Time-Dependent Backgrounds and Four-Dimensional Effective Field Theories

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Based on 1402.5112, 1808.04798, 1907***

I discuss various attempts to construct four dimensional de Sitter spaces

The current observational data from Plank experiments, Supernova experiments and others impose strong constraints on viable cosmological models and suggest that the four dimensional spacetime could be de Sitter.

How can we test this proposal?Embed 4d de Sitter in String Theory- minimum/metastable solution

Around 2003 a proposal was put forward with all moduli fixed by fluxes and nonperturbative efects, with the extra addition of anti D3 branes

The superpotential $W = W_0(\text{complex}) + Ae^{aT}$

All of a sudden there were many solutions, a full Landscape or viable possibilities and seemed to need an Anthropic Principles to select vacua.

But de Sitter proposal was not invulnerable. In June 2018 Ooguri, Vafa et al: All the Landscape could be a Mirage... Maybe no de Sitter solution exists and our Universe does not have Constant Cosmological Constant and slow roll and Inflation did not take place

The de Sitter Swampland conjecture (in the revised version): For any field $\phi : \frac{\frac{\partial V}{\partial \phi}}{V} = a$ with a of order 1 or we are at the maximum of the potential $\frac{\frac{\partial^2 V}{\partial \phi^2}}{V} = -c^2$ with c of order one.

But the consequences are quite striking.

1. de Sitter can't exist: For a de Sitter solution $\frac{\partial V}{\partial \phi} = 0$ but $V > 0$ and $\partial V = 0$ so a can't be one

2. The late time inflation scenario is replaced by a model of Quintessence.

Our contribution in the direction consisted in providing increasingly stronger evidence that there are very strong obstructions in building de Sitter vacua .

1402.5112: along the lines of Maldacena - Nunez, a classical de Sitter solution does not exist but Quantum Corrections contribute to the energy momentum tensor with a potential positive contribution which can help to obtain a positive cosmological constant in 4 dimensions.

In view of the de Sitter Swampland conjecture, in 1808.07498 we reconsidered our work to discuss in more detail the Quantum Corrections, relating them to certain loop expansions of Effective Field Theory

We concluded 1808.07498 by hinting that time dependent fluxes which break de Sitter isometries could gives rise to Kasner geometries or Kasner- de Sitter. The new results of 1907*** show that this is not enough to give a positive cosmological constant in 4 dimensions.

Consider D space-time dimensions and split the D dimensional space into two manifolds M_4 (index μ) and internal M_{D-4} (index m).

Let us first consider an unwarped metric in D dimensions

$$ds_D^2 = g_{\mu\nu}dx^\mu dx^\nu + g_{mn}dx^m\ dx^n$$

If $R_4 = g^{\mu\nu}R_{\mu\nu} > 0$, one gets $(D-6)T^\mu_\mu > 4T^m_m$,
$T^\mu_\mu > T^m_m (D = 10)$.

Possible contributions to the matter Lagrangian
q Fluxes with Lagrangian $F_{a_1\ldots a_q}F^{a_1\ldots a_q}$

True just for $q > 9$ but no 10 form fluxes in string theory so the R_4 will never be positive via fluxes.

We then introduce the D-branes and anti D-branes. The Chern Simons term is topological and the Born Infeld action is $T^\mu_\mu = -4T_p$, $T^m_m = -(p-3)T_p$

The brane tension is positive $T_p > 0$ so $p > 7$ implying that only D9 could contribute in type IIB. The D9 brane do not contribute because of charge cancellation condition. So the branes contribution can't make $R_4 > 0$ either.

