

Title: Hagedorn divergences and Tachyon potential

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Abstract: TBA

Hagedorn divergences and tachyon potential

hep-th/0701205

with Mauro Brigante

Guido Festuccia



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1) From early days of string theory '60

$$Z = \text{Tr} e^{-\beta H} = \int d\epsilon \rho(\epsilon) e^{-\beta \epsilon}$$

divergent when $\beta \ll \beta_H$

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Finite T: $R^q \times \frac{S'}{B}$

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rep-th/0101

aur. brigade
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Finite T:

$$R^d \times \underbrace{S^1}_{\beta}$$

$$m^2 = -\frac{4}{\alpha'} + \left(\frac{n\beta}{2\pi\alpha'} \right)^2$$

n : Winding #

$$n = \pm 1, \quad \beta \leq \beta_H = 4\pi\alpha', \quad m^2 \leq 0$$

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Finite T: $R^q \times \underbrace{S^1}_{\beta}$

$$m^2 = -\frac{4}{\alpha^2} + \left(\frac{n\beta}{2\pi\alpha} \right)^2, \quad n: \text{Winding \#}$$

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Equivalence between ① and ②: modular invariance.

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↑
 β

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 \uparrow
 β

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n : winding # ($n = \pm 1$: thermal scalar)

$n = \pm 1$, $\beta \leq \beta_H = 4\pi\alpha'$, $m^2 \leq 0$

Equivalence between ① and ②: modular invariance.

$m^2 \leq 0$, thermal scalar condenses \Rightarrow new phase.

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 $\uparrow \beta$

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Spacetime. $V = m_\phi^2 \phi^* \phi$

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Spacetime:
$$V = \underbrace{m_q^2}_{m_q^2 \propto P - P_{11}} \phi^* \phi +$$

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$$V = \underbrace{m_\phi^2}_{m_\phi^2 \propto P - P_H} \phi^* \phi + \lambda_4 g^2 (\phi^* \phi)^2 + \dots -$$

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λ_4

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$\lambda_4 > 0$, $\beta = \beta_H$, 2nd order phase transition

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1st order phase transition.

$\lambda_4 < 0$,

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1st order phase transition.

$\lambda_4 < 0$, 1st spacetime.

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Spacetime.

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$\lambda_4 > 0$, $p = p_H$, 2nd order phase transition

$\lambda_4 < 0$, 1st order phase transition

flat spacetime, $\lambda_4 < 0$

$$+ \phi \phi \bar{\phi}$$



+ $\phi\phi\bar{\phi}$

$$+ \phi^* \phi \bar{\Phi}$$

Q:

- 1) all discussion about 1-loop. What happens to higher genus amplitudes?
- 2) What can one make of them?
- 3)

3) Atick Witten (88)

Spacetime.

$$V = \underbrace{m_\phi^2}_{m_\phi^2 \propto \beta - \beta_H} \phi^* \phi + \lambda_4 g^2 (\phi^* \phi)^2 + \dots$$

$\lambda_4 > 0$, $\beta = \beta_H$, 2nd order phase transition

$\lambda_4 < 0$, 1st order phase transition.
1st spacetime, $\lambda_4 < 0$

$$\underline{+ \phi^* \phi \Phi}$$

$$\underline{+ \phi^* \phi \Phi}$$

Q:

- 1) all discussion about 1-loop. What happens to higher genus amplitudes?
- 2) What can one make of them?
- 3) how to find potential for thermal scalar?

Today: 1) all loop divergences

2)

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- 4) reproduce $\text{①} \text{②} \text{③}$ from YM theory.

Today:

- 1) all loop divergences
- 2) they have to resummed
- 3) related simply to thermal scalar potential.
- 4) reproduce ①②③ from YM theory.

1. Higher order divergences.

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(a) one-loop

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$$F_1 = -2 \cdot \frac{1}{2} \log(-\nabla^2 + m_\phi^2(\beta)) + \dots$$

$$m_\phi^2(\beta) \propto \beta - \beta_H$$

1. Higher order divergences.

$$M_{\Phi}^2(\beta) \propto \beta - \beta_H$$

(a) one-loop

$$F_1 = -2 \cdot \frac{1}{2} \log \left(-\nabla^2 + m_{\Phi}^2(\beta) \right) + \dots$$

$$\propto \begin{cases} (m_{\Phi}^2)^{\frac{d}{2}} & d \text{ odd} \\ (m_{\Phi}^2)^{\frac{d}{2}} \log m_{\Phi}^2 & d \text{ even} \end{cases}$$

d : # of uncompact directions

1. Higher order divergences.

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d : # of uncompact directions,

1. Higher order divergences.

$$M_{\text{pl}}^2(\beta) \propto \beta - \beta_H$$

(a) one-loop

$$F_1 = -2 \cdot \frac{1}{2} \log \left(-\nabla^2 + \underbrace{m_{\text{pl}}^2(\beta)}_{\rightarrow 0} \right) + \dots$$

$$\propto \begin{cases} \int (m_{\text{pl}}^2)^{\frac{d}{2}} & d \text{ odd} \\ (m_{\text{pl}}^2)^{\frac{d}{2}} \log m_{\text{pl}}^2 & d \text{ even} \end{cases}$$

d : # of uncompact directions,

In particular $\underline{d=0}$, $F_1 = -\log(\beta - \beta_H)$ ~~divergent at~~ $\beta = \beta_H$

invariant

(b) Higher order div.

