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A note on a class of cosmological string backgrounds

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Abstract: We study a class of four dimensional, anisotropic string backgrounds and analyse their expansion and singularity structure. We will see how O(3,3) duality acts on this class and in particular realizes the Brandenberger-Vafa scenario.

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Contents

In the course of study of string cosmological backgrounds one class of solutions appeared over the time which was origanally introduced by Mueller [1] and was studied in the string frame [2, 3] and in related works [4].

In this note we will study the space of solutions in the Einstein frame which is related to the string frame by a conformal transformation. We will show that if one introduces a new time coordinate within the Einstein frame one can apply techniques known from General Relativity to get a geometrical interpretation of the expansion and singularity structure of the solutions. Furthermore we will see how O(3,3) duality acts on this space and it will be shown that depending on the anisotropy of the solution different types of singularities appear. It will be shown that there are solutions which correspond to contracting respectively expanding cosmological backgrounds which are related by O(3,3) scale factor duality.

These solutions can be thought of as concrete examples of the Brandenberger-Vafa scenario [5] which roughly says: Assume that at some point in the future our universe stops expanding and starts contracting and heating up. The energy density increases to the Hagedorn energy density and stringy effects will take over. If the universe arrives the self dual radius it goes through a bounce and comes out expanding on the other side. The process could repeat giving rise to an oscillatory universe. This scenario is important since it at least allows us to imagine how initial singularities might be avoided in string theory.

Now let us start and consider a string propagating in the presence of a D-dimensional background spacetime metric $G(X)$, a dilaton $\Phi(X)$ and the antisymmetric tensor field $B(X)$ with field strength $H(X)$. The string tree level effective action for these fields is given in the Einstein frame by

$$S = \int d^D x \sqrt{-G} \left[R - 2(\nabla\phi)^2 - e^{-4\phi} \frac{1}{12} H^2 \right] + S_f \,.$$

where S_f denotes that there can be moduli fields coming from compactification and higher loop effects, etc. By varying G, B, ϕ we obtain the equations of motion

$$\begin{aligned} R_{\mu\nu} - \frac{1}{2} G_{\mu\nu} R &= T_{\mu\nu} \,, \\ \nabla_\mu \left(e^{-4\phi} H^\mu_{\nu\lambda} \right) &= 0 \,, \\ \nabla^2 \phi + e^{-4\phi} \frac{1}{12} H^2 &= 0 \,. \end{aligned}$$

with the energy-momentum tensor for the axion-dilaton system given by

$$T_{\mu\nu} = \frac{1}{4} \left(H^2_{\mu\nu} - \frac{1}{6} G_{\mu\nu} H^2 \right) e^{-4\phi} + 2 \left(\nabla_\mu \phi \nabla_\nu \phi - \frac{1}{2} G_{\mu\nu} (\nabla\phi)^2 \right) \,.$$

These equations can also be obtained [6, 7] by the conditions of vanishing β-functions in the corresponding two-dimensional σ model.

Now let us consider as an ansatz the anisotropic spacetime metric which has a time dependent dilaton and a spacetime metric given in the Einstein frame by (setting $B(X) = 0$)

$$ds_E^2 = -e^{-2\phi} dt^2 + \sum_{i=1}^{3} (R_i(t))^2 \left(dX^i \right)^2 \,,$$

where $R_i(t)^2$ is given by $R_i(t)^2 = e^{-2\phi} R_i^S(t)^2$ and the corresponding field equations (cfr. for the stringframe [1, 2]) are

$$\begin{aligned} \sum_{i<j} \frac{\dot{R}_i \dot{R}_j}{R_i R_j} &= \left(\dot{\phi}(t) \right)^2 \\ -e^{2\phi} R_i^2 \left[\frac{\dot{R}_k \dot{R}_l}{R_k R_l} + \frac{\dot{R}_k}{R_k} \dot{\phi} + \frac{\dot{R}_l}{R_l} \dot{\phi} + \frac{\ddot{R}_k}{R_k} + \frac{\ddot{R}_l}{R_l} \right] &= e^{2\phi} R_i(t)^2 \left(\dot{\phi}(t) \right)^2 \,, \end{aligned}$$

with $i, k, l \in \{1,2,3\}$ and $k, l \neq i$ $(k > l)$; further $R_i = R_i(t)$ and $\phi = \phi(t)$. The dot denotes derivative with respect to t.

