A Swampland Update

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Fine Tuning, Sequestering, and the Swampland

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We conjecture and present evidence that any effective field theory coupled to gravity in flat space admits at most a finite number of fine tunings, depending on the amount of supersymmetry and spacetime dimension. In particular, this means that there are infinitely many non-trivial correlations between the allowed deformations of a given effective field theory in the gravitational context. Fine tuning of parameters allows us to obtain some consistent CFTs in the IR limit of gravitational theories. Related to finiteness of fine tunings, we conjecture that except for a finite number of CFTs, the rest cannot be consistently coupled to gravity and belong to the swampland. Moreover, we argue that even though matter sectors coupled to gravity may sometimes be partially sequestered, there is an irreducible level of mixing between them, correlating and coupling infinitely many operators between these sectors.

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AdS and the Swampland

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We study aspects of anti-de Sitter space in the context of the Swampland. In particular, we conjecture that the near-flat limit of pure AdS belongs to the Swampland, as it is necessarily accompanied by an infinite tower of light states. The mass of the tower is power-law in the cosmological constant, with a power of $\frac{1}{2}$ for the supersymmetric case. We discuss relations between this behaviour and other Swampland conjectures such as the censorship of an unbounded number of massless fields, and the refined de Sitter conjecture. Moreover, we propose that changes to the AdS radius have an interpretation in terms of a generalised distance conjecture which associates a distance to variations of all fields. In this framework, we argue that the distance to the $\Lambda \to 0$ limit of AdS is infinite, leading to the light tower of states. We also discuss implications of the conjecture for de Sitter space.

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Branes and the Swampland

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Completeness of the spectrum of charged branes in a quantum theory of gravity naturally motivates the question of whether consistency of what lives on the branes can be used to explain some of the Swampland conditions. In this paper we focus on consistency of what lives on string probes, to show some of the theories with $\mathcal{N} = (1, 0)$ supersymmetry in 10d and 6d, which are otherwise consistent looking, belong to the Swampland. Gravitational and gauge group anomaly inflow on these probes can be used to compute the gravitational central charges (c_L, c_R) as well as the level of the group's current algebra k_L. The fact that the left-moving central charge on the string probes should be large enough to allow *unitary* representations of the current algebra with a given level, can be used to rule out some theories. This in particular explains why it has not been possible to construct the corresponding theories from string theory.

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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 is expected to be $\tilde{c} \sim \mathcal{O}(1)$ 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.

Plan for this talk:

