Swampland Perspective on Early and Late time Cosmology

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Cosmic Controversies
UChicago

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Based on 6 papers

de Sitter Space and the Swampland

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On the Cosmological Implications of the String Swampland

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Distance and de Sitter Conjectures on the Swampland

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Among Swampland conditions, the distance conjecture characterizes the geometry of scalar fields and the de Sitter conjecture constrains allowed potentials on it. We point out a connection between the distance conjecture and a refined version of the de Sitter conjecture in any parametrically controlled regime of string theory by using Bousso's covariant entropy bound. The refined version turns out to evade all counter-examples at scalar potential maxima that have been raised. We comment on the relation of our result to the Dine-Seiberg problem.

H_0 Tension, Swampland Conjectures and the Epoch of Fading Dark Matter

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Motivated by the swampland dS conjecture, we consider a rolling scalar field as the source of dark energy. Furthermore, the swampland distance conjecture suggests that the rolling field will lead at late times to an exponentially light tower of states. Identifying this tower as residing in the dark sector suggests a natural coupling of the scalar field to the dark matter, leading to a continually reducing dark matter mass as the scalar field rolls in the recent cosmological epoch. The exponent in the distance conjecture, $\tilde{c}$, is expected to be an $\mathcal{O}(1)$ number. Interestingly, when we include the local measurement of H_0, our model prefers a non-zero value of the coupling $\tilde{c}$ with a significance of 2.8σ and a best-fit at $\tilde{c} \sim 0.3$. Modifying the recent evolution of the universe in this way improves the fit to data at the 2σ level compared to ΛCDM. This string-inspired model automatically reduces cosmological tensions in the H_0 measurement as well as σ_8.

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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(Dated: September 23, 2019)

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.

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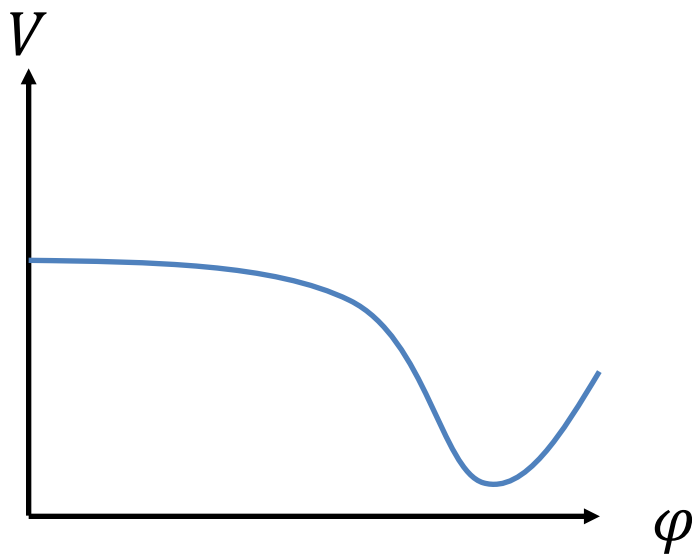
Swampland program: Delineate conditions to distinguish good QFT's (`Landscape') from bad ones (`Swampland') [V., 2005]

In this talk I review Swampland conditions which relate to cosmology and their consequences.

Both early (inflation) and late universe (dark energy) descriptions of the universe seem to require understanding

