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**
- **Summary and Outlook**

Cosmological motivation

- **Data on Ia supernovae**
- **Galaxy clusters measurements**
- **WMAP**

} **Universe exhibits an accelerated expansion**

Equation of state: $p = w\rho,$ $w < 0$ — **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**

Our universe is known to be homogeneous, isotropic and with high accuracy spatially flat.

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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.**
- $w =$ **const** $< -1 \Rightarrow$ **Big Rip singularity.**
- **Phantoms (ghosts) being physical particles look harmful for the theory.**
- **It is possible 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, NPB638 (2002) 3

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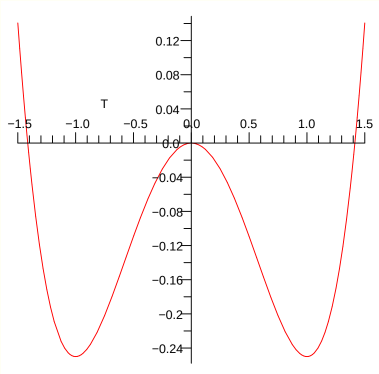

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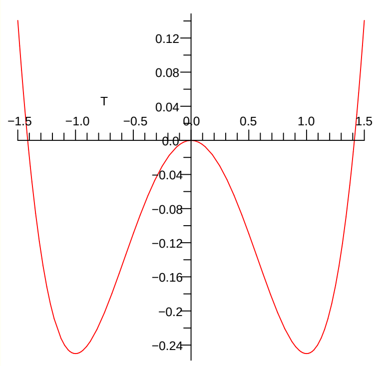

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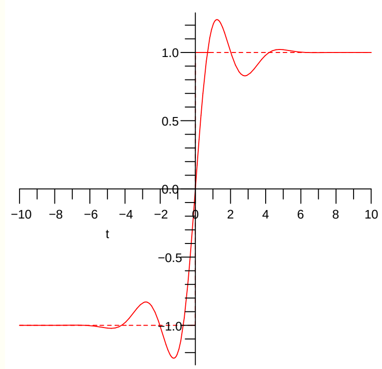

Rolling solution

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**

  Brekke, Freund, Olson, Witten, 1988
- **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** $\Lambda = \frac{\tau}{g_4^2}$. **Its value can be adjusted to a realistic one, e.g. giving the Hubble parameter** $\sim 10^{-60} M_P$.

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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Our expectation:
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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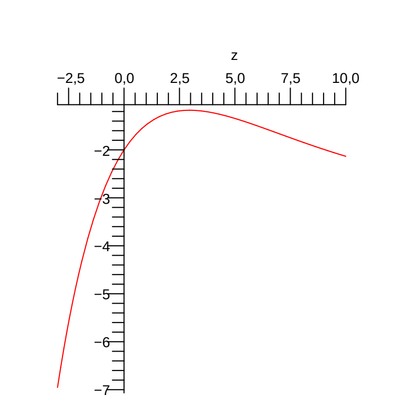


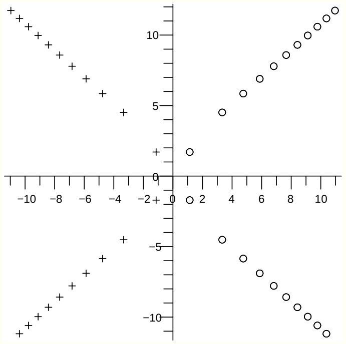
$\mathcal{F}(z) - p$ **in CSSFT**

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**

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

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- **For any signs of parameters one normal and one phantom field present in the system** **Ostrogradski, 1850**
- **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

$$\psi=\alpha e^{-rt}\cos(\nu t+\varphi)$$

$$a=a_0e^{H_0t}+\frac{e^{(H_0-2r)t}}{g_4^2M_P^2}\left(s\sin(2\nu t)+c\cos(2\nu t)\right)$$

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

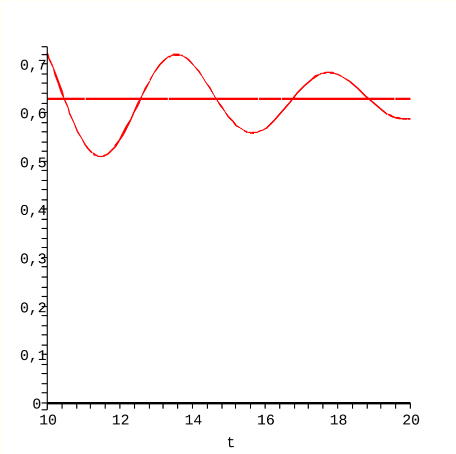
For $r=H_0/2$ oscillations in $a(t)$ will not die despite the fact that oscillations in Φ vanish.

Cosmological properties

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

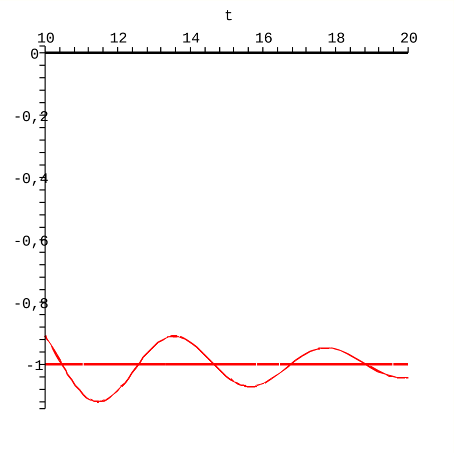
Hubble parameter

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



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

Summary

- **Rolling SFT tachyon is a reliable candidate for the Dark Energy**

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- **Rolling SFT tachyon is a reliable candidate for the Dark Energy**
- **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!