Title: Classical and Quantum SUSY Breaking Effects in IIB String Models

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Abstract: The calculation of soft supersymmery breaking terms type IIB string theoretic models is discussed. Both classical and quantum contributions are evaluated. The suppression of FCNC gives a lower bound on the size of the compactification volume. Essentially what is obtained is a sequestered theory with the dominant pattern of soft masses and gaugino masses being that expected from AMSB and gaugino mediation with a gravitino mass around 100TeV.

Classical and Quantum SUSY Breaking in IIB Models

Perimeter Institute Oct 2009

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Collaborator: Fernando Quevedo

Basic Theory Input

1. A theory of spontaneous SUSY breaking necessarily a SUGRA: CC needs to be tuned to zero!
2. Adding explicit breaking terms to global SUSY too arbitrary
3. Need a SUGRA with a scalar potential which has a minimum that breaks SUSY spontaneously.
4. A SUGRA needs to be embedded in string theory.

Basic Experimental Inputs

- CC is tiny $\sim O((10^{-3}eV)^4)$
- No light scalars with gravitational strength coupling
- SUSY partner masses $\gtrsim O(100GeV)$
- Lightest Higgs $> 114GeV$
- Flavor changing neutral currents (FCNC) suppressed
- No large CP violating phases

Theory of SUSY breaking must satisfy these.

Better still these should emerge naturally from the theory!

General SUGRA framework

$$8\pi G_N = M_P^{-2} = 1$$

$$d^8z \equiv d^4xd^4\theta,\ d^6z \equiv d^4xd^2\theta$$

Action depends on

$$K(\Phi^A, \bar{\Phi}^{\bar{A}}),\ W(\Phi^A),\ f(\Phi^A).A = 1, \ldots N$$

At the two derivative level the form of the action is determined by these.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

SUGRA Inputs

1. W (holomorphic) - no perturbative corrections

2. f (holomorphic) - No higher than one loop perturbative corrections

3. K (real analytic) - Has both perturbative and NP corrections.

String Theory Inputs

Classical K and W given by string theory.

Φ^i: 'Moduli' (gauge singlets)

C^α: MSSM Fields $H_{1,2}$ Higgs.

$$
\begin{aligned}
W &= \hat{W}(\Phi) + \tilde{\mu}_{\alpha\beta}(\Phi) C^\alpha C^\beta + \\
&\quad \frac{1}{6} Y_{\alpha\beta\gamma}(\Phi) C^\alpha C^\beta C^\gamma + \ldots, \\
K &= \hat{K}((\Phi, \bar{\Phi}) + \tilde{K}_{\alpha\bar{\beta}}(\Phi, \bar{\Phi}) C^\alpha \bar{C}^{\bar{\beta}} \\
&\quad + [Z_{\alpha\beta}(\Phi, \bar{\Phi}) C^\alpha C^\beta + h.c.] + \ldots \\
f_a &= f_a(\Phi).
\end{aligned}
$$

a labels gauge groups. $\tilde{\mu}_{\alpha\beta} = \mu \delta_\alpha^{H_1} \delta_\beta^{H_2}$, $Z_{\alpha\beta} = Z \delta_\alpha^{H_1} \delta_\beta^{H_2}$

Potential

$$V(\Phi) = F^A F^{\bar{B}} K_{A\bar{B}} - 3|m_{3/2}(\Phi)|^2 + \sum_a f_{ab} D^a D^b$$

$$F^A = e^{K/2} K^{A\bar{B}} D_{\bar{B}} W,\; D_A W \equiv \partial_A W + K_A W$$

$$|m_{3/2}|^2 \equiv e^K |W|^2,\; K_A = \partial_A K,\; K_{AB} = \partial_A \partial_B K$$

$$D^a = f^{ab} k_b^A D_A W / W$$

$$f_{ab} = f_a \delta_{ab},\; k_a = \text{Killing vector}$$

Requirements for SUSY Breaking

Any theory of SUSY breaking must start from finding a minimum for V which breaks supersymmetry with zero CC:

$$F^i \neq 0, \; |F|^2 = 3m_{3/2}^2,$$

Note: Required for consistency of GMSB also! Without a theory of modulus stabilization it is impossible to claim the dominance of one or other mechanism of SUSY breaking and transmission. Even with such a theory it becomes a matter of landscape statistics!

Extracting LHC physics

KL formulae for soft terms Kaplunovsky+Louis, Brignole+Ibanez+Munoz

$$
\begin{aligned}
\mu_{\alpha\beta} &= e^{\hat{K}/2}\tilde{\mu}_{\alpha\beta} + m_{3/2}Z_{\alpha\beta} - \bar{F}^{\bar{A}}\partial_{\bar{A}}Z_{\alpha\beta}, \\
B\mu_{\alpha\beta} &= F^A D_A \mu_{\alpha\beta} - m_{3/2}\mu_{\alpha\beta}, \\
M_a &= \frac{F^A \partial_A f_a}{2 f_a}, \\
m^2_{\alpha\bar{\beta}} &= V|_0 \tilde{K}_{\alpha\bar{\beta}} + (m^2_{3/2}\tilde{K}_{\alpha\bar{\beta}} - F^A F^{\bar{B}} R_{A\bar{B}\alpha\bar{\beta}}), \\
A_{\alpha\beta\gamma} &= F^A D_A e^{\hat{K}/2} Y_{\alpha\beta\gamma}.
\end{aligned}
$$

Here $D_A = K_A/2 + \nabla_A$. PQ symmetry $\tilde{\mu} = 0$.

Generic possibilities for low scale SUSY breaking

Solving Hierarchy problem requires low energy SUSY breaking

- mSUGRA: $m_{soft} \sim m_{3/2}$. Quantum effects suppressed. Cosmological problems

- Sequestered mSUGRA: No scale and extended no-scale type $m_{soft} \ll m_{3/2}$. Quantum effects comparable to classsical. AMSB special case usually additional contribution of same order.

- GMSB: Need to have $m_{3/2} \ll m_{soft}$. Additional sector for SUSY breaking. Need to stabilize with moduli and additional sector X and find a minimum such that F_X/X dominates over $F_{Modulus}/M_P$. Highly fine-tuned from Landscape point of view. Also need a messenger sector.

