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(A)dS Backgrounds from Asymmetric Orientifolds

Eva Silverstein

Department of Physics and SLAC, Stanford University, Stanford, CA 94305/94309
Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106

I present asymmetric orientifold models which, with the addition of RR fluxes, fix all the NS NS moduli including the dilaton. In critical string theory, this gives new AdS backgrounds with (discretely tunably) weak string coupling. Extrapolating to super-critical string theory, this construction leads to a promising candidate for a metastable de Sitter background with string coupling of order 1/10 and dS radius of order 100 times the string scale. Extrapolating further to larger and larger super-critical dimension suggests the possibility of finding de Sitter backgrounds with weaker and weaker string coupling. This note is an updated version of the last part of my Strings 2001 talk.

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1. Introduction

Because of bounds on Brans-Dicke forces and on time-dependence of couplings, it is of interest to fix the moduli in string/M theory. The diverse ingredients arising in modern string backgrounds, including branes and RR fields, introduce new sources of moduli as well as new forces which can help stabilize the moduli.

In §2 I will present a six-dimensional model where the NS-NS moduli (including the dilaton) are fixed, so that there are no runaway directions in moduli space. The strategy, as outlined in the last few minutes of my Strings 2001 talk, is to balance the first few terms in string perturbation theory off of each other by introducing large flux quanta and/or brane charges, in such a way that a minimum arises in the effective potential in a controlled regime at weak string coupling. The model of §2 has a minimum of the dilaton potential below zero, producing an AdS_6 vacuum (with a string-scale compactification from ten to six dimensions). This sort of approach has been studied in effective field theory in [1][2] and in general terms in string theory in e.g. [3][4]; similar models have been constructed geometrically in [5][6][7].

In §3 I will present a proposal for a construction of stringy dS space which involves much less well understood *noncritical* string theory. In particular, I will show how the naive scalar potential of supercritical string theory on an asymmetric orbifold in the presence of orientifold-antiorientifold pairs and RR fluxes leads to a minimum of the scalar potential above zero. In the simplest model I consider, starting from dimension $D = 12$, the dS_4 radius that results is only larger than the string length scale by two orders of magnitude, and the string coupling g_s is of order $1/10$, so the construction depends on the absence of coefficients at higher orders in perturbation theory that might compensate these small but not arbitrarily small suppression factors. Modulo this issue, the closeness to the string scale raises the interesting possibility that a cosmological analogue of the correspondence principle [8] might account for the entropy suggested by the area of the cosmological horizon.

We will also see that extrapolating this construction to large super-critical dimensionality seems to give better control, in that the string coupling can be made weaker and weaker. This might jive with the idea that one should require more and more degrees of freedom to describe a dS minimum as it gets closer to a general relativistic regime [9].

However, it should be emphasized that it is not completely known how to calculate in non-critical dimensions, and I will make one or two assumptions along the way (which

I believe are plausible given the older results of e.g. [10][11][12]). A complete worldsheet description of the backgrounds here would require explicit use of the Fischler-Susskind effect [13] since the dilaton is fixed by playing different orders of perturbation theory off of each other. Because the candidate dS minimum we find is only metastable, it would probably be necessary to also understand the linear (in time) dilaton theory to which it non-perturbatively decays, which is the solution more traditionally studied, in order to obtain a completely satisfactory construction. However, perturbatively it might be interesting to study the metastable dS minimum in its own right.

In [14], the problem of runaway directions toward weak coupling limits of moduli space was identified, assuming no miraculous small coefficients appear in the expansion around weak coupling. One way around that is to minimize the moduli at strong coupling, as was argued for some examples in [15]. Another, as explored for example in the present work and previous works such as [1][2][3][5], is to introduce large ratios of coefficients via discrete choices of flux quanta and brane and orientifold charges.

This latter freedom is perhaps unsettling because it expands the arbitrariness of the vacuum (the vacuum degeneracy problem). However, it has the redeeming feature that it expands the model-building possibilities enough to plausibly provide quantum vacua with small cosmological constant, as argued in e.g. [16][17][18][4]. As in these works, we will here not be able to provide any rationale for why the initial conditions of the universe favor the choices of discrete parameters that we use in our constructions, and in fact our constructions will not be realistic to begin with. I feel it is nonetheless useful to obtain as concrete a handle as possible on the range of possibilities, particularly before declaring either victory or defeat.