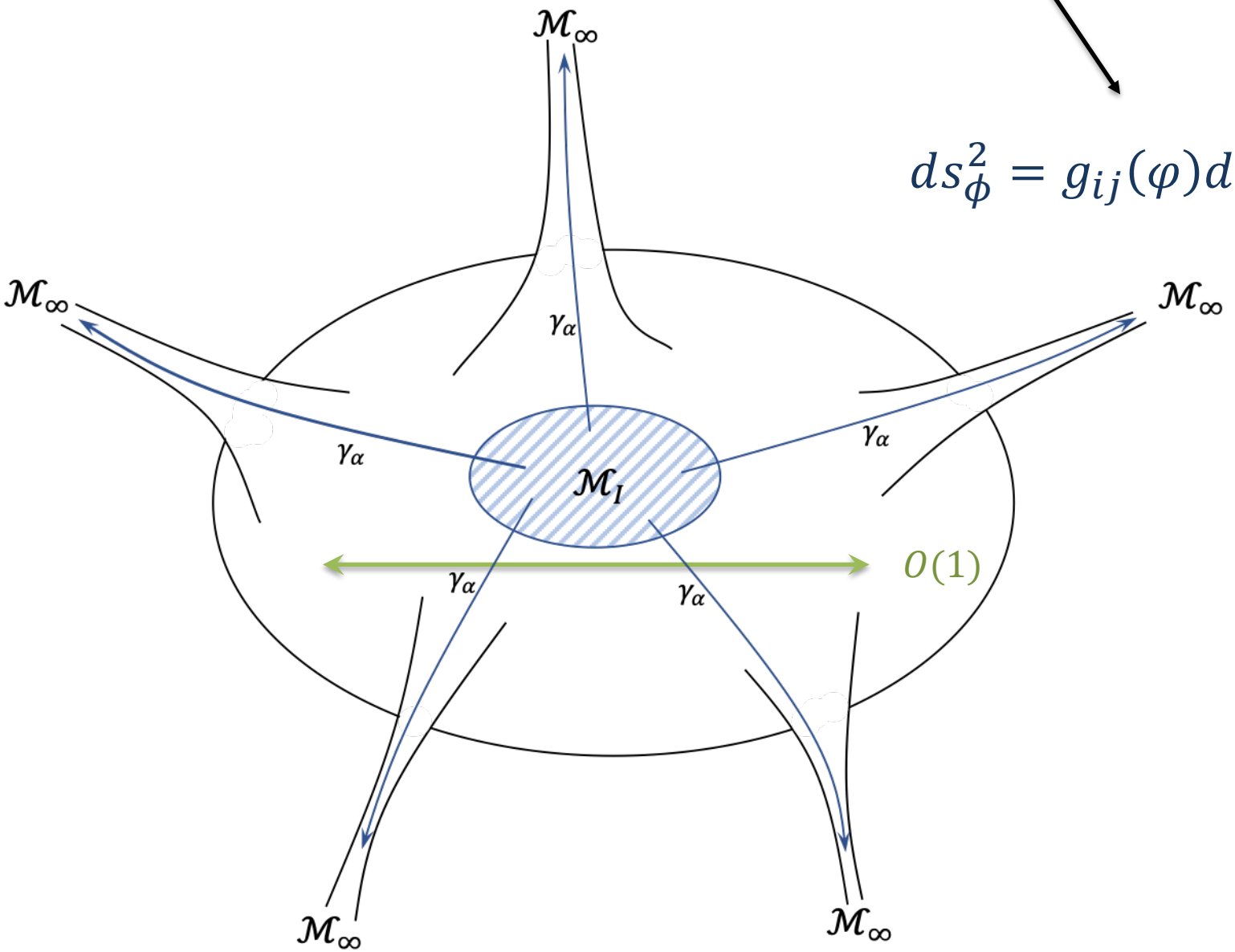


$$V(\varphi) > 0$$

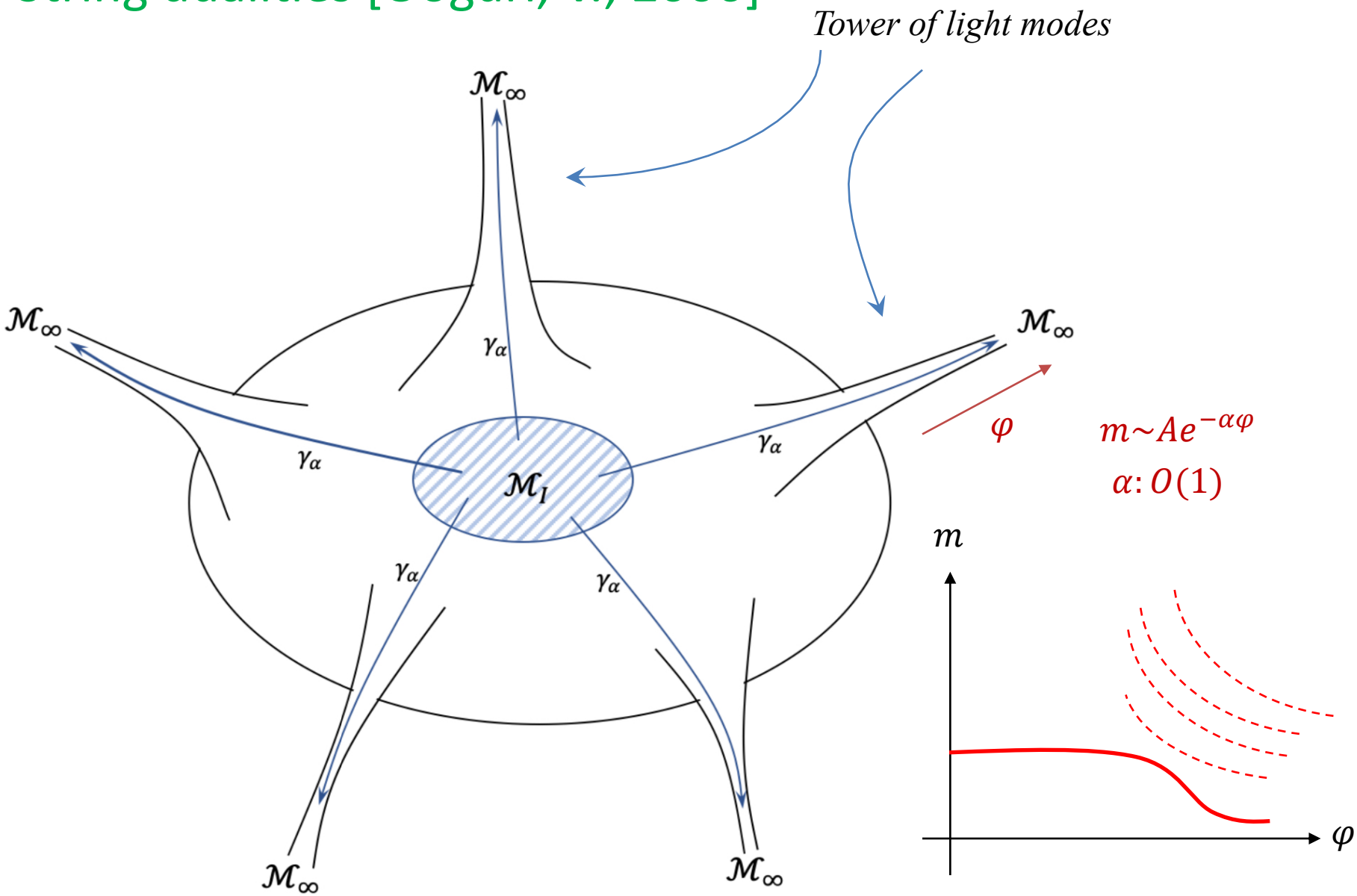
$\varphi - Space$

$$\int g_{ij}(\varphi)\nabla\varphi^i\nabla\varphi^j d^4x$$