IIB String Theory Input

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IIB String Theory Input

Moduli Kaehler potential (classical): α' correction included. $\xi > 0$ for $h_{12} > h_{11}$.

$$\hat{K} = -2\ln\left(\mathcal{V} + \frac{\xi}{2}\left(\frac{(S+\bar{S})}{2}\right)\right) - \ln\left(i\int \Omega\wedge\bar{\Omega}(U,\bar{U})\right) - \ln(S+\bar{S}),$$

$$\hat{W} = W_{flux} + \sum A_i e^{a_i T^i}.$$

S - dilaton, $(S+\bar{S}) \equiv 2g_s$, $U = \{U^a\}$ - $a = 1,\ldots,h_{12}$ - complex structures $\mathcal{V} = \mathcal{V}(T^i,\bar{T^i})$, $i = 1,\ldots,h_{11}$ Kaehler moduli

Even with only one T, (with race track)

$$F^T \sim m_{3/2},\ F^S, F^U \ll m_{3/2},\ |V_0| \sim \frac{m_{3/2}^2}{\ldots}$$

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The LVS Alternative

Much nicer to have (with at least two T^i)

"Swiss Cheese" type - h homogeneous function - degree 3/2. Conlon, Quevedo+...

$$\mathcal{V} = \tau^{3/2} - h(\tau^l),$$

$\tau^l = \frac{1}{2}(T^l + T^{\bar{l}}),\ l = 1, \ldots, h_{11}$ - Kaehler structures. $\tau \equiv \tau^1$

LVS minimum

$$V_0 \sim -\frac{|W|_0^2}{\ln \mathcal{V} \mathcal{V}^3} \sim -\frac{m_{3/2}^2}{\ln m_{3/2} \mathcal{V}}$$

$$\sum A_i e^{-a_i T^i} \sim \frac{W_{flux}}{\mathcal{V}}$$

$$M_{string} \sim \frac{1}{\sqrt{\mathcal{V}}},\ M_{KK} \sim \frac{1}{\mathcal{V}^{2/3}} \sim \frac{1}{\ldots}$$

F-term Estimates

$$F^T F^{\bar{T}} K_{T\bar{T}} \sim 3m_{3/2}^2$$

$$F^i F^{\bar{j}} K_{i\bar{j}} \sim \frac{m_{3/2}^2}{\ln m_{3/2}\mathcal{V}}$$

$$F^S F^{\bar{S}} K_{S\bar{S}} \lesssim \frac{m_{3/2}^2}{\ln m_{3/2}\mathcal{V}}$$

$$F^a F^{\bar{b}} K_{a\bar{b}} \lesssim \frac{m_{3/2}^2}{\ln m_{3/2}\mathcal{V}}$$

Last two non-zero for classical uplift!

MSSM from String Theory?

Matter: On D3 brane at a singularity or D7 brane wrapping a four-cycle. Dynamics of potential minimization drives this below string scale to a collapsed cycle: Conlon, Maharanna, Quevedo 0810.5660, Blumenhagen et al 0711.3389 and 0906.3297

Simplest model (exhibits generic features)

$$\mathcal{V} = \tau_b^{3/2} - \tau_s^{3/2} - \tau_a^{3/2}.$$

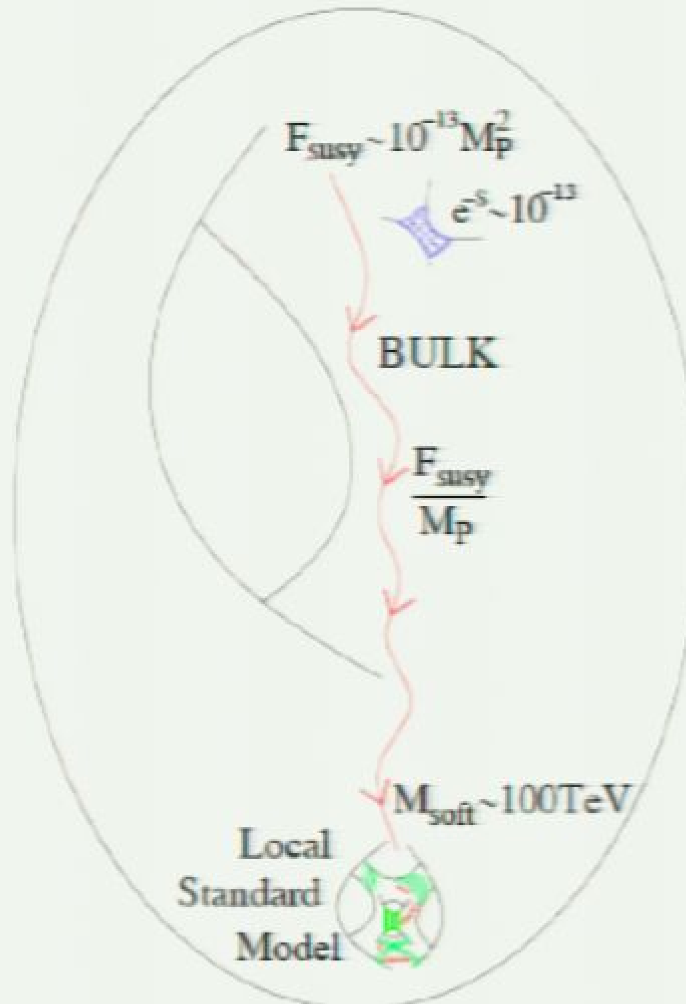
Dynamics $\Longrightarrow \tau^a \to 0$. τ^a size of MSSM 4-cycle wrapped by D7 branes - a-cycle has Anomalous U(1).

$$V_F = \frac{4}{3} g_s (a|A|)^2 \frac{\sqrt{\tau_s} e^{-2a\tau_s}}{\mathcal{V}} - 2 g_s a |A W_0| \frac{\tau_s e^{-a\tau_s}}{\mathcal{V}} + \frac{3\,\xi |W_0|^2}{8\, g_s^{1/2} \mathcal{V}^3} + \dots$$

$$V_D = \frac{\Re f}{\dots} D^2, \; D = \Re f^{-1} k^i K_i, \; f = S + \dots T^a$$

LVS with MSSM on Shrinking cycle

- Susy breaking from large cycle modulus
- Small cycle stabilized by NP effects
- MSSM cycle shrinks below string scale



SUSY Breaking Directions

Assuming charged matter fields zero in vacuum

$$K_a \sim \tau_a^{\alpha}/\mathcal{V},\ \alpha > 0$$

so $D \propto 1/\mathcal{V}$

$$V_D \sim O(\frac{1}{\mathcal{V}^2})$$

.

Minimizing the potential with respect to τ^s and $\mathcal{V}$ give

$$e^{-a\tau_s} \simeq \frac{3\,W_0}{4\,aA\mathcal{V}}\sqrt{\tau_s}\left(1-\frac{3}{4a\tau_s}\right)$$

$$\tau_s^{3/2} \simeq \frac{\hat{\xi}}{2}(1+\frac{1}{2a\tau_s})$$

Classical minimum $D = 0$ so $K_a = 0 \Longrightarrow F^a = 0$.

