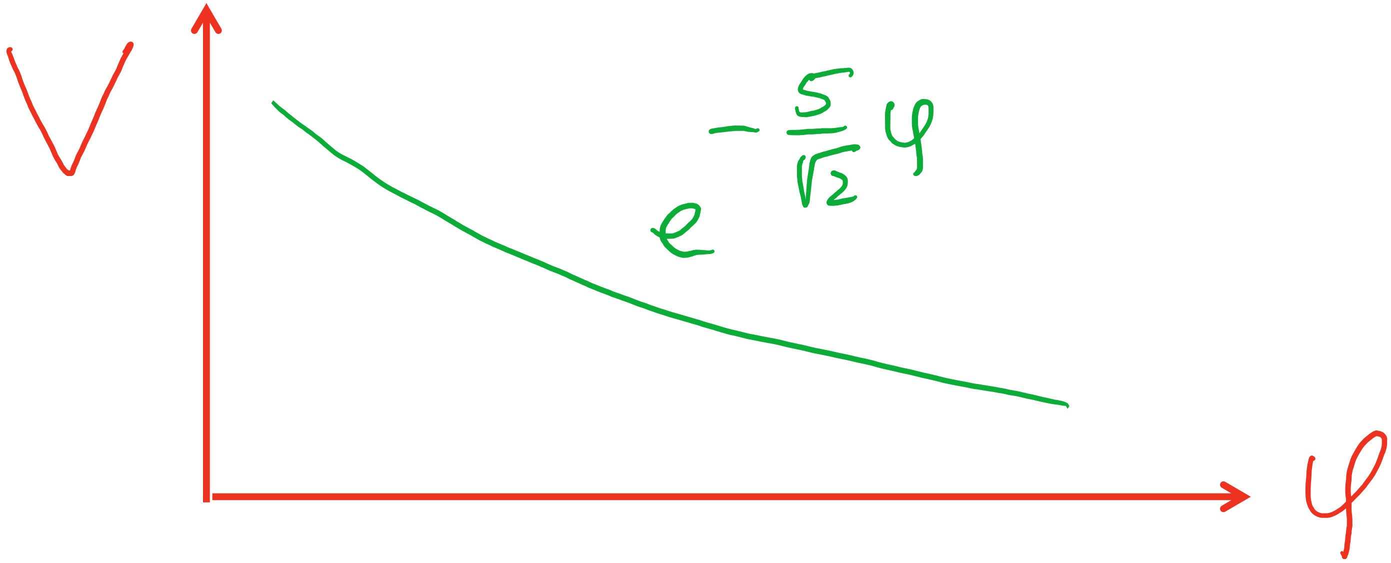
For example D=10, d=4:

The minimum known example: $\lambda_{\cancel{NEC}} > \sqrt{\frac{2}{3}} \sim 0.8$

Other examples:

Heterotic O(16)xO(16) strings. Non-susy, no tachyons in 10 d, and at weak coupling has positive cosmological constant:



$$\left|\frac{\nabla V}{V}\right| = \frac{5}{\sqrt{2}}$$

Heuristic link:

Distance Conjecture —> dS Conjecture

(at weak coupling)

[Ooguri,Palti,Shiu,V]