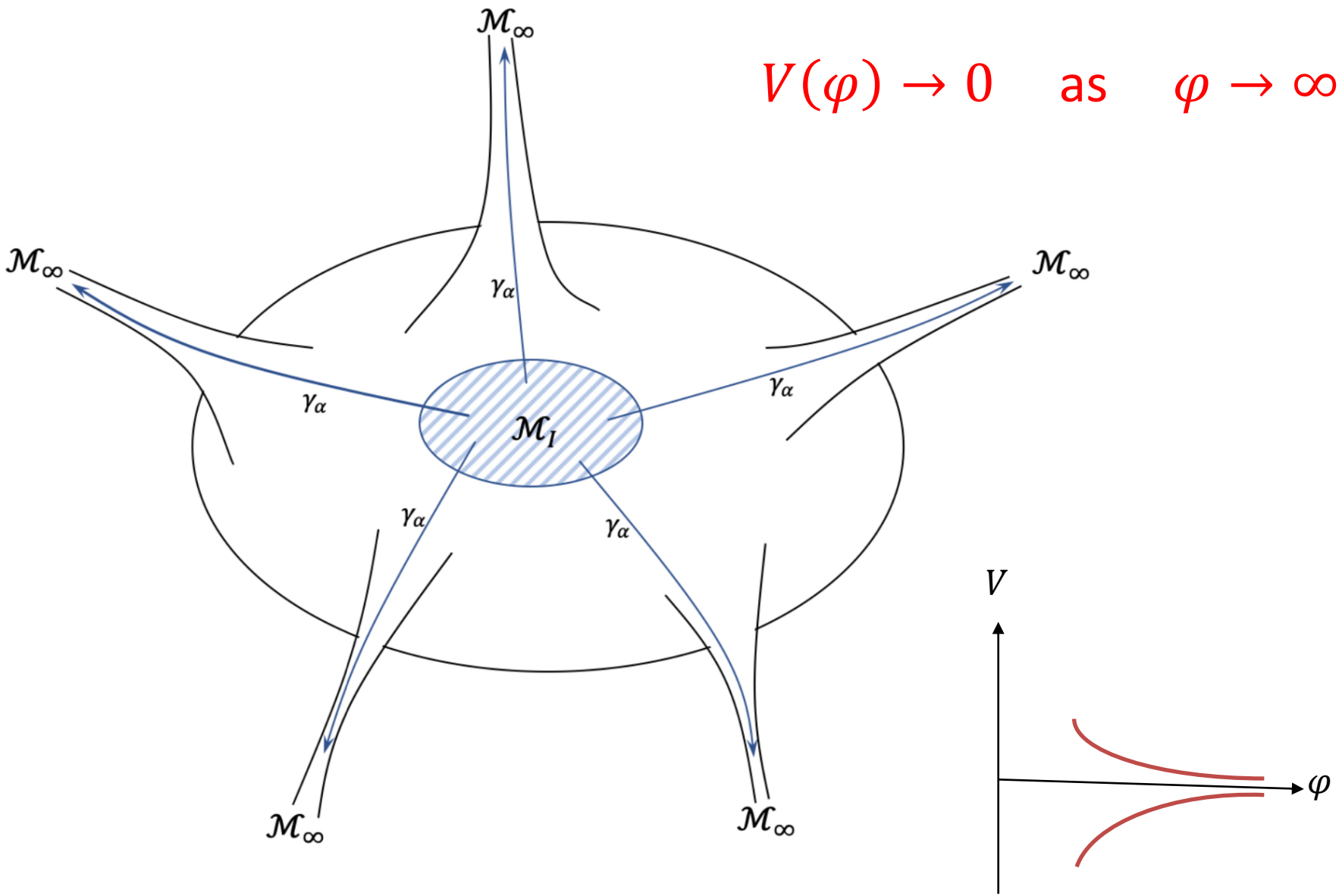
$$ds_\phi^2 = g_{ij}(\varphi)d\varphi^i d\varphi^j$$

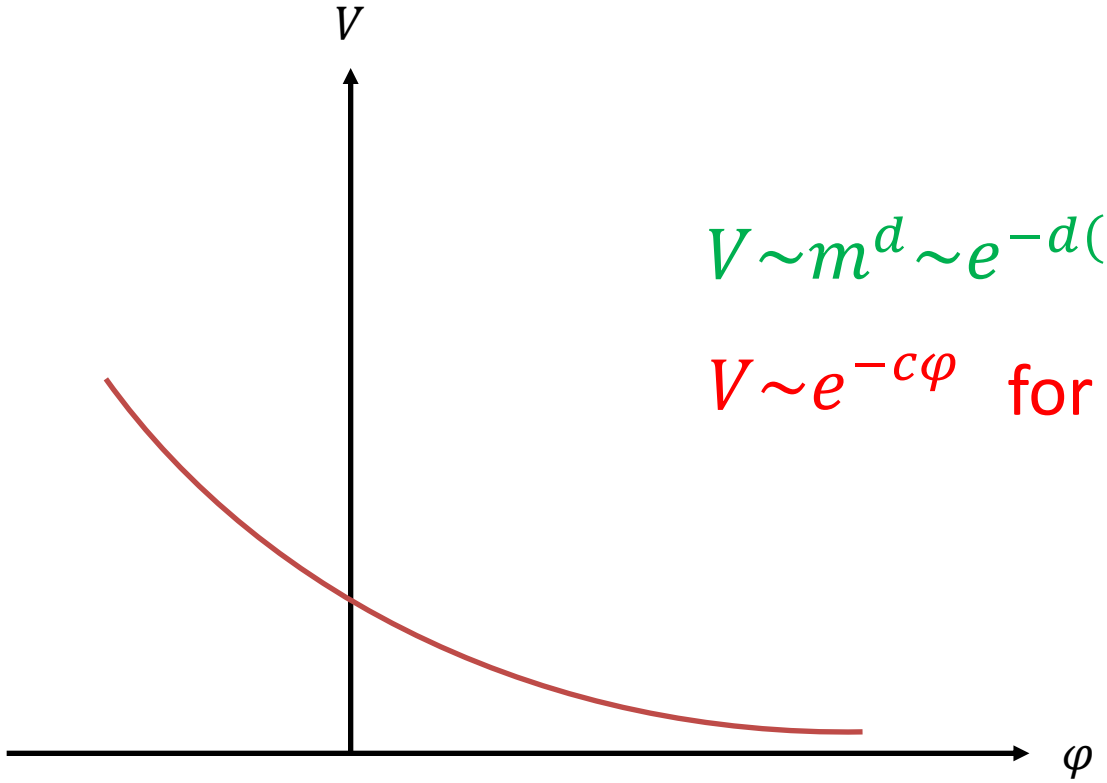


Distance Conjecture is a manifestation of String dualities [Ooguri, V.; 2006]



