On (De Sitter) Vacua in Heterotic Sting Theory

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based on work with

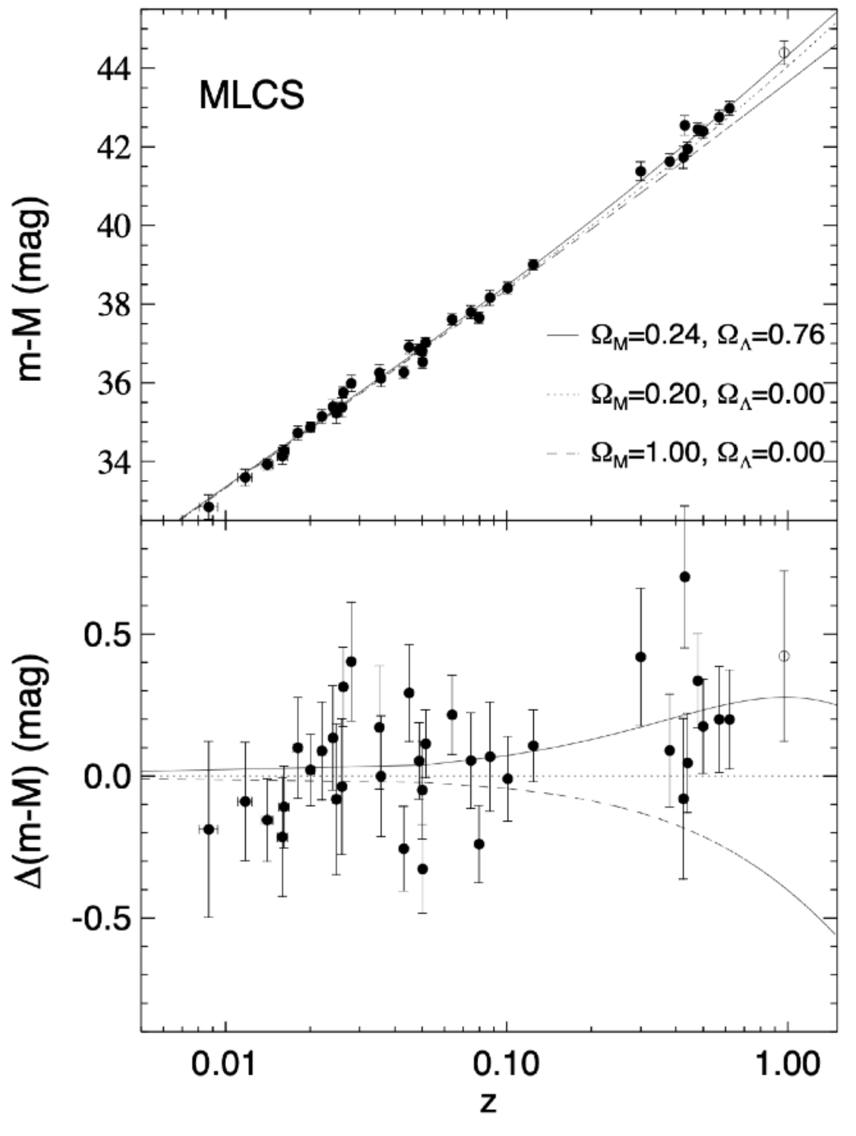
Rafael Álvarez-García, Christian Kneissl,