- For consistency, restrict $d=0$.

angular invariance.

(b) Higher order div. ~~potential~~

- For consistency, restrict $d=0$. ~~discrete~~
~~production~~

Uncompact flat space. Jan's instability.

~~of H^1 L^2~~
 ~~H^1 L^2~~
 ~~H^1 L^2~~
 ~~H^1 L^2~~
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angular invariance.

Higher order div.

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Uncompact flat space. Jensen's instability.

need to put system with IR cut off

... of ... invariance.

Higher order div.

- For consistency, restrict $d=0$.

Uncompact flat space. Jordan's instability.

need to put system with IR cut off
⇒ mass gap.

... INVARIANCE.

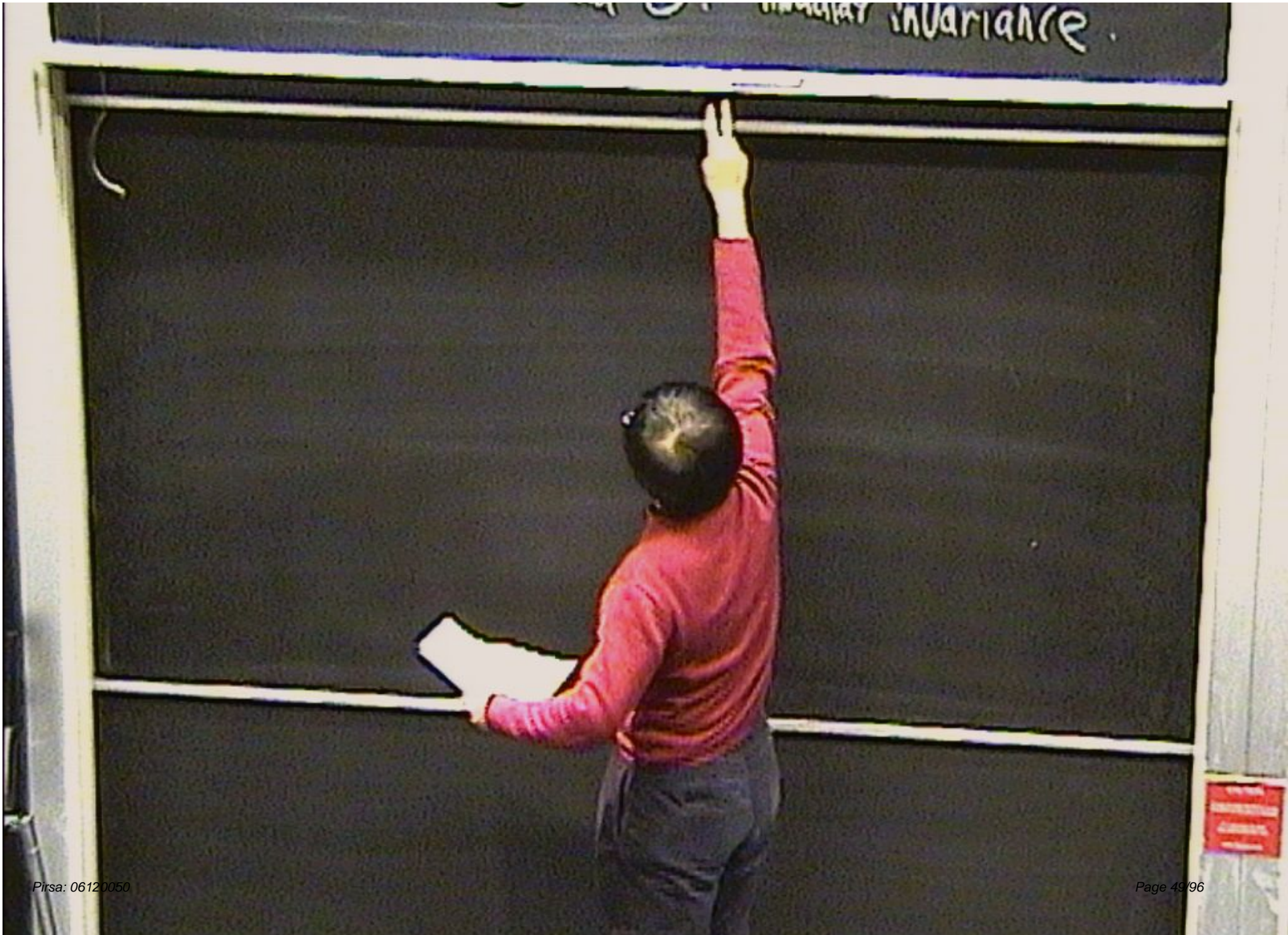
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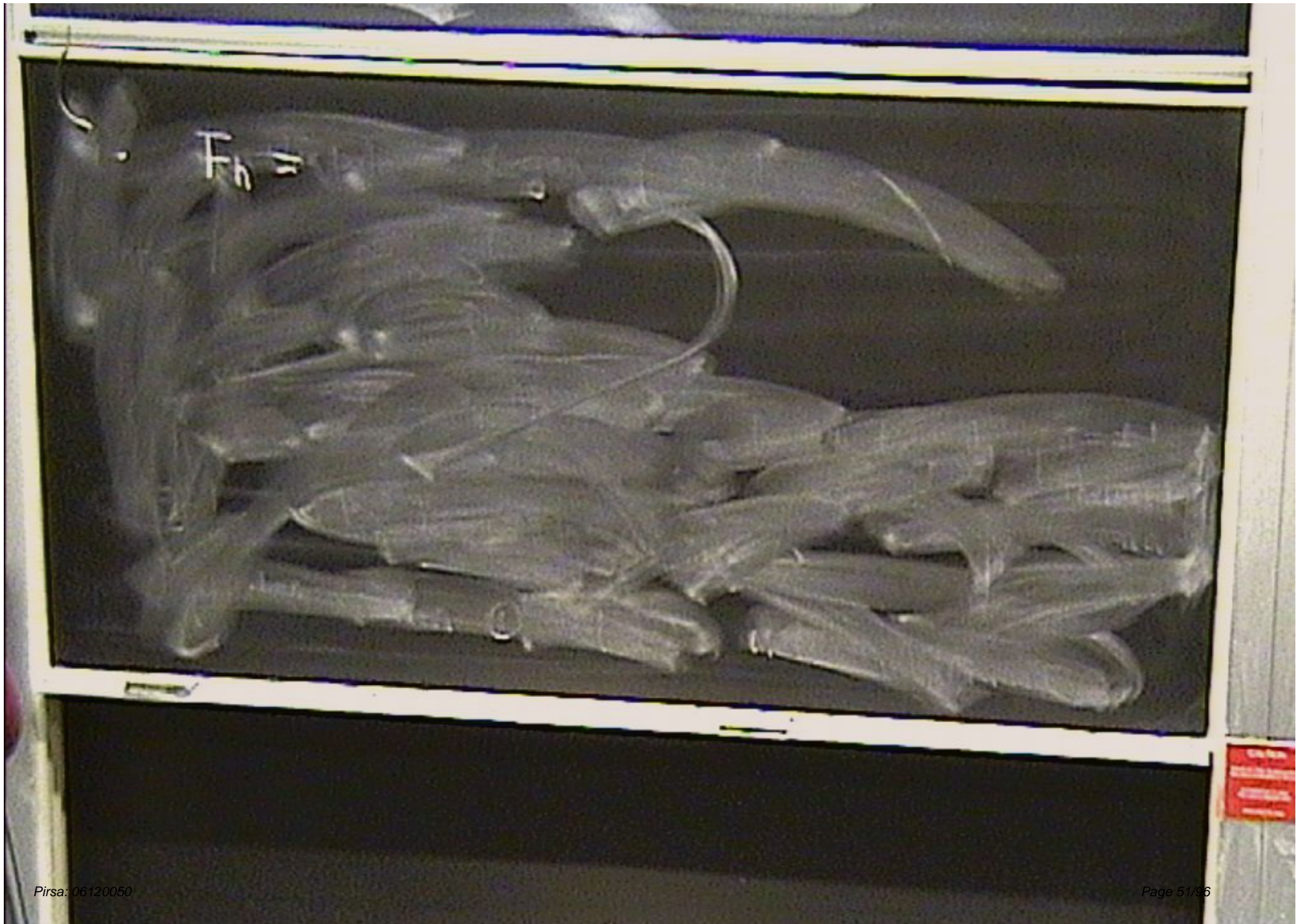
\Rightarrow mass gap, $d=0$

ADS has a mass gap

$\log m$ (87)

$$\frac{d^4}{dt^4} + \left(\frac{16}{2\pi n} \right)^2$$

n : Winding # ($n = \pm 1, \dots$)



Fh 11

CAUTION
DO NOT TOUCH
THIS SURFACE
IT IS RADIOACTIVE

$$F_h = \int d\Sigma_h(\mu) Z_h(\mu)$$

↑
measure
on moduli space

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← σ -model partition function
on a genus- h surface.

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↑

↑
measure
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←

σ-model partition function
on a genus-h surface

Divergences in F_h can only come from boundaries of moduli space.



$$F_h = \int d\Sigma_h(K) Z_h(K)$$

↑

↑
measure
on moduli space

← σ-model partition function
on a genus-h surface

Divergences in F_h can only come from boundaries of moduli space.