$V(\varphi) \to 0 \quad \text{as} \quad \varphi \to \infty$





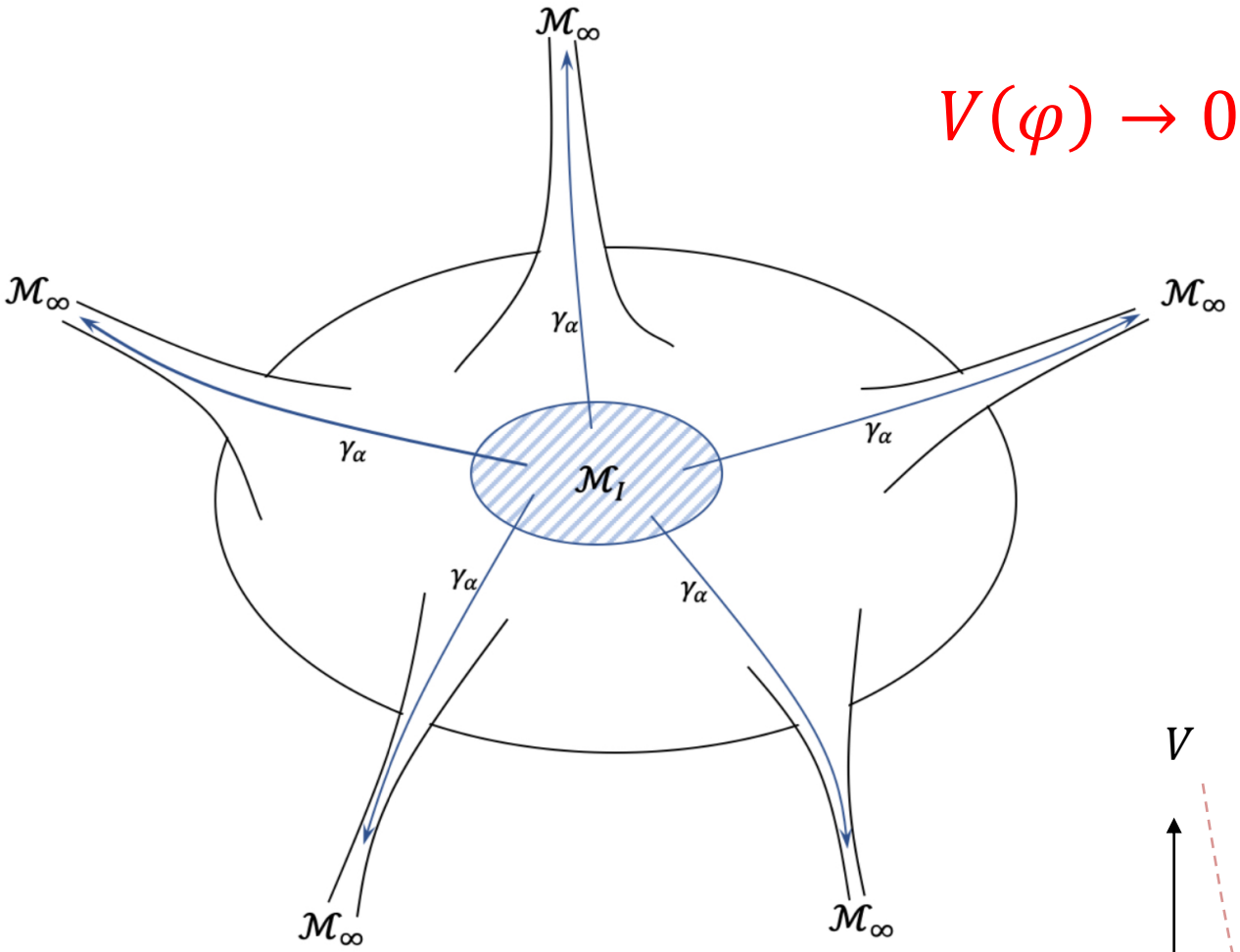
$V \sim m^d \sim e^{-d(\alpha\varphi)}$

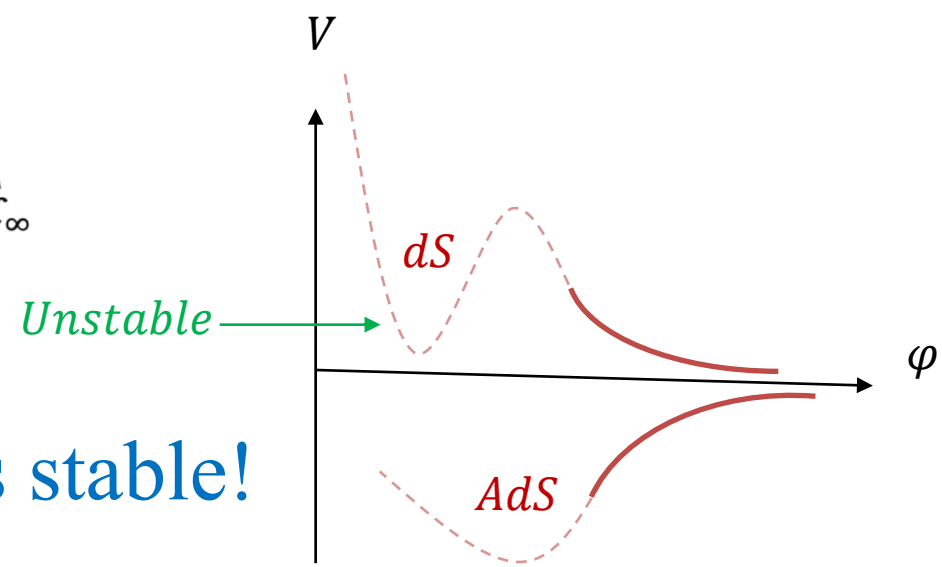
$V \sim e^{-c\varphi}$ for $\varphi \gg 1$