Jacob M. Leedom, Alexander Westphal

2nd COST Meeting, ISU Istanbul 2024

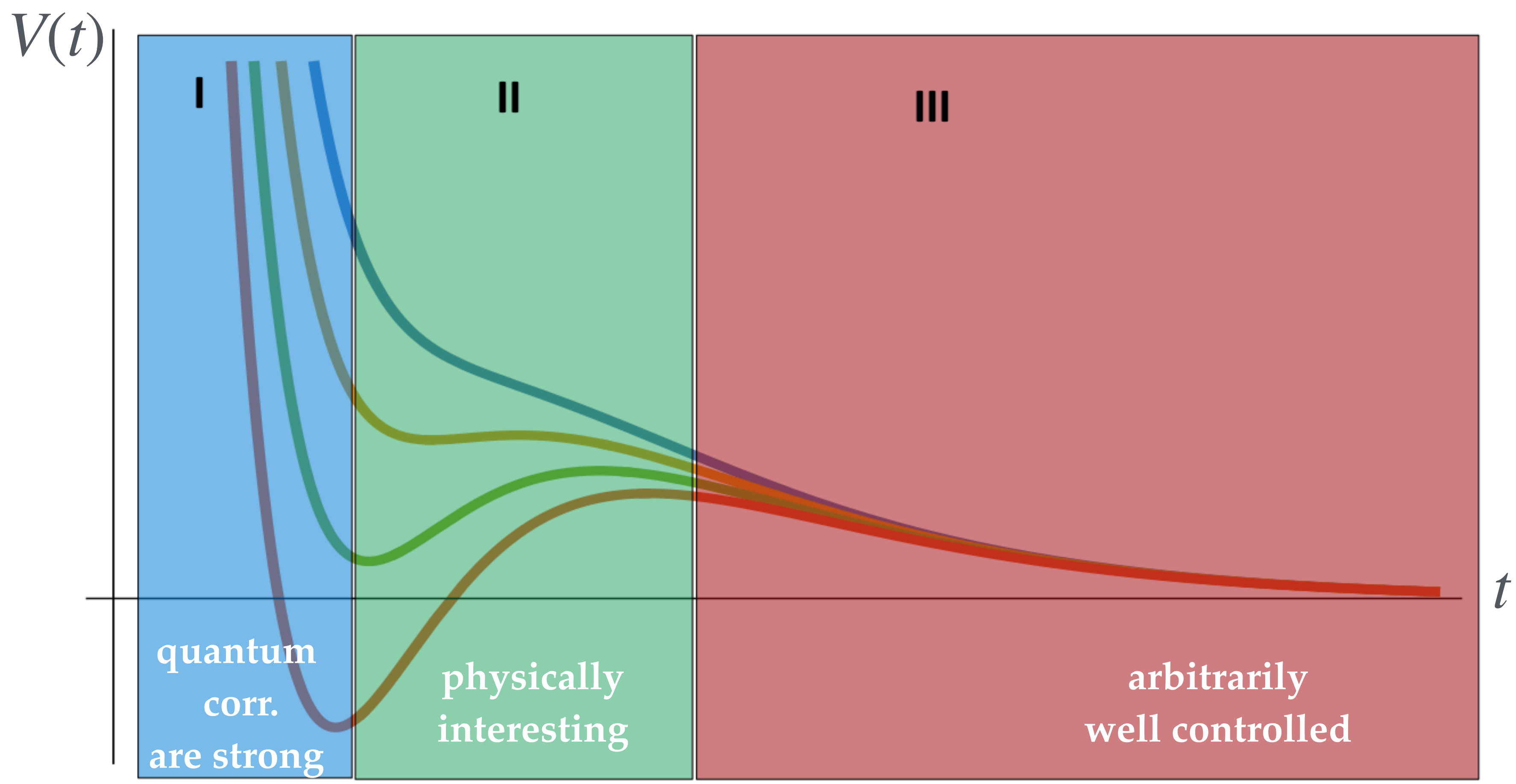
The positive Λ

[Riess et al, '98]



$\Rightarrow$ String theory should reproduce this

Dine-Sieberg Problem



[McAllister, Quevedo, *Moduli Stabilization in String Theory*]

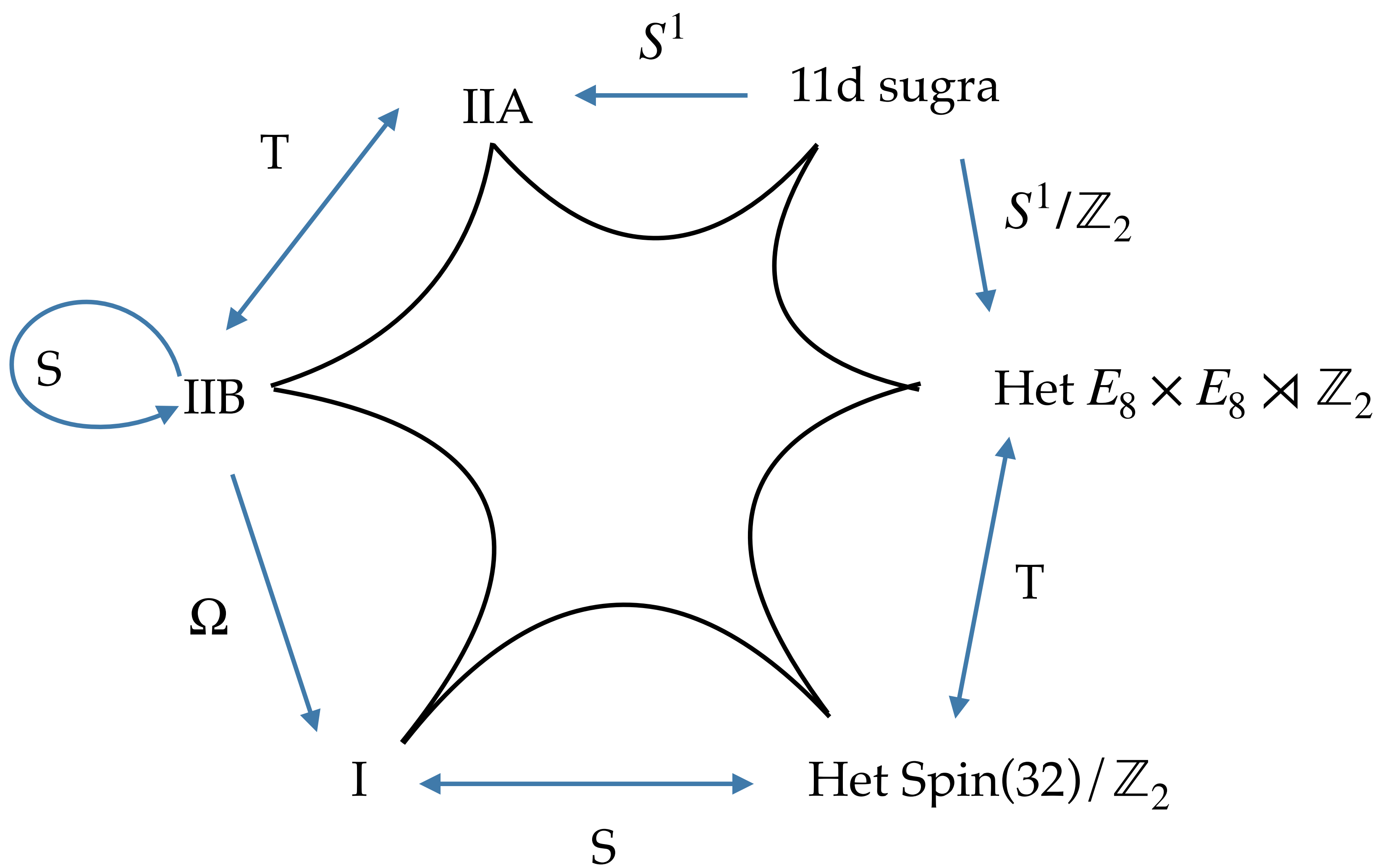
e.g. in IIB on CY orientifolds:

$|W_0| \sim \delta W \gg \delta K$ [Kachru, Kallosh, Linde, Trivedi '03] KKLT

$|W_0| \gg \delta K \sim \delta W$ [Balasubramanian, Berglund, Conlon, Quevedo '05] LVS

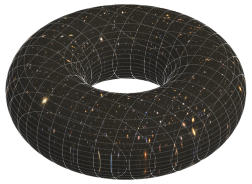
$|W_0| \gg \delta K \gg \delta W$ [Berg, Haack, Kors '05] most plagued by the problem
[Antoniadis, Chen, Leontaris '18]

Motivation for Heterotic



Motivation for Heterotic

Heterotic string is a remarkable playground:

- 4d $N = 2$ heterotic - type II duality
- presence of modular symmetries 
- control of the $N = 1$ EFT from higher susy subsectors ⟶ Can use volumes $1 \lesssim t \lesssim 10$
- outstanding work on **vacua** and **SM** ⟶ No-go thms for de Sitter vacua

$\Rightarrow$ Lessons for the Swampland program

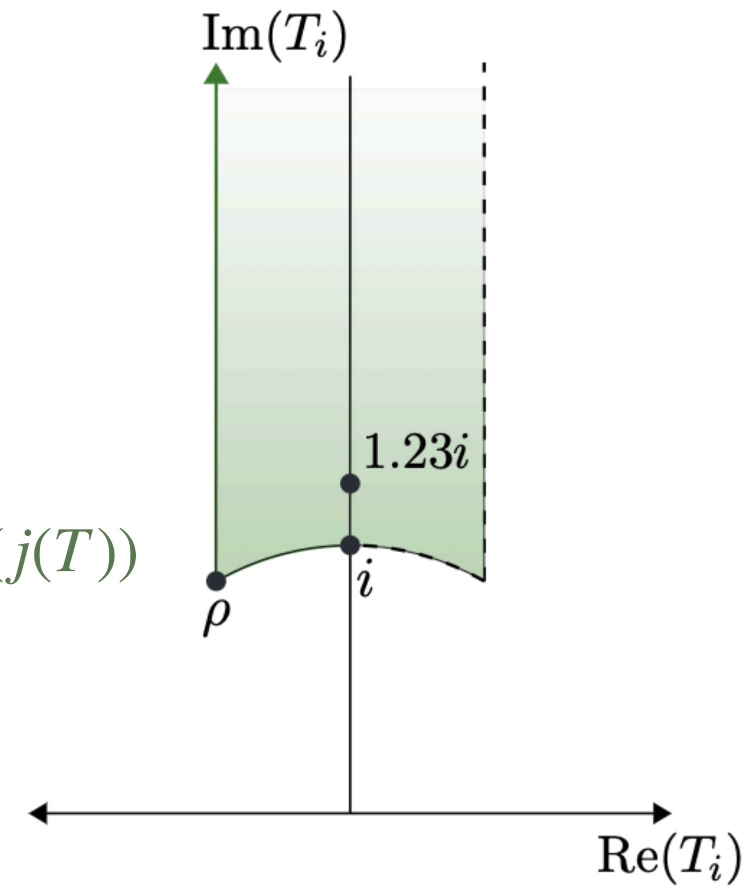
The Potential

Kahler potential $K = k(S,\bar{S}) - 3\ln\left(-i(T-\bar{T})\right)$

Superpotential $W = \dfrac{\Omega(S)H(T)}{\eta^6(T)}$

$\Omega(S) \sim e^{-S}$

$H(T) = \left(\dfrac{E_4(T)}{\eta^8(T)}\right)^n \left(\dfrac{E_6(T)}{\eta^{12}(T)}\right)^m \mathscr{P}(j(T))$



Scalar potential

$$V = e^{k(S,\bar{S})}\, Z(T,\bar{T})\, |\Omega(S)|^2 \left[\left(A(S,\bar{S}) - 3\right)|H(T)|^2 + \widehat{V}(T,\bar{T})\right]$$

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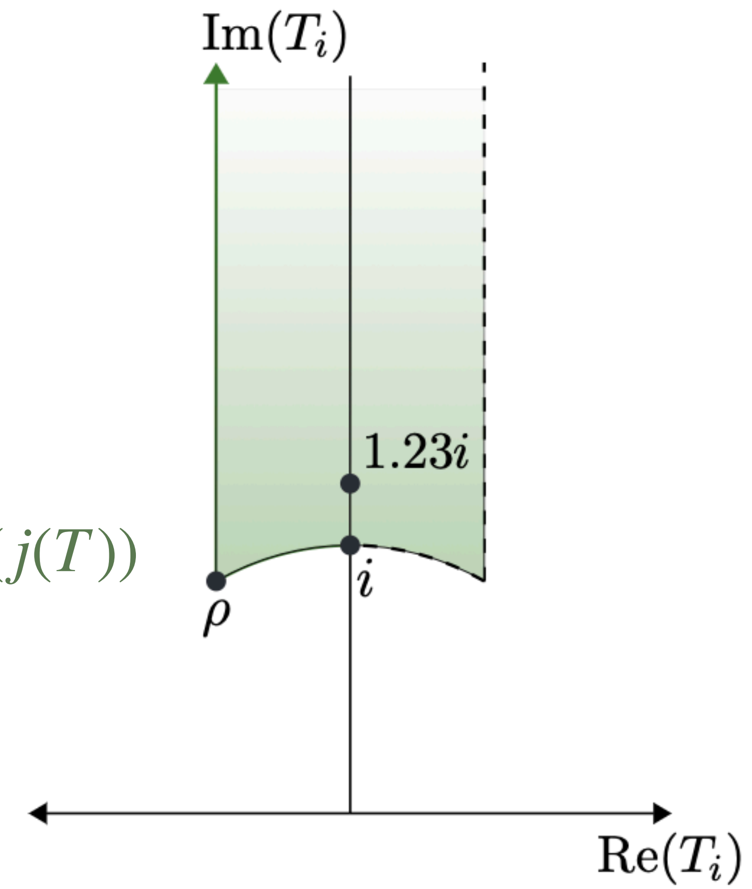