• Boundaries of moduli space \longleftrightarrow Riemann surface degenerates
 \longleftrightarrow certain cycles pinched

Two basic ways:

1. Scale \Rightarrow new phase



(80)

$$V = -\mu \cdot \vec{p} + \frac{1}{2} \mu^2 \phi^2 + \dots$$

dup phase transition

order phase transition

Two - basic ways

Scale reduction \Rightarrow new phase



$$V = -M \phi^2 + \frac{1}{2} \lambda \phi^4 + \dots$$

1st phase transition

2nd phase transition

Two basic ways:

1. Scalar field \Rightarrow new phase



1st phase transition
order-phase transition



typical



Two basic ways



typical



transition
 genus = g .
 pinch
 maximal $\exists g-3$
 Cycles

- For each degenerate cycle



- For each degenerate cycle, associate a propagator.

$$G = \sum_i \frac{8\pi}{2i(-\nabla^2 + m^2 \xi)}$$

- For each degenerate cycle, associate a propagator.

$$G = \sum_i \frac{8\pi}{2^{1/2}(-D^2 + m^2 \epsilon)}$$

↑
all mets in string theory

- For each degenerate cycle, associate a propagator.

$$G = \sum_i \frac{8\pi}{\alpha'(-D^2 + m_i^2)}$$

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all mts in string theory

$$\underline{m_i^2 \rightarrow 0} \Rightarrow G \approx \frac{8\pi}{\alpha'} \frac{1}{m_i^2} \quad \text{for } \beta \rightarrow \beta_H$$

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$$\underline{m_i^2 \rightarrow 0} \Rightarrow G \approx \frac{8\pi}{\alpha'} \frac{1}{m_i^2} \quad \text{for } \beta \rightarrow \beta_H$$

source of divergences



typical



genus = g .
 pinch
 maximal $3g-3$
 cycles

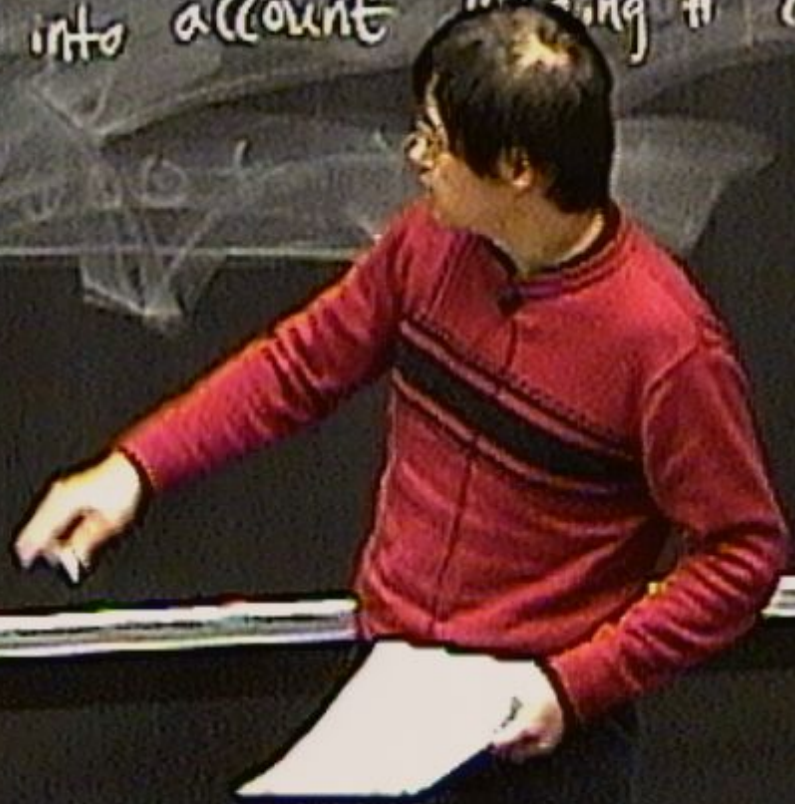
• For each degenerate cycle, associate a propagator.

$$G = \sum_{\substack{\downarrow \\ \uparrow}} \frac{8\pi}{\alpha'(-D^2 + m^2 \epsilon)}$$