A family of solutions introduced originally in the string frame [1]] are given in the Einstein frame by

$$R_i(t) = \alpha_i (t - t_0)^{p_i + \frac{p}{2}} \,, \qquad \phi(t) = -\frac{1}{2} \log \beta^2 (t - t_0)^p \,,$$

where α_i, β, t_0 are arbitrary real numbers; p_i and p are real but restricted through

$$\sum_{i=1}^{3} p_i^2 = 1 \,, \qquad \sum_{i=1}^{3} p_i = 1 - p \,, \qquad \sum_{i<j} p_i p_j = \frac{1}{2}\left(p^2 - 2p\right) \,.$$

Now these equations lead to the geometrical picture that the p_i can be thought of being points on the unit 2-sphere (note that $\sum_i p_i = 1 - p$ determines a codimension one subvariety in this sphere) and every choice of a tuple (p_i) determines a solution of the differential equation system and restricts the range of p. The solutions depend on 7 parameters: α_i, β, t_0 (fixing the initial values of R_i and ϕ) and 2 free coordinates on the 2-sphere. The behavior of the dilaton field depends on whether $p = 0$, $p < 0$ or $p > 0$. If we consider the intersection set (which is either one dimensional or empty) of the hyperplane $\sum_{i=1}^{3} p_i + p - 1 = 0$ with the sphere $\sum_{i=1}^{3} p_i^2 - 1 = 0$ we can further restrict the range of p. If the hyperplane is tangent to the sphere then there are two critical values of p which occur for $1 - p = \pm\sqrt{3}$ and thus the range of p is $\left(1 - \sqrt{3} \leq p \leq 1 + \sqrt{3}\right)$.

Now to get rid of the scale factor in front of our line element let us introduce a new time coordinate τ that leads to a line element which can be studied by known methods from General Relativity.

$$ds_E^2 = -d\tau^2 + \sum_{i}^{3} R_i(\tau)^2 d\left(X^i\right)^2 \,.$$

The corresponding coordinate transformation can be obtained from $\dot{t}(\tau) = t(\tau)^{-\frac{p}{2}}$ where the dot denotes now and in the following the derivative with respect to τ. A solution is given by

$$t(\tau) = \left(\tau + \frac{p}{2}\tau + c\right)^{\frac{1}{1+\frac{p}{2}}} \,, \qquad c = const.$$

The solutions are given in the new time coordinate by

$$R_i(\tau) = t(\tau)^{p_i + \frac{p}{2}} \,, \qquad \phi(\tau) = -\frac{1}{2}\log t(\tau)^p \,,$$

where we have set for simplicity $\alpha_i, \beta = 1$ and $t_0 = 0$.

If we insert our new line element into the equations of motion of our background fields we find

$$\sum_{i<j} \frac{\dot{R}_i \dot{R}_j}{R_i R_j} = p^2 \frac{\dot{t}(\tau)^2}{4t(\tau)^2} \,,$$
$$-R_i^2 \left[\frac{\dot{R}_k \dot{R}_l}{R_k R_l} + \frac{\ddot{R}_k}{R_k} + \frac{\ddot{R}_l}{R_l}\right] = p^2 \frac{t(\tau)^{2p_i + p}\dot{t}(\tau)^2}{4t(\tau)^2} \,,$$

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with $i,k,l \in \{1,2,3\}$ and $k,l \neq i$ and $k > l$. The energy density μ and the pressure $\hat{p}$ of the dilaton matter system are given by

$$T_{00} = \mu(\tau)\,, \qquad T_{ij} = \hat{p}(\tau) G_{ij} = p^2 \frac{\dot{t}(\tau)^2}{4t(\tau)^2} G_{ij}\,.$$

Now to decide which behavior our solutions have (i.e. if they describe a contracting or expanding universe and if there is an initial singularity) we have to consider the energy-momentum conservation which leads to the following equation

$$\begin{aligned} D^\mu T_{\mu\nu} &= G^{\mu\lambda}\partial_\lambda T_{\mu\nu} - G^{\mu\nu}\Gamma^\rho_{\mu\lambda}T_{\rho\nu} - G^{\mu\nu}\Gamma^\rho_{\nu\lambda}T_{\mu\rho} \\ &= -\dot{\mu} - (\mu + \hat{p})\sum_i \frac{\dot{R}_i(\tau)}{R_i(\tau)} \\ &= 0 \end{aligned}$$