No SUSY breaking in MSSM direction – SUSY broken only in moduli directions

Classical Results

Minimize and find F-terms:

Minimum:

$$V_0 \sim -\frac{3\hat{\xi}}{16a\tau_s}\frac{m_{3/2}^2}{\mathcal{V}} \sim -\frac{m_{3/2}^2}{\ln m_{3/2}\mathcal{V}}.$$

$$a\tau_s = |\ln m_{3/2}| + O(1) \gtrsim O(10)$$

$$\begin{aligned} m^2_{\alpha\bar{\beta}} &= V_{class}|_0 \tilde{K}_{\alpha\bar{\beta}} + m^2_{3/2}\tilde{K}_{\alpha\bar{\beta}} - F^b F^{\bar{b}} R_{b\bar{b}\alpha\bar{\beta}} \\ &\quad -2Re F^b F^{\bar{s}} R_{b\bar{s}\alpha\bar{\beta}} - F^s F^{\bar{s}} R_{s\bar{s}\alpha\bar{\beta}} \end{aligned}$$

$$\begin{aligned} F^b &= -\tau^b\left(2 + \frac{3\ \hat{\xi}\ 1}{8a\tau^s\mathcal{V}} + O\left(\frac{1}{(a\tau^s)^2\mathcal{V}}\right)\right)m_{3/2} \\ F^s &= -\frac{3\ \tau^s}{2a\tau^s}m_{3/2}(1 + O(\mathcal{V}^{-1})) \end{aligned}$$

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Matter Metric

For MSSM on D3 branes calculate from GGJL

$$K_{\alpha\bar{\beta}} = \frac{c}{\mathcal{V} + \hat{\xi}/2}(\sqrt{\tau^b}\omega^b_{\alpha\bar{\beta}} - \sqrt{\tau^s}\omega^s_{\alpha\bar{\beta}}) \qquad (1)$$

$\omega^{b(s)}$ harmonic $(1,1)$ form at D3 or D7 collpased cycle.

Drop ω^s for now

$$R_{b\bar{b}\alpha\bar{\beta}} = \frac{1}{4(\tau^b)^2}(1 + \frac{15}{16}\frac{\hat{\xi}}{a\tau^s\mathcal{V}})$$

$$R_{b\bar{s}\alpha\bar{\beta}} = -\frac{9}{16}\frac{(\tau^s)^{1/2}}{(\tau^b)^{5/2}}K_{\alpha\bar{\beta}}$$

$$R_{s\bar{s}\alpha\bar{\beta}} = \frac{3}{16}\frac{(\tau^s)^{-1/2}}{(\tau^b)^{3/2}}K_{\alpha\bar{\beta}}$$

$$m^2_{\alpha\bar{\beta}} = V_0 K_{\alpha\bar{\beta}} + \frac{3}{8}\frac{\hat{\xi}}{a\tau^s}\frac{m^2_{3/2}}{\mathcal{V}}K_{\alpha\bar{\beta}}$$

$$= +\frac{3}{\ldots}\frac{\hat{\xi}}{\ldots}\frac{m^2_{3/2}}{\ldots}K_{\alpha\bar{\beta}}$$

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$$R_{s\bar s\alpha\bar\beta} = \frac{3}{16}\frac{(\tau^s)^{-1/2}}{(\tau^b)^{3/2}}K_{\alpha\bar\beta}$$

$$m^2_{\alpha\bar\beta} = V_0 K_{\alpha\bar\beta} + \frac{3}{8}\frac{\hat\xi}{a\tau^s}\frac{m^2_{3/2}}{\mathcal{V}}K_{\alpha\bar\beta}$$

$$= +\frac{3}{\cdots}\frac{\hat\xi}{\cdots}\frac{m^2_{3/2}}{\cdots}K_{\alpha\bar\beta}$$

FCNC Issues

Matter metric:

$$K_{\alpha\bar\beta} = \frac{c}{\mathcal{V}+\xi/2}(\sqrt{\tau^b}\omega^b_{\alpha\bar\beta} - \sqrt{\tau^s}\omega^s_{\alpha\bar\beta})$$

$$\begin{aligned} R_{T\bar T\alpha\bar\beta} &= \partial_T\partial_{\bar T}K_{\alpha\bar\beta} - K^{\gamma\bar\delta}\partial_T K_{\alpha\bar\delta}\partial_{\bar T}K_{\gamma\bar\beta} + O(\phi) \\ &= \frac{1}{3}K_{T\bar T}c[\frac{\omega_b}{\tau_b} - \frac{7}{4}\frac{\omega_s}{\tau_b}\sqrt{\frac{\tau_s}{\tau_b}}]_{\alpha\bar\beta} \end{aligned}$$

Not proportional to $K_{\alpha\bar\beta}$

$$m^2_{\alpha\bar\beta} = \frac{3}{16}\xi\frac{m^2_{3/2}}{\ln m_{3/2}\mathcal{V}}K_{\alpha\bar\beta} + m^2_{3/2}\frac{3}{4}\sqrt{\frac{\tau_s}{\tau_b}}K'_{\alpha\bar\beta}.$$

$$K'_{\alpha\bar\beta} \equiv c\omega^s_{\alpha\bar\beta}/\tau_b$$

Note: $T \equiv T^b$

Phenomenology requires

$$\frac{\Delta m^2}{m^2} \lesssim 10^{-3}\frac{m}{500GeV}.$$

Need to suppress $K'_{\alpha\bar\beta}$

Alternatives

- $\omega^a \ll \omega^b$ at position of brane? Need $\omega^a \lesssim 10^{-3}\frac{1}{\ln m_{3/2}^{-1}}\omega^b$. No rigorous argument to justify this.But if small cycle blow up of a singularity then ω^a falls off as R^{-6} - R distance to location of $D3$- Luetkin $\mathcal{V} \gtrsim 10^{12}$. So $M_{string} \sim M_P/\sqrt{\mathcal{V}} \lesssim 10^{12} GeV$. No GUT scenario but viable intermediate scale phenomenology. Consistent with old LVS work Conlon Quevedo et al. But need to consider quantum contributions to gaugino and scalar masses

- Compactifications with just one Kaehler modulus. LVS solution not possible. But including α' corrections and/or race track get intermediate volume ($\mathcal{V} \sim 10^{3-4}$) solution. W_0 higly fine tuned to get $m_{3/2} \ll M_p$.

