A natural solution to the gravitino overabundance problem

Based on the work : "R symmetry and gravitino abundance",
I. Dalianis, Phys. Rev. D 85 061130(R) (2012)

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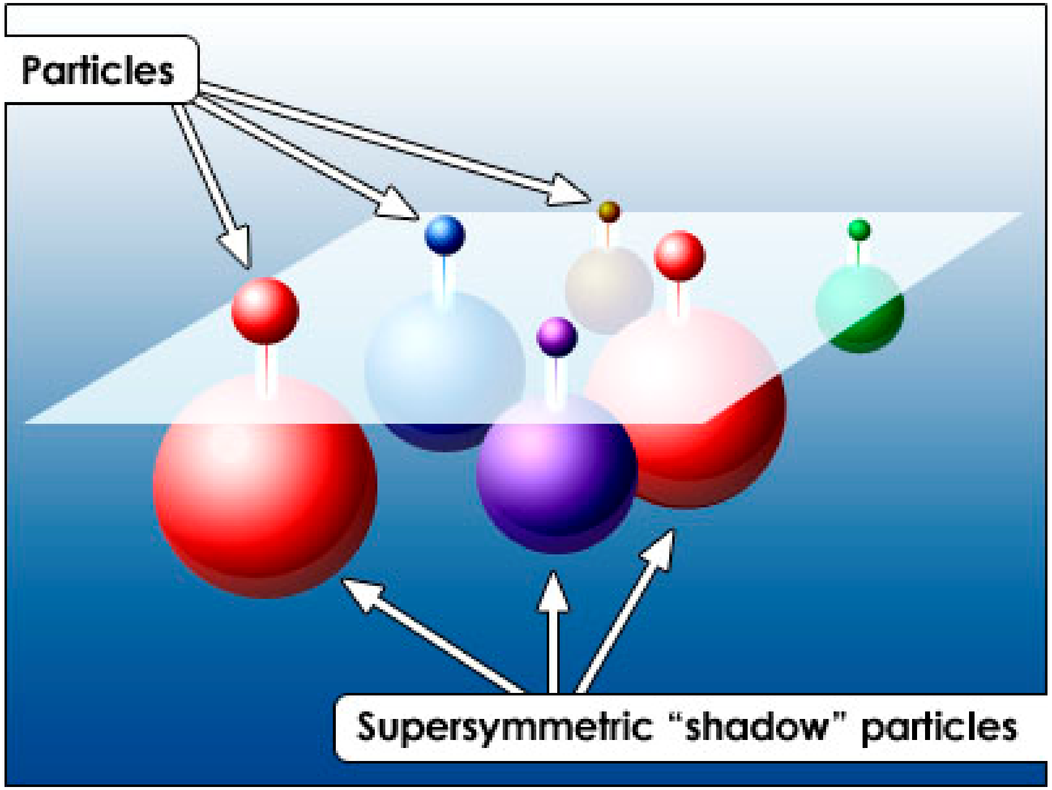
Outline

- Supersymmetry breaking sectors generically have a global U(1) R symmetry, exact or approximate
- R Symmetry must be broken in order for Majorana gaugino masses to be generated
- However, R Symmetry can be restored at finite temperature
- R Symmetry restoration implies suppressed gaugino masses hence, a suppressed generation rate of gravitinos from the heat bath
- We derive a *new* formula for the relic abundance of gravitinos produced by scattering in the thermal plasma that does *not* depend on the reheating temperature

FrameWork

- The discovery of a SM-like Higgs supports the ElectroWeak scale Supersymmetry (susy)
- Local Susy theories predict the existence of the gravitino
- The Early Universe was in thermal equilibrium
- A Supersymmetric Universe means that the thermal bath contains the Standard Model and their Supersymmetric Partners



$$m_{\rm soft} = \tilde{m}, \;\; m_\lambda \propto \frac{F}{M_{\rm messenger}} > M_{\rm experiment}$$