Since $\frac{\dot{R}_i}{R_i}$ measures the expansion respectively contraktion of the universe with respect to the i-th coordinate, we learn

$$\frac{\dot{R}_i}{R_i} > 0 \iff \text{Expansion}\,; \qquad \frac{\dot{R}_i}{R_i} < 0 \iff \text{Contraction}\,.$$

Finally we have to study the Raychandhuri equation in order to decide if we have an initial singularity [8]. This equation can be derived if one considers the energy-momentum tensor of our dilaton matter system which can be thought of as a perfect fluid and is given by

$$T_{\mu\nu} = \hat{p} G_{\mu\nu} + (\mu + \hat{p}) V_\mu V_\nu\,.$$

where V_μ is the tangential vector to a congruence of timelike curves (with $g(\mathbf{V},\mathbf{V}) = -1$). Now every congruence of timelike geodesics converges if $R_{\mu\nu}V^\mu V^\nu \geq 0$ [8]. The equations of motion satisfies this condition if the energy-momentum tensor satisfies

$$T_{\mu\nu}V^\mu V^\nu - \frac{1}{2}V^\mu V_\mu T \geq 0\,, \qquad \mu + \hat{p}_i \geq 0\,, \qquad \mu + \sum_i \hat{p}_i \geq 0\,,$$

where $T = TrT_{\mu\nu}$. This condition will be satisfied if the energy-momentum tensor is diagonal $T_{\mu\nu} = diag(\mu, \hat{P}_i)$ with $\hat{P}_i = \hat{p}_i G_{ij}$; the left hand side of this equation is the source term in the contracted Einstein equations

$$R_{\mu\nu} = -8\pi S_{\mu\nu}\,,$$

where $S_{\mu\nu} = T_{\mu\nu} + \frac{1}{2}G_{\mu\nu}T = \frac{1}{2}(\mu - \hat{p}) + (\hat{p} + \mu)V_\mu V_\nu$. Here we used the energy-momentum tensor. With our above ansatz $S_{\mu\nu}$ reduces to

$$S_{00} = \frac{1}{2}(\mu + 3\hat{p})\,, \qquad S_{0i} = 0\,, \qquad S_{ij} = \frac{1}{2}(\mu - \hat{p})R_i(\tau)\Omega_{ij}(X)\,,$$

where $\Omega_{ij}(X)$ is the metric of the three-dimensional area of constant curvature. The time-time component of $R_{\mu\nu}$ is then

$$R_{00} = 4\pi(\mu + 3\hat{p})\,.$$

and if we use $R_{00} = -\sum_i \frac{\ddot{R}_i(\tau)}{R_i(\tau)}$ we find the Raychandhuri equation[1]

$$\sum_i \frac{\ddot{R}_i(\tau)}{R_i(\tau)} = -4\pi(\mu + 3\hat{p})\,.$$

From the energy-momentum conservation we learn that the density of the universe vanishes for $R(\tau) \to \infty$ and grows up to infinity for $R(\tau) \to 0$. Since the density is a scalar we can conclude that also the scalar curvature grows up and at $R = 0$ we have a singularity which is no coordinate singularity and leads usually to the break down of the Einstein theory. Thus from the Raychandhuri equation we learn that if $\mu + 3\hat{p} > 0$ we have an initial singularity [8].