Soft parameters

$$\begin{aligned}
M_a &= \frac{F^i\partial_i f_a}{2f_a} = \frac{F^S}{2S} \lesssim O\left(\frac{m_{3/2}}{\sqrt{\ln m_{3/2}\mathcal{V}}}\right), \\
m^2_{\alpha\bar{\beta}} &= V_{class}|_0\tilde{K}_{\alpha\bar{\beta}} + \\
&\quad (m^2_{3/2}\tilde{K}_{\alpha\bar{\beta}} - F^A F^{\bar{B}} R_{A\bar{B}\alpha\bar{\beta}}) \\
&\sim (O\left(\frac{m^2_{3/2}}{\ln m_{3/2}\mathcal{V}}\right))\tilde{K}_{\alpha\bar{\beta}} + \ldots, \\
A_{\alpha\beta\gamma} &= \frac{W^*_m}{|W_m|}F^A D_A Y_{\alpha\beta\gamma} \lesssim O\left(\frac{m_{3/2}}{\sqrt{\mathcal{V}}}\right) Y_{\alpha\beta\gamma}, \\
\mu_{\alpha\beta} &\lesssim O\left(\frac{m_{3/2}}{\sqrt{\ln m_{3/2}\mathcal{V}}}\right) Z_{\alpha\beta} \\
B\mu/\mu &\lesssim O\left(\frac{m_{3/2}}{\sqrt{\ln m_{3/2}\mathcal{V}}}\right),
\end{aligned}$$

- Note we have estimated size of generic uplift terms in S, U directions to get gaugino A, mu and Bmu terms

Effective Field Theory - 1 Loop Effects

Coeff of quadratic divergence in CW formula:

$$\mathrm{Str}M^2(\Phi) \equiv \sum_J (-1)^{2J}(2J+1)\mathrm{tr}M^2(\Phi) \neq 0$$

$$\begin{aligned}
V|_0 &= (F^m F^{\bar{n}} K_{m\bar{n}} - 3m_{3/2}^2)(1 + \frac{(N-5)\Lambda^2}{16\pi^2}) \\
&\quad + \frac{\Lambda^2}{16\pi^2}(m_{3/2}^2(N-1) - F^T F^{\bar{T}} R_{T\bar{T}}), \\
m_{\alpha\bar{\beta}}^2 &= V|_0 Z_{\alpha\bar{\beta}} + (m_{3/2}^2 Z_{IJ\alpha\bar{\beta}} - F^T F^{\bar{T}} R_{T\bar{T}\alpha\bar{\beta}}) \times \\
&\quad (1 + \frac{(N-5)\Lambda^2}{16\pi^2}) \\
&\quad - \frac{\Lambda^2}{16\pi^2}(''R^{2''})O(m_{3/2}^2)
\end{aligned}$$

Gaillard and Jain, Ferrara Kounnas Zwirner, Choi, Lee, Munoz hep-ph/9709250.

One Loop Correction to Soft Mass

Using $R_{b\bar{b}} \sim \frac{1}{3} N_V K_{b\bar{b}}$ and $F^b K_{b\bar{b}} F^{\bar{b}} \sim 3m_{3/2}^2$ (N_V =# MSSM/GUT fields)

CC $= 0 \Rightarrow$:

$$3m_{3/2}^2 - F^i K_{i\bar{j}} F^{\bar{j}} \sim \frac{\Lambda^2}{16\pi^2} m_{3/2}^2 (N - N_v) \sim \frac{\Lambda^2}{16\pi^2} m_{3/2}^2 h_{21}$$

$$\Delta m_{\alpha\bar{\beta}}^2 = O\left(h_{21} \frac{\Lambda^2}{48\pi^2} m_{3/2}^2\right) \tilde{K}_{\alpha\bar{\beta}} + \ldots$$

SdA 0806.2627

Cut off $\Lambda \lesssim M_{string}$? Need $M_{string} \gtrsim M_{GUT}$?

Comparison with String 1-Loop Calculation

- Berg et al, Ciccoli et al Matter metric correction assumed

$$K_q = \frac{\alpha(S,\bar{S},U,\bar{U})}{T+\bar{T}} + O\left(\frac{1}{(T+\bar{T})^2}\right)$$

In simple models α independent of τ^i

$$V_q \sim O(\frac{m_{3/2}^2}{(T+\bar{T})^2})$$

$O(m_{3/2}^2/(T+\bar{T}))$ leading term cancels - extended no-scale structure.

Compare with effective field theory:

$$\Lambda \sim \frac{1}{T+\bar{T}}$$

$$K = -3\ln(T+\bar{T}) + \frac{\alpha}{T+\bar{T}} + \frac{C^{\alpha}C^{\bar{\beta}}}{T+\bar{T}}(1+\frac{\beta}{T+\bar{T}})k_{\alpha\bar{\beta}}.$$

This generates a soft mass contribution

$$\Delta m_{\alpha\bar{\beta}}^2 = \frac{2(\alpha/3-\beta)}{T+\bar{T}} m_{3/2}^2 \tilde{K}_{\alpha\bar{\beta}}.$$

Implies

$$m_s \sim \frac{m_{3/2}}{} \sim \sqrt{\Lambda} m_{3/2}$$

Comparison with String 1-Loop Calculation 2

$$m_s \sim \frac{m_{3/2}}{\sqrt{(T+\bar{T}}} \sim \sqrt{\Lambda} m_{3/2}$$

- Larger than classical $m_s^{cl} \sim m_{3/2}/\ln m_{3/2}(T+\bar{T})^{3/4}$.
- Contradicts effective field theory calculation $m_s \sim \Lambda m_{3/2}$ unless $(\alpha/3-\beta)=0$!

Comparison with String 1-Loop Calculation

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$$V_q \sim O\left(\frac{m_{3/2}^2}{(T+\bar{T})^2}\right)$$

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Implies

$$m_s \sim \frac{m_{3/2}}{\ldots} \sim \sqrt{\Lambda}\, m_{3/2}$$

Comparison with String 1-Loop Calculation 2

$$m_s \sim \frac{m_{3/2}}{\sqrt{(T+\bar{T}}} \sim \sqrt{\Lambda} m_{3/2}$$

- Larger than classical $m_s^{cl} \sim m_{3/2}/\ln m_{3/2}(T+\bar{T})^{3/4}$.
- Contradicts effective field theory calculation $m_s \sim \Lambda m_{3/2}$ unless $(\alpha/3-\beta)=0$!

Comparison with String 1-loop Calculation 3

In general we may not have these cancellations

In $K_q \sim \alpha/(T+\bar{T})$, α dependent on (τ^s/τ^b).

Leading quantum contribution

$$V_q \sim \frac{m_{3/2}^2/\ln m_{3/2}}{(T+\bar{T})}\xi \qquad (2)$$

Compare with cut-off Field theory:

$$\Lambda \sim \frac{1}{\sqrt{T+\bar{T}}}$$

$$m_s \sim \frac{m_{3/2}(\alpha/3-\beta)^{1/2}}{\sqrt{(T+\bar{T})}} \sim \Lambda m_{3/2}$$

In agreement with effective field theory - no need to demand $\alpha/3-\beta=0$!

Comparison with String 1-loop Calculation 4

But

$$\Lambda \sim \mathcal{V}^{1/6} M_{string} > M_{string}$$

And LVS classical vacuum destabilized!

$$|V_{cl}| \sim \frac{m_{3/2}^2}{\ln m_{3/2}\mathcal{V}} < |V_q| \sim \frac{m_{3/2}^2}{\mathcal{V}^{2/3}}$$

Assuming a new min exists get,

$$m_s \sim m_s^q \sim \frac{|W|}{\mathcal{V}^{4/3}}$$

So $m_s \sim 1TeV,\ W \sim O(1) \Rightarrow \mathcal{V} \sim 10^{11}$

$$M_{string} \sim 10^{13} GeV,\ \Lambda \sim 10^{15} GeV$$

To get GUT scale M_{string} and TeV soft masses need $|W| \sim 10^{-10}$!