Stable Gravitino Relic Abundance

- Scatterings in the thermal plasma and decays of thermalized particles

$$\frac{dn_{\tilde{G}}}{dt} + 3Hn_{\tilde{G}} = (\gamma_{sc} + \gamma_{dec})\left(1 - \frac{n_{\tilde{G}}}{n_{\tilde{G}}^{eq}}\right)$$

Scatterings, the dominant contribution:

$$\gamma_{sc} = T^6 \frac{g^2}{M_P^2}\left(1 + \frac{m_{\tilde{g}}^2}{3m_{\tilde{G}}^2}\right) C$$

- Non thermal decays (Model Dependent)
- *Thermalized gravitinos* (?)

Thermal Production of Gravitinos the *textbook* formula:

- The gravitino abundance is essentially ***linear*** in the reheating temperature:

$$\Omega_{\tilde{G}} h^2 \simeq 0.2 \left(\frac{T_{rh}}{10^8\,\mathrm{GeV}} \right) \left(\frac{1\,\mathrm{GeV}}{m_{\tilde{G}}} \right) \left(\frac{m_{\tilde{g}}(\mu)}{1\,\mathrm{TeV}} \right)^2$$

- *Ellis, Kim, Nanopoulos, Phys.Lett.B (1984)*
- *Morroi, Murayama, Yamaguchi, Phys.Lett.B (1993)*
- *Bolz, Brandenburg, Buchmueller, Nucl.Phys.B (2001)*
- *Pradler, Steffen, Phys. Rev. D (2007)*
- *Rychkov, Strumia, Phys. Rev. D (2007)*

A Dynamic Mass Spectrum, Symmetries, Heat Bath

- The susy breaking sector is *dynamic*.

  The standard paradigm of gauge mediation:

$$\delta K = |X|^4/\Lambda^2$$

$$W = FX + \lambda X \phi\bar{\phi}$$

R-Charged Spurion

Charged Messengers

Sparticle Masses:

- Gauginos: $$\int d^2\theta \ln X W^\alpha W_\alpha + \text{h.c.}$$

- Sfermions: $$\int d^4\theta \ln(X^\dagger X) Q^\dagger e^V Q$$

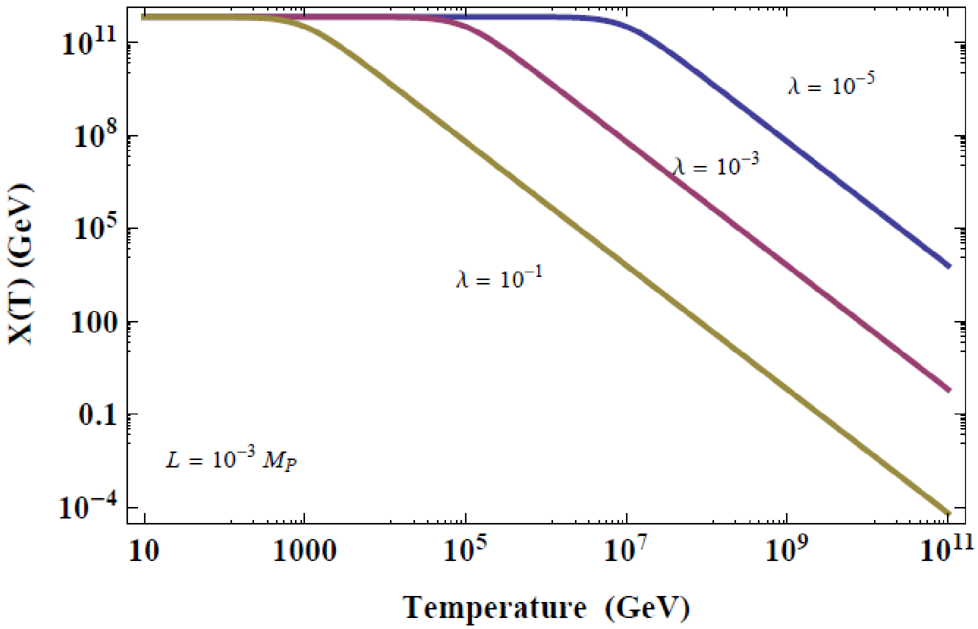
R Symmetry In the Thermalized Universe

- The U(1)-R symmetry can be restored at high temperatures
- The characteristic temperature of the R-phase transition

I.Dalianis and Z.Lalak, JHEP (2010) 045

$$T_0 = \frac{4}{\sqrt{N}} \frac{F}{\lambda \Lambda}$$

Thermal VEV – evolution



The VEV tends to the zero ->
R-Symmetry restoration!