What about orientifolds $T_p < 0$? R_4 is not positive in the presence of orientifold and the trigerred fluxes

Conclusion: for a non-warped compactification, fluxes, branes and orientifolds can't make R_4 positive

Next step: consider a warped compactification
$ds^2 = e^{2A(x^n)} g_{\mu\nu} dx^\mu dx^\nu + e^{-2A(x^n)} g_{mn} dx^m \; dx^n$

$A(x^n)$ is the warping factor depending only on some of the internal coordinates. Same conclusion: no de Sitter

Try going to M theory. M theory on T^2 is dual to IIB on a circle or one can view M theory as a strongly coupled IIA

The IIB fluxes G_3, τ, F_5 of IIB become a four form G_4, The IIA D6 become Taub-Nut and the IIA O6 becomes Atiyah Hitchin which are smooth spaces

The corresponding relation involving energy momentum tensor implies again $R_4 < 0$ when everything is smooth

The conclusion is the one gets a non positive curvature in four dimenson for any two-derivative gravity theory arising from String/M theory if one considers the classical equations of motion.

Is there any idea one can still get a positive R_4 in four dimensions?

Consider quantum corrections and analyze the problem from M theory and then go to type IIB. We use the duality between M theory compactified to 3 dimensions and IIB compactified to 4 dimensions.

We want a IIB compactification which would give a flat sliced de Sitter in 4 dimensions (dilaton is constant)

$$ds^2 = \frac{1}{\Lambda|t|^2\sqrt{h}}(-dt^2 + dx_1^2 + dx_2^2 + dx_3^2) + \sqrt{h}g_{mn}dy^m dy^n$$

Use the IIB/M theory duality, lift to M theory and demand G_{mnpq} on the internal space to be time-independent in order to preserve de Sitter in the space time

$$ds_8^2 = \frac{g_{mn}\ dy^m dy^n}{\Lambda^{1/3}|t|^{2/3}} + \Lambda^{2/3}|t|^{4/3}|d\ z|^2$$

Fluxes: $G_{mnpq}, G_{mnpa}, G_{mnab}$, a, b are on T^2

There is an extra component needed

$$G_{m\mu\nu\rho} = \partial_m(\frac{\epsilon_{\mu\nu\rho}}{h\Lambda^2|t|^4})$$

Consider the Quantum Correction

The quantum series involves derivatives of the Ricci scalar and of the 4-form flux

$\partial^m R^n, \partial^p G^q, \partial^m (R^n)_{rs} \partial^p (G^q)^{rs}$ and the power $M_p^{-(2m+2p+q+2n-8)}$

The energy momentum tensor is

$$T_{MN} = \sum h^{1/3} (\Lambda |t|^2)^{\alpha_i} C^{(i)}_{MN}$$

where $C^{(i)}_{MN}$ are time independent.

The C_{MN} capture the precise quantum effects, including perturbative, local, non-local and non-perturbative terms (including the 4 fermion terms recently considered)

The string coupling g_s is proportional to $\sqrt{\Lambda |t|^2}$ so expansion $g_s^{2\alpha_i}$

For $\alpha_i = 0$ we lose the loop expansion for $g_s < 1$.

The energy-momentum tensor takes the following form

$$\Sigma_k (\Lambda |t|^2)^{\alpha_k} C^{(k)}_{MN} = \Sigma_k \, g_s^{2\alpha_k} (\Sigma \, \frac{(c_{kb})_{MN}}{M_p^{\beta_{kb}}})$$

But β_{ij} can be positive or negative so there is no more M_p hierarchy.

What about g_s hierarchy?

The result is that the equations of motion for both internal metric and spacetime metric do not depend on g_s.

So for time independent fluxes it is impossible to discuss loop corrections because the quantum corrections do not arrange themselves in loops.

Unfortunately the quantum correction were one of our main hopes to get a four dimensional de Sitter is the quantum pieces add up to some negative value

$$\int d^8x\sqrt{g}h^{4/3}\sum(\text{quantum pieces}) < 0$$

But we do not even have a hierarchy so we do not know how to group them on loops.

The only hope is to use time dependent fluxes but they would of course break de Sitter isometries and lead to other spacetime metric.