all m's in string theory

Naively $F_H \sim \frac{1}{(\beta - \beta_H)^3}$

- One needs to take into account winding # conservation



Naively $F_H \sim \frac{1}{(\beta - \beta_H)^{3/2}}$

• One needs to take into account winding # conservation



at most two of them can have ± 1

Naively $F_H \sim \frac{1}{(P - P_H)^{2g-3}}$

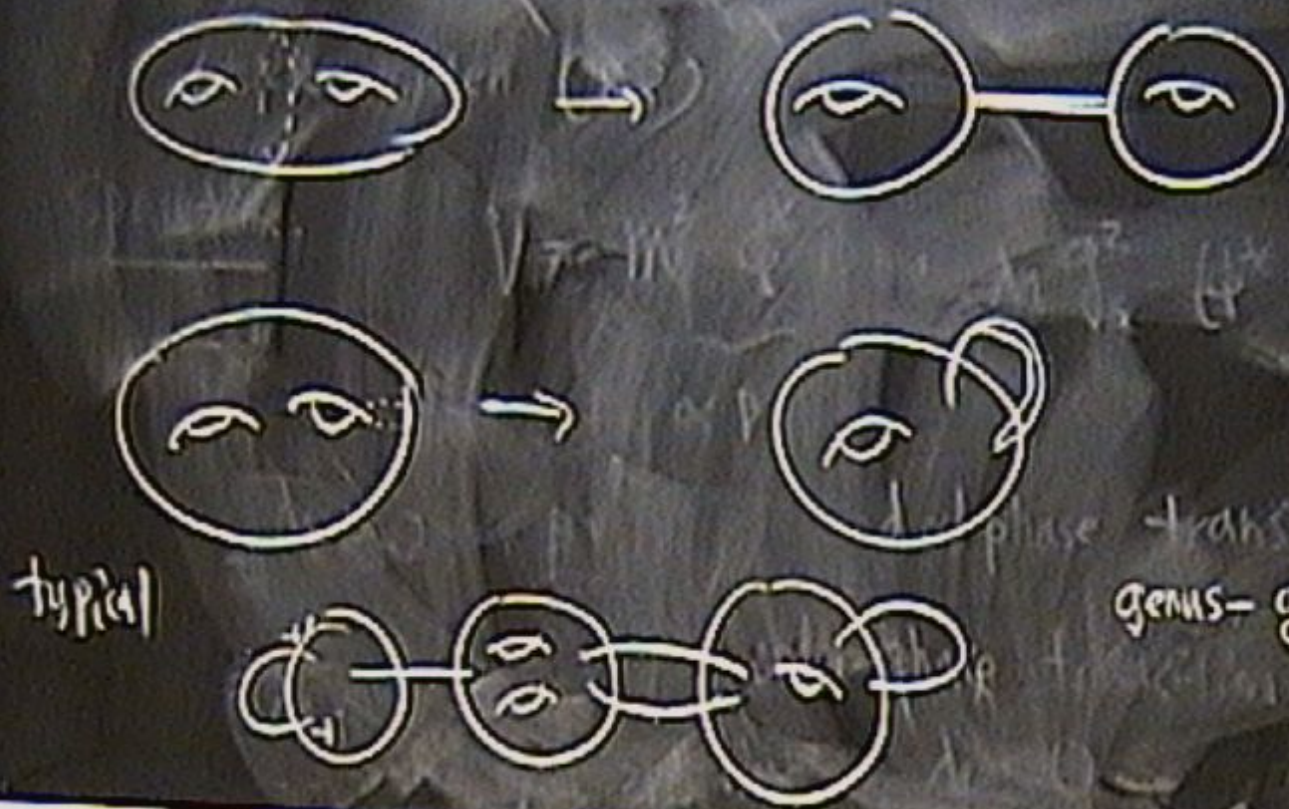
- One needs to take into account winding # conservation



at most two of them can have ± 1

\Rightarrow

$$F_g \sim \frac{1}{(P - P_H)^{2g-2}}$$



typical

genus = g .
 maximal $3g-3$
 cycles

- For each degenerate cycle, associate a propagator.

$$G = \sum_{\text{cycles}} \dots$$

maximal divergence is achieved if all
 vertices in a degenerate limit

$$M_4^2(\beta) \propto \beta - \beta_H$$



maximal divergence is achieved if all
 vertices in a degenerate limit

$$M_4^2(\beta) \propto \beta - \beta_H$$



$$= g_s^2 \lambda^4$$

$g=2$



$g=3$



Most divergent terms to all orders.

$$F_{\text{sing}} = -\log(P-P_H) + \frac{a_2 \lambda_4 \beta^2}{(P-P_H)^2} + a_3 + a_4 \frac{\beta^3}{\lambda_4}$$

Most divergent terms to all orders.

$$F_{\text{sing}} = -\log(\beta - \beta_H) + \frac{a_2 \lambda_4 \beta^2}{(\beta - \beta_H)^2} + \dots + a_g \frac{\lambda_4 \beta^{g-2}}{(\beta - \beta_H)^{g-2}}$$

+ ... (*)

Most divergent terms to all orders.

$$F_{sing} = -\log(\beta - \beta_H) + \frac{a_2 \lambda_4 \beta^2}{(\beta - \beta_H)^2} + \dots + a_g \frac{\lambda_4 \beta^{g-1}}{(\beta - \beta_H)^{g-2}}$$

One normally argues.

$$\beta \rightarrow \beta_H$$

$$\underline{g_s \rightarrow 0}$$

ignore higher order terms

(*)

Most divergent terms to all orders.

$$F_{\text{sing}} = -\log(\beta - \beta_H) + \frac{a_2 \Lambda_4 \beta^2}{(\beta - \beta_H)^2} + \dots + a_g \frac{\Lambda_4^g \beta^{2g-2}}{(\beta - \beta_H)^{2g-2}} + \dots$$