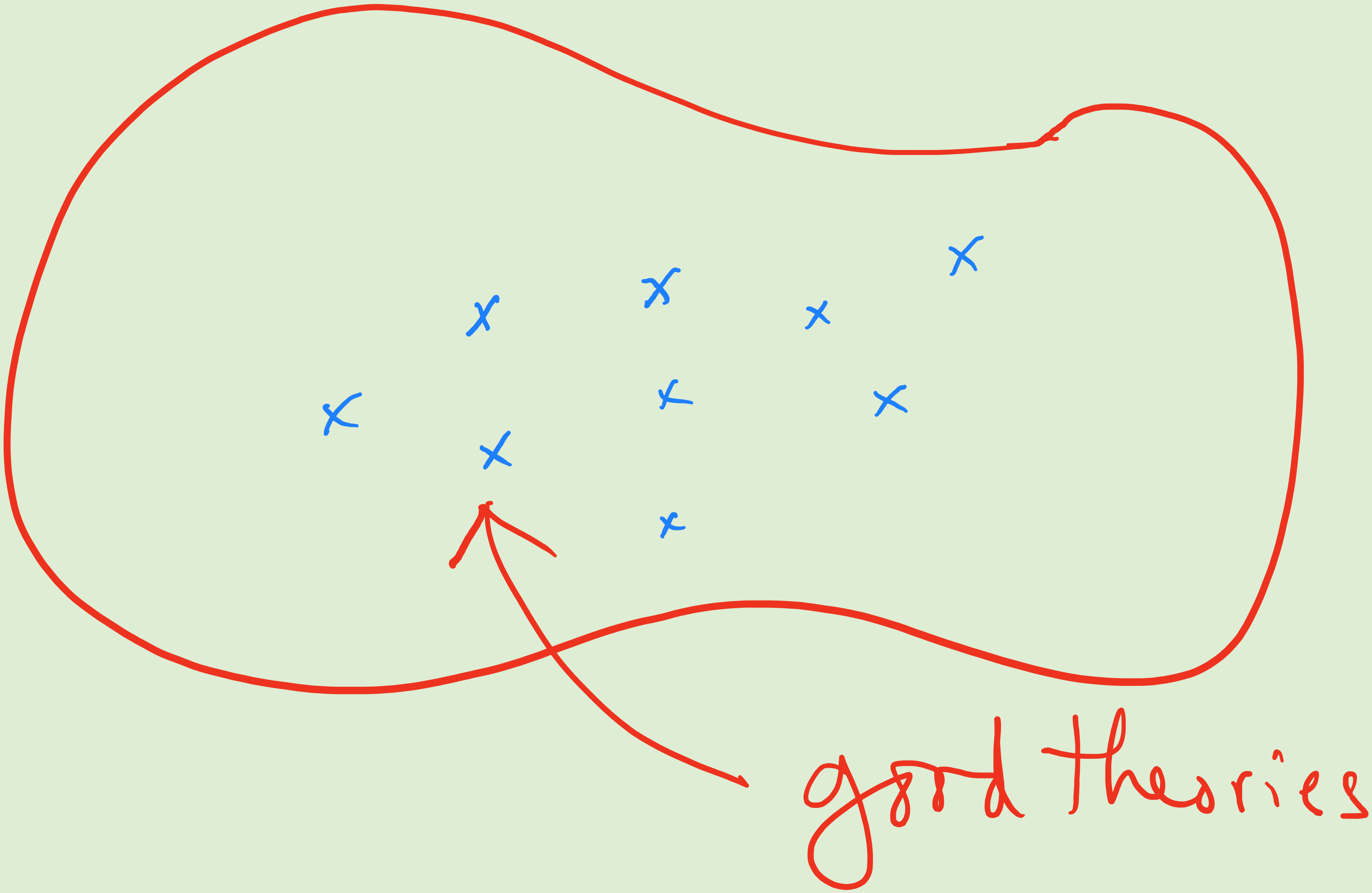
-Finite Tuning and Sequestering

-Branes and the Swampland

-AdS and the Swampland

-Fading Dark Sector and the Swampland

Fine Tuning and Sequestering



$$\mathcal{L} = \sum c_i \, \mathcal{O}_i$$

$$c_i \longrightarrow \langle \Phi_i \rangle = c_i$$

[OV]

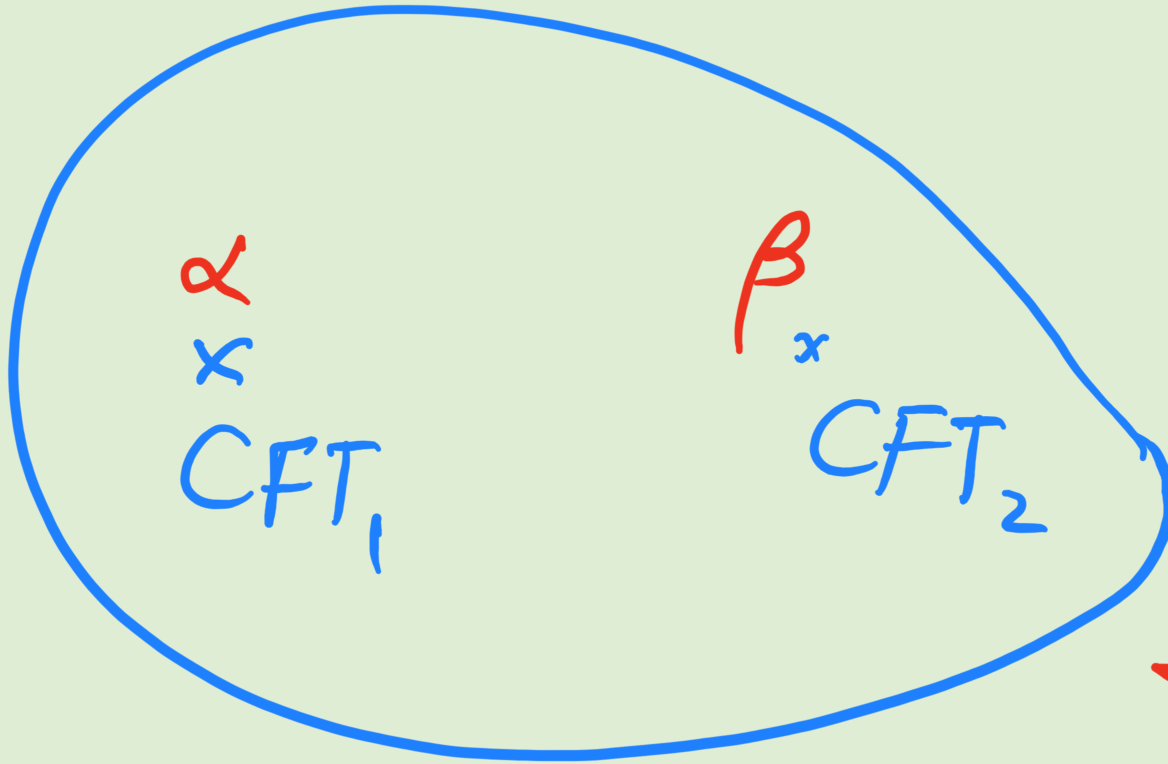
finite # $\Phi_i \longrightarrow$

∞-ly many relations

among c_i

Only a finite number of CFT's don't belong to the Swampland!