Now we are able to study the structure of our model where we have

$$R_{00} = \frac{p^2 \dot{t}(\tau)^2}{2t(\tau)^2}\,, \qquad R_{ii} = 0\,, \qquad R = -\frac{p^2 \dot{t}(\tau)^2}{2t(\tau)^2}\,, \qquad \mu = \hat{p} = \frac{p^2 \dot{t}(\tau)^2}{4t(\tau)^2}\,.$$

1. Duality transformation

Since our model is independent of three coordinates we can perform a O(3,3) duality transformation (for a review on O(d,d) duality see [9] and references therein). We do this in the string frame which is related to the Einstein frame by the conformal transformation $G^S_{\mu\nu} = e^{2\phi} G^E_{\mu\nu}$ and then transform back to the Einstein frame and find the dual line element

$$ds_D^2 = -d\tau^2 + \sum_i \left(R_i^D\right)^2 \left(dX^i\right)^2\,,$$

where $d\tau^2 = e^{-2\phi^D} d\bar{t}^2$ and $(R_i^D)^2 = e^{-2\phi^D} \tilde{R}_i^{-2}$. The equations of motion are solved by

$$R_i(\tau)^D = \bar{t}(\tau)^{-p_i - \frac{p}{2} + 1}\,, \qquad \phi(\tau)^D = -\frac{1}{2} \log \bar{t}(\tau)^{2-p}\,,$$

where $\bar{t}(\tau)$ is given by rescaling of the dual metric. The duality transformation $p_i \longrightarrow -p_i$, $p \longrightarrow -p+2$ or equivalently $R_i \longrightarrow \frac{1}{R_i}$, $p \longrightarrow -p+2$, $(i = 1, 2, 3)$ relates the two string backgrounds to each other. Remember the range of p was given by

[1] $\frac{\ddot{R}_i}{R_i}$ measures the acceleration of the expansion resp. contraction and implies

$$\sum_i \frac{\ddot{R}_i}{R_i} < 0 \iff \mu + 3\hat{p} > 0\,; \qquad \sum_i \frac{\ddot{R}_i}{R_i} > 0 \iff \mu + 3\hat{p} < 0\,.$$

$p_{\min} = 1 - \sqrt{3} \leq p \leq 1 + \sqrt{3} = p_{\max}$, and therefore $p \to -p + 2$ maps $p_{\min} \to p_{\max}$ resp. $p_{\max} \to p_{\min}$, i.e. the duality transformation operates on the space of solutions. For the dual model we find

$$R_{00}^D = \frac{(-p+2)^2 \dot{\bar{t}}(\tau)^2}{2\bar{t}(\tau)^2}, \qquad R_{ii}^D = 0, \qquad \bar{t}(\tau) = \left(\tau\left(2 - \frac{p}{2}\right) + c\right)^{\frac{1}{2-\frac{p}{2}}},$$
$$R^D = -\frac{(-p+2)^2 \dot{\bar{t}}(\tau)^2}{2\bar{t}(\tau)^2}, \qquad \mu_D = \hat{p}_D = \frac{(-p+2)^2 \dot{\bar{t}}(\tau)^2}{4\bar{t}(\tau)^2}.$$

2. Singularities

Let us study the singularity structure. Setting $c = 0$ we obtain $\Big($using $\frac{\dot{t}(\tau)^2}{t(\tau)^2} = (\tau(1+\frac{p}{2}))^{\frac{-2p-4}{2+p}}$ and $\frac{\dot{\bar{t}}(\tau)^2}{\bar{t}(\tau)^2} = (\tau(2-\frac{p}{2}))^{\frac{2p-8}{-p+4}}\Big)$ for the scalar curvatures R, R^D and the energy densities μ, μ^D

$$R = -\frac{p^2}{2}\left(\tau\left(1+\frac{p}{2}\right)\right)^{\frac{-2p-4}{2+p}}, \qquad \mu = \frac{p^2}{4}\left(\tau\left(1+\frac{p}{2}\right)\right)^{\frac{-2p-4}{2+p}},$$
$$R^D = -\frac{(2-p)^2}{2}\left(\tau\left(2-\frac{p}{2}\right)\right)^{\frac{2p-8}{-p+4}}, \qquad \mu^D = \frac{(2-p)^2}{4}\left(\tau\left(2-\frac{p}{2}\right)\right)^{\frac{2p-8}{-p+4}}.$$

2.1 $p \neq 0$

For solutions with $p \neq 0$ both space-times are singular at $\tau = 0$ which can be checked by inserting p_{max} and p_{min} into the equations above. Furthermore for all $p \neq 0$ we have

$$\mu + 3\hat{p} > 0, \qquad \mu^D + 3\hat{p}^D > 0,$$

and the energy density has the $\frac{1}{\tau^a}$ behavior typical for cosmological solutions and will grow up to infinity if $\tau \to 0$.