(*)

One normally argues,

$$\underline{g_s \rightarrow 0}$$

ignore higher order terms

$$\beta \rightarrow \beta_H \text{ if } \underline{\beta - \beta_H \propto g_s^2}$$

then all higher order terms equally important.

$$F_{\text{sing}} = -\log(\beta - \beta_H) + \frac{a_2 \lambda_4 \beta^2}{(\beta - \beta_H)^2} + \dots + a_g \frac{\lambda_4 g_5^{2g-2}}{(\beta - \beta_H)^{2g-2}}$$

One normally argues,

$$g_5 \rightarrow 0$$

ignore higher order terms

$$\beta \rightarrow \beta_H \text{ if } \beta - \beta_H \propto g_5$$

then all higher order terms equally important.

then all higher order terms equally important.

I want to argue.

$$F_{\text{sing}} = \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^\dagger \phi - g_s^2 \lambda_\phi (\phi^\dagger \phi)^2}$$

then all higher order terms equally important.

I want to argue.

$$F_{\text{sing}} = \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^* \phi - g_s^2 \lambda_4 (\phi^* \phi)^2} \quad (**)$$
$$= \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^* \phi} \sum_{n=0}^{\infty} \frac{g_s^{2n} \lambda_4^n}{n!} (\phi^* \phi)^{2n}$$

$$\begin{aligned}
 & \dots + \frac{g_5^2}{(\beta - \beta_H)^2} + \dots \rightarrow \mathcal{O}_g \left(\frac{g_5}{(\beta - \beta_H)^{2g-2}} \right) \\
 & \dots + \dots \quad (*) \\
 & \text{One normally angles, } \underline{g_5 \rightarrow 0} \quad \text{ignore higher order terms} \\
 & \underline{\beta \rightarrow \beta_H} \text{ if } \underline{\beta - \beta_H \propto g_5^2}
 \end{aligned}$$

in all higher order terms equally important.

I want to argue.

$$\begin{aligned}
 F_{\text{sing}} &= \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^* \phi - g_5^2 \lambda_4 (\phi^* \phi)^2} \quad (***) \\
 &= \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^* \phi} \sum_{n=0}^{\infty} \frac{g_5^{2n} \lambda_4^n}{n!} (\phi^* \phi)^{2n}
 \end{aligned}$$

maximal divergence is achieved if all
 vertices in a degenerate limit

$$M_{\phi}^2(\beta) \propto \beta - \beta_H'$$

$$\text{[Diagram: A circle with two internal lines crossing, labeled +1 and -1 at vertices]} = g_s^2 \lambda q$$

$g=2$



$g=3$



$$F_{\text{sing}} = -\log(P - P_H) + \frac{a_2 \lambda_4 g_s^2}{(\beta - \beta_H)^2} + \dots + a_9 \left(\frac{\lambda_4 g_s^{2g-2}}{(\beta - \beta_H)^{2g-2}} \right)$$

+ ... (*)

One normally argues, $g_s \rightarrow 0$ ignore higher order terms

$$\beta \rightarrow \beta_H \text{ if } \beta - \beta_H \propto g_s^2$$

then all higher order terms equally important.

I want to argue.

$$F_{\text{sing}} = \log \int d\phi d\phi^* e^{-\frac{m_\phi^2 \phi^\dagger \phi - g_s^2 \lambda_4 (\phi^\dagger \phi)^2}{}} \quad (**)$$

$$= \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^\dagger \phi} \sum_{n=0}^{\infty} \frac{g_s^{2n} \lambda_4^n}{(n!)^2}$$

then all higher order terms equally important.

I want to argue.

$$F_{\text{sing}} = \log \int d\phi d\phi^* e^{-\frac{m_\phi^2 \phi^* \phi - g_s^2 \lambda (\phi^* \phi)^2}{\Lambda^2}} \quad (**)$$
$$= \log \int d\phi d\phi^* e^{-m_\phi^2 \phi^* \phi} \sum_{n=0}^{\infty} \frac{g_s^{2n} \lambda^n}{n!} (\phi^* \phi)^{2n}$$

basic theory of scalar (multiplication) new physics

$$V(\phi) = m_\phi^2 \phi^* \phi + \lambda_\phi \phi^2 (\phi^* \phi)^2$$

basic theory of scalar potential \Rightarrow new physics

$$V(\phi) = m_\phi^2 \phi^* \phi + \lambda_1 \phi^2 (\phi^* \phi)^2 + \lambda_2 \phi^4 (\phi^* \phi)^3 + \dots$$

basic \rightarrow scalar potential \rightarrow new physics

$$V(\phi) = m_\phi^2 \phi^* \phi + \underline{\lambda_\phi} \int dS (\phi^* \phi)^2 + \lambda_\phi (\phi^* \phi)^3 + \dots$$

$$+ m_\phi (\phi^* \phi) + \dots$$

translating into
 \rightarrow ϕ
 \rightarrow ϕ
 \rightarrow ϕ

$$V(\phi) = m_\phi^2 \phi^* \phi + \frac{\lambda_\phi}{4!} \phi^2 (\phi^* \phi)^2 + \frac{\lambda_\phi'}{4!} \phi^4 (\phi^* \phi)^3 + \dots$$