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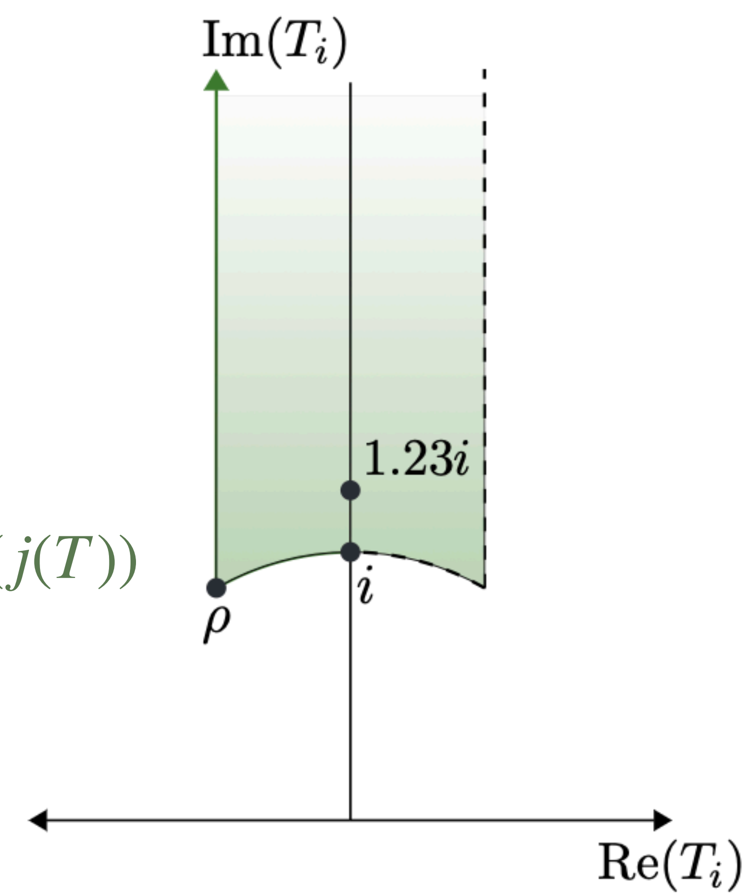
$Z(T,\bar{T}) > 0$, $\quad A(S,\bar{S}) \sim |F_S|^2 \geq 0$, $\quad \widehat{V}(T,\bar{T}) > 0$

The Potential



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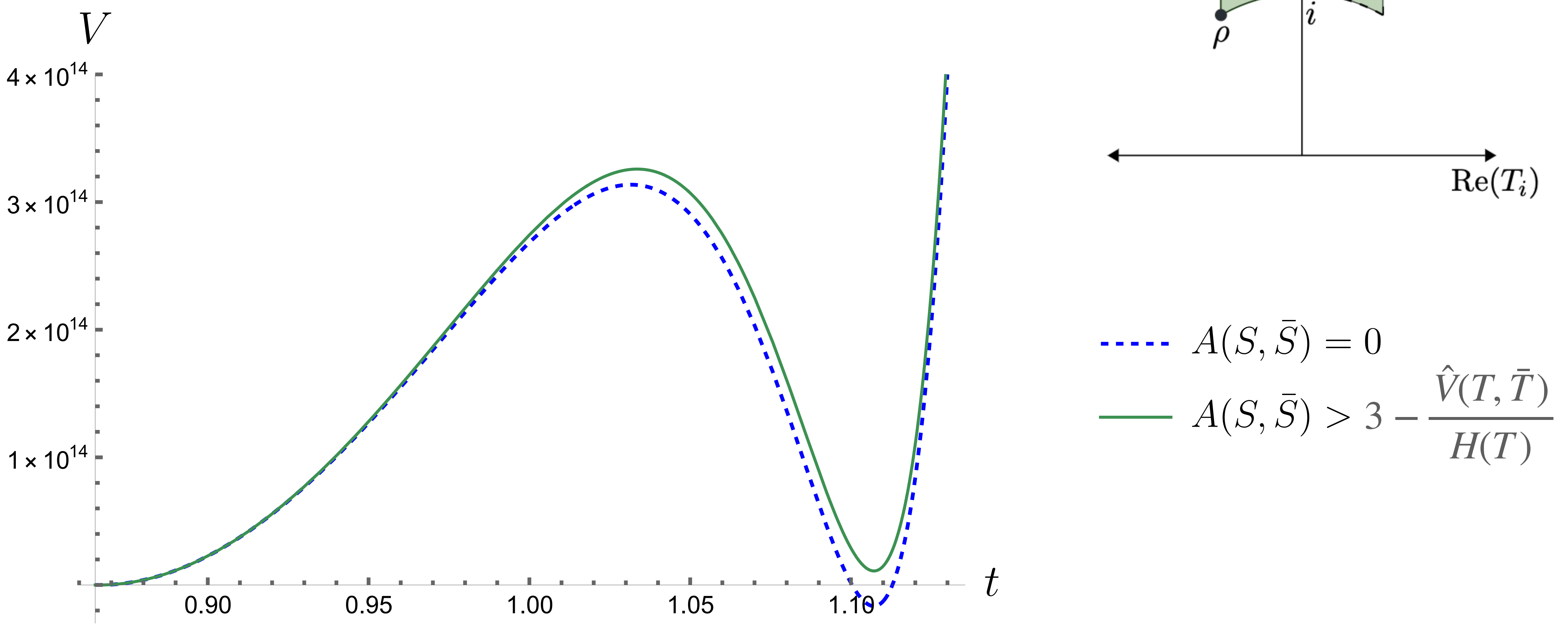
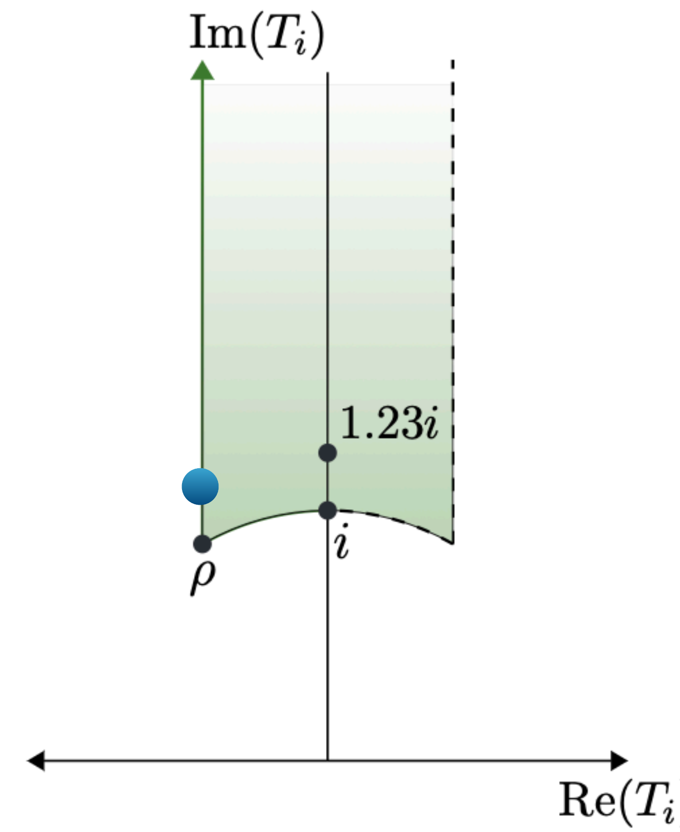
$$V = e^{k(S,\bar{S})} \underbrace{Z(T,\bar{T})}_{>0} |\Omega(S)|^2 \left[\Big(\underbrace{A(S,\bar{S})}_{\sim |F_S|^2 \geq 0} - 3 \Big) |H(T)|^2 + \underbrace{\widehat{V}(T,\bar{T})}_{>0} \right]$$

