Non-local SFT Tachyon and Cosmology

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Mainly based on JHEP **02** (2007) 041, `hep-th/0605085` by I.Ya. Aref'eva, A. K.
and JHEP **04** (2007) 029, `hep-th/0701103` by A. K.

Plan

- Overview of the problem
  - Cosmological motivations
  - Problems and challenge
  - Why String Field Theory?
- Tachyon spectroscopy
- Infinitely many scalars vs. the non-locality
- Emergence of a phantom
- Real Cosmology
- Comments, Summary and Outlook

Cosmological motivation

- Data on Ia supernovae
- Galaxy clusters measurements
- WMAP

} Universe exhibits an accelerated expansion

Equation of state: $p = w\rho, \qquad w < 0$ — Dark Energy

$$w = -1.06^{+0.13}_{-0.08}$$

Perlmutter et. al., 1999
Riess et. al., 2004
Spergel et. al., 2006

Theoretical issues

- $w > -1$ — Quintessence models
- $w = -1$ — Cosmological constant
- $w < -1$ — Phantom models

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$(1+3)$ dimensional spatially flat FRW universe,

$$ds^2 = -dt^2 + a(t)^2 d\vec{x}^2$$

Theoretical problems

- Just a cosmological constant has no theoretical explanation so far
- It is difficult to cook a Phantom divide ($w = -1$) crossing.
- $w = \mathrm{const} < -1 \Rightarrow$ Big Rip singularity.
- Phantoms (ghosts) being physical particles look harmful for the theory.
- There are signals that w changes with time.

Challenge

We need a dynamical model of Dark Energy which might be able to cross the Phantom divide.

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Proposal

Derive a scalar field model of Dark Energy starting from initially reliable theory with (probably) non-local interaction for this scalar field.

SFT (p-adic) Tachyon

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

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

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, NP**B638** (2002) 3

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

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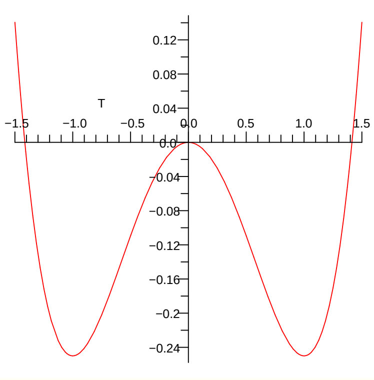

Tachyon potential (odd p)

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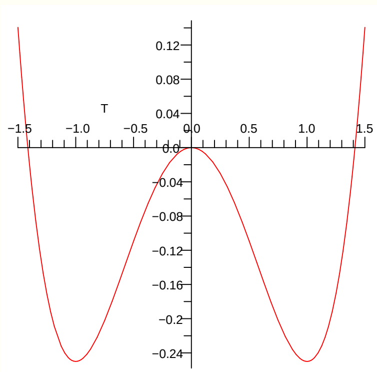

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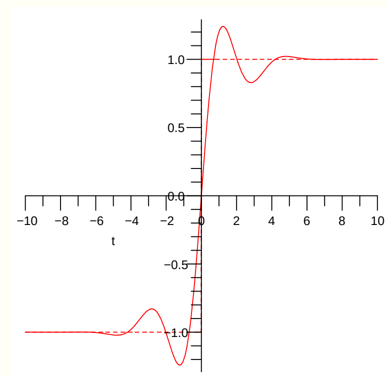

Rolling solution

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

Good points of SFT

- The theory is UV complete
- Quantum computations in p-adic action ($\xi = 0$) can be carried out analytically up to all orders and the resulting finite effective action can be constructed
- The interaction is non-local thus giving a chance for the Phantom divide crossing

Minimal coupling to gravity

$$S = \int dx\sqrt{-g}\left(\frac{R}{2\kappa^2} + \frac{1}{g_4^2}\left(\frac{1}{2}\Phi\mathcal{F}(\Box_g)\Phi - \frac{1}{p+1}\Phi^{p+1}(x) - \frac{p-1}{2(p+1)} - \tau\right)\right)$$