Example: N=4 YM with rank(G)>22 in Swampland!



$$\sum c_{\alpha\beta} O_\alpha O_\beta$$

Only partial Sequestering possible

almost all $c_{\alpha\beta} \neq 0$

Branes and the Swampland

One of the swampland conditions:

Spectrum is complete.

If so we can use this to study consistency of putative brane theories interacting with the bulk and the rest of the branes.

We apply this idea to 1-branes for
$N=(1,0)$ supersymmetric theories in 10d and 6d.

Anomaly cancellations (both gravitational and gauge anomalies) are crucial for consistency of these theories:

$$d=10 \longrightarrow \begin{cases} E_8 \times E_8 \\ SO(32) \\ E_8 \times U(1)^{248} \quad \times \\ U(1)^{496} \quad \times \end{cases}$$

$$d=6 \longrightarrow \begin{cases} k \text{ tensors}, G_i, R_i \\ \Downarrow \\ \text{consistent for} \\ \underline{\infty\text{-ly}} \text{ many cases} \end{cases}$$

Anomaly cancellations involve Green-Schwarz mechanism. B-fields, play key role.

$d=10$

$$dH = \mathrm{tr}\, R\wedge R - \sum_i \mathrm{tr}\, F_i \wedge F_i$$

$\Longrightarrow$ cancel anomaly inflow from bulk:

$c_L = 16$, $k_i = 1$ (apart from c.o.m.)

$\Longrightarrow$ $U(1)^{496}$ or $U(1)^{248} \times E_8$ X

Similarly in 6d case we get:

$$c_L = 3\,Q\cdot Q - 9\,Q\cdot\vec{a} + 2$$

$$k_i^L = Q\cdot\vec{b}$$

$(\vec{a},\vec{b})$: given by bulk anomaly cancellation

Unitarity: $\displaystyle\sum_i \frac{k_i^L \dim G_i}{k_i^L + h_i^\vee} \leq c_L$

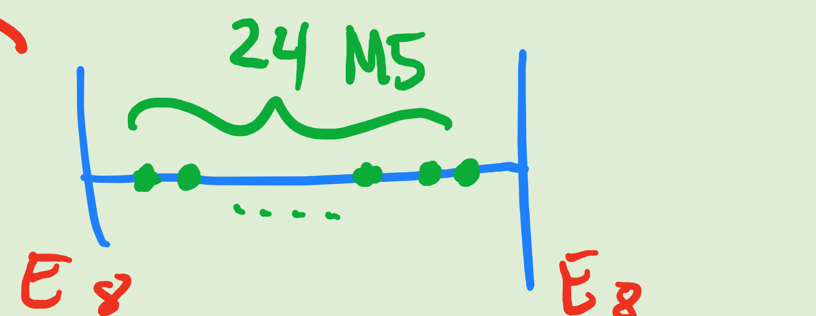
This eliminates an infinite number of theories which are anomaly free. Example:

$$T = 8k+9 \quad ; \quad G = E_8^k$$ [Kumar, Morrison, Taylor]

$k > 2$ × violate unitarity

$k \leq 2$ OK

$k = 2$



AdS and Swampland

Ordinary distance conjecture: [Ooguri,V]

$$m \sim e^{-c\,\Delta\varphi}$$

$$\int g_{ij}(\phi)\,\nabla_\mu\varphi^i\,\nabla_\mu\varphi^j$$

$$\Delta\varphi = \int\sqrt{g_{ij}(\varphi)\,\partial_\tau\varphi^i\,\partial_\tau\varphi^j}\;d\tau$$

Generalized formulation of distance conjecture leads to new statements:

AdS: Λ

$$g \to e^{\tau} g$$

$$\Delta g = \Delta \tau = |\Delta \ln \Lambda|$$

$$m \underset{\Lambda \to 0}{\simeq} \Lambda^{a}$$

$m \sim \Lambda^{1/2}$

AdS NO!

$AdS \times X$

$m \sim \Lambda^{a}$ $a \sim O(1)$

This turns out to be related to two other swampland conjectures:

Refined dS conjecture:

$$|\nabla V|^2 \geq c^2 V^2$$

$$\nabla_i \nabla_j V < -c' V$$

AdS: $m^2 \lesssim |\Lambda|$

(Van Riet et. al.)

Bounded number of massless modes.