1) if $K = -\log(S+\bar{S}) \;\Rightarrow\; V \leq 0$

2) if $K = -\log(S+\bar{S}) + \delta K_{np} \;\Rightarrow\; V$ can be positive!

De Sitter Vacua





De Sitter Vacua: Sanity Checks

1) can we really ignore KK modes? i.e. do we have scale separation?

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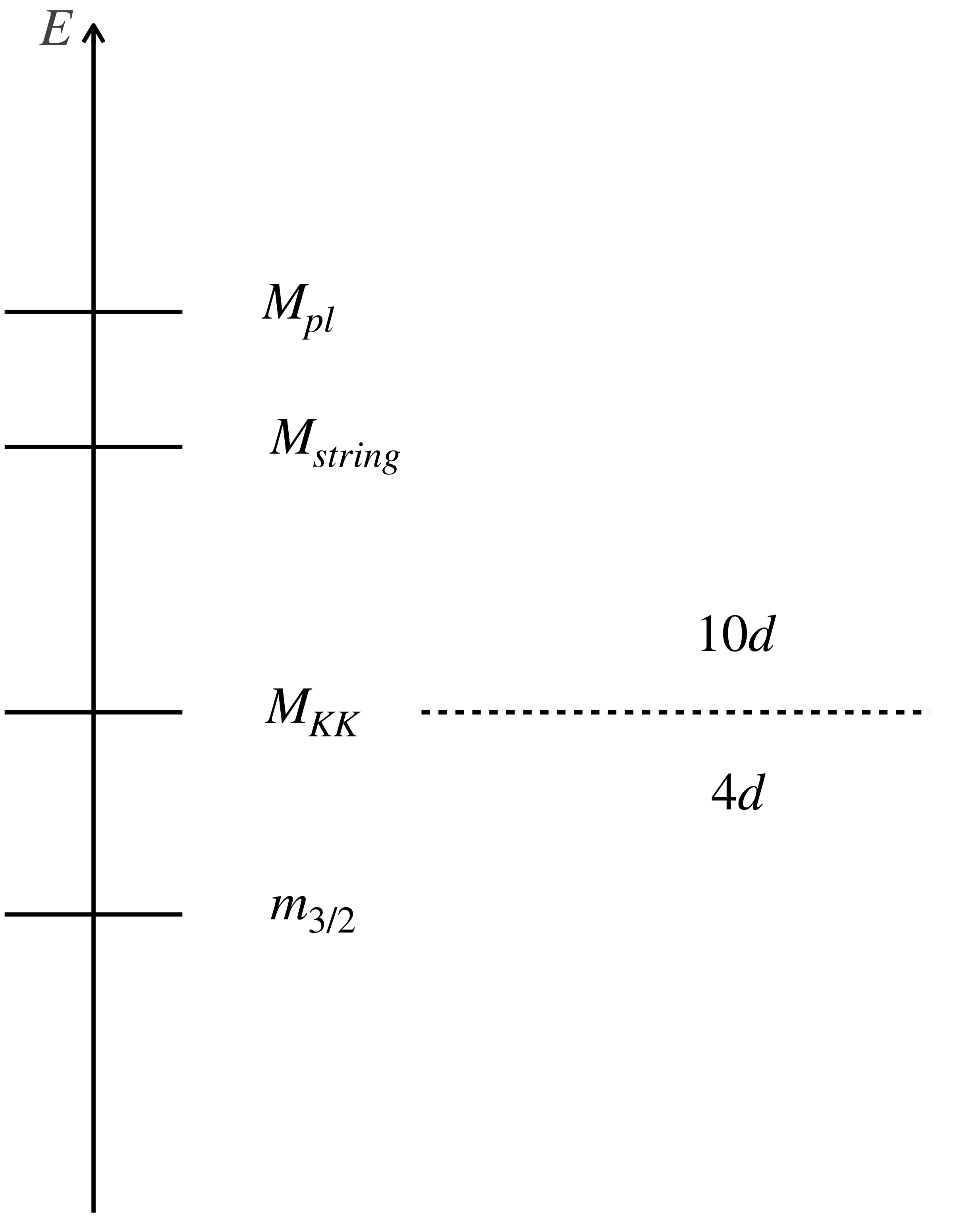
2) can a δK_{np} of the right magnitude exist? [Álvarez-García, Kneissl, Leedom, NR, '24]