General String compactification analysis suggests:

$$\left.\frac{|V'|}{V}\right|_{\infty} \geq \sqrt{\frac{2}{3}}$$

$$V(\varphi) \to 0 \quad \text{as} \quad \varphi \to \infty$$

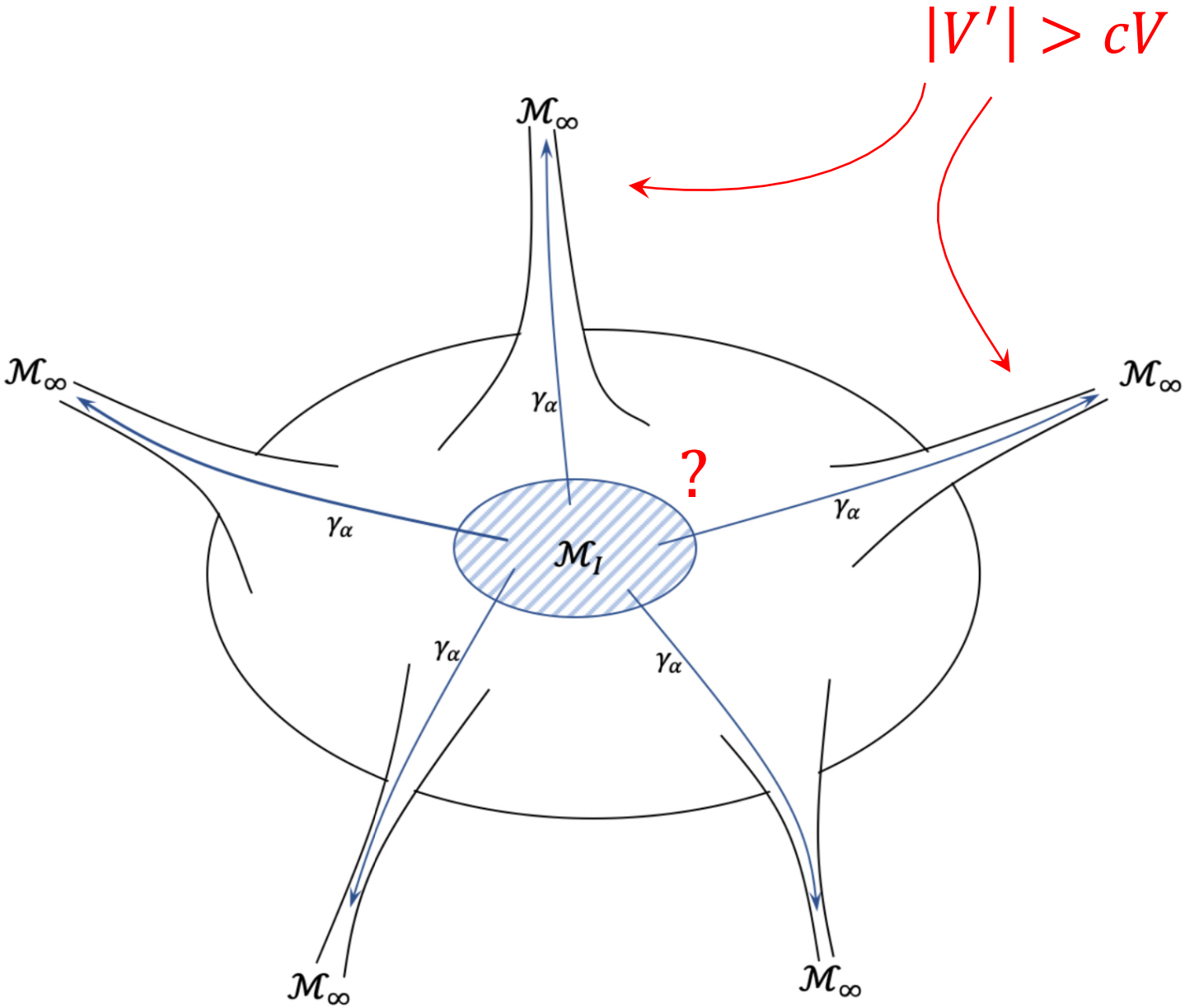




No model of dark energy is stable!

For AdS we have very simple constructions.
In fact many supersymmetric examples.
AdS/CFT, etc.

For dS the story is very different. Currently we have not even a single example where we can control the approximation. The best available ideas are KKLT scenario and LVS scenario which propose ways one can go about constructing solutions, but due to their complexity not even one example has been actually constructed.
We are not sure if dS exists and if they do, how unstable they may be.


