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Tachyon-Dilaton Inflation as an α'-non perturbative solution in first quantized String Cosmology

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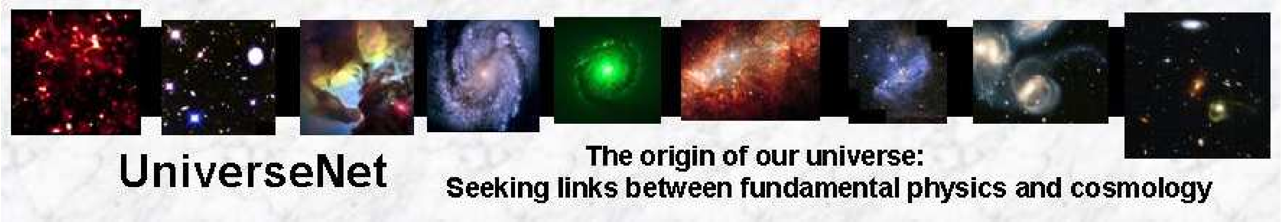


Outline

- Motivation: String Inflation in 4 dimensions

- Closed Bosonic String in Graviton, Dilaton and Tachyon Backgrounds; a non – perturbative configuration

- Conformal Invariance of this model

- Cosmological Implications of this model: FRW universe & inflation (under conditions)

- Open Issues: Exit from the inflationary phase; reheating

Motivation

Inflation:

• elegant & simple idea

• explains many cosmological observations (e.g. "horizon problem", large - scale structure)

Inflation in String Theory:

• effective theory

• in traditional string theories: compactification of extra dimensions of space-time is needed

• other models exist too, but no longer "simple & elegant"

Proposal

- Closed Bosonic String
- graviton, **dilaton** and **tachyon** background
- field configuration non-perturbative in α'

$$
\begin{aligned}
g_{\mu\nu} &= \frac{A}{(X^0)^2}\eta_{\mu\nu} \\
\phi &= \phi_0 \ln\left(\frac{X^0}{\sqrt{\alpha'}}\right) \\
T &= \tau_0 \ln\left(\frac{X^0}{\sqrt{\alpha'}}\right)
\end{aligned}
$$

Does it satisfy conformal invariance conditions?

Conformal properties of the configuration

General field redefinition: $g^i \;\rightarrow\; \tilde{g}^i \equiv g^i + \delta g^i$

- Theory is invariant
- The Weyl anomaly coefficients transform:

$$\beta^i \;\rightarrow\; \tilde{\beta}^i$$

$$\tilde{\beta}^i = \beta^i + \delta g^j \frac{\delta \beta^i}{\delta g^j} - \beta^j \frac{\delta(\delta g^i)}{\delta g^j}$$

$$\left(\begin{array}{l} g^i = (\, g_{\mu\nu},\; \phi,\; T \,) \\ \beta^i = (\, \beta^g_{\mu\nu},\; \beta^\phi,\; \beta^T \,) \end{array} \right)$$

Conformal properties of the configuration

• 1-loop beta-functions: homogeneous dependence on X^0, besides one term in the tachyon beta-function

$$\beta^g_{00} = -\frac{\alpha'}{(X^0)^2}(D-1+\tau_0^2)$$

$$\beta^g_{ij} = -\frac{\alpha'\delta_{ij}}{(X^0)^2}(D-1+2\phi_0)$$

$$\beta^\phi = \frac{D-26}{6} + \frac{\alpha'}{2}(D-1+2\phi_0)\frac{\phi_0}{A}$$

$$\beta^T = -2T + \frac{\alpha'}{2}(D-1+2\phi_0)\frac{\tau_0}{A}$$

• Power counting → Every other term that appears at higher loops in the beta-functions is homogeneous

Conformal properties of the configuration

One can find a general field redefinition, that:

1. Doesn't change the ***X***^{0} - dependence of the fields
2. Cancels the inhomogeneous term in β^T
3. Only adds new homogeneous terms to the beta functions

$$\tilde{\beta}^g_{00} = \frac{\tilde{E}_1}{(X^0)^2}$$

$$\tilde{\beta}^g_{ij} = \frac{\tilde{E}_2}{(X^0)^2}\delta_{ij}$$

$$\tilde{\beta}^\phi = \tilde{E}_3$$

$$\tilde{\beta}^T = \tilde{E}_4$$

Enough freedom in the parameters of the redefinition to make the Weyl – anomaly coefficients vanish