Scale Separation



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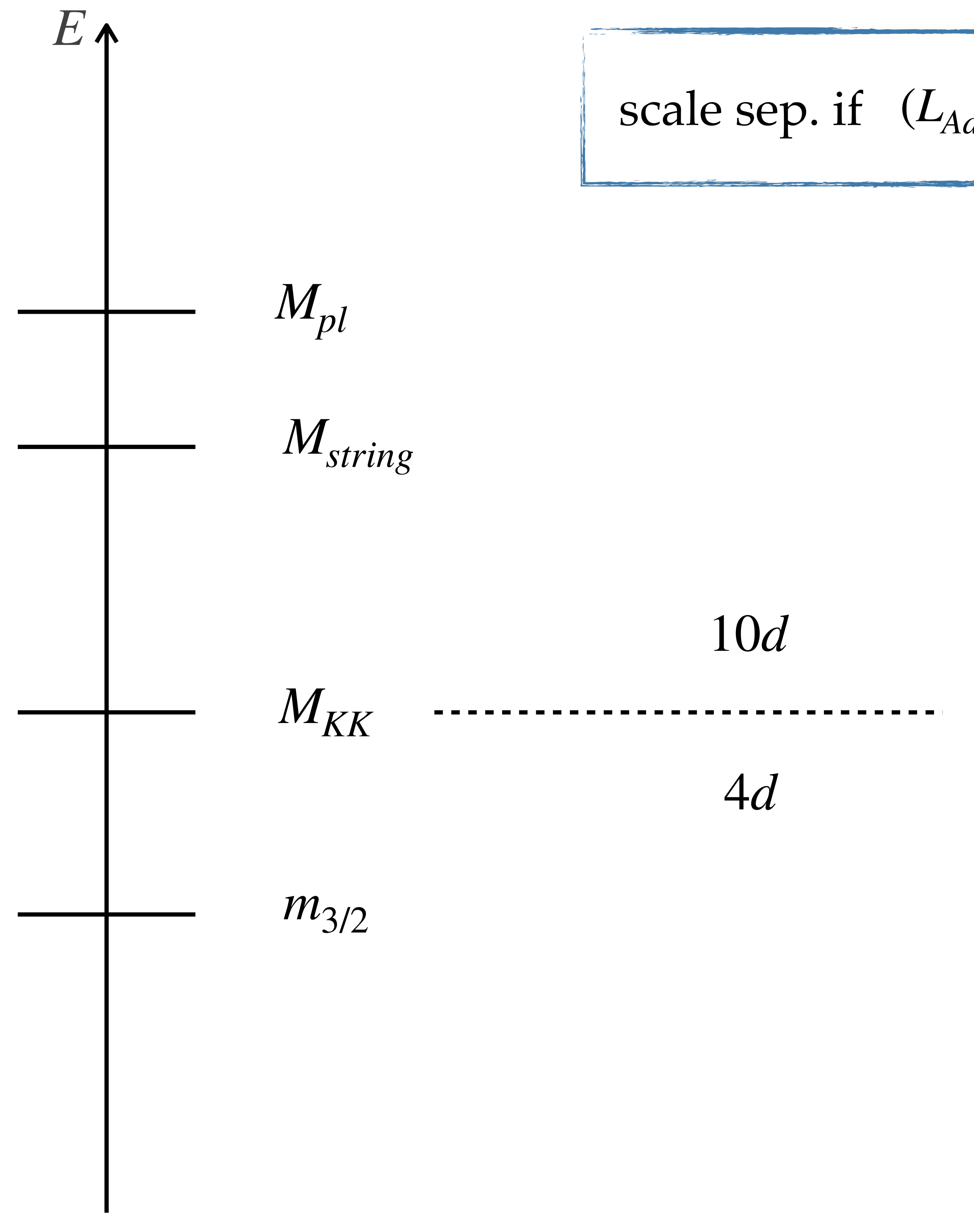

scale sep. if $(L_{AdS} M_{KK})^{-1} \ll 1$

Scale Separation

[NR *WiP*]

