R-symmetry Breaking and O'Raifeartaigh Model with Global Symmetries at Finite Temperature

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Shin Sasaki

(Tokyo Institute of Technology)

with M. Arai (Czech Technical Univ.), Y. Kobayashi (Tokyo Tech.)

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Introduction

SUSY breaking in meta-stable vacua

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SUSY breaking in meta-stable vacua is a good candidate for hidden sector

The most famous meta-stable SUSY breaking model – ISS model [Intriligator-Seiberg-Shih (2006)]

IR physics – Seiberg dual of UV theory – SUSY is broken at meta-stable vacua but R-symmetry is not broken

R-symmetry breaking in meta-stable vacua

Generalized O'Raifeartaigh model with global symmetry

[Shih (2007), Ferretti (2007)]

Generalized O'Raifeartaigh model with $U(N)$ global symmetry

$$\begin{aligned} W &= fX + XN_5\phi^a_{(5)}\phi_{(-5)a} + XN_3\phi^a_{(3)}\phi_{(-3)a} \\ &\quad + M_7\phi^a_{(7)}\phi_{(-5)a} + M_5\phi^a_{(5)}\phi_{(-3)a} + M_3\phi^a_{(3)}\phi_{(-1)a}, \end{aligned}$$

Dynamical fields : $\phi_{(i)}, X, \; R(\phi_{(i)}) = i, \; R(X) = 2$
Parameters : $N_3, N_5, M_3, M_5, M_7, f$

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- The modulus X is stabilized at one-loop order (Coleman-Weinberg potential)
- At one-loop $\langle X \rangle \neq 0$ for some parameter choice – R-symmetry is broken
- The global symmetry can be gauged and SUSY breaking is mediated to the visible sector (by messenger)

The model has runaway SUSY vacua:

$$X = -\frac{M_5}{N_3}\frac{\phi_5}{\phi_3}\epsilon^{-2}, \quad \phi_{(3)} = \epsilon\phi_3, \quad \phi_{(5)} = \epsilon^{-1}\phi_5, \quad \phi_{(7)} = \frac{N_5 M_5}{N_3 M_7}\frac{\phi_5^2}{\phi_3}\epsilon^{-3},$$

$$\phi_{(-1)} = \frac{N_3 M_5}{N_5 M_3}\frac{\phi_{-3}^2}{\phi_{-5}}\epsilon^{-3}, \quad \phi_{(-3)} = \epsilon^{-1}\phi_{-3}, \quad \phi_{(-5)} = \epsilon\phi_{-5},$$

$$f + 2N_5\phi_5\phi_{-5} = 0, \qquad N_3\phi_3\phi_{-3} = N_5\phi_5\phi_{-5}$$

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$\longrightarrow \phi_{(i)} = 0$ with moduli X is a meta-stable SUSY and R-symmetry breaking vacuum once one chooses appropriate parameters $M_3, M_5, M_7, N_3, N_5, f$

Parameter region allowing $U(1)_R$ breaking

For the model to have a meta-stable R-symmetry breaking vacuum, the parameter region should be chosen appropriately.

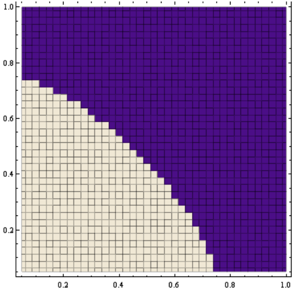

Figure: Contour plot for the parameters M_3/M_5 and M_7/M_5. The white area allows the $U(1)_R$ breaking local minimum. We choose parameters $N_3 = N_5 = 1, f/M_5^2 = 0.001$.

White: $\langle X \rangle \neq 0$, Blue: $\langle X \rangle = 0$

This is the story in zero temperature.

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We are interested in finite temperature effect in the model since the structure of vacua ("landscape") drastically change by finite temperature effects (ex. meta-stable vacua at early universe)

Finite temperature effect

Finite temperature effect [Arai-Kobayashi-S.S (2011)]

Finite temperature effective potential for the modulus X at one-loop level is given by

$$V_{\rm eff}(X,T) = V_{\rm tree} + V_{\rm eff}^{\rm CW} + V_B^{(1)} + V_F^{(1)}$$
$$V_B^{(1)}, V_F^{(1)} : \text{bosonic/fermionic contributions}$$

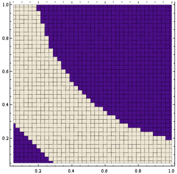
$$V_B^{(1)}(X,T) = \frac{T^4}{2\pi^2} J_B[m_B^2(X)/T^2],$$
$$V_F^{(1)}(X,T) = -2\frac{T^4}{2\pi^2} J_F[m_F^2(X)/T^2]$$

Thermal functions:

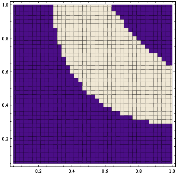
$$
\begin{aligned}
J_B[m^2\beta^2] &= \int_0^\infty dx\ x^2 \log\left(1 - e^{-\sqrt{x^2+\beta^2 m^2}}\right), \\
J_F[m^2\beta^2] &= \int_0^\infty dx\ x^2 \log\left(1 + e^{-\sqrt{x^2+\beta^2 m^2}}\right), \\
\beta &= T^{-1}
\end{aligned}
$$

Numerical studies are useful for evaluating the thermal functions.