Comparison with String 1-loop Calculation 5

However

$$\Lambda > M_{string} \sim 1/(T+\bar{T})^{3/4}$$

In conflict with expectation field theory should be valid only upto M_{string}. How to avoid this conclusion?

Followed from assumption

$$N \sim h_{21} \sim 10^2$$

Not unreasonable to have larger values for h_{21}. Compare two calculations:

$$\frac{m_{3/2}^2}{T+\bar{T}} O(1) \sim \frac{\Lambda^2}{32\pi^2} N m_{3/2}^2$$

Imposing $\Lambda \lesssim M_{string} \sim 1/(T+\bar{T})^{3/4}$

$$\Lambda^2 \sim \frac{32\pi^2}{N} \frac{1}{T+\bar{T}} \lesssim \frac{1}{(T+\bar{T})^{3/2}}$$

$$T+\bar{T} \lesssim (N/32\pi^2)^2$$

Restrictions on Volume

Even for $N \sim 10^4$

So $$T + \bar{T} \lesssim 10^3$$

And we have $\mathcal{V} \lesssim 3 \times 10^4$

This in incompatible with an LVS scenario. Can have one Kaehler modulus case stabilized by race-track on NP terms and alpha' corrections.
To avoid this need to assume $O(m_{3/2}^2/(T+\bar{T})$ cancel.

LVS minimum survives only if $\Lambda \sim 1/(T+\bar{T})$ and $\alpha/3 = \beta$ is satisfied.

AMSB 1

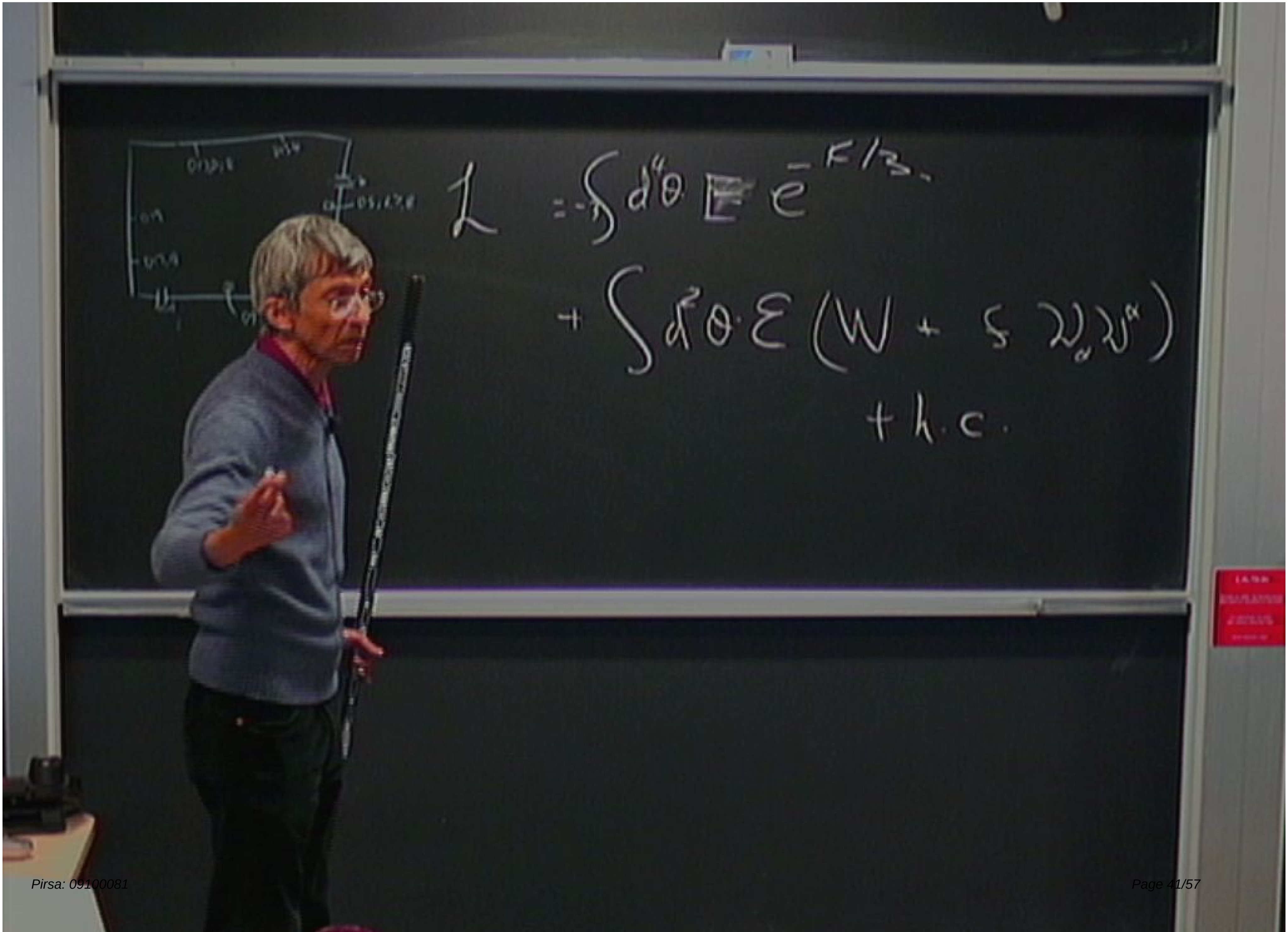
AMSB - Kaplunovsky and Louis, Randall+Sundram, Giudice et al, SdA