2.2 $p = 0$

If $p = 0$ then the dilaton is constant and the energy density vanishes. The scalar curvature and energy density are given by

$$R = 0, \qquad \mu = 0, \qquad R^D = -\frac{1}{2\tau^2}, \qquad \mu^D = \frac{1}{\tau^2}.$$

Further $\mu + \hat{p}$ vanishes for Ricci-flat spacetimes. To get some information about singularities one has to check if the Riemannian tensor gets singular for $\tau \to 0$. In our case we find $R_{\mu\nu\lambda\sigma}R^{\mu\nu\lambda\sigma} \sim \frac{1}{\tau^2}$ which will be singular at $\tau = 0$. Thus the duality transformation maps a Ricci-flat spacetime onto spacetime with singular scalar curvature.

3. Expansion behavior

To understand the expansion behavior we have to consider $\frac{\dot{R}_i}{R_i} = \frac{p_i+\frac{p}{2}}{1+\frac{p}{2}}\left(\frac{1}{\tau}\right)$ and $\frac{\dot{R}_i^D}{R_i^D} = \frac{-p_i-\frac{p}{2}+1}{2-\frac{p}{2}}\left(\frac{1}{\tau}\right)$.

3.1 $p = 0$

The expansion behavior for $p = 0$ is simply given by

$$\frac{\dot{R}_i}{R_i} = \frac{p_i}{\tau}\,, \qquad \frac{\dot{R}_i^D}{R_i^D} = \frac{-p_i+1}{2\tau}\,.$$

Now remember p_i are coordinates of points on the unit sphere with values in [-1,1]. Since our solutions are 4-dimensional we exclude cases with $p_1 = 1, p_i = 0$ $\{i = 2,3\}$ and $p_i = 0$ $\{i = 1,2,3\}$. Taking into account that the dual expansion coefficient being positive for all p_i we learn that our dual solution describes an expanding space-time. The original solution describes also an expanding space-time if p_i is positive with respect to the i-th coordinate and describes an contracting space-time if p_i is negative with respect to the i-th coordinate

$$p = 0: \qquad p_i \begin{cases} > 0: & \text{EXPANSION} \rightarrow \text{EXPANSION} \\ < 0: & \text{CONTRACTION} \rightarrow \text{EXPANSION} \end{cases}$$

If we solve the equation system $\sum_i p_i = 1, \;\; \sum_i p_i^2 = 1$ we will find coordinates for p_i. For example if we fix p_3 then we will obtain p_1 and p_2:

$$p_1 = \frac{1}{2}\left(1 - p_3 \mp \sqrt{1+2p_3-3p_3^2}\right)\,, \qquad p_2 = \frac{1}{2}\left(1 - p_3 \pm \sqrt{1+2p_3-3p_3^2}\right)\,.$$

3.2 Example

$$p = 0\,, \qquad p_3 = \frac{1}{2} > 0\,, \qquad p_1 = \frac{1}{4} - \frac{\sqrt{5}}{4} < 0\,, \qquad p_2 = \frac{1}{4} + \frac{\sqrt{5}}{4} > 0$$

In the example duality maps a Ricci-flat space-time which expands in $i = 3,2$ and contracts in $i = 1$ to a space-time which expands in $i = 1,2,3$. Both space-times are singular for $\tau \rightarrow 0$ but with different singularity structure. The former has an infinite THREAD singularity if $\tau \rightarrow 0$ and the latter a POINT singularity.

3.3 $p \neq 0$

Now let us come to the case $p \neq 0$ where the range for p and p_i is $1-\sqrt{3} \leq p \leq 1+\sqrt{3}$ and $-1 < p_i < 1$ respectively. Since the denominator of $\frac{\dot{R}_i}{R_i}$ and $\frac{\dot{R}_i^D}{R_i^D}$ is always positive we are left to check the nominator. We find that we can distinguish the following four cases:

1. Static $\longrightarrow$ Expansion:

$$\left(p_i + \frac{p}{2}\right) = 0 \longrightarrow -\left(p_i + \frac{p}{2}\right) + 1 > 0\,.$$