AdS / CFT

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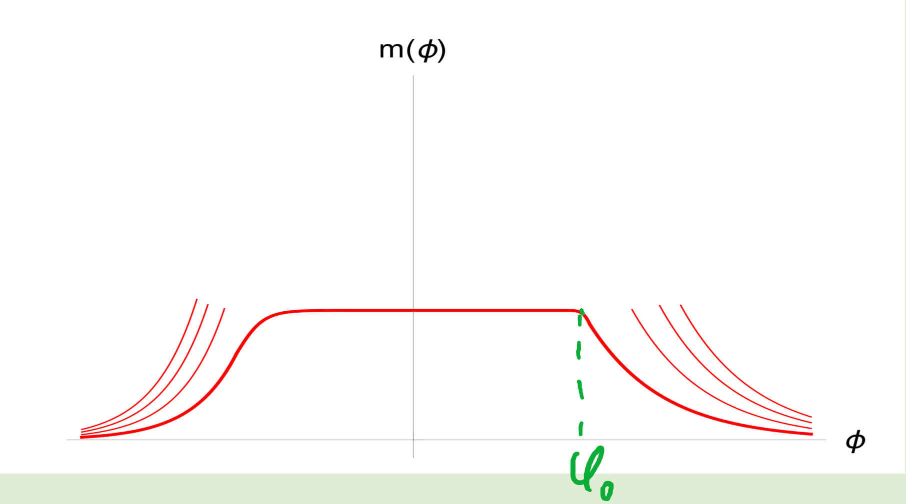
(Van Riet et. al.)

Bounded number of massless modes.

AdS X / CFT !

Fading Dark Sector and the Swampland

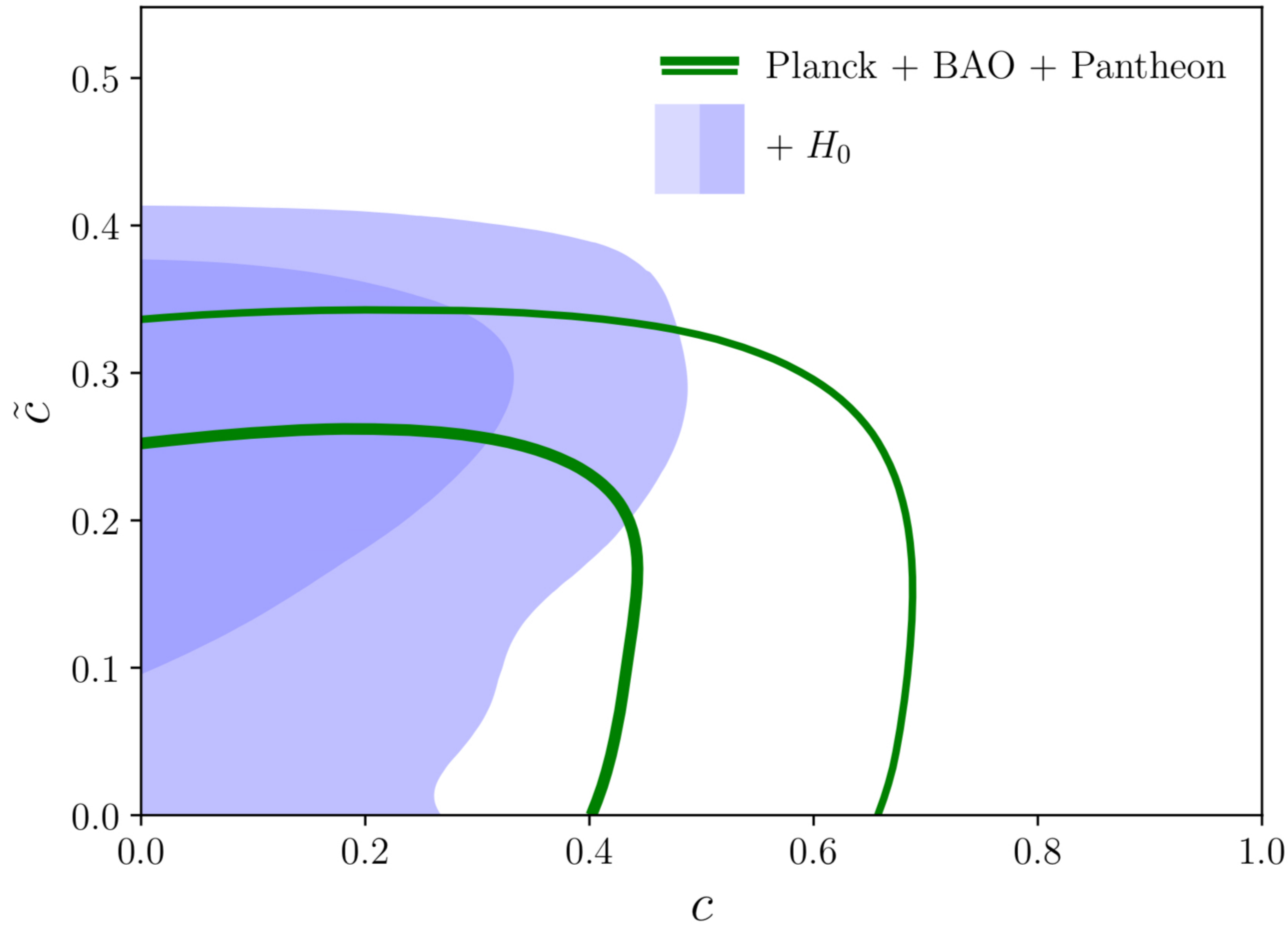
dS Swampland conjecture forbids quasi-dS.
If so, current cosmology must be governed by a quintessence field. But it seems variation of the quintessence field has been already order 1 in Planck units. So we should expect a tower of light states; The Dark Sector!