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

Three possibilities, studied so far, for V inside:

1) No restrictions. (Unnatural, given very specific boundary behavior for V leading to instability)

Related

2) The dS Swampland conjecture: Either V is sufficiently unstable ($V''/V < -c'$) or $|V'| > cV$ everywhere (with c,c' O(1)). [OOSV],[KG, OPSV]

3) Trans-Planckian Censorship Conjecture (TCC): sub-Planckian modes cannot cross the Hubble horizon [BV]: $$\frac{a_f}{a_i} \cdot l_p < \frac{1}{H_f}$$

Explains the asymptotic behavior $\Rightarrow \left.\frac{|V'|}{V}\right|_\infty \geq \sqrt{\frac{2}{3}}$ ✓

Present and Future:

Assuming (2) we can only be in rolling potential situation. Moreover, in a short time we will roll more than Mp leading to a phase transition. Estimated time

$$\tau < N \frac{1}{H_0}$$

$$(N \sim 30)$$

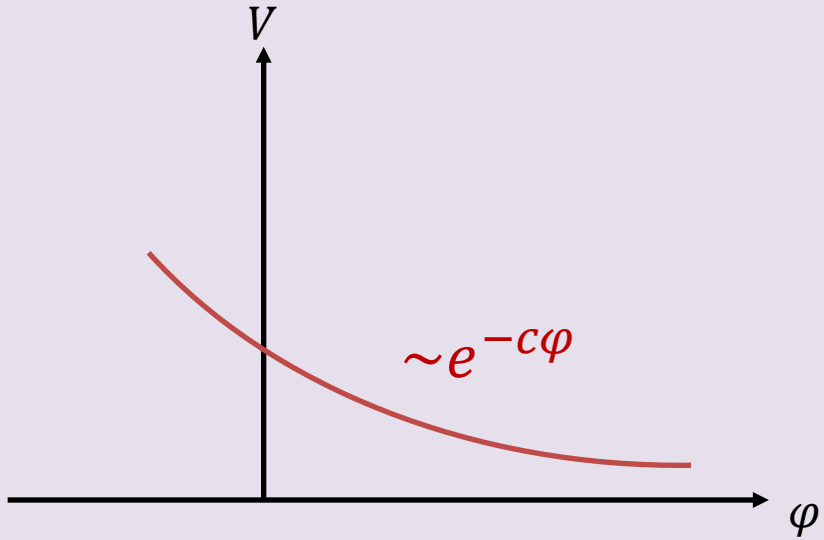
Assuming (3) (TCC) it can be either the above scenario, or short-lived meta-stable dS:

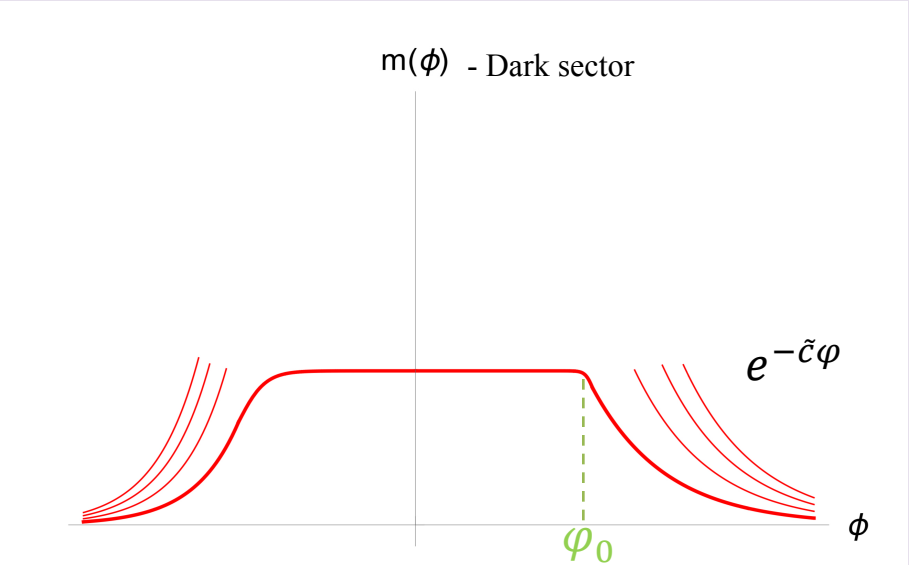
$$\tau < \frac{1}{\sqrt{\Lambda}} \ln \frac{1}{\sqrt{\Lambda}} \sim 2\ Tyrs$$

Either version of the conjecture explains the coincidence problem of why the time scale associated to measured value of the dark energy $\tau \sim \frac{1}{\sqrt{\Lambda}}$ is close to the current age of the universe. The lifetime of the universe cannot be much longer. So in any universe where dark energy is measured (i.e. is a sizable fraction of energy budget) the associated time scale is the same scale as the age of that universe (e.g. it could not have been discovered much later, because the universe would have decayed or transitioned to a new phase!).

Swampland ideas motivate taking rolling scalar fields more seriously as a source of dark energy today.

