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About a new self–tuning mechanism in string theory

Abstract

We briefly review the main points of a new self-tuning mechanism in string theory which is very distinguished from the existing theories. PACS number: 11.25.-w, 11.25.Uv

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Introduction

Recently a new type self-tuning mechanism has been proposed to address the cosmological constant problem in the framework of the string theory.[1] This self-tuning mechanism is very distinguished from the conventional theories in which the cosmological constant λ is directly determined from the scalar potential $\mathcal{V}_{scalar}$ alone (see for instance).[2,3] In the self-tuning mechanism λ contains a supersymmetry breaking term v_{scalar} besides the usual $\mathcal{V}_{scalar}$ of the $N=1$ super gravity and where λ has its own gauge arbitrariness. Also in this mechanism, whether λ vanishes or not is basically determined by the tensor structure of $\mathcal{V}_{scalar}$, not by the zero or nonzero values of $\mathcal{V}_{scalar}$ itself, unlikely to the ordinary theories. In,[1] this self-tuning mechanism has been applied to the well-known KKLT model[3] and it was shown that λ must be fine-tuned to zero $\lambda=0$, at the supergravity level.

Such a story is continued in[4] to the case where the α'-corrections of the string theory is not neglected anymore. In,[4] it was shown that λ is still fine-tuned to zero as in[1] at the super gravity level. But once we admit α'-corrections, the fine-tuning $\lambda=0$ changes into $\lambda=\frac{2}{3}Q$, where Q is a constant representing quantum correction of the 6D action defined on the internal dimensions and its value is determined by the α'-corrections. Also in[4] it was shown that the nonzero value of λ acquired from the α'-corrections must be very small and positive.

In,[4] the complex structure moduli (or the geometry) of the internal dimensions are still stabilized by the three-form fluxes as in the the usual flux compactifications. But the scale factor (or the K ä hler moduli) of the internal dimensions is not fixed by the KKLT scenario. In[4] it is assumed that the internal dimensions are basically allowed to evolve with time. But nevertheless, it can be shown that the scale factor (as well as ä) is fixed at the super gravity level by a set of 4D equations including an extra (a constraint) equation which is associated with the self-tuning of ä , not by the K ä hler modulus-dependent nonperturbative corrections of KKLT. So in,[4] the new type self-tuning mechanism of[1] has still been used, but this time it has not been applied to the KKLT because the scale factor of the internal dimensions is allowed to evolve with time.

As described above, the self-tuning mechanism used in[1] and[4] is very new and distinguished from the conventional theories. But at the same time it is also true that the structures of the scenario in[1] and[4] are quite complicated and this acts as an obstacle for readers to understand the scenarios thoroughly. For this reason, in this short report we want to briefly review the cores of the scenario in[1] so that the readers can understand the points of the self-tuning mechanism used in[1] more easily and quickly, and then later we can make a similar discussion on the scenario presented in.[4]

The core principle of the self-tuning mechanism in[1] can be described by the two independent equations for λ: i.e. Equations. (3.20) and (3.41) of.[1] The first equation takes the form[1]

$$\lambda=\frac{\kappa^2}{8\kappa_{10}^2 g_s^2}\int d^6y\sqrt{h_6}\,(\mathcal{N}-1)V+\frac{\kappa^2}{2}(\hat{I}_{brane}+\hat{I}_{topological}),(1)$$

Where $\mathcal{N}$ is a functional operator defined by $\mathcal{N}\equiv h^{mn}\frac{\partial}{\partial h^{mn}}$ (where h_{mn} represents the 6D internal metric) and V represents the scalar potential density related with $\mathcal{V}_{scalar}$ by the equation

$$\mathcal{V}_{scalar}=\frac{1}{2\kappa_{10}^2 g_s^2}\int d^6y\sqrt{h_6}\,V.(2)$$

Since $\mathcal{N}$ is a number operator, it pulls out the number of the contracted indices of the given density V_n. Namely if $V_n\sim A_{m_1\cdots m_n}B^{m_1\cdots m_n}$ it gives $\mathcal{N}V_n=nV_n$ because the number of contracted indices of $V_n\sim A_{m_1\cdots m_n}B^{m_1\cdots m_n}$ is n.