The Regulative Role of the R Symmetry

- We define the R-breaking parameter:

$$b_R(T) \equiv \frac{X(T)}{X_0} = \frac{1}{1 + \left(\frac{T}{T_0}\right)^2}$$

- The expected suppression of the gaugino masses:

$$m_\lambda(T) \sim b_R(T) m_\lambda$$

- The cross section is modulated:

$$\Sigma_{\tilde{G}}(p, T) \propto \frac{g^2}{M_P^2}\left(1 + b_R^2(T)\frac{m_{\tilde{g}}^2}{3m_{\tilde{G}}^2}\right)$$

(New) Light Gravitino Abundance from Scatterings in the Thermal Plasma

I. Dalianis, Phys. Rev. D 85 061130(R) (2012)

After computing the yield
$$Y_{\tilde{G}}(T) = -\mathrm{D}\left\{\frac{n_{rad}\left\langle\Sigma^{(1/2)}_{\tilde{G}}v\right\rangle}{HT}\right\}\int_{T_{rh}}^{T} dT\, b_R^2(T)$$

We find the *gravitino abundance*:

for $T_{rh} > T_0$
$$\Omega_{\tilde{G}}h^2 \simeq 0.1\left(\frac{\theta_{rh}T_0}{10^8\,\mathrm{GeV}}\right)\left(\frac{\mathrm{GeV}}{m_{\tilde{G}}}\right)\left(\frac{m_{\tilde{g}}(\mu)}{1\,\mathrm{TeV}}\right)^2$$

where $\theta_{rh} \equiv \mathrm{Arctan}(T_{rh}/T_0) \longrightarrow \pi/4 < \theta_{rh} < \pi/2$

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Substituting

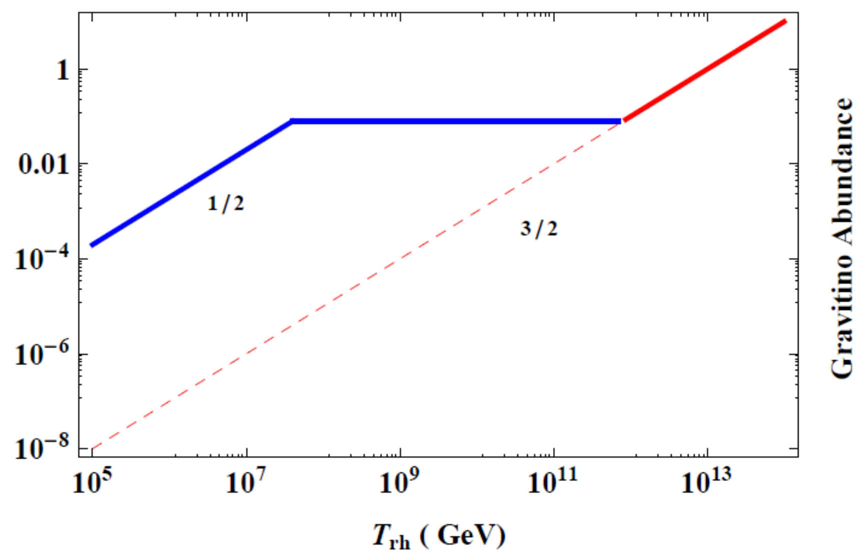
$$T_0 = \frac{4}{\sqrt{N}}\frac{F}{\lambda\Lambda}$$