In that vein, before proceeding to the constructions, I would like to make a few comments on recent discussions in the literature on the issue of dS space (or more generally accelerating universes). On the one hand, we have observational evidence for a currently accelerating universe (with the dark energy just now having become commensurate with matter). On the other hand, if this were to persist indefinitely, then the dark energy would dominate in the future, and one would have a situation with cosmological event horizons with the concommitant difficulties involved in formulating observables (in particular the lack of an S-matrix) [9][19][20][21].[1] These difficulties may well have resolutions [26][27][19],

[1] Another argument often used against the possibility of having dS space in M theory involves the "no go" theorem of [22]. However, the arguments there were directed not just at dS space, but

but if they do not, one can still have perfect agreement with observations in a universe which will tunnel or roll out of a dS phase in the future. In inflationary scenarios, there are mechanisms for our universe to have exited from inflation in the past, and it seems to me that a similar mechanism could occur in the future to prevent eternal acceleration.

Because of the tendency of string-theoretic effective potentials to decrease toward weak coupling [14], in the dS construction we will explore here, the minimum is indeed only metastable and would not pose as great a problem in terms of observables. However, as discussed by T. Banks, if it holds up (i.e. if the perturbative description does not break down), it may provide an inroad into the problem of understanding how a finite number out of the infinite available number of degrees of freedom arrange themselves to describe the physics associated with the dS minimum (though he points out that the dS minimum may not be accessible from the linear dilaton regime after all for reasons similar to those discussed in [28][29] for other backgrounds). Other proposals for dS constructions have appeared in [30].[2] (This work is related to comments made in the last few minutes of

at nontrivial warped compactifications including ones preserving Poincare invariance. In [22], the assumptions that went into this theorem are catalogued. These include the absence of orientifold planes, whose inclusion is known to yield warped compactifications [23][5]. In our construction in §3, both orientifold planes and a tree-level potential coming from being away from the critical dimension will be crucial, and these are both elements of perturbative string theory which are excluded by the assumptions of [22]. It seems to me that "no-go" arguments based mostly on supergravity (or on supergravity plus a partial list of known resolved singularities)–while very useful for pointing toward the need for non-supergravity model-building ingredients– are likely to be unreliable as indicators of what physics is possible within the full theory (as other examples in the past have illustrated [24][25]).

[2] Arguments against accelerating cosmologies have also been made based on the fact that no satisfactory dS background has been built in string/M theory. To me such arguments about what has (not) been accomplished to date are weakened by the fact that there has been a preponderance of effort in the field directed (understandably) toward backgrounds with unbroken SUSY. It is also hard to make precisely the (supersymmetric) Standard Model in string theory (particularly including appealing elements such as unification of couplings), and it hasn't quite been done, but few would argue at this point that the absence of such a construction portends a serious clash between string theory and experiment. The problem is messy, and because of the many moduli in string theory the problem of building a model describing even a temporarily accelerating universe is also grungy and may have resisted solution for that reason alone. In particular, one would expect the problem of fixing moduli in systems with low-energy supersymmetry breaking to require detailed knowledge of the full superpotential and Kahler potential in the regime of the minimum.

my Strings 2001 talk; the material in the bulk of that talk can be found in [31]. There are independent and probably more elegant geometrical constructions of AdS and/or dS backgrounds in progress by other authors [6][7]).

2. An AdS orientifold model in six dimensions

I will here present a perturbative string model in which all the non-periodic (i.e NS-NS) moduli are fixed, so that there are no runaway directions. A subset of this model was studied in [32].

Begin with type II string theory on a square T^4 at the self-dual radius R. Mod out by the asymmetric orientifold group generated by the following actions on the left and right movers of the string:

$$g_1 : (0, s^2)_1 (0, s^2)_2 (0, s^2)_3 (0, s^2)_4 \tag{2.1}$$

$$g_2 : \Omega I_4 \tag{2.2}$$

$$g_3 : (-1)^F (0, s^2)_1 (0, s^2)_2 \tag{2.3}$$

$$g_4 : (-1)^{F_R} (-1, s^2)_1 (-1, s^2)_2 (-1, 1)_3 (-1, 1)_4 \tag{2.4}$$

Here s represents an asymmetric shift so that $(0, s^2)_j$ acts as $(-1)^{m_j + n_j}$ where m_j and n_j are momentum and winding numbers on the jth circle. I_4 denotes reflection on four coordinates. The first of these actions (2.1) generates the $SO(8)$ lattice from the $SU(2)^4$ lattice we started with, which is needed here for level-matching. The elements g_2 and $g_2 g_3$ introduce orientifold 5-planes and anti-orientifold 5-planes at locations separated by the shifts. Important combinations of these elements include space-filling orientifolds and antiorientifolds $\Omega(-1)^F, \Omega(0, s^2)^2$ and an element

$$h_1 = I_4 (-1)^F. \tag{2.5}$$

Let us choose the discrete torsion such that g_3 projects out the NS-NS scalars from the $|g_3 g_4 >$ and $|g_4 >$ twisted sectors (these are compatible in this model). Let us also choose the discrete torsion such that h_1 kills the twisted gravitini from the $|g_3 g_4 >$ twisted sector, and such that $g_3 g_4$ projects out the NS-NS scalars from the $|h_1 >$ twisted sector (these

These quantities are still in the process of being computed in most M-theoretic realizations of $4d$ N=1 supergravity.

are compatible in this model, with the 2π rotations implicit in the $(-1)^F$ actions acting in internal compactified directions, a distinction that affects the twisted sectors).

With these specifications, this model has no NS NS moduli. The element g_4 projects out all the untwisted NS-NS moduli of the torus. None reemerge from twisted sectors. In the g_3 sector, the lightest states are massless fermions. In the g_4 sector, one finds NS-NS moduli that are killed by the above choice of discrete torsion, as is the case in the $|h_1>$ sector. Similarly, in other sectors obtained by products of group elements (which are isomorphic to those already discussed), potential NS-NS moduli are projected out when they arise.

This theory includes RR fields. RR moduli do not lead to runaway behavior since they are periodic, and they only couple derivatively to the rest of the theory. The RR field strengths will also be important in the construction. In particular, we can include combinations of RR fluxes which respect the orbifold symmetries.

Including these ingredients, the potential energy of this theory is, in string frame

$$V_s(g_s) \sim -32\frac{T_O}{g_s} + F_{RR}^2 + \mathcal{O}(g_s) \tag{2.6}$$

where F_{RR} encodes the RR fluxes (each type of which integrates to an integer Q_{RR} over cycles in the compactification which survive the orientifolding) and T_O/g_s is the tension of a single orientifold or antiorientifold 5-plane (this first term in (2.6) also then includes the contribution of the T-dual $O9$-planes and $\bar{O}9$-planes). We are here taking the flux quanta to be large so that the one-loop contribution to the vacuum energy is dwarfed by the F_{RR}^2 contribution to the potential energy at order g_s^0. In the six-dimensional Einstein frame, the potential is

$$V_E(g_s) \sim -32T_O g_s^2 + F_{RR}^2 g_s^3 + \mathcal{O}(g_s^4) \tag{2.7}$$

From (2.7) we see that if we introduce a large number of RR flux quanta, we can balance the first and second terms in this perturbation expansion off of each other and obtain a stable minimum of the potential energy [1][4]. This minimum has negative potential energy and leads to an AdS_6 spacetime in the noncompact dimensions. It would be interesting to understand the dual $5d$ CFT determined by the string theory on this background. Since here the internal space is string-scale, there is no large "sphere" or more general Einsteins space component of the geometry, so the matter content and symmetries of this case are quite different from other examples of AdS backrounds.

Because here $1 << 1/g_s \sim Q_{RR}^2 << 1/g_s^2$, the curvature AdS space in this model is much smaller than string-scale curvature m_s^2 (and therefore also much smaller than the compactification scale in this model). The mass of the dilaton is also much smaller than m_s. In realistic applications, this mass must be at least as big as an inverse millimeter (or nearly decouple at long distance for some other reason [33]). Of course this model is not realistic in any case because, because of the dimensionality and the sign of the cosmological constant (among other things).