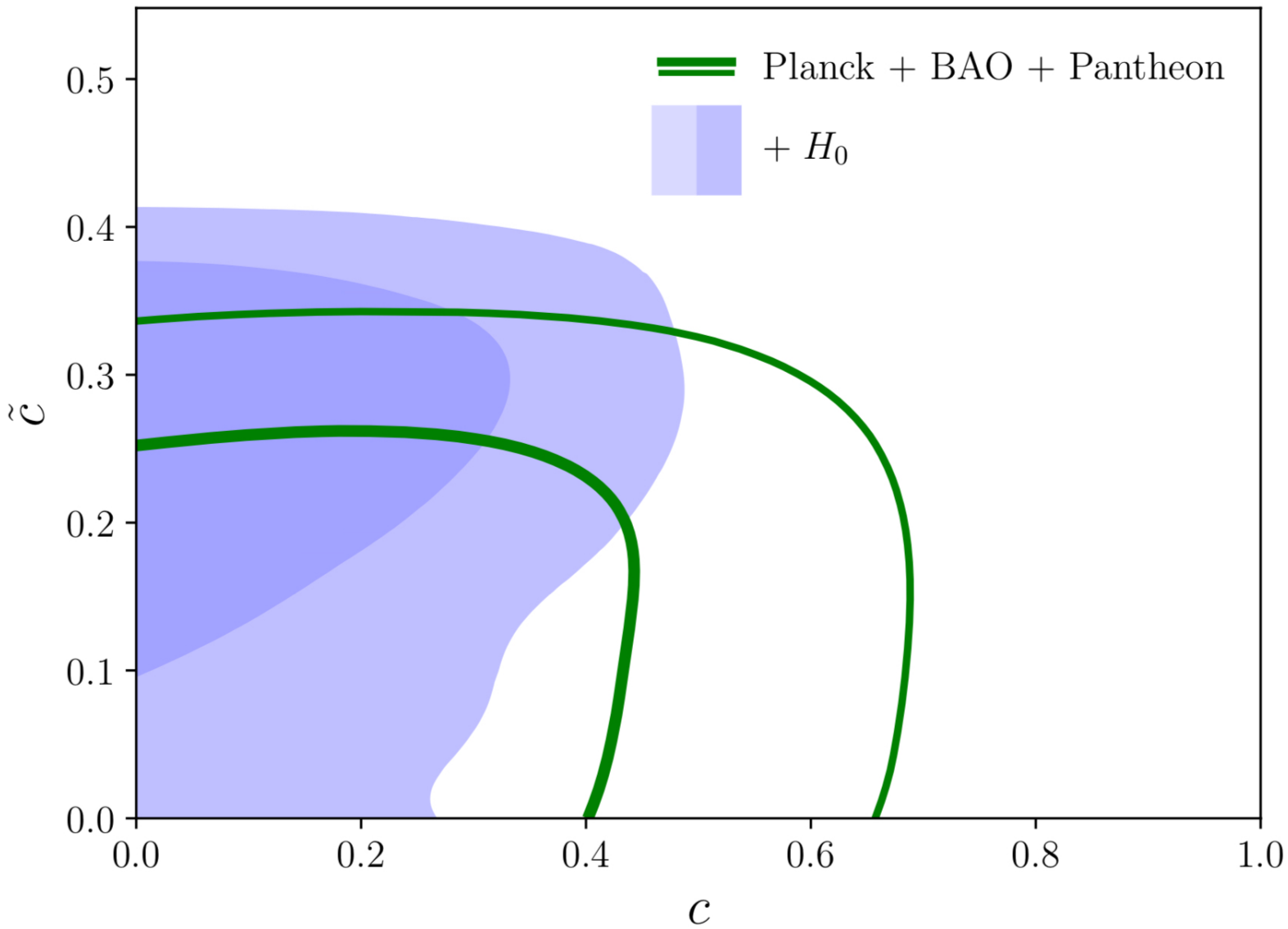
The scalar fields should be part of the dark sector and interact very weakly with visible sector (similar to the rest of dark sector) . Moreover it should couple strongly at least to a fraction of dark sector and as it rolls, it should lead to a fading of dark matter, due to the Swampland distance conjecture.





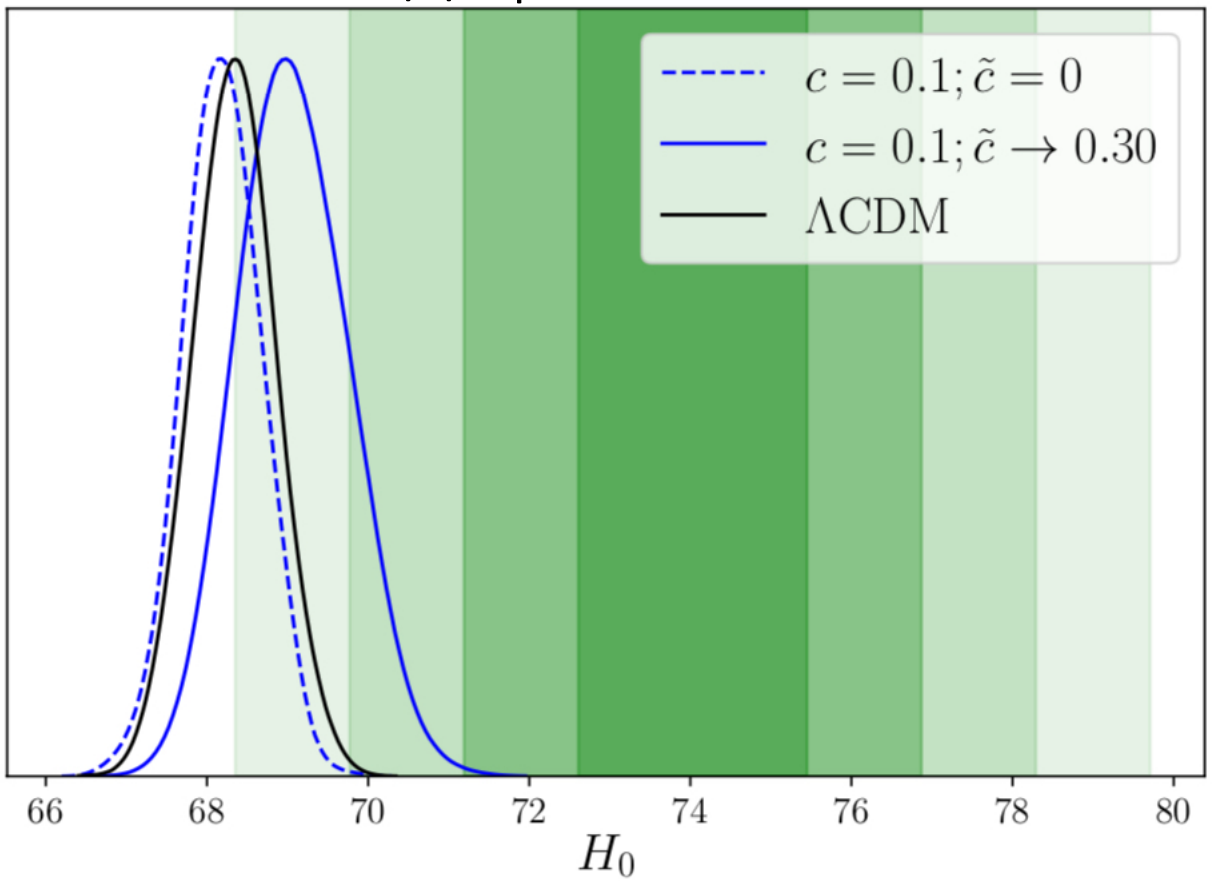
$$\rho_{DM} \xrightarrow[\varphi > \varphi\_0]{} e^{-\tilde{c}\varphi} \rho_{DM}^{0}$$