$$4F \simeq 16.6\times 10^{18} m_{\tilde{G}}\mathrm{GeV}$$

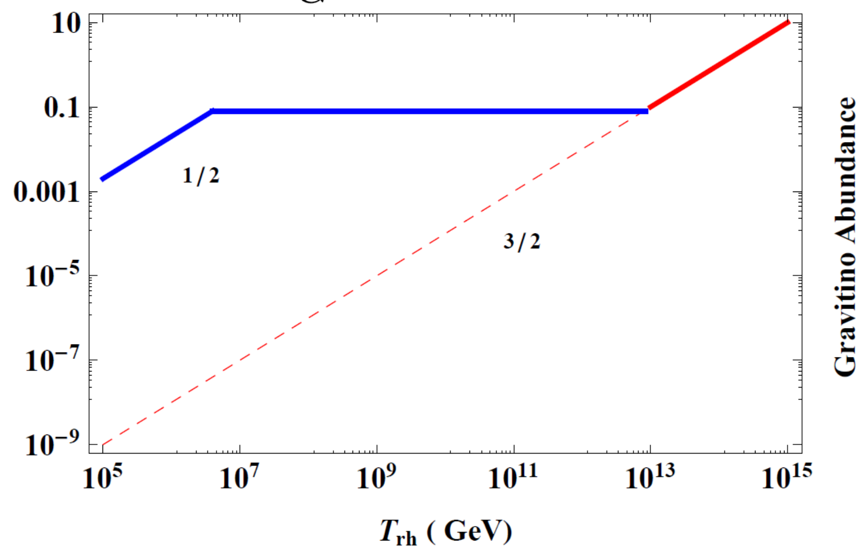
$$\boxed{\Omega_{\tilde{G}}h^2 \sim 0.15\times\frac{16.6}{\sqrt{N}}\left(\frac{10^{10}\,\mathrm{GeV}}{\lambda\Lambda}\right)\left(\frac{m_{\tilde{g}}(\mu)}{1\,\mathrm{TeV}}\right)^2}$$

Gravitino Abundance VS Reheating Temperature

$m_{\tilde{G}} = 1\,\mathrm{GeV}$



$m_{\tilde{G}} = 0.1\,\mathrm{GeV}$



Implications

- The reheating temperature constraints are relaxed several orders of magnitude. *No contradiction with thermal Leptogenesis*
- The gravitino production depends essentially on the hidden sector and *not* on the MSSM parameters
- The gravitino abundance gives us a direct insight into the hidden sector and the dynamics of susy breaking (*interplay with data from colliders*)
- If the (conventional) freeze out temperature for the gravitinos is

$$T^{f}_{\tilde{G}} \sim 2 \times 10^{10}\text{GeV}\left(\frac{m_{\tilde{G}}}{10\,\text{MeV}}\right)^{2}\left(\frac{m_{\tilde{g}}(\mu)}{1\,\text{TeV}}\right)^{2} > T_0$$

then the gravitinos do *not* equilibrate (there is *no* freeze out temperature)

- General (standard) models of gauge mediation 'predict' the observed dark matter abundance for gravitinos

Gravitino Dark Matter Abundance

$$\Omega_{\tilde{G}} h^2 \sim 0.15 \times \frac{16.6}{\sqrt{N}} \left(\frac{10^{10}\,\mathrm{GeV}}{\lambda\Lambda} \right) \left(\frac{m_{\tilde{g}}(\mu)}{1\,\mathrm{TeV}} \right)^2$$