$$\rho_{DM} \xrightarrow[\varphi > \varphi_0]{} e^{-\tilde{c}\varphi} \rho^0_{DM}$$

$$V(\varphi) \sim e^{-c\varphi}$$

$$c, \tilde{c} \quad O(1)$$



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

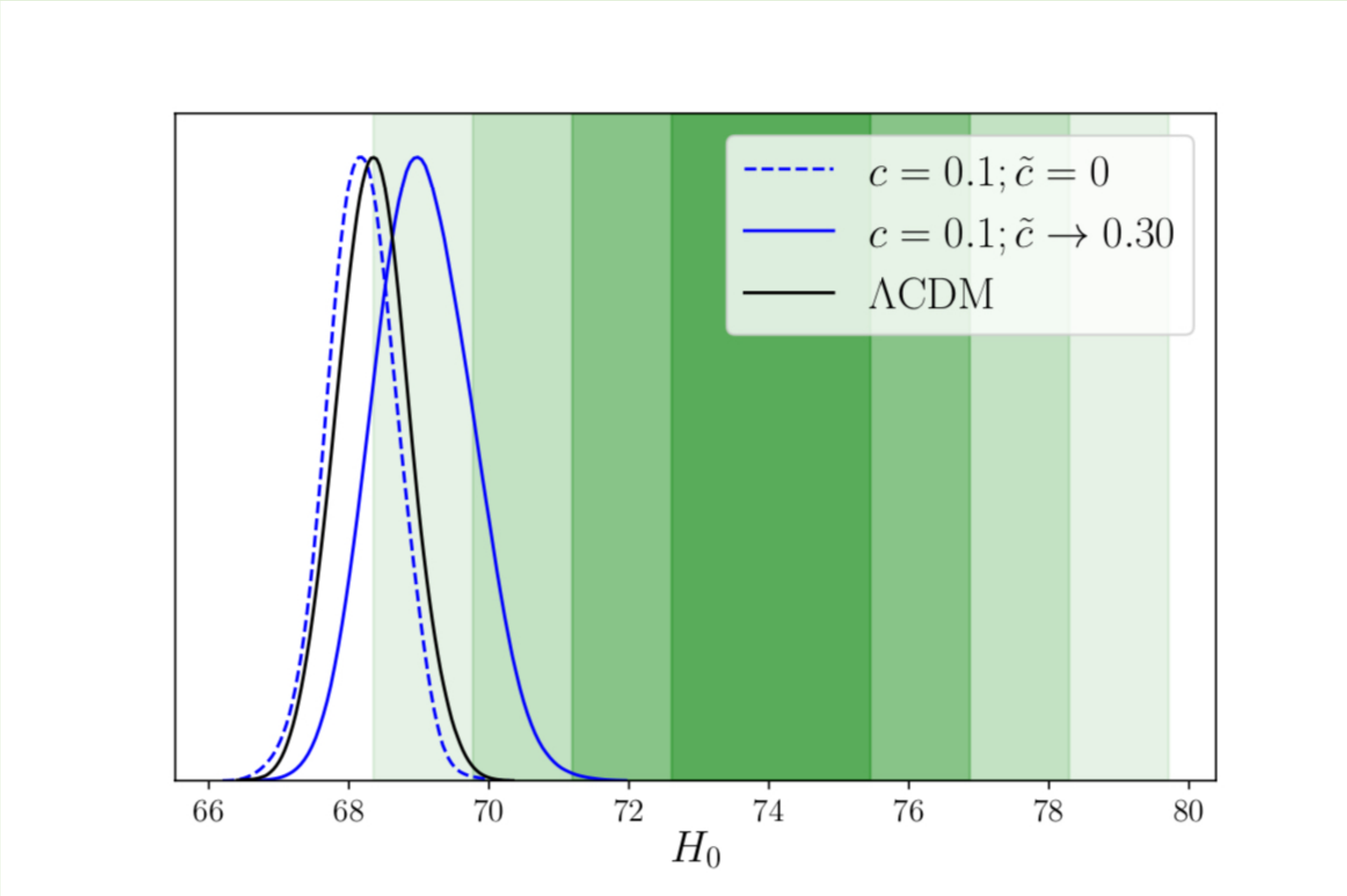
$c \simeq 0 - 0.2$

$\tilde{c} \simeq 0.3$

Better fit than ΛCDM by 2σ!

