Non-local cosmology from String Field Theory and cosmological perturbations

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Mainly based on JHEP 02 (2007) 041, `hep-th/0605085` **by I.Ya. Aref'eva, A. K.,**
JHEP 04 (2007) 029, `hep-th/0701103` **by A. K.**
JHEP 0908 (2008) 068, `arXiv:0804.3570`**, by I.Ya. Aref'eva, A. K.**
and `arXiv:0903.5176` **by A. K. and S. Vernov**

Plan

- **Motivations**
- **Open String Field Theory and Cosmology**
- **Background**
- **Perturbations**
- **Summary and Outlook**

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Motivations

String Field Theory is the UV-complete theory

Non-locality is the key point of UV completion.

Novel observationally distinguishable effects are found in application to Inflation and Dark Energy.

Barnaby, Biswas, Calcagni, Cline, Kamran, Lidsey, Nunes, . . .

Phantom phase and phantom divide crossing are easily obtained.

Aref'eva, Joukovskaya, A. K., Vernov

- Motivations
- **Open String Field Theory and Cosmology**
  - Rolling tachyon in flat background
  - Rolling tachyon in curved background
  - Mathematical aspects
  - Non-local $\leftrightarrow$ local equivalence
- Background
- Perturbations
- Summary and Outlook

SFT Tachyon

Tachyon effective action $(\alpha' = 1)$

$$S = \frac{1}{g_4^2}\int d^4x\sqrt{-\eta}\left(\frac{1}{2}T\mathcal{F}(\Box)T - \frac{1}{p+1}T^{p+1}(x)\right)$$

Cubic Fermionic SFT: $\mathcal{F}(z) = \left(\xi^2 z + 1\right) e^{-\frac{1}{4}z}$, $\xi^2 \approx 0.9556$, $p = 3$

Aref'eva, Belov, A.K., Medvedev, NPB638 (2002) 3

Tachyon EOM looks very simple: $\mathcal{F}T = T^p$

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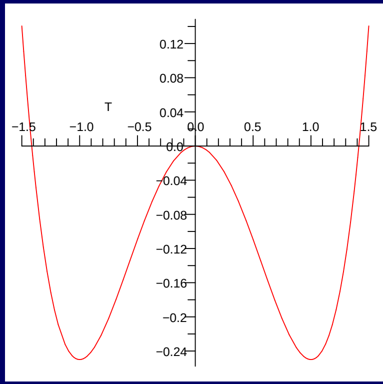

Tachyon potential (odd p)

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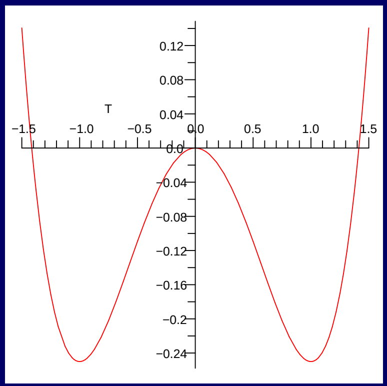

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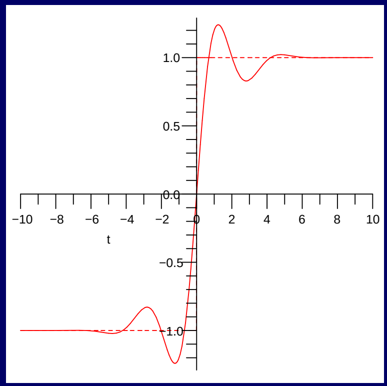

Rolling solution

Aref'eva, Joukovskaya, A.K., JHEP 09 (2003) 012

Late time tachyon spectroscopy

We consider a generalization:

- $\mathcal{F}(z)$ **is analytic at** 0**, i.e.** $\mathcal{F}(z) = c_n z^n$**,** $\mathcal{F}(0) = 1$**,** $c_n \in \mathbb{R}$
- **Any analytic in** T **potential** $V(T)$
- **Curved metric** g

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Our expectation:

Tachyon rolls down to the minimum and is expected to stop at the bottom in infinite time

$$T = 1 - \psi \Rightarrow S_\psi = \frac{1}{g_4^2}\int d^4x\sqrt{-g}\left(\frac{1}{2}\psi\mathcal{F}(\Box_g)\psi - \frac{V''(1)}{2}\psi^2\right)$$

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EOM: $(\mathcal{F} - V''(1))\psi = 0$

If $\Box_g\psi = \omega^2\psi$ **and** $\mathcal{F}(\omega^2) = V''(1)$ **then**

this ψ **solves the equation of motion**

Mathematical aspects

Ostrogradski statement (1850): local theory with more than two derivatives is equivalent to a theory with extra degrees of freedom some of which are either ghosts or tachyons (or both).