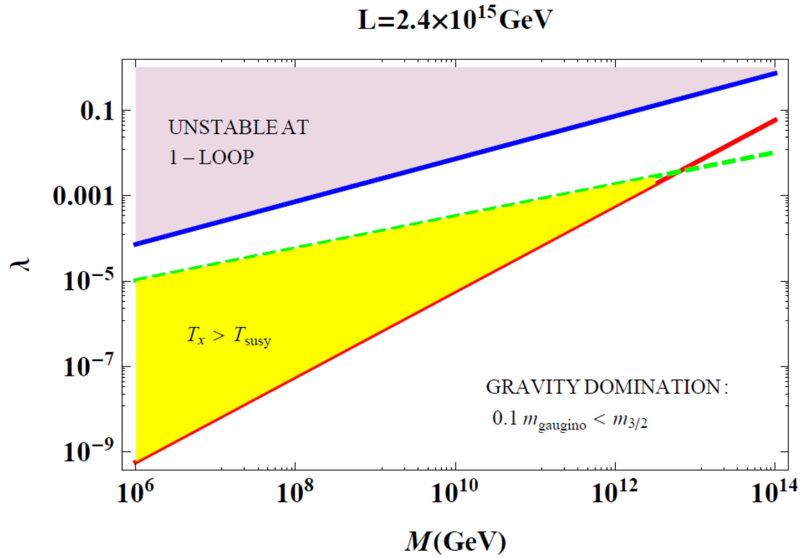
The gravitino does ***not*** *overclose the universe if*

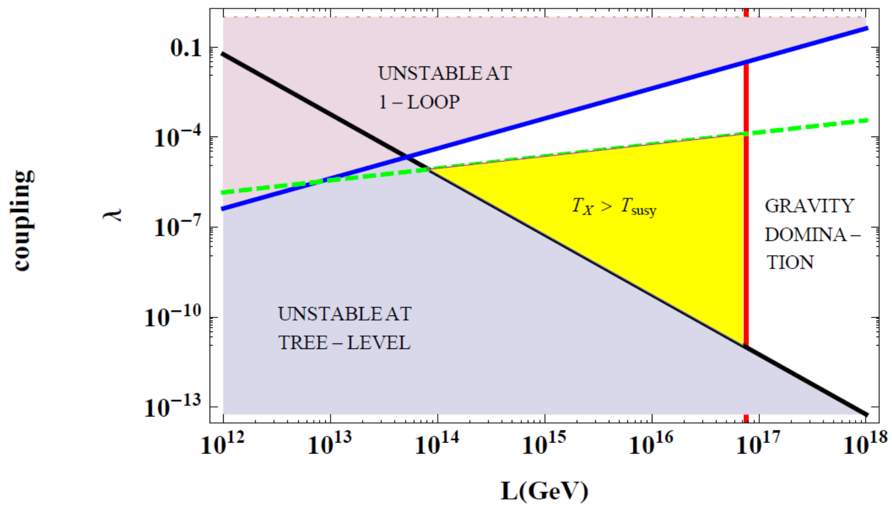
$$\lambda\Lambda \gtrsim 10^{10}\,\mathrm{GeV}$$

Thermally Favourable Gauge Mediation

I.Dalianis and Z.Lalak, Phys. Lett. B (2011) 385

The Yukawa coupling at the messenger superpotenial: $\lambda \lesssim 10^{-4}$





A large part of the parameter space makes the susy breaking vacuum thermally attractive