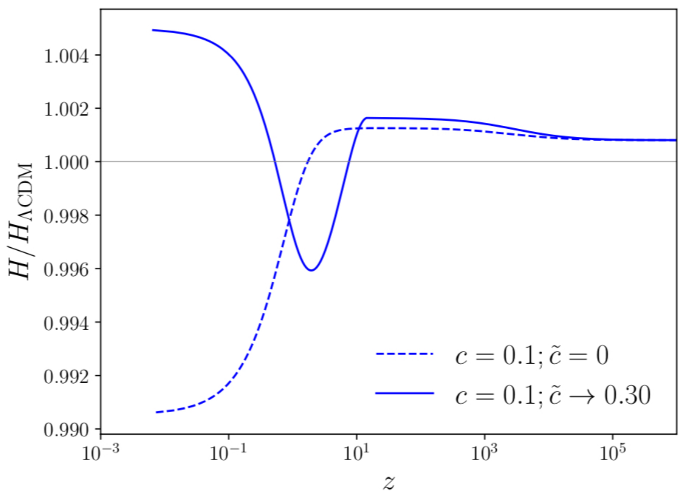
Dark matter fading by 10% beginning around redshift z=15.

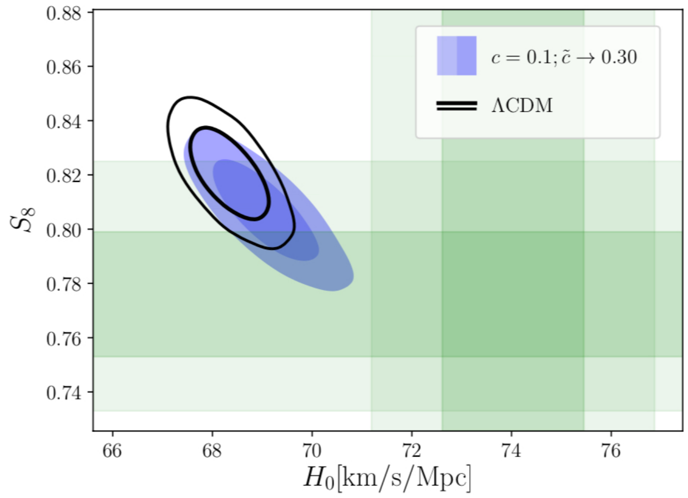
Moreover as a by-product, our model automatically improves the Ho (and S8) tension.



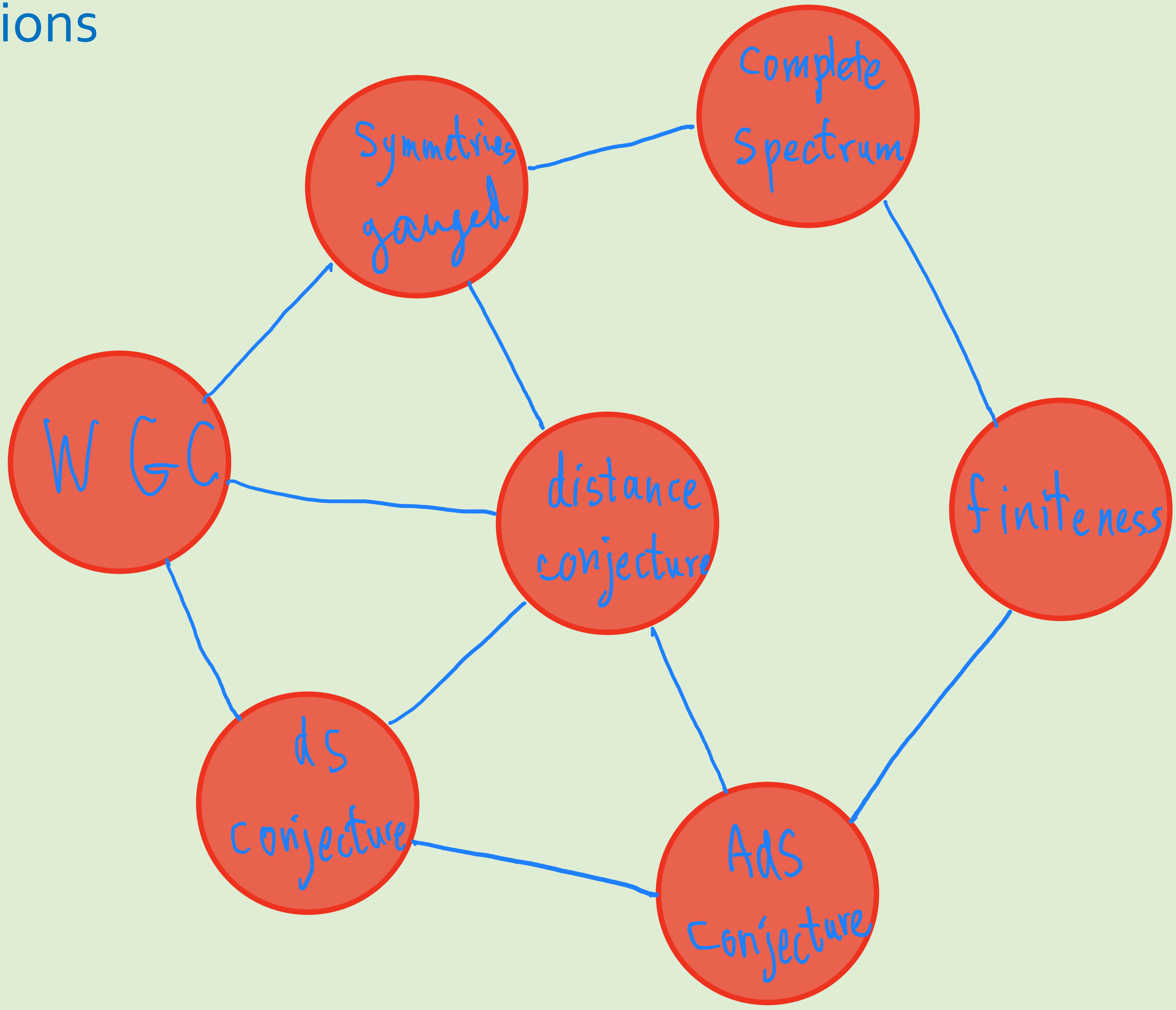
$c = 0.1; \tilde{c} = 0$
$c = 0.1; \tilde{c} \to 0.30$
ΛCDM
66
68
70
72
74
76
78
80
H_0