3. A "noncritical" approach to dS space

Since all observational indications are that we have, at least currently, a positive cosmological term (scalar potential) with the dark energy having an equation of state $p/\rho \equiv w \leq -0.66$, it is of interest to either locally fix the moduli at a point where the potential is positive or find an extroardinarily flat potential to describe "quintessence". One typically finds runaway behavior toward weakly-coupled boundaries of moduli space [14], so that the simplest possibility is a local minimum above zero obtained by playing the first three terms in perturbation theory off of one another. In this section we will discuss such a minimum in the context of noncritical string theory.

I will take the point of view (see e.g. [10][11][12]) that non-critical string theory may be formulated in any dimension as long as one solves the resulting string equations of motion in a reliable regime with a background that has no perturbative instabilities. In the simplest construction here, we will have a perturbative description controlled by dimensionless parameters of order 1/10 or 1/100, not ones that can be made arbitrarily small for a fixed dimensionality, so I will not be able to prove the background exists. I will simply assume that these ratios are sufficient to give a reliable perturbation expansion. However, even given this, it is worth saying from the start that the resulting background is not realistic due to the scales that emerge. Still, it is potentially worth pursuing this sort of solution because of the conceptual issues involved in formulating and studying accelerating cosmologies.

Consider a background with dimension D not necessarily equal to the critical dimension $D_c = 10$ and with orientifold planes and RR field strengths. In D-dimensional string

frame, for regimes where effective field theory applies, one has an action [10][34]

$$
\begin{aligned}
S_{string} &= \frac{1}{2\kappa_0^2}\int d^D x\sqrt{-G_s}e^{-2\Phi}\left[R - \frac{2(D-D_c)}{3\alpha'}\right] \\
&- \sum_{O_p} T_{O_p}\int d^{p+1}\eta e^{-\Phi}\sqrt{-\gamma_s} \\
&- \frac{1}{4\kappa_0^2}\int d^D x\sqrt{-G_s}\sum_{F_{RR}}|F_{RR}|^2
\end{aligned}
\tag{3.1}
$$

where the second line involves a sum over all orientifold planes that are present in the background and the third line involves a sum over all RR field strengths F_{RR} that are turned on in the background. Here so far the D-dimensional metric G_s and the brane metric γ_s are in the string frame.

In the absence of the last two lines of (3.1), one finds a linear dilaton background to solve the dilaton equation of motion arising from (3.1), a solution which is in fact exact in α' [35][36]. Much of the literature on noncritical string theory involves this solution. However in the presence of the other terms, there is a priori the possibility of other solutions. In particular, here we will argue that there are compactified solutions with meta-stabilized dilaton.

If we dimensionally reduce to four dimensions and switch to Einstein frame, we obtain an effective potential for Φ of the form

$$
U(\Phi) \propto \left(ae^{2\Phi} - be^{3\Phi} + ce^{4\Phi}\right) \tag{3.2}
$$

where a, b, and c are positive constants read off from the first three lines of (3.1) which will be specified explicitly below given T_{O_p}. Extremizing this gives

$$
e^{\Phi_\pm} = \frac{3b \pm \sqrt{9b^2 - 32ac}}{8c} \tag{3.3}
$$

If this potential is reliable, and if

$$
9b^2 > 32ac \tag{3.4}
$$

then there is a metastable minimum of the dilaton potential at $\Phi = \Phi_+$.

The other moduli of the string background can be stabilized in a manner similar to that employed in §2. In fact, starting in $D = 12$ dimensions we can consider a simple generalization of the model of (2.1)- (2.4). That orbifold/orientifold group acted on four dimensions, giving a reduction of $10d$ critical string theory down to $6d$. With the same

action on twice as many coordinates, we can reduce from $D = 12$ to $D = 4$, and again fix all the NS-NS moduli, leaving invariant some combinations of Ramond fields. This leaves us with a string-scale compactification manifold, and we can put Ramond flux along diagonal directions of the torus so as to yield a small separation of scales between the RR q-form field strengths and the inverse radii of the corresponding cycles. This gives

$$c \sim \frac{1}{4} \sum \frac{(Q_{RR}^{(q)})^2}{V_q} \tag{3.5}$$

where V_q is the volume in string units of the cycle carrying q-form flux $Q_{RR}^{(q)}$.