- $\kappa^2 = 8\pi G = \frac{1}{M_P^2}$
- τ is a correction to the brane tension dictated by an existence of the rolling solution

  Aref'eva, `astro-ph/0410443`; Aref'eva, A.K., Vernov, `astro-ph/0412619`

- τ is expected to be generated through coupling to closed string excitations
- We introduce $\Lambda = \frac{\tau}{g_4^2}$ (to be discussed later)

Late time tachyon spectroscopy

We consider a generalization:

- $\mathcal{F}(z)$ is analytic in $\mathbb{C}$, i.e. $\mathcal{F}(z) = c_n z^n$, $\mathcal{F}(0) = 1$, $c_n \in \mathbb{R}$
- Any $p > 1$

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

$$\Phi = 1 - \psi \Rightarrow S_\psi = \frac{1}{g_4^2}\int dx\sqrt{-g}\left(\frac{1}{2}\psi\mathcal{F}(\Box_g)\psi - \frac{p}{2}\psi^2 - \tau\right)$$

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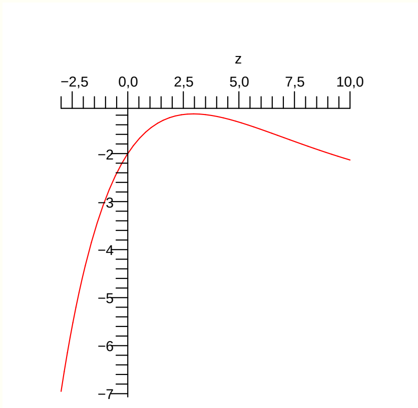
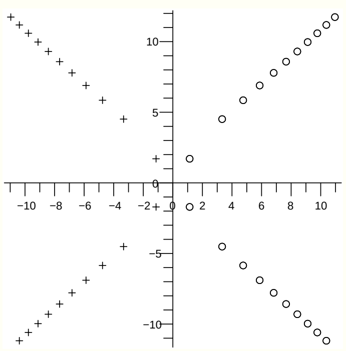


$\mathcal{F}(z) - p$ in CSSFT

EOM: $(\mathcal{F} - p)\psi = 0$

Characteristic equation:
$\mathcal{F}(\omega^2) = p$



Roots ω in CSSFT

Infinitely many scalars vs. the non-locality

New action

$$S=\frac{1}{g_4^2}\int dx\sqrt{-g}\frac{1}{2}\sum_k\left(\mathcal{F}'(\omega_k^2)\psi_k(\Box_g-\omega_k^2)\psi_k+\mathcal{F}'(\omega_k^{2*})\bar{\psi}_k(\Box_g-\omega_k^{2*})\bar{\psi}_k\right)$$

- EOMs are manifestly local and linear.
- Sum over k is indefinite until $\mathcal{F}$ is not specified explicitly
- On the solution $\psi_k=\psi_{k+}+\psi_{k-}$ because $\Box_g$ is the second order differential operator

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- Spectrum and Energy momentum tensor are reproduced in this way
- The construction does not depend on a particular metric
- It is consistent to keep only one mode, say ψ_{k+} afterwards

Phantom emergence

Simplest consistent possibility: only single $\psi_{k+} \not\equiv 0$

We put $\psi = \alpha + i\beta$, $\omega^2 = M + iN$, $\mathcal{F}'(\omega^2) = x + iy$

Action for fields α and β becomes

$$S = \frac{1}{g_4^2} \int dx \sqrt{-g} \left(\alpha (x\mathcal{D} - xM + yN)\alpha - \beta (x\mathcal{D} - xM + yN)\beta - \right.$$
$$\left. -2\alpha (y\mathcal{D} - yM - xN)\beta \right).$$

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- For any signs of parameters one normal and one phantom field present in the system
- Only field α is physical one since $\alpha = \frac{\psi+\psi^*}{2}$
- $N \neq 0$ because there are no real roots
- $M,\ x,\ y$ are not restricted but at least one of x or y is non-zero

This action may serve as a toy model for the tachyon around its vacuum.