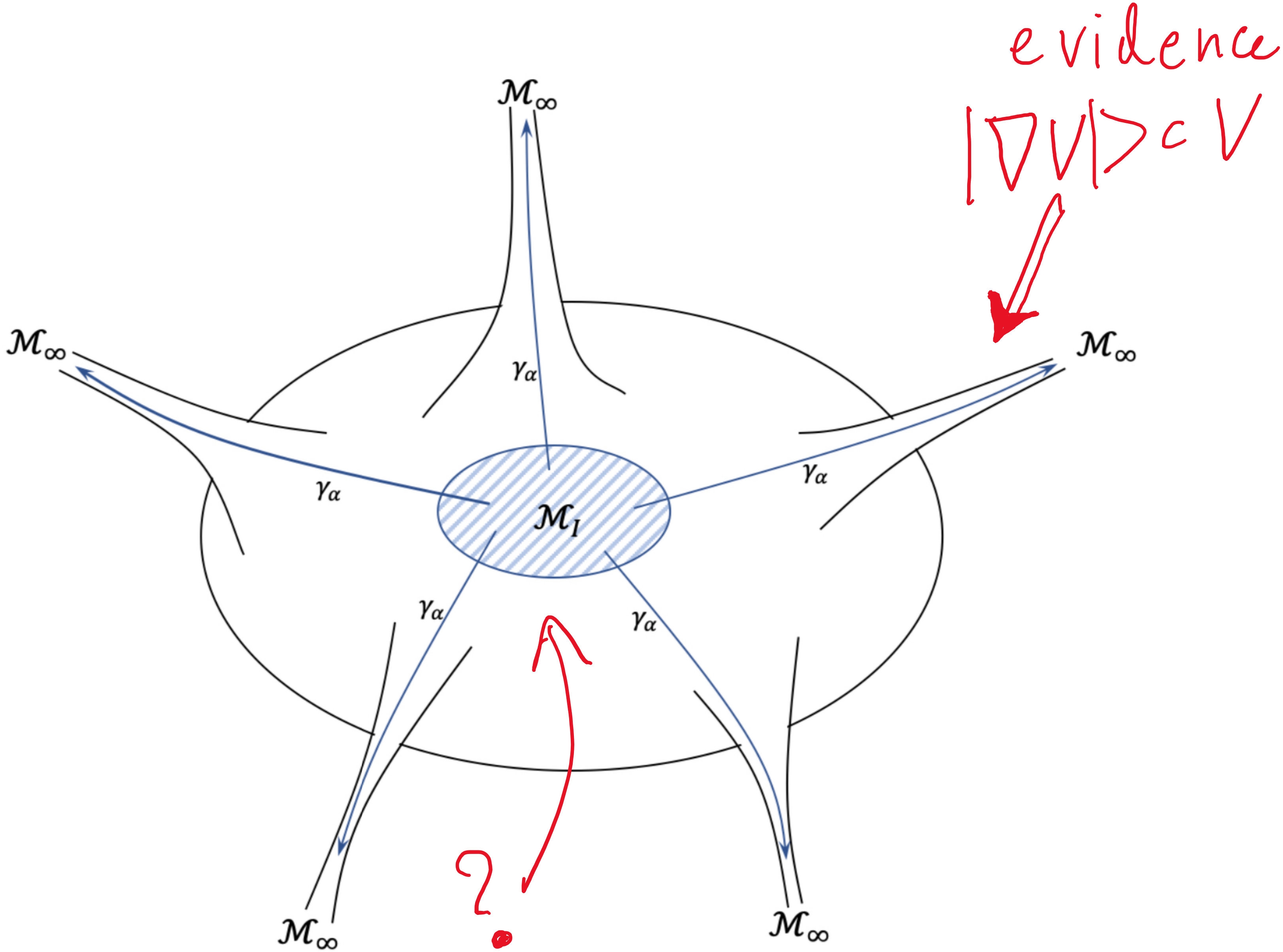
Weak couplings—> correspond to points where some scalars field traverse super-Planckian distances.

We thus get towers of light states with energy

$$m \sim exp(-\alpha \Delta \varphi)$$

If there are N such towers then we expect $\frac{dN}{d\varphi} \geq 0$

This leads to the statement that at parametrically weak couplings we expect the conjecture is true and this is compatible with the no-go theorems we did find in the context of string theory.



evidence
$|\partial V| > cV$
$\mathcal{M}_\infty$
$\mathcal{M}_\infty$
$\mathcal{M}_\infty$
γ_α
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γ_α
$\mathcal{M}_I$
γ_α
γ_α
?
$\mathcal{M}_\infty$
$\mathcal{M}_\infty$

Also this leaves open the question:

Even if dS conjecture is true, what is the quantum gravity rationale for it?