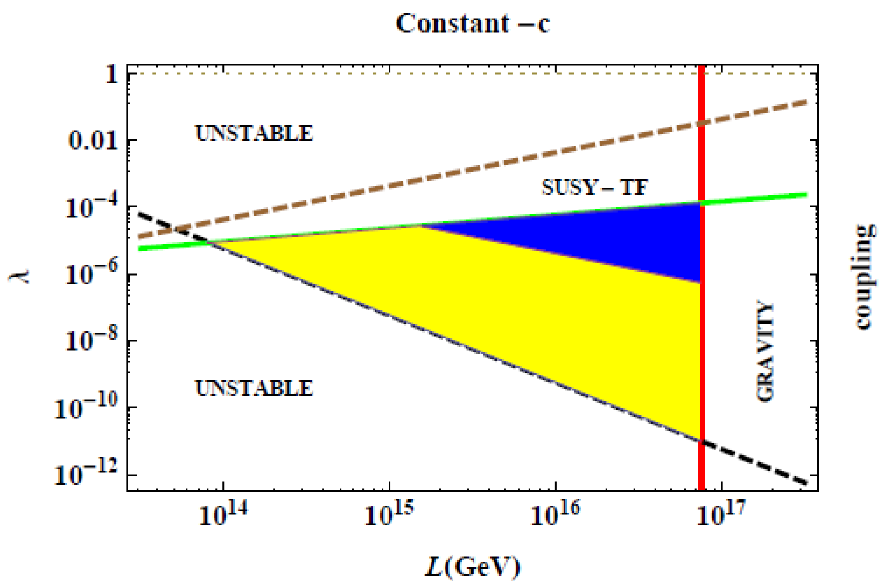
‘Predicted’ Dark Matter Abundance

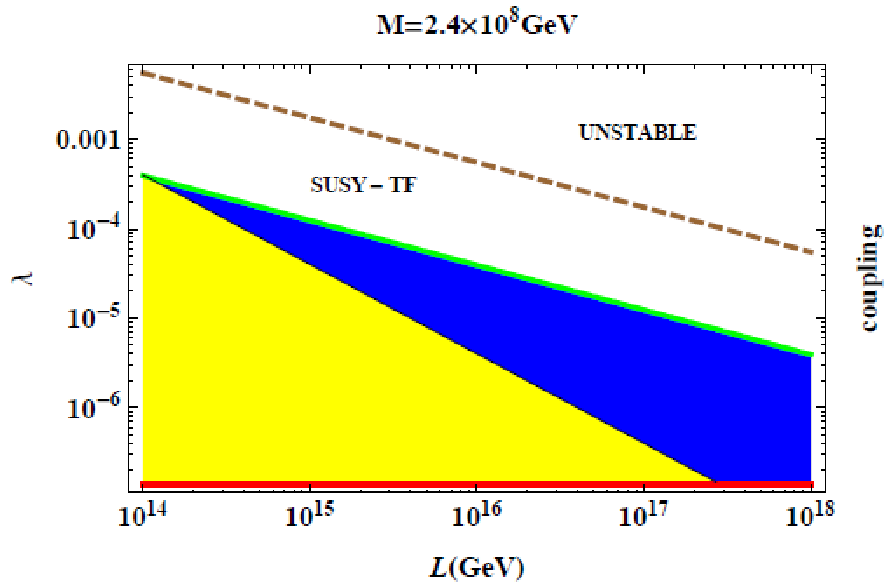
$$\boxed{\Omega_{\tilde{G}} h^2 \sim 0.15 \times \frac{16.6}{\sqrt{N}} \left(\frac{10^{10}\,\mathrm{GeV}}{\lambda \Lambda} \right) \left(\frac{m_{\tilde{g}}(\mu)}{1\,\mathrm{TeV}} \right)^2}$$

The gravitino accounts for the bulk dark matter of the universe if

$$\lambda \sim 10^{-5} \text{ and } \Lambda = \mathcal{O}(\mathrm{GUT})$$

Cosmology - Collider Interplay





Collider data will select/exclude parts of the parameter space constrained by cosmological arguments

Natural Dark Matter Candidates

The neutralino case:

$$\Omega_{WIMP}h^2 \simeq 0.1 \left(\frac{x_f}{10}\right) \left(\frac{1 \times 10^{-26}\mathrm{cm\,s}^{-1}}{\langle \sigma v \rangle}\right)$$

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The gravitino case:

$$\Omega_{\tilde{G}}h^2 \simeq 0.1 \left(\frac{\theta_{rh}T_0}{10^8\,\mathrm{GeV}}\right)\left(\frac{\mathrm{GeV}}{m_{\tilde{G}}}\right)\left(\frac{m_{\tilde{g}}(\mu)}{1\,\mathrm{TeV}}\right)^2$$

Gravitino: A Natural and Compelling Dark Matter Candidate

The **gravitino** abundance:

$$\Omega_{\tilde{G}} h^2 \simeq 0.1 \left(\frac{\theta_{rh} T_0}{10^8\, \mathrm{GeV}} \right) \left(\frac{\mathrm{GeV}}{m_{\tilde{G}}} \right) \left(\frac{m_{\tilde{g}}(\mu)}{1\, \mathrm{TeV}} \right)^2$$