In Ads:

HP transition

$$T_{HP} \sim O\left(\frac{1}{R}\right)$$

$$T_H \sim O\left(\frac{1}{R^2}\right)$$

$$T_H \gg T_{HP}$$

low energy scale (IR) \Rightarrow new physics

$$V(\phi) = m_\phi^2 \phi^* \phi + \frac{\lambda_4}{4} \phi^2 (\phi^* \phi)^2 + \frac{\lambda_6}{6} \phi^2 (\phi^* \phi)^3 + \dots$$

In Ads:

HP transition

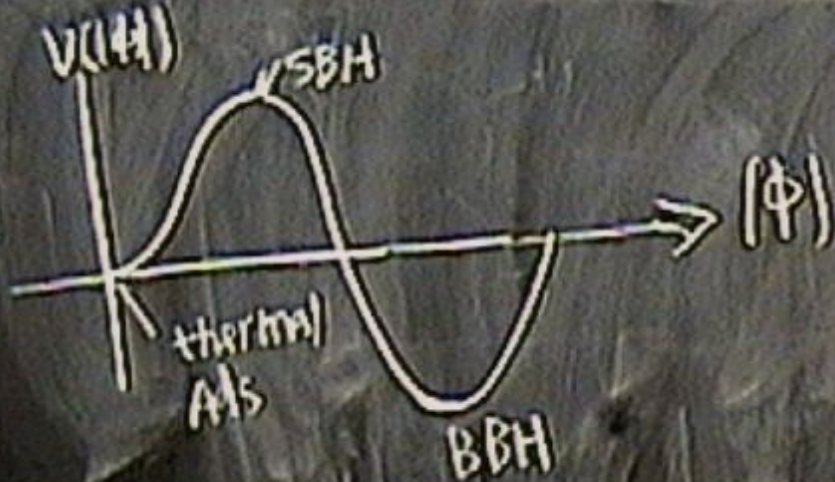
$$T_{HP} \sim O\left(\frac{1}{R}\right)$$