In order to determine b in (3.2), we need to know the orientifold tensions T_{O_p} in (3.1). These will in general be a function of D (or equivalently $d \equiv D - 2$) and the spatial dimension p of the O_p-plane. We can start to analyze this by generalizing the calculations of D-brane tensions [34] to arbitrary dimension, following a similar analysis [12] of the closed string partition function and spectrum in noncritical dimensions. In the case of the superstring, this gives an NS-NS exchange between Dp-branes separated by a distance y

$$\mathcal{A}_{NS-NS} = i \frac{V_{p+1}}{(8\pi^2\alpha')^{\frac{p+1}{2}}} \int_0^\infty dt t^{-\frac{(p-d+3)}{2}} e^{-\frac{ty^2}{2\pi\alpha'}} e^{\frac{d\pi}{8t}} (de^{-\pi/t} + \ldots) \tag{3.6}$$

where $\ldots$ represents an infinite series of terms suppressed relative to the first term in the $t \to 0$ infrared limit in the closed-string channel. For the critical superstring case of $d = 8$, this reduces to the formula (13.3.1) in [34], in which this leading exchange is massless. More generally, it describes noncritical strings propagating on a linear dilaton background, as in the corresponding closed-string analysis of partition functions in [12]. In sub-critical dimensions $d < 8$, the mode is effectively massive due to the linear dilaton, corresponding to the surviving exponential suppression $e^{\frac{\pi}{t}\frac{(d-8)}{8}}$. On the other hand, for $d > 8$ one finds the leading modes to be effectively tachyonic in the linear dilaton background. However, as discussed in [12], in an effective action description the fields all have nontachyonic m^2 as in the critical string; the instability for $d > 8$ arises as a result of the effect of the dilaton coupling on the equation of motion.

We are interested in looking for solutions (3.3) in which the dilaton is fixed. In such a background, there is no linear dilaton and the masses are not even effectively tachyonic. I will now assume that in fact the only effect of stabilizing the dilaton on the calculation of D-brane and orientifold tensions is to shift the effective masses of the exchanged particles in (3.6), in particular shifting the graviton exchange to the massless level. In particular

we will assume it does not change the normalization of the amplitude. In particular, this amounts to assuming that the multiplicities of particles, particularly the low-lying ones like the graviton, do not change when one considers a different solution of the dilaton equation of motion, which appears to me a reasonable assumption given that the effective action appears self-consistently reliable in the models we will study.

Doing this and comparing the result to the appropriate low-energy Greens function in D dimensions gives the result

$$T_p = \frac{2^{4-d/4}\pi^{1/2}}{\kappa_0(2\pi\alpha'^{1/2})^{p+1-d/2}} \tag{3.7}$$

for the Dp-brane tension. One finds for the orientifold tensions

$$2^{(d+2)-(p+1)}T_{Op} = -\frac{2^{4+d/4}\pi^{1/2}}{\kappa_0(2\pi\alpha'^{1/2})^{p+1-d/2}} \tag{3.8}$$

where we have included all $2^{(d+2)-(p+1)}$ orientifold p-planes present in $d+2$ dimensions on a torus.

In our model with $D = d+2 = 12$, let us take $\kappa_0 = (4\pi^2\alpha')^{5/2}$. $2\pi(\alpha')^{1/2} = 2\pi R_{sd}$ is the linear size of the self-dual compactification manifold, so this amounts to setting the dimensionful coupling κ_0 to be at the self-dual compactification scale. The choice of κ_0 does not affect any physics. However, rescaling κ_0 does rescale the coefficients in the string coupling expansion, and in our problem we will not have the luxury of parametrically lowering the dilaton to achieve an arbitrarily well controlled series. Instead, as we will see, with this choice of κ_0, our string coupling will be of order 1/10. Because we picked a natural scale for κ_0, I expect generically the coefficients in the g_s expansion to be of order one, so that our use of the first three terms only in will be valid. However, the possibility remains that large coefficients arise at higher orders in perturbation theory in which case our approximation would fail. In addition to factors of $g_s \sim 1/10$, higher orders in the loop expansion come with powers of $1/2\pi$ from loop momentum integrals, which aids our cause.[3] In any case however, because of the fact that there are no arbitrarily negative contributions in the b term at fixed d, we cannot tune the dilaton to be arbitrarily weak, and so cannot be completely sure that the candidate minimum we will study exists.