$$\frac{L_{AdS}^{-1}}{M_{KK}} \simeq \frac{|H(T)||\Omega(S)|}{t|\eta(T)^6|}$$

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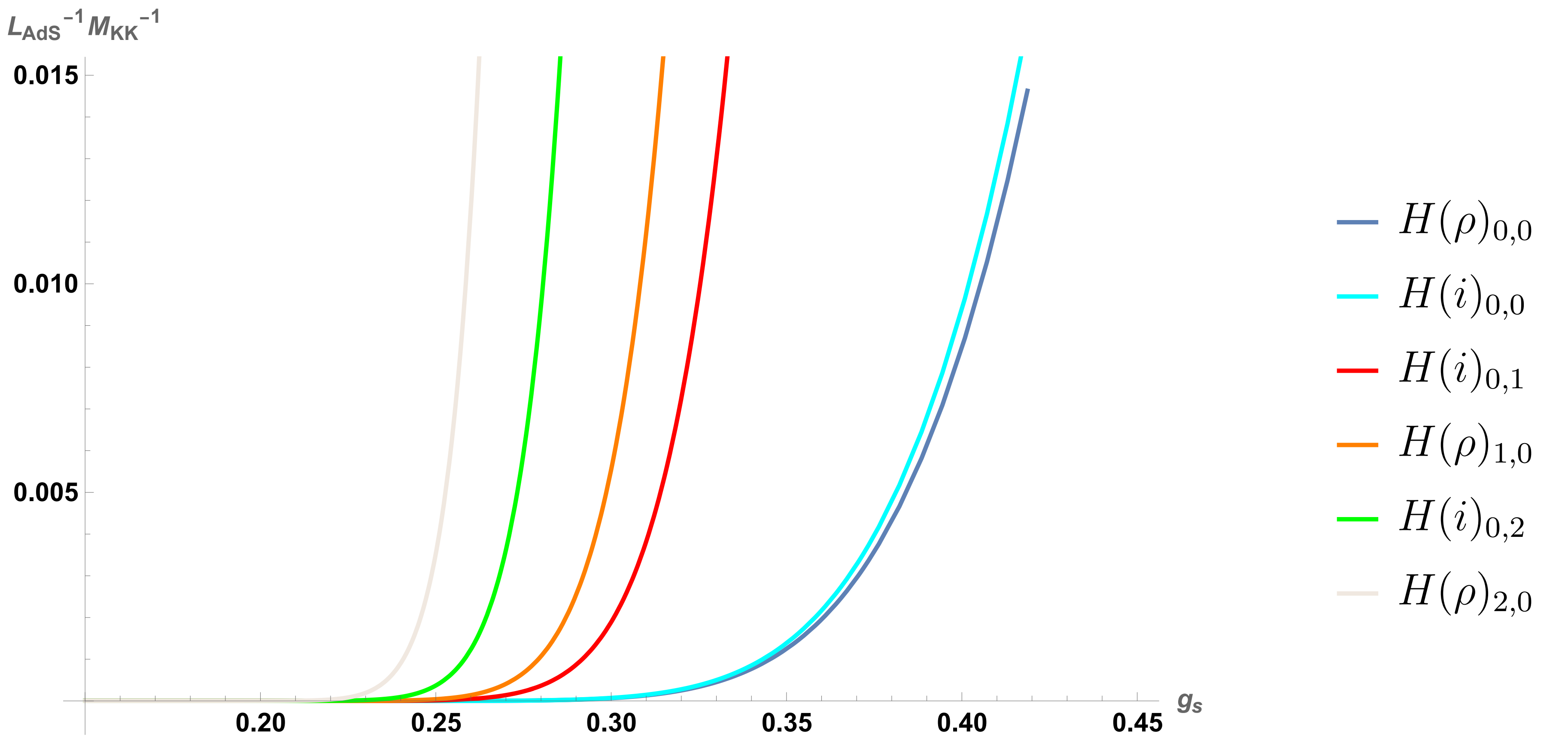
susy-preserving vev