Conformal properties of the configuration

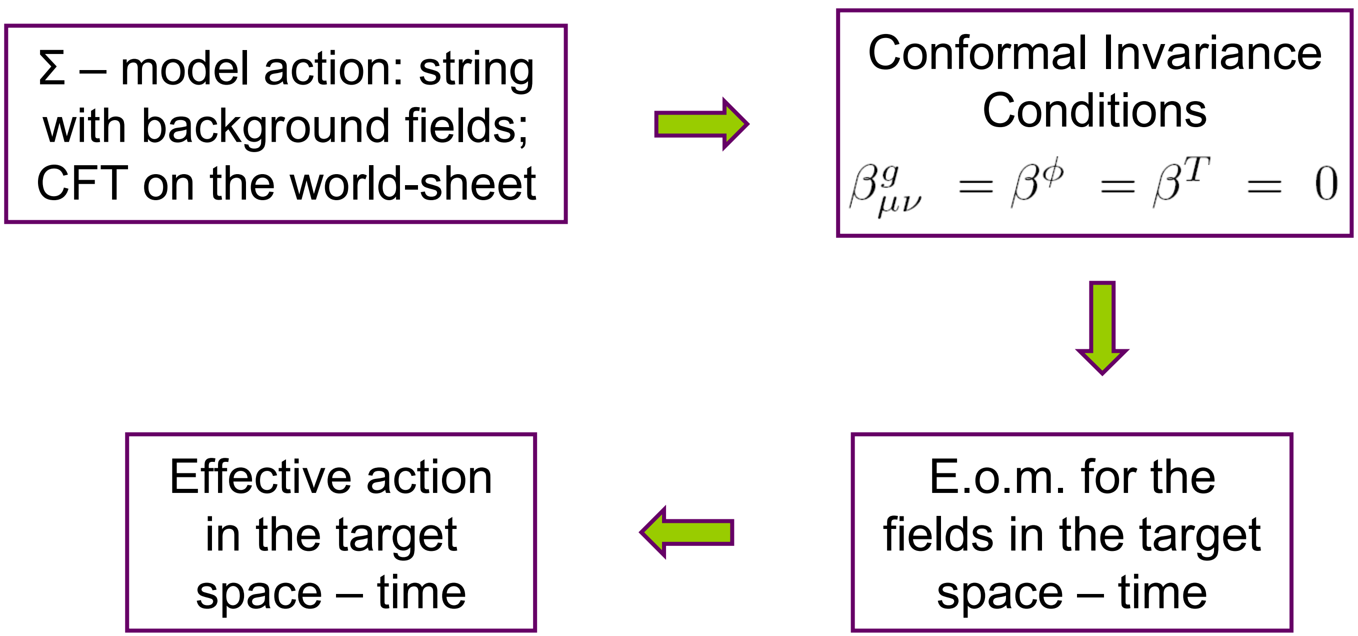
Analysis can be repeated order-by-order, to all orders in α′

→ **Conformal Invariance to all orders in α′**

Cosmology

• So far we checked that our configuration satisfies conformal invariance of the theory

• To study the cosmological implications of this model we need to study the space – time effective theory



Effective action

"*Sigma–model frame*" (to lowest order in the derivative expansion):

$$S^{\sigma} = \int d^D x \sqrt{-g} e^{-2\phi} \left\{ \frac{D-26}{6\alpha'} + f_0(T) + f_1(T) R + f_2(T)\partial_\mu \phi \partial^\mu \phi + f_3(T)\partial_\mu T \partial^\mu T + f_4(T)\partial_\mu T \partial^\mu \phi \right\}$$

$$\int d^D x \sqrt{-g} e^{-2\phi} f_1(T) R$$

(Einstein – Hilbert term)

need to pass to the "*Einstein frame*"

$$g_{\mu\nu} \rightarrow g^E_{\mu\nu} = e^{\omega(\phi,T)} g_{\mu\nu}$$

$$\omega(\phi,T) = \frac{-4\phi + 2\ln f_1(T)}{D-2}$$

$$S^E \sim \int d^D x \sqrt{-g^E} \left[R^E + \ldots \right]$$

Sigma-model frame

metric configuration: $g_{\mu\nu} = \frac{A}{(x^0)^2}\eta_{\mu\nu}$

$$ds^2 = \frac{A}{(x^0)^2}\left(dx^0\right)^2 - \frac{A}{(x^0)^2}\delta_{ij}dx^i dx^j$$

$$\left.\begin{aligned} y^0 &= -\sqrt{A}\ln\frac{x^0}{\sqrt{\alpha'}} \\ x^i &\rightarrow \sqrt{\frac{A}{\alpha'}}x^i \end{aligned}\right\}$$

$$ds^2 = (dy^0)^2 - e^{2y^0/\sqrt{A}}(d\mathbf{x})^2$$

$$\boxed{\begin{aligned} a(y^0) &= e^{y^0/\sqrt{A}} \\ H &= \frac{1}{\sqrt{A}} \end{aligned}}$$