2. Contraction $\longrightarrow$ Expansion:

$$\left(p_i + \frac{p}{2}\right) < 0 \longrightarrow -\left(p_i + \frac{p}{2}\right) + 1 > 0\,.$$

3. Expansion $\longrightarrow$ Expansion:

$$0 < \left(p_i + \frac{p}{2}\right) < 1 \longrightarrow -\left(p_i + \frac{p}{2}\right) + 1 > 0\,.$$

4. Expansion $\longrightarrow$ Contraction:

$$\left(p_i + \frac{p}{2}\right) > 1 \longrightarrow -\left(p_i + \frac{p}{2}\right) + 1 < 0\,.$$

4. Conclusion

In this note we showed that one can get a geometrical interpretation of the space of solutions which is parametrised by p and p_i using methods known from classical General Relativity. The duality transformation $p_i \to -p_i, p \to -p + 2$ acting on this space maps for $p = 0$ and $p_i > 0$ expanding to expanding backgrounds and for $p = 0$ and $p_i < 0$ contracting to expanding backgrounds and if $p \neq 0$ the cases A-D appear. Furthermore it has been shown that depending on the possible combinations of A-D there are backgrounds with THREAD singularities as well as POINT or PANCAKE singularities as a consequence of having an anisotropic spacetime.

In particular the cases where a contracting background is mapped onto an expanding backround supporting strongly the assumption that string dynamics is consistent even if the background geometry is singular. From the string point of view the universe starts out in a contracting phase, goes through a bounce (which is represented by the self dual point in the scale factor duality) and then emerges as an expanding universe. Thus we have seen that the Brandenberger-Vafa scenario (mentioned above) is realized within the class of solutions we considered.

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References

[1] M. Mueller, *Nucl. Phys.* **B 337** (1990) 37.

[2] D. Lüst, hep-th/9303175.

[3] A.A. Tseytlin and C. Vafa, *Nucl. Phys.* **B 372** (1992) 443 [hep-th/9109048].

[4] E. Kiritsis, C. Kounnas and D. Lüst, *Int. J. Mod. Phys.* **A 9** (1994) 1361 [hep-th/9308124];
I. Bakas, *Nucl. Phys.* **B 428** (1994) 374 [hep-th/9402016];
I. Antoniades, S. Ferrara and C. Kounnas, *Nucl. Phys.* **B 421** (1994) 343 [hep-th/9402073];
M. Gasperini and G. Veneziano, *Phys. Rev.* **D 50** (1994) 2519 [gr-qc/9403031];
A.A. Tseytlin, *Phys. Lett.* **B 334** (1994) 315 [hep-th/9404191];
M. Gasperini and R. Ricci, *Class. and Quant. Grav.* **12** (1995) 677 [hep-th/9501055];
N.A. Batakis and A.A. Kehagias, *Nucl. Phys.* **B 449** (1995) 248 [hep-th/9502007];
A. Kehagias and A. Lukas, *Nucl. Phys.* **B 477** (1996) 549 [hep-th/9602084];
A. Lukas, B.A. Ovrut and D. Waldram, *Phys. Lett.* **B 393** (1997) 65 [hep-th/9610238]; *Nucl. Phys.* **B 495** (1997) 365 [hep-th/9610238];
E. Kiritsis and C. Kounnas, *Nucl. Phys.* **41** *(Proc. Suppl.)* (1995) 365 [gr-qc/9701005];
J.D. Barrow and K.E. Kunze, *Phys. Rev.* **D 56** (1997) 741 [hep-th/9701085];
M.P. Dabrowski, A.L. Larsen, *Phys. Rev.* **D 57** (1998) 5108 [hep-th/9706020].

[5] R.H. Brandenberger and C. Vafa, *Nucl. Phys.* **B 316** (1989) 391.

[6] M.B. Green, J. Schwarz and E. Witten, *Superstring theory*, Cambridge University Press 1987.

[7] C.G. Callan, D. Friedan, E.J. Martinec, M.J. Perry, *Nucl. Phys.* **B 262** (1985) 593.

[8] S.W. Hawking and G.F.R. Ellis, *The large scale structure of space-time*, Cambridge Monographs on Mathematical Physics.

[9] A. Giveon, M. Porrati and E. Rabinovici, *Phys. Rep.* **244** (1994) 77 [hep-th/9401139].