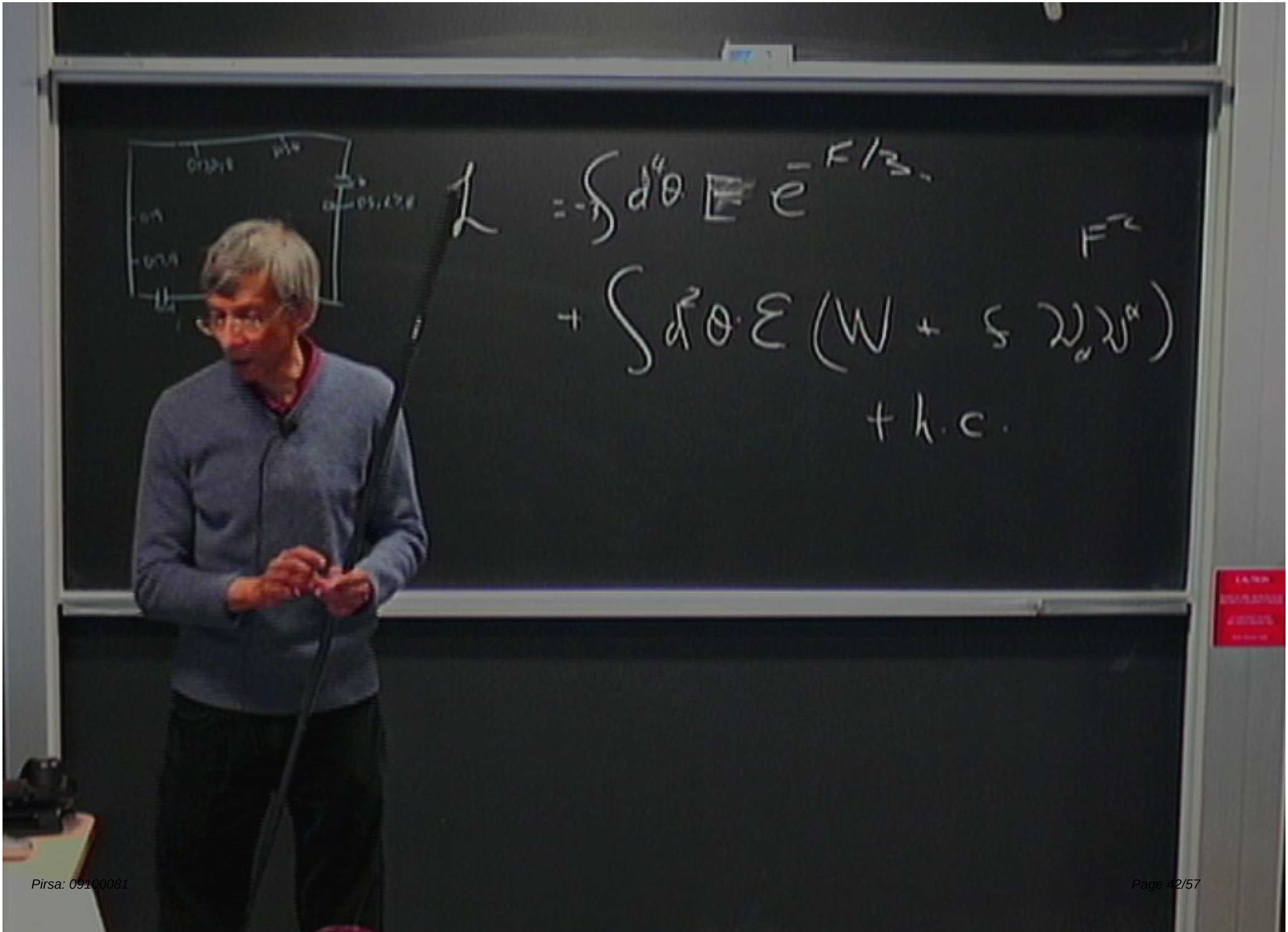
Effective gauge coupling with Weyl anomaly terms.

$$H_i = f_i - \frac{3c_a}{8\pi^2}\tau - \sum_r \frac{T_{ai}(r)}{4\pi^2}\tau_r - \frac{T(G_i)}{4\pi^2}\tau_i$$

$c_i = T(G_i) - \sum_r T_i(r)$, $T(G_i), T_i(r)$ trace of a squared generator. f_i - classical coupling function. τ, τ_r, τ_i chiral fields.

$$\begin{aligned} \tau + \bar{\tau} &= \frac{1}{3} K|_{\text{harm}}, \\ \tau_r + \bar{\tau}_r &= \ln\det \tilde{K}^{(r)}_{\alpha\bar{\beta}}|_{harm}, \\ \exp[-(\tau_i + \bar{\tau}_i)]|_{\text{harm}} &= \frac{1}{2}(H_i + \bar{H}_i). \end{aligned}$$