$$T_H \sim O\left(\frac{1}{R^2}\right)$$

$$\underline{T_H \gg T_{HP}}$$

$$M_H^2(\beta) \propto \beta - \beta_H$$

$$T_H > T > T_{HP}$$



$g=2$

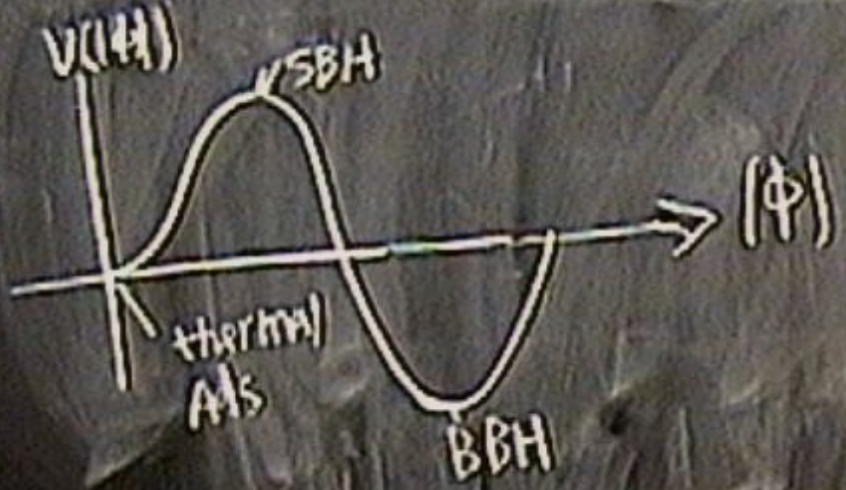


$g=3$



$$M_{\text{pl}}^2(\beta) \propto \beta - \beta_H$$

$$T_H > T > T_{\text{HP}}$$



$g=2$

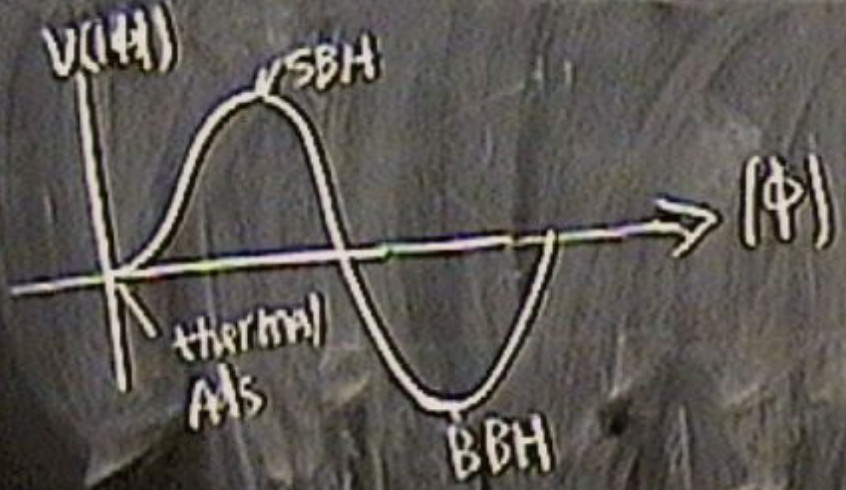
$g=3$



$$-\log(\beta - \beta_H)$$

$$M_{\text{pl}}^2(\beta) \propto \beta - \beta_H$$

$$T_H > T > T_{HP}$$



$g=2$



$g=3$



$$T_H > T > \underline{T_{HP}}$$

$V(H)$

SBH

$|\Phi|$

thermal
ALS

BBH



$$\underline{T \rightarrow T_H}$$

$$M_{\text{pl}}^2(\beta) \propto \beta - \beta_H$$

$$-\log(P_{\text{BH}})$$



+

$$V(\phi) = m_\phi^2 \phi^* \phi + \frac{\lambda_1}{8} \phi^2 (\phi^* \phi)^2 + \left(\frac{\lambda_2}{24} \phi^3 (\phi^* \phi)^3 + \dots \right)$$

In Ads:

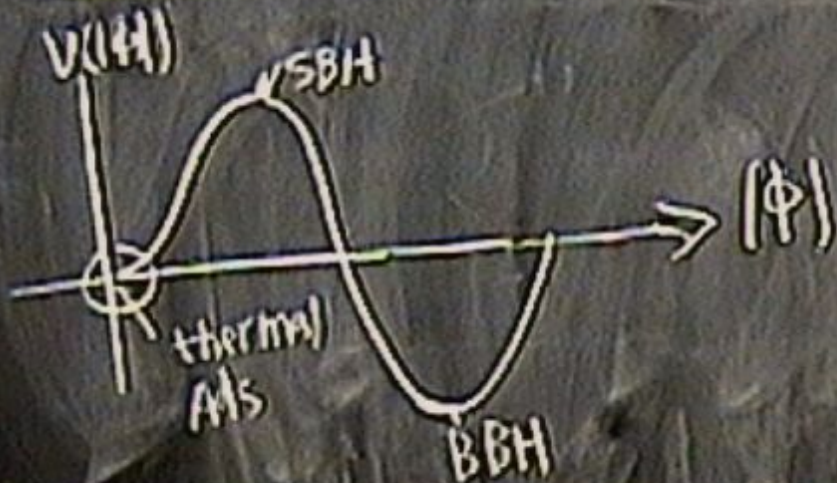
HP transition

$$T_{HP} \sim O\left(\frac{1}{R}\right)$$

$$T_H \sim O\left(\frac{1}{\sqrt{R}}\right)$$

$$\underline{T_H \gg T_{HP}}$$

$$T_H > T > T_{HP}$$

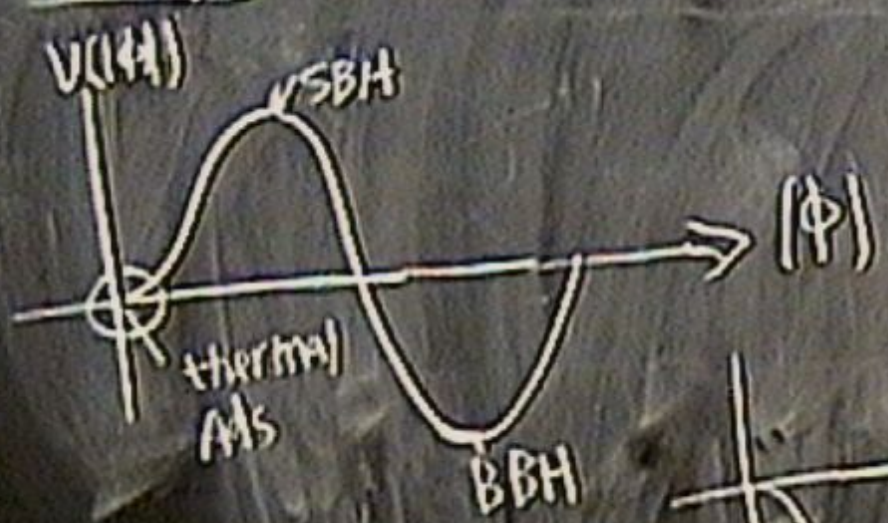


$$M_{\text{pl}}^2(\beta) \propto \beta - \beta_H$$



$$- \log \left(\frac{\beta}{\beta_H} \right) \approx \dots$$

$$T_H > T > T_{HP}$$



$$M_{\dot{\phi}}^2(\beta) \propto \beta - \beta_H$$