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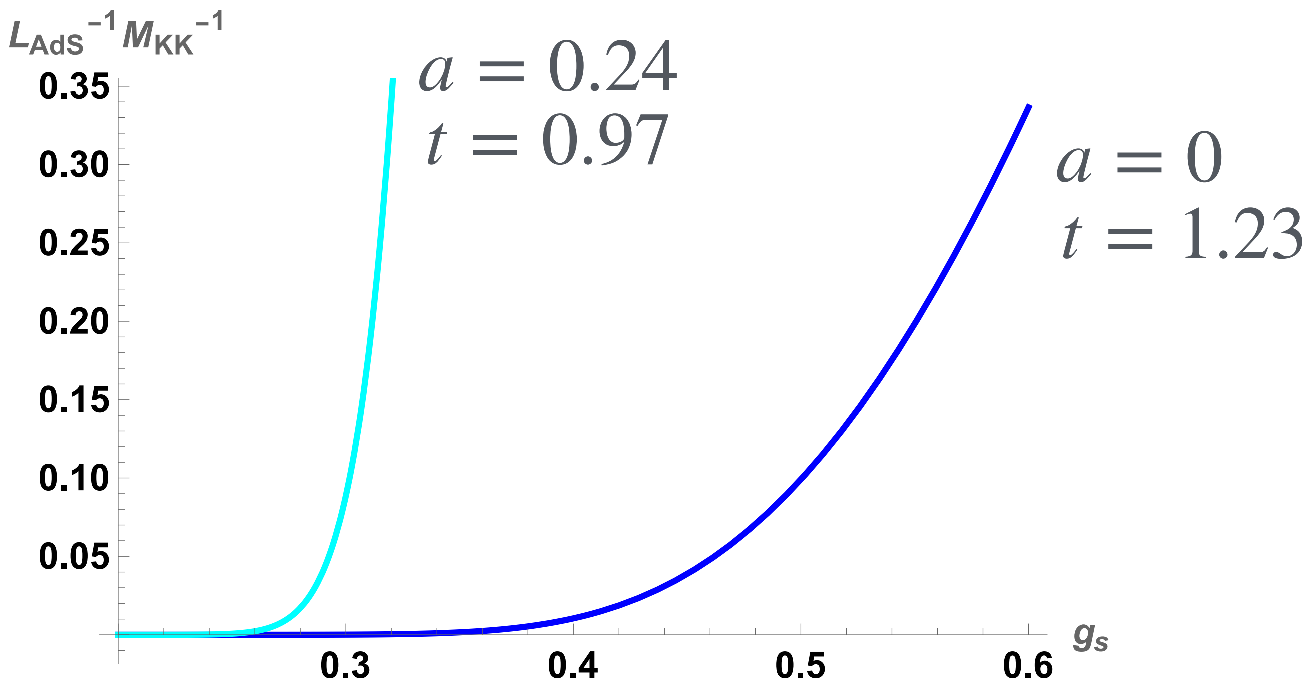
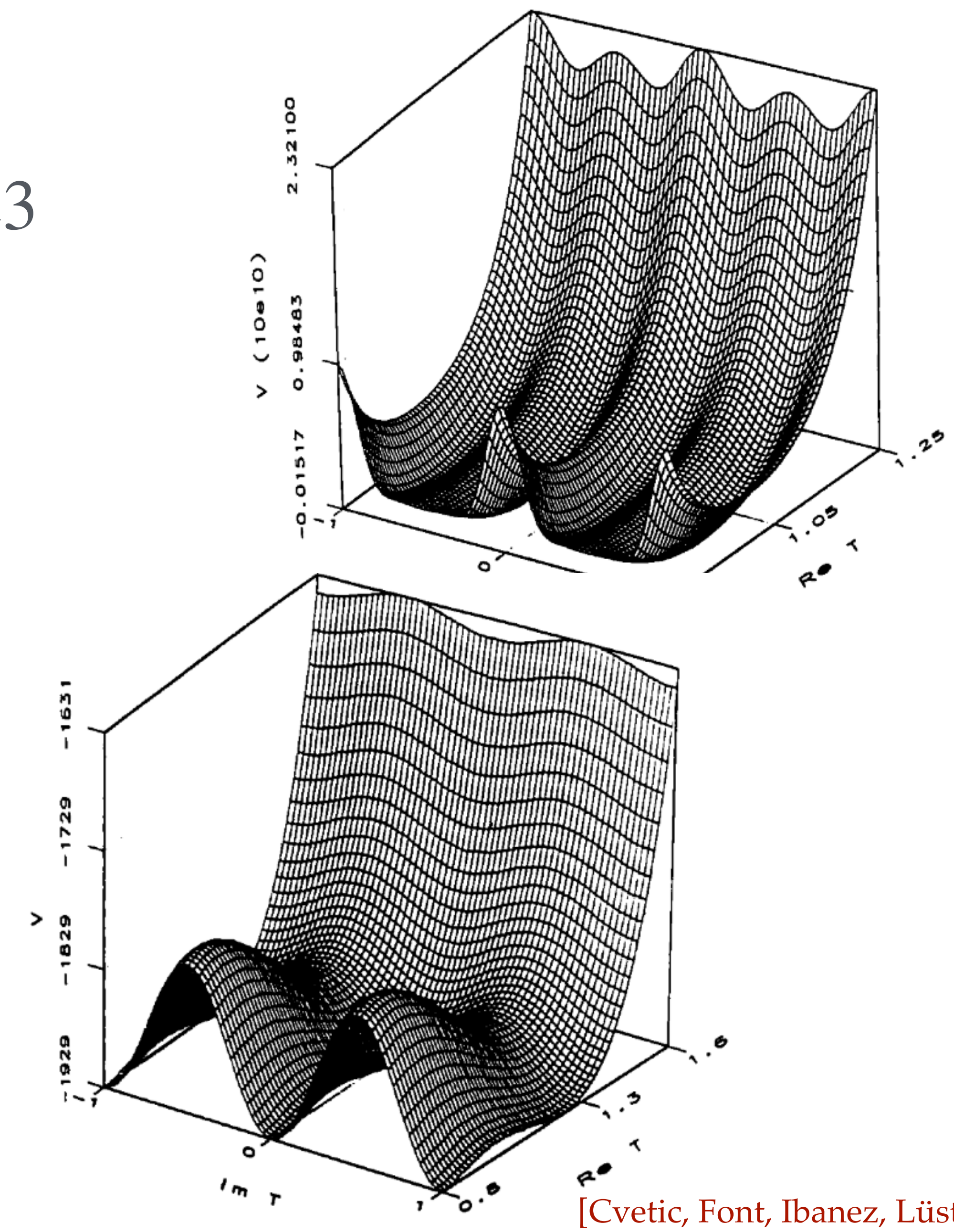


susy-breaking vev



[Cvetic, Font, Ibanez, Lüst, Quevedo '91]

Heterotic Open Strings

$$K = -\ln(S + \bar{S}) + \delta K_{np}$$

All closed string theories have nonperturbative contributions of strength $\sim e^{-1/g_s}$

[Shenker '90]

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but there are “”D-branes””! [Hull, '97 & '98] [Polchinski, '05]

the e^{-1/g_s} should come from a 10d instanton

(at least for $\mathrm{Spin}(32)/\mathbb{Z}_2$) [Álvarez-García, Kneissl, Leedom, NR, '24]

What have we found + What has to be done

- Constructed new de Sitter vacua in heterotic
- Found the critical ingredient: $\delta K_{np} \sim e^{-1/g_s}$
- Started checking its consistency via scale separation & 10d origin
    - scale separated dS vacua?
    - 10d instanton: need of an action
    - What about 10d $E_8 \times E_8$?
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Thank you

Heterotic Open Strings: Arguments

- Hull's orientifold introduces a D1-string
- Inflow of fermion d.o.f from spacetime to worldsheet
- Disk diagrams from the D1 with endpoints on the instanton giving e^{-1/g_s} contributions

Shenker's argument, explained in HO by a D(-1)-brane

- Confirmed by 4-graviton 10d scattering amplitudes
- $\pi_9(\text{SemiSpin}(32)) = \mathbb{Z}_2$ + Derrick's theorem $\quad + \quad \Omega_{10}^{Spin}(B\text{SemiSpin}(32)) = 10\mathbb{Z}_2$