+ h.c.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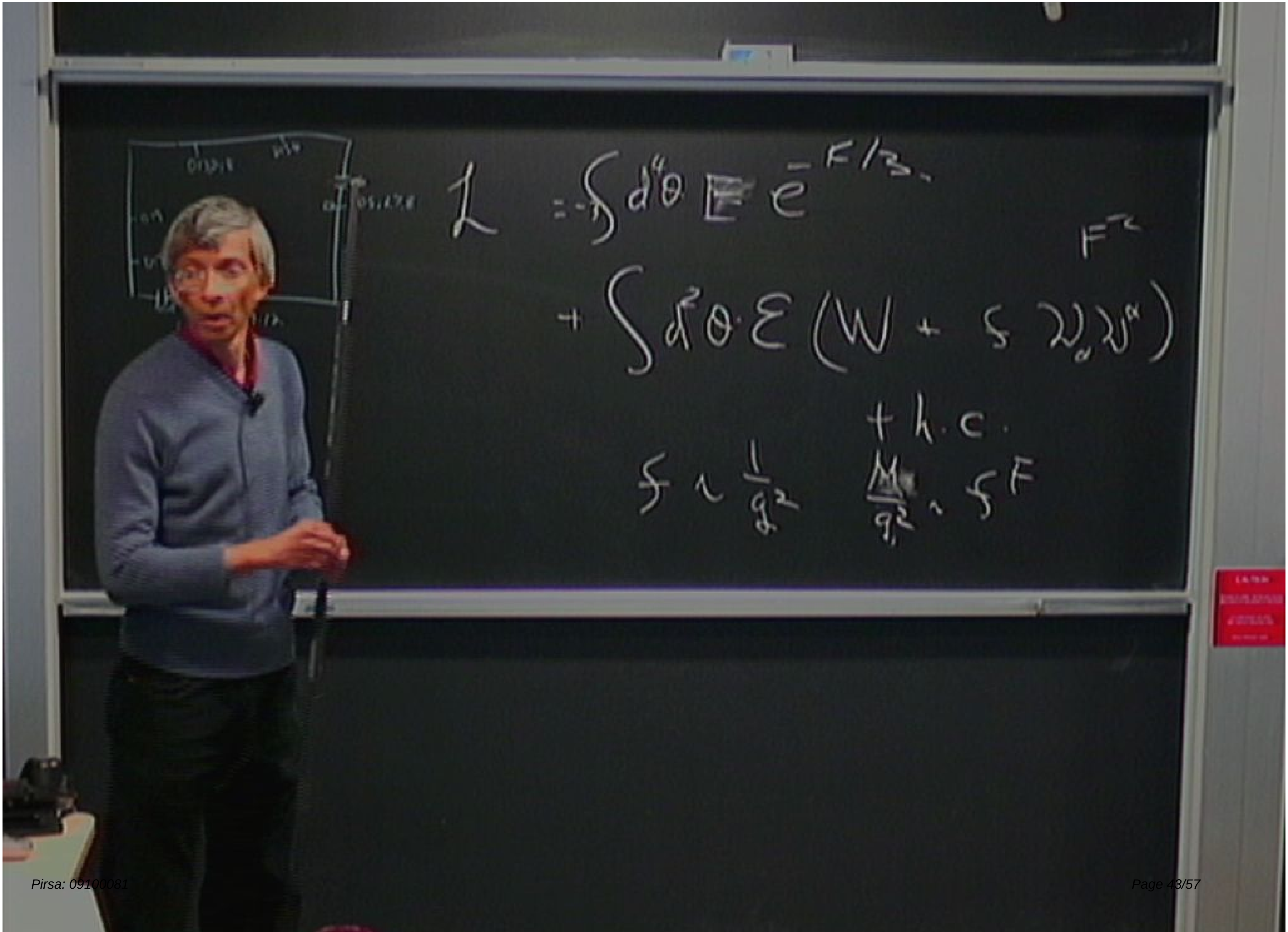
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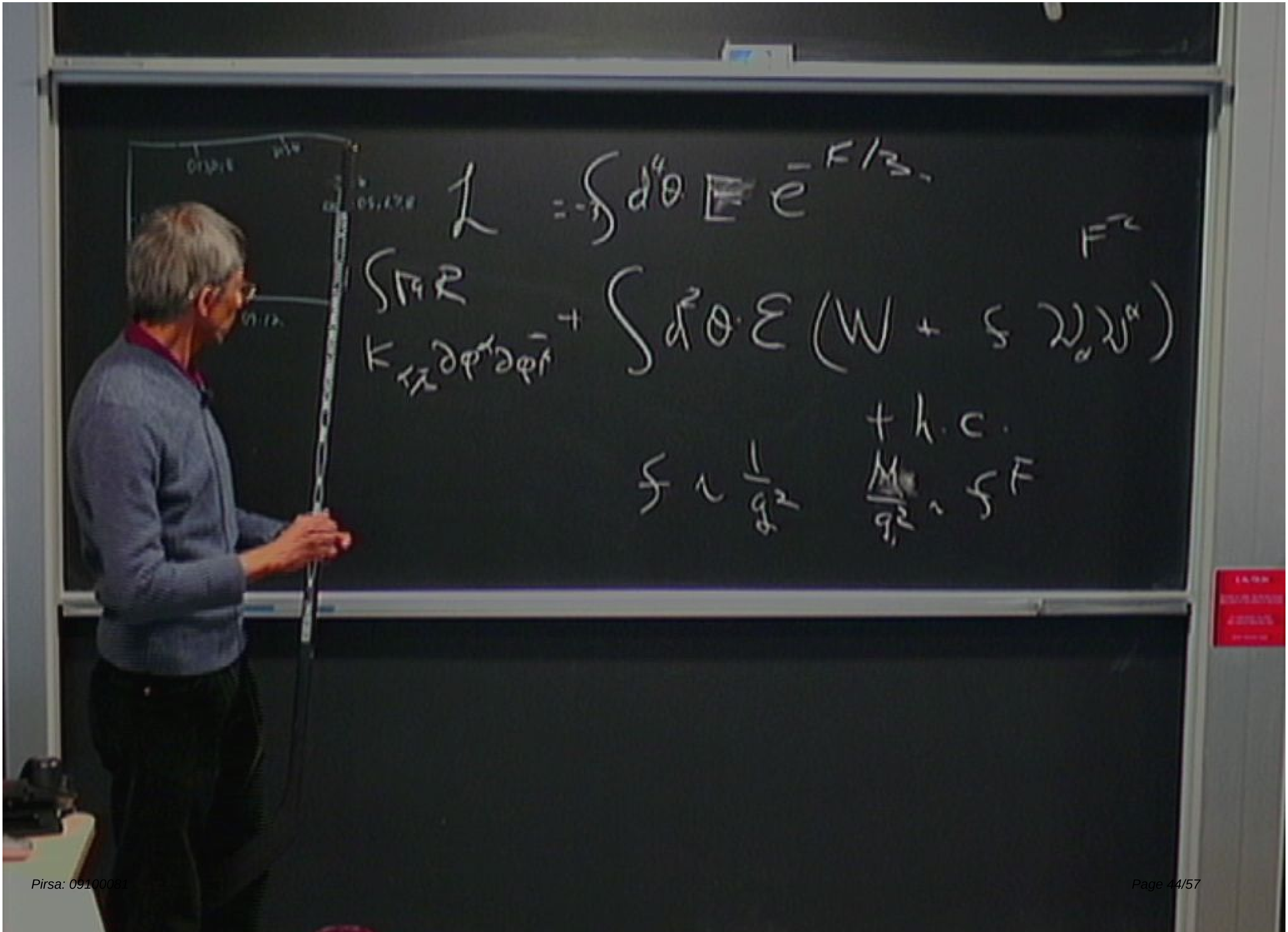
L = ∫ d⁴θ E e^(−K/3)
∫ √g R
+ ∫ d²θ 𝓔 (W + f W_α W^α)
+ h.c.
f ~ 1/g²
M/g² ~ f F