First modification: consider Kasner - de Sitter in IIB

$$ds^2 = \frac{1}{\Lambda|t|^2\sqrt{h}}(-dt^2+e^{f_1(t)}dx_1^2+e^{f_2(t)}\,dx_2^2+e^{f_3(t)}\,dx_3^2)+\sqrt{h}g_{mn}dy^m dy^n$$

with M theory uplift:

$$ds^2 = e^{2A(y,t)}(-dt^2+e^{f_1(t)}dx_1^2+e^{f_2(t)}dx_2^2)+e^{2B(y,t)}g_{mn}dy^m dy^n+e^{2C(y,t)}|dz|^2$$

Now $g_s = \sqrt{\Lambda|t|^2}\ h^{1/4} = exp(-\frac{f_3(t)}{2})$

EFT breakdown still occurs so we need radical changes.

Next change IIB

$$ds^2 = \frac{1}{\Lambda|t|^2\sqrt{h}}(-dt^2+\cdots+dx_3^2)+\sqrt{h}(F_1(t)g_{\alpha\beta}(y)dy^\alpha dy^\beta+F_2(t)g_{mn}dy^m dy^n)$$

with two choices:

1) volume of the internal space is time independent

$F_1(t) = F_2(t)^{-2}$, M_4 and M_2 separate

2) Newton's constant G_N is kept constant

$F_1(t)F_2^2(t) = a + \frac{bg_s^2}{\sqrt{h}}$; ((a=1,b=0) is de Sitter)

F_1, F_2, G_{MNPQ} get perturbative and nonperturbative contributions

$$F_2(t) = \sum c_{kn}(\frac{g_2}{\sqrt{h}})^{\Delta k}\exp(-\frac{-nh^{\Delta/4}}{g_s^{\Delta}})$$

$$G_{MNPQ}(y,t) = \sum_{k,n} G^{(k,n)}_{MNPQ}(\frac{g_2}{\sqrt{h}})^{\Delta k}\exp(-\frac{-nh^{\Delta/4}}{g_s^{\Delta}})$$

Flux components with upper indices depend on F_1, F_2.
The curvatures, derivatives depend on F_1, F_2

The quantum corrections are

$$Q_T \equiv [\mathbf{g}^{-1}]^{H_1+H_2+H_3+H_4+H_5+n/2}\partial^n(\prod_{i=1}^{18}(\mathbf{R}_{MNPQ})^{l_i}\prod_{k=19}^{29}(\mathbf{G}_{RSTU})^{l_k})$$

which are suppressed by M_p^{σ} with

$$\sigma \equiv \sigma(l_i, n) = n + 2\sum_{i=1}^{18} l_i + \sum_{k=19}^{29} l_k.$$

and expanded as

$$g_s^{\theta_k}(1 + \mathcal{O}(g_s^{\Delta}, e^{-1/g_s^{\Delta}}))$$

and the quantum contribution is

$$V_Q \equiv \sum_{l_i,n}\int d^8y\sqrt{\mathbf{g}_8}\frac{(Q_T^{(l_i,n)}}{M_p^{\sigma(l_i,n)-8}}$$

θ_k is a function of values for l_i, k, n.

The Einstein equation involve Ricci tensors (where F_1, F_2 are present) and energy momentum tensor which is also expanded in terms of F_1, F_2.

The result: some combinations of fluxes and derivatives avoid $\theta_k = 0$ and have a proper contribution to the loop corrections for the EFT.

Time independent: infinite degeneracy which resembles the Distance conjecture.

Time depedent: the degeneracy is eliminated

The time dependence of the internal manifold seems to cure the EFT ilnesses.

Stability of solution: the classical metric is plugged into every order of g_s and determines further relations between coefficients in F_1, F_2, fluxes and the quantum corrections.

Conclusions

• The de Sitter solutions are very hard to build in String Theory

• This led to the conjecture that de Sitter can't appear as EFTs from string compactifications - de Sitter Swampland conjecture

• In 2018 we have shown is that time independent fluxes do not give rise to well defined effective field theories.•

• One extra ingredient: time independent internal manifolds when there might be a chance that a de Sitter vacuum could be obtained.

• (Non)perturbative contributions to the internal metric and fluxes conspire could provide a well defined EFT

• This studies are in infancy, specific models, time dependent instanton contributions are needed