Fading DM model

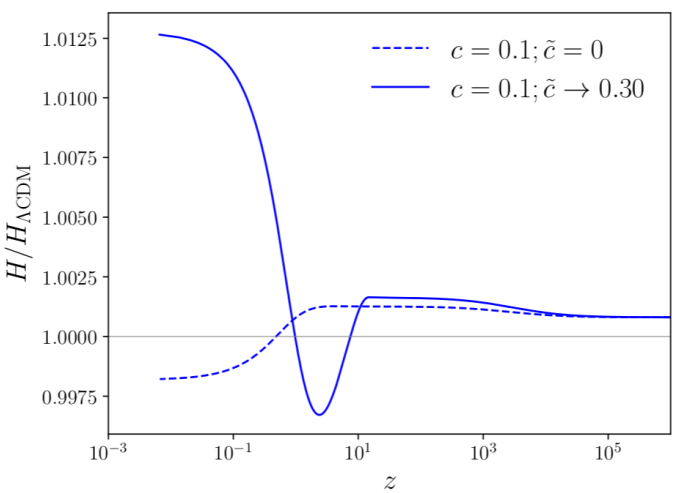

Planck + BAO + Pantheon
+ H_0
0.5
0.4
0.3
0.2
0.1
0.0
$\tilde{c}$
0.0
0.2
0.4
0.6
0.8
1.0
c

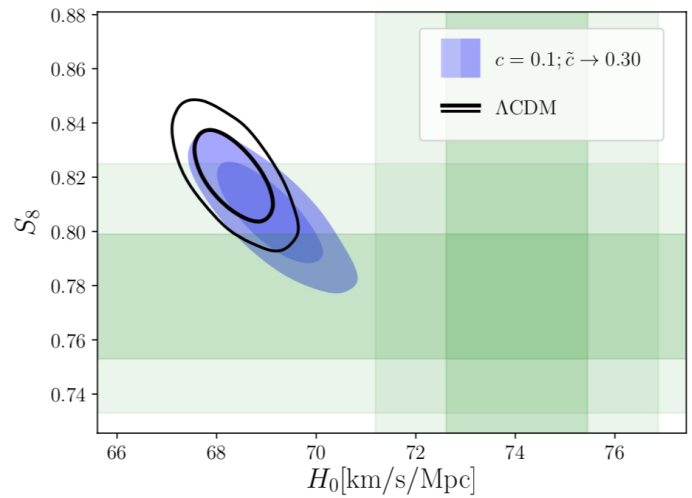
	χ^2	$\Delta\chi^2$				
	ΛCDM	$c = 0.1$		$c = 0.2$		$c \to 0.0014$
		$\tilde{c} = 0$	$\tilde{c} \to 0.30$	$\tilde{c} = 0$	$\tilde{c} \to 0.31$	$\tilde{c} \to 0.31$
Planck-high ℓ	2440.12	1.12	-0.44	1.50	-0.14	-0.74
Planck-low ℓ	10496.03	0.23	-0.13	0.38	0.028	-0.11
Planck-lensing	9.48	-0.18	0.88	-0.10	0.90	1.06
BAO	1.80	-0.022	0.18	-0.022	0.18	0.22
Pantheon	1026.89	0.066	0.086	0.13	0.046	0.19
HST	16.56	0.72	-4.62	0.80	-4.40	-5.30
low-z BAO	1.88	-0.18	0.86	-0.16	0.86	1.00
Total	13992.77	1.77	-3.21	2.49	-2.55	-3.71
Improvement (σ)	-	-1.3σ	1.8σ	-1.6σ	1.6σ	1.9σ

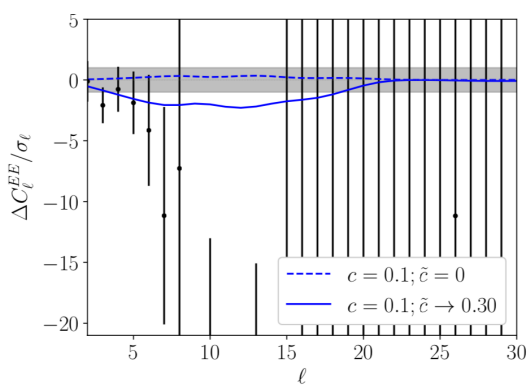
Improves, but does not resolve the H0 tension.
H0=69.1 km/s/Mpc



Dark matter fading by 10% beginning around redshift z=15.







Difference in EE polarization signal between our best-fit fading DM models and ΛCDM normalized to the cosmic variance per ℓ mode. The grey band shows the cosmic variance limit and the data points and errorbars are from *Planck* 2015.

Swampland Conjectures and Inflation:

Inflation not ruled out but typical scenarios seem at least highly fine tuned! The distance conjecture leads to prediction that we cannot have natural arbitrarily large field inflation, because we get a tower of light states and that interferes with inflation. Multi-field may overcome this.

(2) Slope conjecture: For example Plateau models, c<0.02 lead to rather small numbers.

(3) TCC:

$$V \lesssim M_{pl}^{\frac{8}{3}} (T_0 T_{eq})^{\frac{2}{3}} \sim (10^9 GeV)^4$$

$$\epsilon < 10^{-31}$$

$$r < 10^{-30}$$

Conclusion

Swampland Conditions can lead to potentially observable consequences for cosmology.

Broadly these ideas suggest positive energy in the context of quantum gravity lead to local and global instabilities—explains coincidence problem.

Models of rolling scalar fields interacting with DM (leading to fading DM) should be taken seriously.

Inflation is in tension—Worthwhile studying alternatives.