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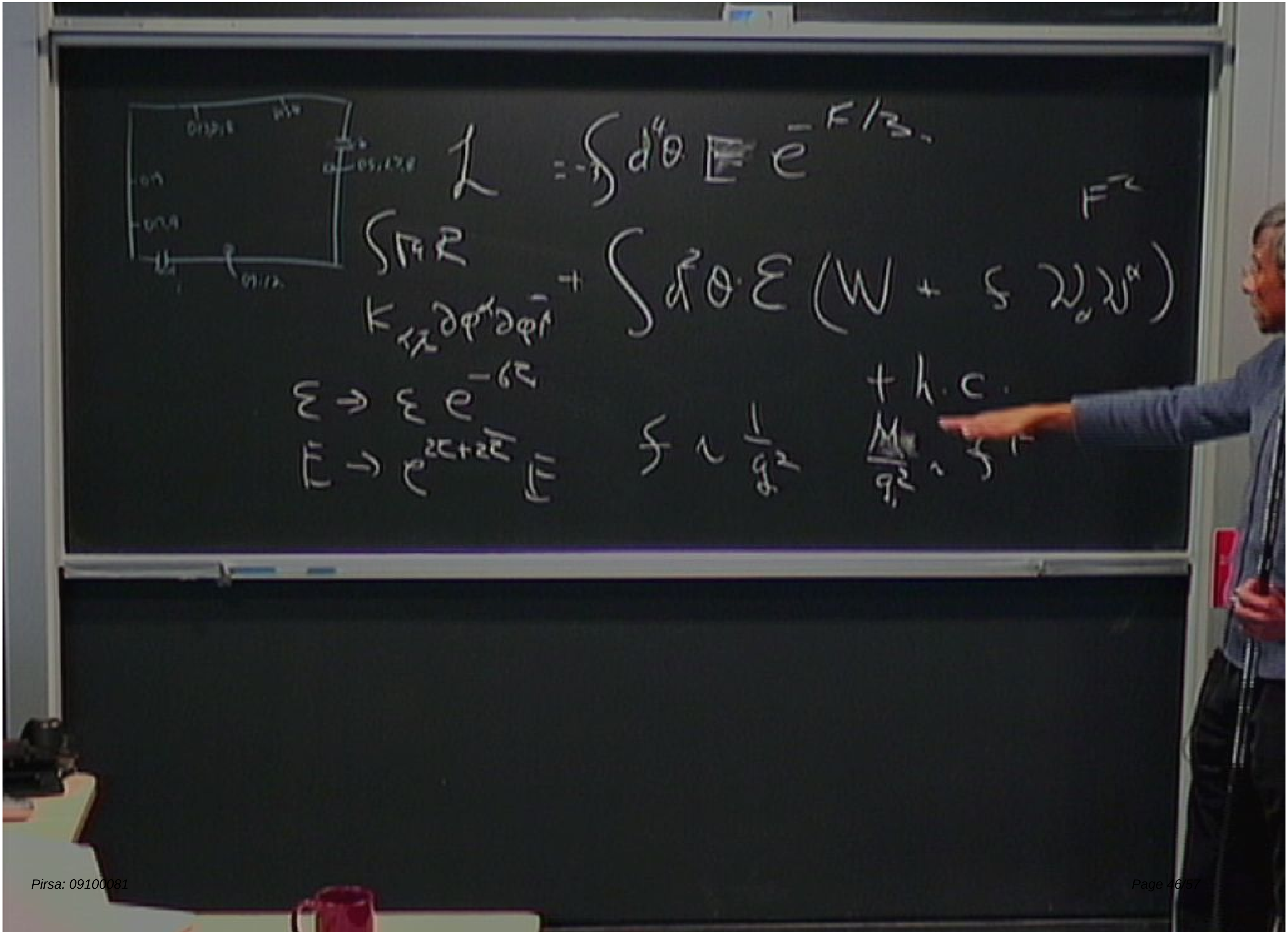
$\mathcal{L} = \int d^4\theta \, E \, e^{-K/3}$
$\int \sqrt{g} R$
$K_{i\bar{j}} \partial\phi^i \partial\bar{\phi}^{\bar{j}} + \int d^2\theta \, \mathcal{E} (W + f \, W_\alpha W^\alpha)$
$+ h.c.$
$\mathcal{E} \to \mathcal{E} e^{-6C}$
$E \to e^{2C+2\bar{C}} E$
$f \sim \frac{1}{g^2}$

AMSB 2

Chiral rotations:

- τ rotation - needed to get to Einstein-Kaehler frame.
- τ_r field redefinition to get canonical Kinetic terms for MSSM fields
- τ_i field redefinition to get canonical Kinetic terms for gauge fields

Formula valid at high scale Λ.

To get gauge coupling function at scale μ; replace

$$f_i \to f_i - \frac{b_i}{16\pi^2} \ln \frac{\Lambda}{\mu}. \qquad (3)$$

$b_i = 3T(G_i) - \sum_r T_i(r)$

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AMSB 3

Taking the lowest and highest components:

$$\frac{1}{g^{(i)2}_{\text{phys}}} = \Re f_i - \frac{b_i}{16\pi^2}\ln\frac{\Lambda}{\mu} - \frac{c_i}{16\pi^2}K|_0 - \sum_r \frac{T_i(r)}{8\pi^2}\ln\det \tilde{K}^{(r)}_{\alpha\bar{\beta}}|_0 + \frac{T(G_i)}{8\pi^2}\ln\frac{1}{g^{(i)2}_{\text{phys}}}$$

NSVZ+KL

$$\frac{M_i}{g^{(i)2}_{\text{phys}}} = (F^A\partial_A f_i - \frac{c_i}{8\pi^2}F^A K_A - \sum_r \frac{T_i(r)}{4\pi^2}F^A\partial_A \ln\det \tilde{K}^{(r)}_{\alpha\bar{\beta}}) \times(1 - \frac{T(G_i)}{8\pi^2}g^{(i)2}_{\text{phys}})^{-1}$$

AMSB + Gaugino Mediation

To one loop order

$$M_i = b_i \frac{g^{(i)2}}{8\pi^2} m_{3/2} = b_i \frac{\alpha_i}{4\pi} m_{3/2}$$

Using $F^T = -(T+\bar{T})m_{3/2}$, $K_T = -3/(T+\bar{T})$ and $\tilde{K}_{\alpha\beta} = k_{\alpha\beta}/(T+\bar{T})$.

Agrees with original AMSB formulae! RS

Reasoning different.

NO AMSB for Scalar masses

Gaugino mediation contribution: KKS, CLNP

$$\frac{dm^2_{scalar}}{dt} = -\frac{c(r)}{2\pi^2} g_i^2 M_i^2,$$

Integrate - use β function eqn and RG invariance of M_i/g_i^2,

$$m^2_{scalar} = \frac{2c(r)}{b_i}\left[\frac{g_i^4(\mu)}{g_i^4(\Lambda)} - 1\right] M_i^2 \simeq 2c(r)\alpha_{GUT} \ln\frac{\Lambda}{\mu} M_i^2.$$

Gaugino Mediation

At UV scale ($\lesssim M_{GUT}$)

$$M_1 = \frac{33}{5}\frac{\alpha_{GUT}}{4\pi} m_{3/2},$$
$$M_2 = \frac{\alpha_{GUT}}{4\pi} m_{3/2},$$
$$M_3 = -3\frac{\alpha_{GUT}}{4\pi} m_{3/2}.$$

Use as initial values for RG evolution. Gives scalar masses at TeV scale:

$$m_1^2 \sim m_2^2 \sim 10^{-6} m_{3/2}^2, \; m_3^2 \sim 10^{-4} m_{3/2}^2$$

FCNC suppression

$$\frac{\Delta m_{FCNC}^{2(classical)}}{m_3^2} \lesssim 10^{-3}.$$

Only requires

$$\mathcal{V} \gtrsim 10^5.$$

String scale $M_{string} \lesssim M_P/\sqrt{\mathcal{V}} \sim 10^{15.5} GeV$

Conclusions

- In IIB models with MSSM on D3 branes at a singularity or D7 branes on a 4-cycle (driven by dynamics to shrink below string scale) and soft masses are $\frac{m_{3/2}}{\sqrt{\ln m_{3/2}\mathcal{V}}} \ll m_{3/2}$.
- In LVS models need more than one Kaehler modulus - Suppression of FCNC gives a lower bound on the volume.
- String theoretic 1-loop corrections calculated in some models show a cancellation of leading order (in inverse large modulus) corrections. Comparison with effective field theory calculation imply a similar calculation in soft mass calculation.
- The dominant contribution to gaugino masses is then coming from AMSB. RG evolution then generates soft masses (gaugino mediation). Given the lower bound on the volume these effects dominate classical and one-loop string contributions.