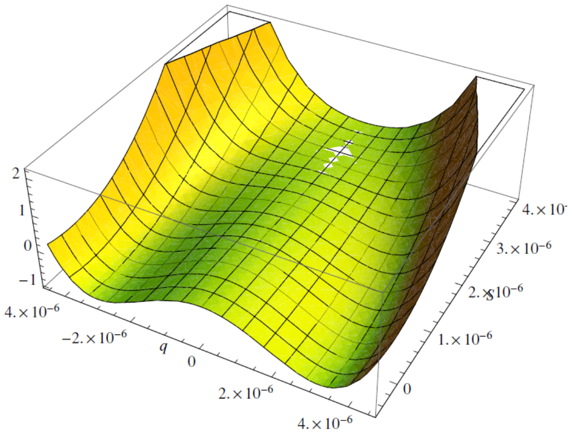
for $T_{rh} > T_0$

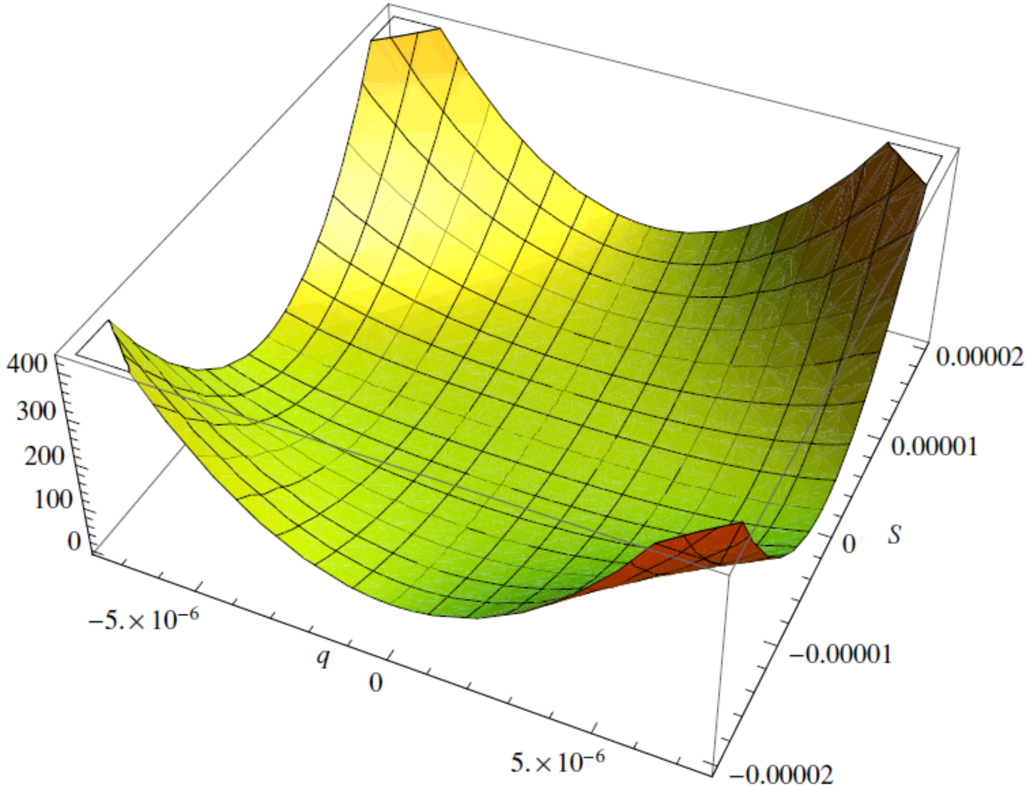
Thank you!

Thermal Effects

The potential at finite temperature

The potential at T=0





I.Dalianis and Z.Lalak,JHEP (2010) 045

KKLT uplifted by Matter Superpotentials