In the heterotic string theory the three-form structure of the potential density with a gaugino condensation $<tr\bar{\lambda}\Gamma^{mnp}\lambda>$ is manifest in the action[5–8]

$$I_{het}=-\frac{1}{2\kappa_{10}^2}\int e^{-\phi}(H_{(3)}-\frac{\alpha'}{16}e^{\phi/2}tr\bar{\lambda}\Gamma_{(3)}\lambda)^2.(3)$$

But in the type IIB theory the tensor structure of $\mathcal{V}_{scalar}$ is not quite obvious, unlikely to the case of the heterotic theory. So in the case of type IIB theory we need further discussion to find the tensor structure of $\mathcal{V}_{scalar}$. Indeed, through a complicated analysis one can show that the density V of the type IIB $\mathcal{V}_{scalar}$ also belongs to v_{scalar} (see Sec. 4 of[1]) as follows.

The $\mathcal{V}_{scalar}$ of the type IIB theory consists of two part. The first is

[1]Equation (3.20) of[1] must include the term $\hat{I}_{topological}$ as in Equation (1) of this paper. But the omission of this term will not change the story of Reference[1] at all. See the footnotes 2 and 3 of Reference.[4]

the no-scale part $\mathcal{V}_{no-scale}$. In KKLT the superpotential of the AdS vacuum is given by

$$W=W_0+Ae^{ia\rho} ,(4)$$

Where W_0 is a tree level contribution arising from the fluxes:

$$W_0=\int_{\mathcal{M}_6} G_{(3)}\wedge\Omega\,,\ (G_{(3)}=F_{(3)}-\tau H_{(3)})\,,(5)$$

And the second term is a nonperturbative correction coming from Euclidean $D7$ -branes,[9] or the gaugino condensation generated by the stack of coincident $D7$ -branes.[10] The superpotential $\mathcal{V}_{no-scale}$ acquires the nonzero contribution from the three fluxes $G_{(3)}$ in W_0 . It takes the form

$$\mathcal{V}_{\text{no}-scale}=\frac{1}{12\kappa_{10}^2 Im\tau}\int d^6y\sqrt{h_6}\frac{\chi^{1/2}}{g_s}G^+_{mnp}\bar{G}^{+mnp}\,,(6)$$

Where G^+_{mnp} represents the ISAD part of $G_{(3)}$. In the ISD compactications in which W is given by $W=W_0$, G^+_{mnp} vanishes and therefore $\mathcal{V}_{\text{no}-scale}$ also vanishes. But once we add the nonperturbative term as in (4), G^+_{mnp} does not vanish anymore and hence $\mathcal{V}_{\text{no}-scale}$ acquires nonzero values in this case.

In addition to this $\mathcal{V}_{\text{no}-scale}$ there is another important contribution to the type IIB scalar potential when the "no-scale structure" is broken by the nonperturbative term as in (4). In the AdS vacua of KKLT we have

$$\mathcal{V}_{\text{AdS}}=-\frac{3}{2\kappa_{10}^2}e^{\mathcal{K}}|W|^2\,(7)$$

In addition to (6) and through a complicated discussion (see Sec. 4 of[1]) One can show that this $\mathcal{V}_{\text{AdS}}$ also has the same tensor structure as $\mathcal{V}_{no-scale}$ in (6). Namely the densities $V_{no-scale}$ and $V_{\text{no}-scale}$ of $\mathcal{V}_{no-scale}$ and $\mathcal{V}_{\text{AdS}}$ both belong to V_3 :

$$\mathcal{N}V_{\text{no}-scale}=3V_{\text{no}-scale}\,,\quad \mathcal{N}V_{\text{AdS}}=3V_{\text{AdS}}\,,(8)$$

And therefore λ in (1) reduces to

$$\lambda=\frac{\kappa^2}{2}(\mathcal{V}_{\text{scalar}}+\hat{I}_{\text{brane}}+\hat{I}_{topological})\,,(9)$$

In the AdS vacua and this becomes the first equation for λ . The equation in (9) tells about the constituents of λ . Now we have second equation for λ of the form

$$\beta=\frac{1}{6}\chi^{1/2}(\mathcal{N}-1)(\mathcal{N}-3)(1-3b_0\Pi(\mathcal{N}))V\,,(10)$$