Einstein Frame

$$\begin{cases} ds^2 \equiv dt^2 - a^2(t)d\mathbf{r}^2 = e^{\omega}\left[(dy^0)^2 - e^{2y^0/\sqrt{A}}(d\mathbf{x})^2\right] \\ \omega(\phi, T) = \dfrac{-4\phi + 2\ln f_1(T)}{D-2} \end{cases}$$

Cosmology can be derived from here $\rightarrow$

$$t = t(y^0) = \cdots$$

$$a(t) = \cdots$$

Important role:

- Form of the function $f_1(T)$
- Form of the configuration $\phi(y^0),\ T(y^0)$
- For us: $\phi(y^0) = -\phi_1 y^0/\sqrt{A}, \quad -T(y^0) = -\tau_1 y^0/\sqrt{A}$

Einstein Frame: "Eternal" Inflation

- **choice for f_1 :**

$$f_1(T) = e^{-T}$$

$$e^{\omega} = \exp\left[\frac{2(2\phi + T)}{2 - D}\right] = \exp\left[\frac{2(2\phi_1 + \tau_1)}{D - 2}\frac{y^0}{\sqrt{A}}\right]$$

If $2\phi_1 + \tau_1 = 0$ → Einstein frame ≡ Sigma – model frame

Inflation (in both frames)

$$a(t) = a_0 \exp\left(\frac{t}{\sqrt{A}}\right)$$

Einstein Frame: Power-law expansion

• **choice for f_1 :**

$$f_1(T) = e^{-T}$$

$$e^{\omega} = \exp\left[\frac{2(2\phi + T)}{2 - D}\right] = \exp\left[\frac{2(2\phi_1 + \tau_1)}{D - 2}\frac{y^0}{\sqrt{A}}\right]$$

If $2\phi_1 + \tau_1 \neq 0$ →

Power-law expansion in the Einstein frame

$$a(t) \propto t^{1+(\phi_1+\tau_1/2)^{-1}}$$

$2\phi_1 + \tau_1 > 0$ → no horizons

Exit from "eternal" inflation?

Is there a way to exit from the "eternal" inflation era, and enter a power-law expansion (or even Minkowski) era?

- Different choices for f_1 will give different cosmologies

  We can even find solutions in which the scale factor interpolates between an exponential and a power-law expansion

- The condition $2\phi_1 + \tau_1 = 0$ has to be disturbed

  for example: (yet unknown) mechanism which makes the tachyon field decay to zero

Stability of the model

Effective action in the Einstein frame:

$$\int d^D x \sqrt{-g} \Bigg\{ R - \left[\frac{4(D-1)}{D-2} - e^{\frac{4\phi}{D-1}} \left(f_1(T)\right)^{-\frac{D}{D-2}} f_2(T) \right] \partial\phi \cdot \partial\phi$$

$$- \left[\frac{D-1}{D-2} \left(\frac{f_1'(T)}{f_1(T)} \right)^2 - e^{\frac{4\phi}{D-1}} \left(f_1(T)\right)^{-\frac{D}{D-2}} f_3(T) \right] \partial T \cdot \partial T$$

$$+ \left[\frac{D-1}{D-2} \frac{4 f_1'(T)}{f_1(T)} + e^{\frac{4\phi}{D-1}} \left(f_1(T)\right)^{-\frac{D}{D-2}} f_4(T) \right] \partial\phi \cdot \partial T$$

$$+ e^{\frac{4\phi}{D-1}} \left(f_1(T)\right)^{-\frac{D}{D-2}} \left[\frac{D-26}{6\alpha'} + f_0(T) \right] \Bigg\}$$

- dilaton and tachyon kinetic terms: right sign (no ghost fields)
- important role of f_1 for vacuum energy and tachyon potential

Summary & Conclusions

- Started from an α´-non-perturbative configuration for graviton, dilaton and tachyon backgrounds of a closed bosonic String Theory

- Showed that it is consistent with conformal invariance conditions to all oders in α´

- Studied the Cosmological implications of this model (in the Einstein frame) and found that a de-Sitter Universe is possible

- Also found a power-law expanding universe, that can be chosen to be free of horizons

Open Issues & Outlook

- "Eternal" inflation universe is characterized by cosmic horizons → S–matrix not well defined (problem for perturbative String Theory!)

- The dilaton-tachyon "anti-alignment" requirement spans a zero-density subspace in the space of theories. Thus, the "eternal" inflation model can be viewed as a classical model, which in String theory represents a Cosmological Constant dominating vacuum

- Exit from this classical phase? (for example: (yet unknown) mechanism which makes the tachyon field decay to zero)

- Reheating?

- Contact with phenomenology…

Thank you