[3] On the other hand, another natural choice for κ_0 might be to take $\kappa_0 = R_{sd}^5 = \alpha'^{5/2}$. Doing this would cancel the powers of $1/2\pi$ from the loop momentum integrals, leaving us still with the suppression by powers of 1/10 only.

It is interesting to contemplate extrapolating to large dimensionality, in which case the negative contribution from (3.8) grows exponentially whereas the leading positive term grows only linearly (3.1). This may lead to better control, though going very far from the critical dimension might introduce even more subtleties.

The above results and assumptions lead to the following contributions to the effective potential in four-dimensional Einstein frame:

$$S_E = \int d^4x \sqrt{g_E} \frac{1}{(4\pi^2\alpha')^2} \left[ae^{2\Phi} - be^{3\Phi} + ce^{4\Phi} \right] \tag{3.9}$$

where $a = 8\pi^2/3$, $b = \pi^{1/2}2^{15/2}$ (including a factor of two for the fact that there are two sets of orientifolds in our model) and c is given by (3.5).

Let us choose the RR flux to get the smallest possible value of the string coupling e^{Φ_+}. This means taking c such that $32ac \sim 9b^2$, so that

$$e^{\Phi_+} \sim \frac{4a}{3b} \sim 0.11. \tag{3.10}$$

Given this, we find the cosmological constant at the minimum, $\Lambda \equiv U(\Phi_+)$, to be bounded by

$$\Lambda \sim \frac{1}{(2\pi R_{sd})^4}(0.05) \tag{3.11}$$

so that the curvature radius L of the dS space is greater than string scale $(\alpha')^{1/2}$ by two orders of magnitude (using the relation that the general relativistic dimension two cosmological constant is given by $\Lambda_{GR} = 1/L^2 = \Lambda/M_4^2 = (1/\alpha')(0.03/4\pi^2)$, reading off M_4 from the $4d$ Einstein frame action).

Clearly, establishing completely the validity (and utility) of this approach to constructing dS space will require getting a handle on the worldsheet description of the CFT including the Fischler-Susskind [13] description of the competition between different orders in perturbation theory that is central to the mechanism. If this can be accomplished, it is intriguing that increasing the dimensionality (and therefore the naive number of degrees of freedom) seems to give a better and better perturbative description of dS space.

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References

[1] R. Sundrum, "Effective field theory for a three-brane universe," Phys. Rev. D **59**, 085009 (1999) [hep-ph/9805471].

[2] N. Arkani-Hamed, S. Dimopoulos and J. March-Russell, "Stabilization of sub-millimeter dimensions: The new guise of the hierarchy problem," Phys. Rev. D **63**, 064020 (2001) [hep-th/9809124].

[3] S. Gukov, C. Vafa and E. Witten, "CFT's from Calabi-Yau four-folds," Nucl. Phys. B **584**, 69 (2000) [hep-th/9906070].

[4] R. Bousso and J. Polchinski, "Quantization of four-form fluxes and dynamical neutralization of the cosmological constant," JHEP **0006**, 006 (2000) [hep-th/0004134].

[5] S. B. Giddings, S. Kachru and J. Polchinski, "Hierarchies from fluxes in string compactifications," hep-th/0105097.

[6] S. Giddings, S. Kachru, and J. Polchinski, work in progress

[7] S. Kachru, S. Trivedi,..., work in progress.

[8] L. Susskind, hep-th/9309145; G. T. Horowitz and J. Polchinski, "A correspondence principle for black holes and strings," Phys. Rev. D **55**, 6189 (1997) [hep-th/9612146].

[9] T. Banks, "Cosmological breaking of supersymmetry or little Lambda goes back to the future. II," hep-th/0007146.

[10] S. P. de Alwis, J. Polchinski and R. Schimmrigk, "Heterotic Strings With Tree Level Cosmological Constant," Phys. Lett. B **218**, 449 (1989).

[11] D. Kutasov and N. Seiberg, "Noncritical Superstrings," Phys. Lett. B **251**, 67 (1990).

[12] A. H. Chamseddine, "A Study of noncritical strings in arbitrary dimensions," Nucl. Phys. B **368**, 98 (1992).

[13] W. Fischler and L. Susskind, "Dilaton Tadpoles, String Condensates And Scale Invariance," Phys. Lett. B **171**, 383 (1986).