Where $\beta=4\lambda$ for maximally symmetric spacetime. Equation (10) can be obtained from the 6D Einstein equation of the internal space and it acts as a constraint (or a self-tuning) equation for $\beta=\,\to\lambda=0$. Note that (10) becomes

$$\beta=0\ \to\lambda=0(11)$$

For the AdS background because in the AdS vacua of KKLT belongs $V_{scalar}(\equiv V_{\text{no}-scale}+V_{\text{AdS}})$ to V_3 : $\mathcal{N}V_{\text{scalar}}=3V_{\text{scalar}}$ as mentioned above and therefore (10) requires (11). So in the new self-tuning mechanism the background geometry of the AdS vacua does not necessarily mean that $\lambda<0$. (Note that the AdS vacua of KKLT are simply defined by $V_{\text{scalar}}<0$.) Rather, λ in (9) must be fine-tuned as in (11) even in the AdS vacua.

The fine-tuning of λ in (9) can be achieved as follows. First, $\hat{I}_{brane}$ in (9) can be decomposed into three parts. We have

$$\hat{I}_{\text{brane}}=(\hat{I}^{(NS)}_{brane}(\text{tree})+\hat{I}^{(R)}_{\text{brane}}(\text{tree}))+(\delta_Q\hat{I}^{(NS)}_{\text{brane}}+\delta_Q\hat{I}^{(R)}_{\text{brane}})-\mathcal{E}_{\text{SB}}\,.(12)$$

In (12) $\hat{I}^{(NS)}_{brane}(\text{tree})$ and $\hat{I}^{(R)}_{\text{brane}}(\text{tree})$ are NS-NS and R-R parts of the tree level actions while $\delta_Q\hat{I}^{(NS)}_{\text{brane}}$ and $\delta_Q\hat{I}^{(R)}_{\text{brane}}$ represent quantum fluctuations of the gravitational and standard model degrees of freedom with support on the D3-brane. So $\delta_Q\hat{I}^{(NS)}_{\text{brane}}+\delta_Q\hat{I}^{(R)}_{\text{brane}}$ correspond to the gravitational plus electroweak and QCD vacuum energies of the standard model configurations of the brane region. Among these terms the tree level term $\hat{I}_{\text{brane}}(\text{tree})(\equiv\hat{I}^{(NS)}_{\text{brane}}(\text{tree})+\hat{I}^{(R)}_{brane}(\text{tree}))$ vanishes by field equations in the ISD (i.e. tree level) background (Secction VIII of[1]). Similarly the topological term $\hat{I}_{topological}$ in (9) can be decomposed as $\hat{I}_{\text{topological}}=\hat{I}_{topological}(\text{tree})+\delta_Q\hat{I}_{topological}$ and where $\hat{I}_{brane}(\text{tree})$ also vanishes by field equations as in the case of $\hat{I}_{\text{brane}}(\text{tree})$. So after all these Eq. (9) reduces to

$$\lambda=\frac{\kappa^2}{2}(\mathcal{V}_{\text{scalar}}+\delta_Q\hat{I}^{(NS)}_{\text{brane}}+\delta_Q\hat{I}^{(R)}_{\text{brane}}+\delta_Q\hat{I}_{\text{topological}}-\mathcal{E}_{\text{SB}})\,.(13)$$

Now in (13) the last term $\mathcal{E}_{SB}$ plays crucial role in the fine-tuning of $\lambda=0$ as follows. First, $\mathcal{E}_{SB}$ is given by

$$\mathcal{E}_{\text{SB}}=-\delta_0\int r^5 dr\varepsilon_5\rho^{(1)}_{\text{T}}\,,\ (\delta_0=\text{constant})\,,(14)$$

Where ε_5 is the volume-form of the base of the cone in the conifold metric, and $\rho^{(1)}_{\text{T}}$ is defined by

$$\rho^{(1)}_{\text{T}}(y)=v^m_{(1)}f_m(y)\,,(15)$$

Where $D3$ represent quantum excitations on the brane with components along the transverse directions of the $D3$ -branes and $f_m(y)$ are arbitrary gauge parameters appearing in the gauge transformation of the four-form (Section VI of[11]):

$$A_{(4)}\to A_{(4)}+\delta A_{(4)}\ \text{with}\ \delta A_{(4)}=d\Lambda_{(3)}\,,(16)$$