The violation of the Ostrogradski statements for infinite derivatives theories was noted a long time ago. Lalesco (1908), Davis (1931)

Weierstrass product:

$$\mathcal{F}(z) = z^m e^{g(z)} \prod_{k=1}^{\infty} (z - z_k)\,.$$

Example: $z - m^2$ and $(z - m^2)e^{\beta z}$ have identical sets of roots and therefore corresponding propagators have the same sets of poles.

Mathematical aspects of the equations with infinitely many derivatives were studied in the mathematical literature. Davis, Carmichael, Carleson

Non-local ↔ local equivalence

The non-local model

$$S=\int d^4x\sqrt{-g}\left(\frac{R}{16\pi G_N}+\frac{1}{2g_4^2}\psi\mathcal{F}(\Box_g)\psi-\Lambda\right)$$

is equivalent to the local one

$$S_{local}=\int d^4x\sqrt{-g}\left(\frac{R}{16\pi G_N}+\frac{1}{2g_4^2}\sum_i\mathcal{F}'_{,M}(M_i)\left(-g^{\mu\nu}\partial_\mu\psi_i\partial_\nu\psi_i-M_i\psi_i^2\right)-\Lambda\right)$$

Here M_i are the roots of the characteristic equation $\mathcal{F}(M)=0$.

This equivalence is background independent.

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Background

$$3H^2 = 4\pi G \sum_i \mathcal{F}'_{,M}(M_i)\left(\dot{\psi}_i^2 + M_i\psi_i^2\right) + 8\pi G_N \Lambda$$
$$\dot{H} = -4\pi G \sum_i \mathcal{F}'_{,M}(M_i)\dot{\psi}_i^2$$
$$\ddot{\psi}_i + 3H\dot{\psi}_i + M_i\psi_i = 0$$

We use $G = G_N/g_4^2$ **and** $8\pi G_N = 1/M_P^2$

Corrections to the background solution without tachyon is an oscillating function

$$\psi = \alpha e^{-rt}\cos(\nu t + \varphi), \quad a = a_0 e^{H_0 t} + \frac{e^{(H_0-2r)t}}{g_4^2 M_P^2}\left(s\sin(2\nu t) + c\cos(2\nu t)\right)$$

where $r + i\nu = \frac{3}{2}H_0 \pm \sqrt{\frac{9}{4}H_0^2 - M}$, $H_0 = \sqrt{\frac{\Lambda}{3M_P^2}}$

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- **Dilaton and open-closed strings coupling**
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Perturbations

Thanks to non-local $\leftrightarrow$ local equivalence perturbations in the linearized system are fully equivalent to the perturbations in the local model with many scalar fields. **A.K., Vernov**

$$\ddot{\zeta}_{ij}+\left(3H+\frac{\ddot{\psi}_i}{\dot{\psi}_i}+\frac{\ddot{\psi}_j}{\dot{\psi}_j}\right)\dot{\zeta}_{ij}+\left(-3\dot{H}+\frac{k^2}{a^2}\right)\zeta_{ij}=$$

$$=\left(\frac{M_i\psi_i}{\dot{\psi}_i}-\frac{M_j\psi_j}{\dot{\psi}_j}\right)\left(\sum_m\frac{\mathcal{F}'_{,M}(M_m)\dot{\psi}_m^2}{\varrho+p}(\dot{\zeta}_{im}+\dot{\zeta}_{jm})+\frac{2}{1+w}\varepsilon\right)$$

$$\ddot{\varepsilon}+\dot{\varepsilon}H(2+3c_s^2-6w)+\varepsilon\left(\dot{H}(1-3w)-15H^2w+9H^2c_s^2+\frac{k^2}{a^2}\right)=$$

$$=\frac{k^2}{a^2}\frac{1}{\varrho}\frac{2}{\varrho+p}\sum_{m,l}\mathcal{F}'_{,M}(M_m)\mathcal{F}'_{,M}(M_l)M_m\psi_m\dot{\psi}_m\dot{\psi}_l^2\zeta_{ml}.$$

We have shown that thanks to special structure of the local fields perturbations <u>do not grow</u> despite the fact that phantom phase exists during the evolution.

Summary

- **Non-local action with a general operator $\mathcal{F}$ is analyzed and its linearization near a non-perturbative vacuum is studied.**
- **Mathematical aspects of specific non-local actions are reviewed and an equivalence to a local model in the linearized theories is established.**
- **It is shown that the tachyon scalar field generates crossing of the phantom divide in the cosmological constant background. This crossing is periodic.**
- **Equations for perturbations are presented and it is argued that linear perturbation do not grow.**

Thank you!