Usually we have arguments motivated by black hole physics or other quantum gravity reasoning for swampland conditions which go beyond string constructions.

Is there any such reasoning for the dS conjecture?

Transplanckian Censorship Conjecture

The idea is: In a consistent QG, Sub-Planckian quantum fluctuations should remain quantum (and not classicalize)— i.e., in an expanding universe sub-Planckian quantum fluctuations cannot grow bigger than the Horizon and freeze.

$$\frac{a_f}{a_i} \cdot l_p < \frac{1}{H_f}$$

$$\int_i^f H\,dt < \ln(M_p/H_f)$$

Consequences of TCC:

There cannot be a prolonged period of accelerating expansions. This leads to

1-The slope of the potential at infinity cannot be too small:

$$\left[|V'| \geq \frac{2}{\sqrt{(d-1)(d-2)}} V \right]_{\infty}$$

at $d=4$: $\sqrt{\frac{2}{3}} \sim 0.8$

2-The expansionary epoch till time t is bounded by H(t):

$$t_{age} < \frac{1}{H(t)} \log \frac{M_p}{H(t)}$$

This follows from monotonically decreasing H (which is the case assuming $w \geq -1$).

For current Hubble parameter leads to

$t_{age} < 2$ trillion yrs ✓

3-Classically TCC does not allow V to have a stable critical point but unlike dS conjecture quantum mechanically it does allow as long as it is sufficiently short lived.

Meta-stable dS:

$$\tau_{dS}^{\Lambda} < \sqrt{\frac{(d-1)(d-2)}{2\Lambda}} \log\left(\sqrt{\frac{(d-1)(d-2)}{2\Lambda}}\right)$$

For the interior of field space TCC gives conditions resembling the dS conjecture:

$$\left|\frac{|V'|}{V}\right|_{max} \geq \frac{1}{4(d-1)(d-2)} \cdot \Delta\phi \, \frac{1}{\ln^2 \sqrt{\frac{\frac{2}{(d-1)(d-2)}}{V_{min}}}}$$

$$V''<0: \quad \left| V'' / V \right|_{max} \geq \frac{4}{(d-2)(d-1)} \ln\left(\sqrt{\frac{(d-1)(d-2)}{2V_{min}}}\right)^{-2}$$

Distance Conjecture

$$V < A e^{-\frac{2\phi}{\sqrt{(d-1)(d-2)}}}$$

assuming $V \sim m^d \Rightarrow$

distance conjecture

$$m < A' e^{-\frac{2\phi}{d\sqrt{(d-1)(d-2)}}}$$

Cosmological Implications: PAST

Inflation is severely restricted and fine-tuned

$$\text{TCC} \Longrightarrow \begin{cases} V < \left(10^{9}\,\text{GeV}\right)^{4} \\ \epsilon < 10^{-31} \\ r < 10^{-30} \end{cases}$$