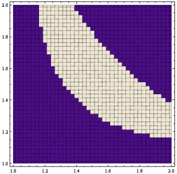
Parameter region in high temperature



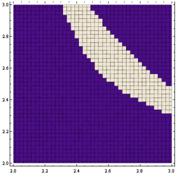
(a) $T = 0.2$



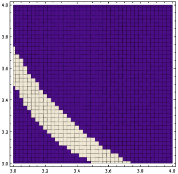
(b) $T = 0.3$



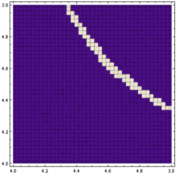
(c) $T = 0.5$



(d) $T = 0.7$

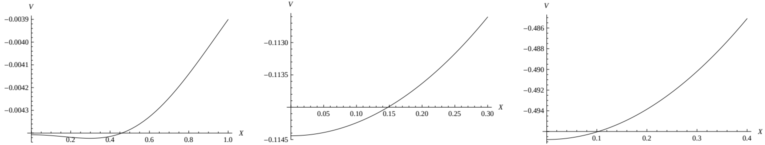


(e) $T = 0.8$



(f) $T = 1.0$

Figure: Contour plots of the allowed region of the $U(1)_R$ breaking against the parameters $(M_3/M_5, M_7/M_5)$ for $|X| < 3$. $N_3 = N_5 = 1$, $f/M_5^2 = 0.001$.

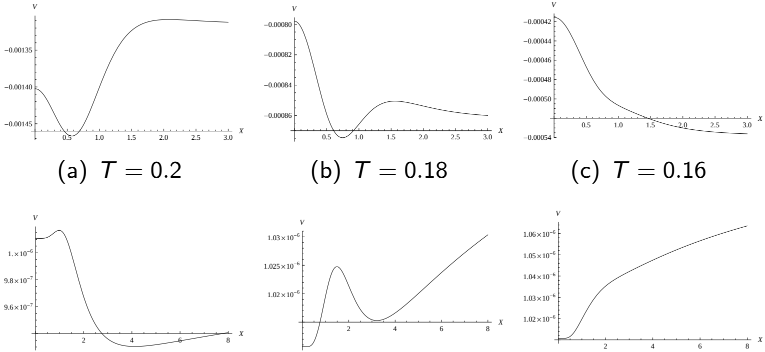


(a) $T = 0.25$ (b) $T = 0.5$ (c) $T = 0.7$

Figure: Plots of the potentials against X with $T = 0.25, 0.5$ and 0.7. We have chosen $N_3 = N_5 = 1, M_3/M_5 = M_7/M_5 = 0.4$ and $f/M_5^2 = 0.001$. In the plots the numerical value is evaluated with $M_5 = 1$.

At very high temperature, the moduli X roll down to origin $\langle X \rangle = 0$ and R-symmetry is restored

Pseudo moduli potential in low temperatures



(a) $T = 0.2$ (b) $T = 0.18$ (c) $T = 0.16$

(d) $T = 0.02$ (e) $T = 0.015$ (f) $T = 0.01$

Figure: Plots of potentials for X with temperatures ranging from $T = 0.2$ to $T = 0.01$.

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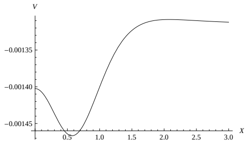

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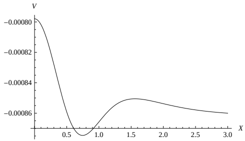
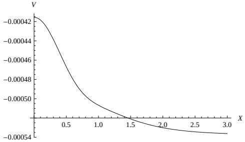
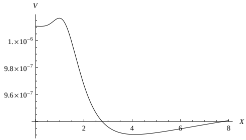


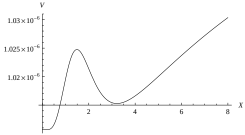
(b) $T = 0.18$



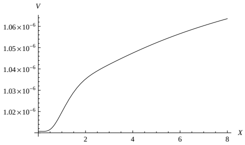
(c) $T = 0.16$



(d) $T = 0.02$



(e) $T = 0.015$



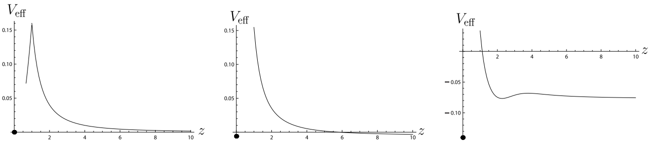
(f) $T = 0.01$

Figure: Plots of potentials for X with temperatures ranging from $T = 0.2$ to $T = 0.01$.

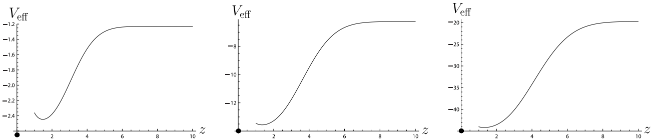
A new meta-stable vacuum $\langle X \rangle \neq 0$ appears near the origin of the moduli space

Phase transition in cooling process?

It is interesting to study the behaviour of the meta-stable vacua in the cooling process (possibility of phase transition).



(a) $T = 0, X_0 = 0.221$ (b) $T = 0.25, X_0 = 0.301$ (c) $T = 0.5, X_0 = 0$



(d) $T = 1.0, X_0 = 0$ (e) $T = 1.5, X_0 = 0$ (f) $T = 2.0, X_0 = 0$

There is parameter region that the meta-stable vacua do not roll down to the runaway.

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