Where gauge parameter $\Lambda_{(3)}$ is given by

$$\Lambda_{(3)}=F(y)\sqrt{-g_4}dx^1\wedge dx^2\wedge dx^3\,,(17)$$

And where y^m , an arbitrary function of the internal coordinates y^m , is related with $f_m(y)$ in (15) by the equation

$$f_m(y)=\partial_m F(y)\,.(18)$$

So $\mathcal{E}_{SB}$ in (14) has a gauge arbitrariness because it contains arbitrary gauge parameters $\mathcal{V}_{scalar}$, and any nonzero $\mathcal{V}_{scalar}$ together with the quantum fluctuations $\delta_Q\hat{I}^{(NS)}_{\text{brane}}+\delta_Q\hat{I}^{(R)}_{\text{brane}}+\delta_Q\hat{I}_{\text{topological}}$ in (13), can be gauged away (cancel out) by $\mathcal{E}_{SB}$ so that λ in (13) vanishes as a result. Such a cancellation between $V_{\text{scalar}}+\delta_Q\hat{I}^{(NS)}_{\text{brane}}+\delta_Q\hat{I}^{(R)}_{\text{brane}}+\delta_Q\hat{I}_{\text{topological}}$ and $\mathcal{E}_{SB}$ is of course forced by the self-tuning equation (10). So far we have briefly reviewed the main point of the self-tuning mechanism proposed in.[1] In the scenario in[1] the new self-tuning mechanism is basically discussed in the framework of KKLT. However, there is a crucial difference between the scenario in[1] and the scenario in KKLT. In the scenario in[1] the background geometry of our present universe is described by AdS vacua, which are supersymmetric and stable. But in the KKLT the AdS minimum is uplifted to a dS minimum by introducing anti-D3-branes at the tip of the KS throat and such a dS vacuum generally suffers from the two different kinds of tunneling instabilities (Section 5.2.2 of[1]) unlikely to the case of the AdS vacuum. So in the KKLT type models using these dS vacua the authors need show that their background vacua are sufficiently stable enough.

Besides this, the really important (and unique) point of the self-tuning mechanism proposed in[1] (and in[4] as well) is that there is neither any parameter nor any coefficient to be fine-tuned in the AdS vacuum scenario in [1]. $\lambda=0$ is automatically achieved by the cancelation between $V_{scalar}+\delta_Q\hat{I}^{(NS)}_{\text{brane}}+\delta_Q\hat{I}^{(R)}_{\text{brane}}+\delta_Q\hat{I}_{topological}$ and $\mathcal{E}_{SB}$, forced by (10). Hence in the scenario in[1] fine-tuning $\lambda=0$ is radically stable. Any nonzero contribution to $\mathcal{V}_{scalar}$ and quantum fluctuations (vacuum energies) on the visible sector D3-branes are all automatically gauged away by $\mathcal{E}_{SB}$ (and by (10)) and as a result $\lambda=0$ is always preserved.

Conclusion

Finally in,[4] the above theory is continued to the case where the α'-corrections of the string theory are not neglected anymore. In[4] it was shown that α' acquires nonzero values due to α'-corrections and these nonzero λ must be very small and positive. The scenario is distinguished from the conventional theories in which the kähler modules of the internal dimensions is fixed by the nonperturbative corrections in (4). In the scenario in[4] the scale factor of the internal dimensions is basically allowed to change with time, unlikely to the scenario of the nonperturbative mechanism of KKLT. This scenario might be more natural as compared with the scenarios based on the KKLT because the cosmology based on the KKLT looks somewhat artificial in the sense that the internal dimensions are fixed by hand (i.e. by the nonperturbative corrections) while the external are expanding. Using this scenario the authors of[4] anticipate that the well-known constants of nature like electric charges (or the coupling constants) might not be real constants. According to the scenario "the electric charges of our present universe" decrease in magnitudes at the rate in which they become half the original magnitude during about 10^{10} years.

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Conflicts of interest

Authors declare there is no conflict of interest.

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