bounds on inflation

+ fine tuning

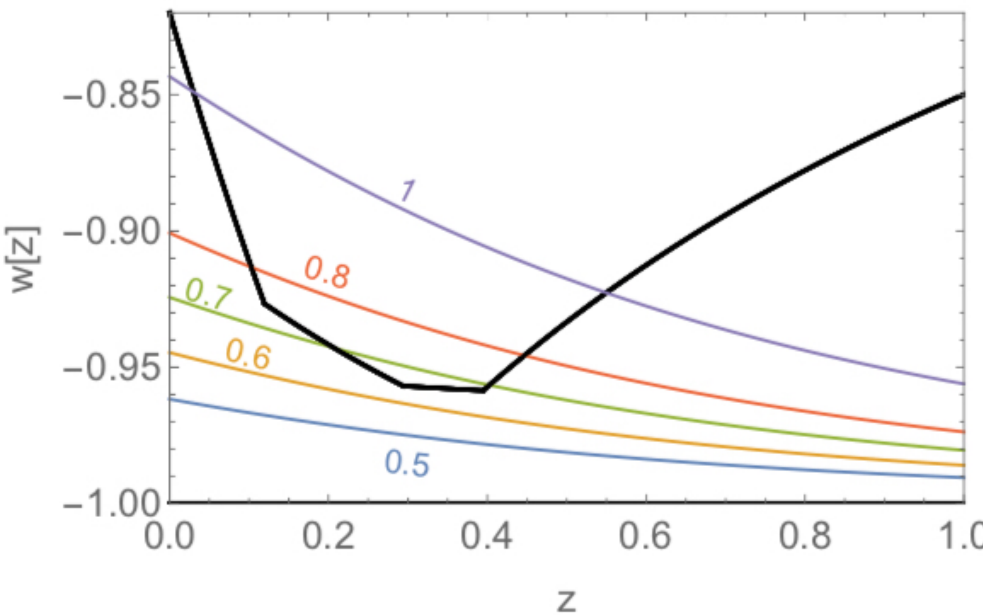
$$\Delta\phi < 10^{-13}\, M_{pl}$$

Present

Present epoch: Two possibilities:

Quintessence with as long as c < 0.6 :

$$V = V_0 e^{-c\varphi}$$



$$w = \frac{p}{\rho}$$

Another Possibility:

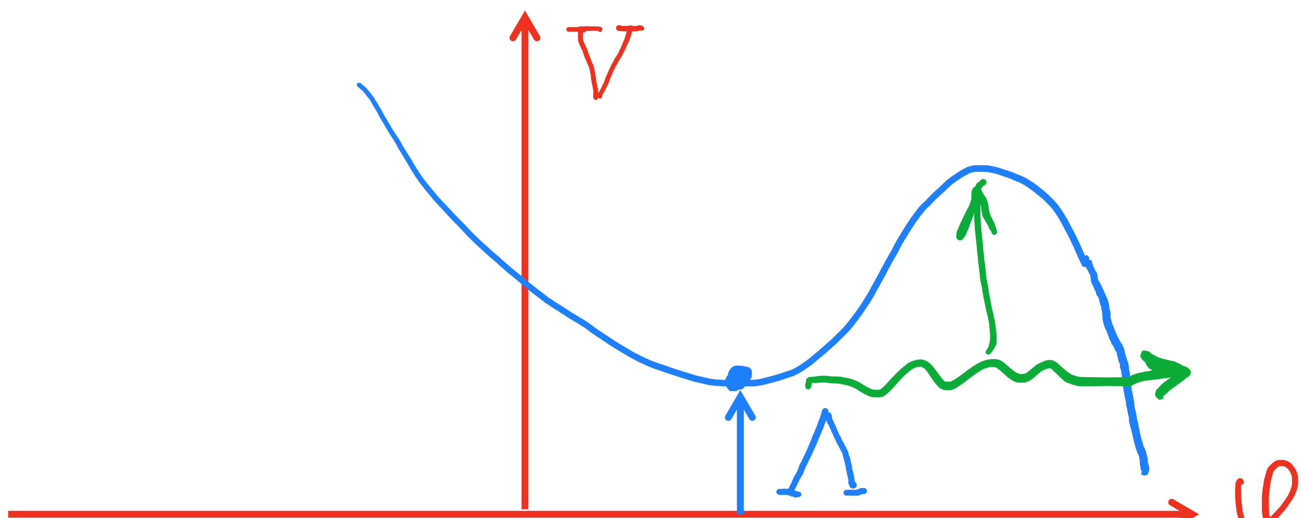
Meta-stable dS

$$\tau^{\Lambda}_{dS} < \sqrt{\frac{(d-1)(d-2)}{2\Lambda}} \log\left(\sqrt{\frac{(d-1)(d-2)}{2\Lambda}}\right)$$