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

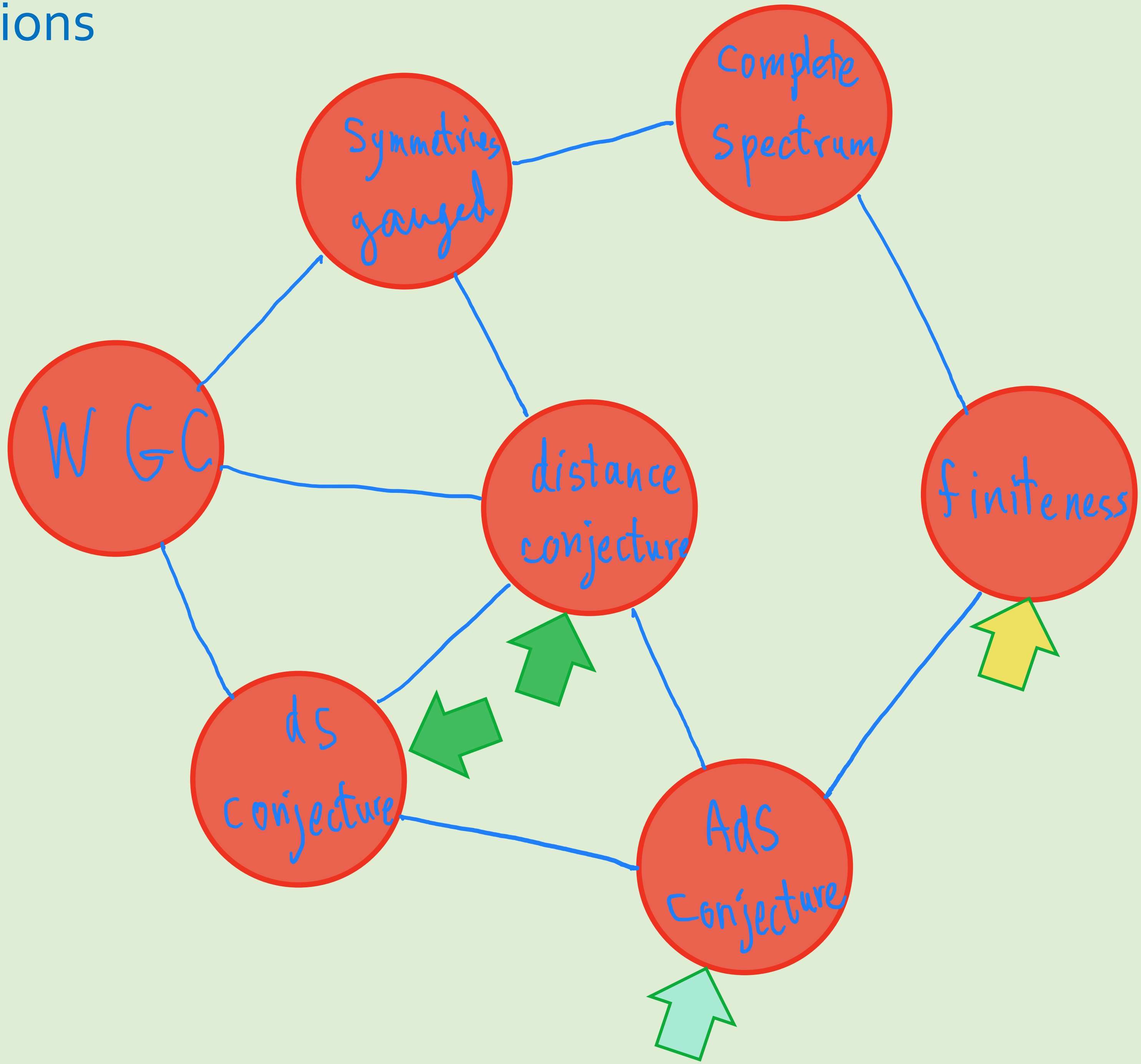




Connections



Connections



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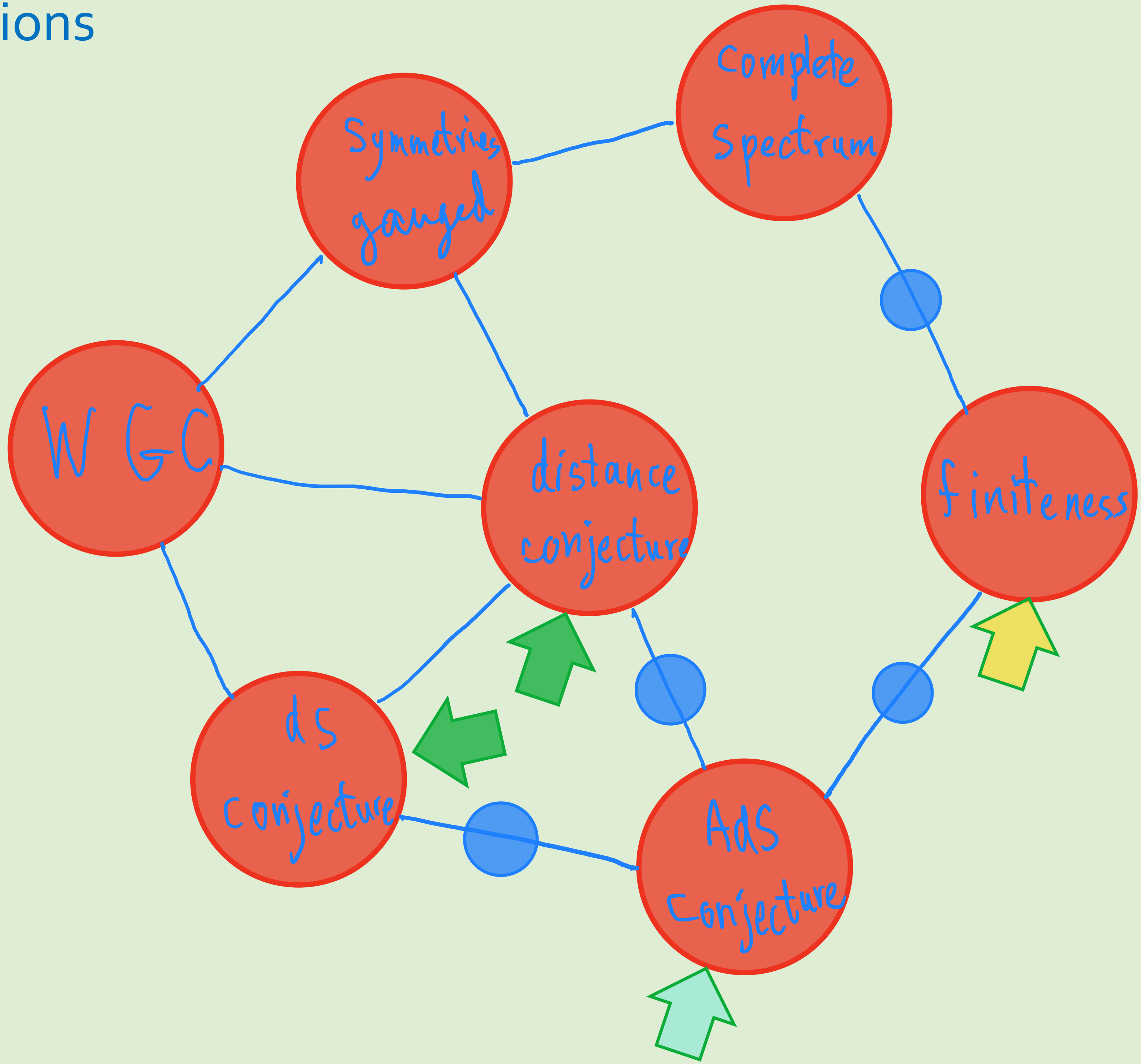

Recalling that scalar fields typically come from vev of internal metric and anti-symmetric field leads to a generalization:

$$\mathcal{L} = G^{M_1 \cdots M_k N_1 \cdots N_k} D\theta_{M_1 \cdots M_k} D\theta_{N_1 \cdots N_k}$$

$$\Delta\theta = \int_{\tau_i}^{\tau_f} \left\langle \sqrt{G \partial_\tau \theta \, \partial_\tau \theta} \right\rangle d\tau$$

$$\langle \cdots \rangle = \frac{1}{V_M} \int_M \cdots$$