Tachyon at large times must have phantom properties

Cosmological scenarios

$$S = \int dx \sqrt{-g} \left(\frac{R}{2\kappa^2} + \frac{1}{g_4^2} \left(\frac{1}{2} \psi \mathcal{F}(\Box_g) \psi - \frac{p}{2} \psi^2(x) \right) - \Lambda \right)$$

Using the developed machinery we pass to a local theory with many scalars and under an assumption that only one specific mode $\psi_{k+} \not\equiv 0$ one has as first approximation

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

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

For $r = H_0/2$ oscillations in $a(t)$ will not die despite the fact that oscillations in Φ vanish.

Cosmological properties

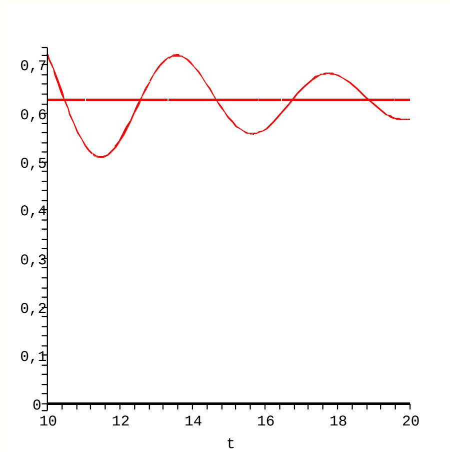
Generic parameters, i.e. not necessarily $r = H_0/2$.

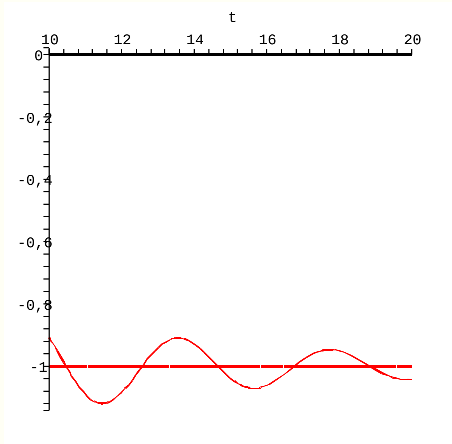
Hubble parameter

$$H = \frac{\dot{a}}{a}$$

Total effective state parameter

$$w = -1 - \frac{2}{3}\frac{\dot{H}}{H^2}$$





Quintessence and Phantom phases change one each other.

No Big Rip singularity

Crossing of the phantom divide

Comments on Λ

- Λ is important to have non-trivial solutions.
- On the other hand, $\Lambda \neq 0$ is the must for the existence of a rolling solution.
- Λ is expected to be generated dynamically through the open-closed strings coupling.
- Moreover, its value is estimated to be a realistic one, e.g. giving the Hubble parameter $\sim 10^{-60} M_P$.

Summary

- Non-local action with a general operator $\mathcal{F}$ is analyzed and a local formulation for a linearization near a non-perturbative vacuum is given.
- The energy and pressure can be easily computed for a general function $\mathcal{F}$ without specifying its explicit form as well as an arbitrary metric.
- It is shown that tachyon scalar field generates a crossing of the phantom divide in the cosmological constant background. This crossing is periodic one and a condition of non-vanishing oscillations is formulated.
- There is no Big Rip singularity in the model.

Further directions

- Coupling to dilaton. A.K., in progress
- Coupling to vector field etc.
- Proof of stability of found solutions
- Cosmological perturbations of theories with infinitely many derivatives
- Numeric and may be analytic solution to full equations

- As well as many other questions

Thank you!