if dS $\longrightarrow$ $\tau_{universe} < 2$ trillion yrs

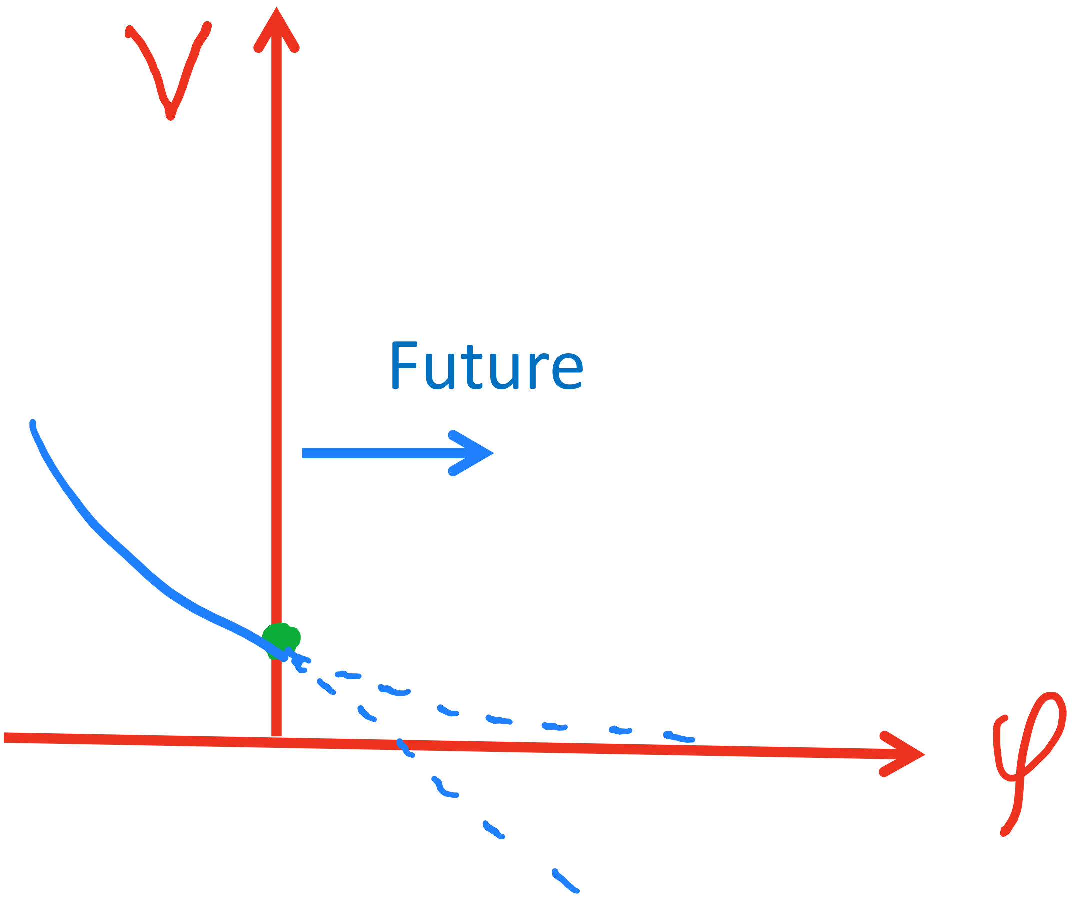
Future

If we lived in dS space, the lifetime of the universe, before there is a phase transition can be arbitrarily large and typically has nothing to do with the time scale set by the dark energy:



This leaves a puzzle: Why current age is related to

$$\tau \sim H^{-1} \sim 1/\sqrt{\Lambda} \;?$$



or meta-stable dS.

TCC:

$$\tau_{dS} < \frac{\#}{\sqrt{\Lambda}} \ln\left[\frac{\#}{\sqrt{\Lambda}}\right] \sim 2 \text{ trillion yrs}$$

Provides an explanation of this coincidence

Of course TCC also allows quintessence structure as well and that also gives a phase transition of the order of 30 Hubble times ~ 0.3 trillion yrs

Conclusion

Stringy ideas suggest that our current cosmology can be based on either a short-lived meta-stable dS or evolving scalar field.

In either case the lifetime of our universe cannot be more than about 2 trillion years.

We should be able to distinguish these two alternatives by looking for the violation of equivalence principle in the dark sector.