[14] M. Dine and N. Seiberg, "Is The Superstring Weakly Coupled?," Phys. Lett. B **162**, 299 (1985).

[15] M. Dine and E. Silverstein, "New M-theory backgrounds with frozen moduli," hep-th/9712166.

[16] S. Kachru, M. Schulz and E. Silverstein, "Self-tuning flat domain walls in 5d gravity and string theory," Phys. Rev. D **62**, 045021 (2000) [hep-th/0001206]; N. Arkani-Hamed, S. Dimopoulos, N. Kaloper and R. Sundrum, "A small cosmological constant from a large extra dimension," Phys. Lett. B **480**, 193 (2000) [hep-th/0001197].

[17] S. Kachru, "Lectures on warped compactifications and stringy brane constructions," hep-th/0009247.

[18] E. Silverstein, "Gauge fields, scalars, warped geometry, and strings," Int. J. Mod. Phys. A **16**, 641 (2001) [hep-th/0010144].

[19] E. Witten, "Quantum gravity in de Sitter space," hep-th/0106109.

[20] S. Hellerman, N. Kaloper and L. Susskind, "String theory and quintessence," JHEP **0106**, 003 (2001) [hep-th/0104180].

[21] W. Fischler, A. Kashani-Poor, R. McNees and S. Paban, "The acceleration of the universe, a challenge for string theory," hep-th/0104181.

[22] J. Maldacena and C. Nunez, "Supergravity description of field theories on curved manifolds and a no go theorem," Int. J. Mod. Phys. A **16**, 822 (2001) [hep-th/0007018].

[23] H. Verlinde, "Holography and compactification," Nucl. Phys. B **580**, 264 (2000) [hep-th/9906182].

[24] E. Witten, "Fermion Quantum Numbers In Kaluza-Klein Theory," PRINT-83-1056 (PRINCETON) *IN *APPELQUIST, T. (ED.) ET AL.: MODERN KALUZA-KLEIN THEORIES*, 438-511. (IN *SHELTER ISLAND 1983, PROCEEDINGS, QUANTUM FIELD THEORY AND THE FUNDAMENTAL PROBLEMS OF PHYSICS*, 227-277).*

[25] P. Horava and E. Witten, "Heterotic and type I string dynamics from eleven dimensions," Nucl. Phys. B **460**, 506 (1996) [hep-th/9510209].

[26] T. Banks and W. Fischler, "M-theory observables for cosmological space-times," hep-th/0102077.

[27] A. Strominger, "The dS/CFT Correspondence," hep-th/0106113.

[28] T. Banks, "On isolated vacua and background independence," hep-th/0011255.

[29] T. Banks and M. Dine, work in progress.

[30] C. M. Hull, "Timelike T-duality, de Sitter space, large N gauge theories and topological field theory," JHEP **9807**, 021 (1998) [hep-th/9806146]; V. Balasubramanian, P. Horava and D. Minic, "Deconstructing de Sitter," JHEP **0105**, 043 (2001) [hep-th/0103171].

[31] S. Dimopoulos, S. Kachru, N. Kaloper, A. E. Lawrence and E. Silverstein, "Small numbers from tunneling between brane throats," hep-th/0104239; S. Dimopoulos, S. Kachru, N. Kaloper, A. Lawrence and E. Silverstein, "Generating Small Numbers by Tunneling in Multi-Throat Compactifications," hep-th/0106128.

[32] J. Harvey, S. Kachru, G. Moore, and E. Silverstein, unpublished

[33] T. Damour and A. M. Polyakov, "The String dilaton and a least coupling principle," Nucl. Phys. B **423**, 532 (1994) [hep-th/9401069].

[34] J. Polchinski, "String theory. Vol. 1: An introduction to the bosonic string," *Cambridge, UK: Univ. Pr. (1998) 402 p*; J. Polchinski, "String theory. Vol. 2: Superstring theory and beyond," *Cambridge, UK: Univ. Pr. (1998) 531 p.*

[35] R. C. Myers, "New Dimensions For Old Strings," Phys. Lett. B **199**, 371 (1987).

[36] I. Antoniadis, C. Bachas, J. Ellis and D. V. Nanopoulos, "Cosmological String Theories And Discrete Inflation," Phys. Lett. B **211**, 393 (1988).