Cosmological Signature of Tachyon Condensation

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Plan

- Overview of the problem

- Open String Field Theory and Cosmology

- Dilaton and open-closed strings coupling

- Cosmological model

- Perturbations

- Summary and Outlook

- **Overview of the problem**

  – **Observational facts**
  – **Problems and challenges**

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Observational facts

- Data on Ia supernovae
- Galaxy clusters mea-
  surements
- WMAP

Universe exhibits
an accelerated expansion

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

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

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

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

$$w = -1^{+0.14}_{-0.11}$$

Komatsu et. al., 2008

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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- Just a cosmological constant has no theoretical explanation so far

- A Phantom divide ($w = -1$) crossing is not excluded.

- Phantoms (ghosts) being physical particles look harmful for the theory.

- Varying with time w is not exluded.

Challenge

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Proposal

Derive a model of Dark Energy starting from the initially reliable theory.
We will give a try to String Field Theory.

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- **Open String Field Theory and Cosmology**

  - **Rolling tachyon in flat background**
  - **Rolling tachyon in curved background**

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SFT Tachyon

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

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

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**

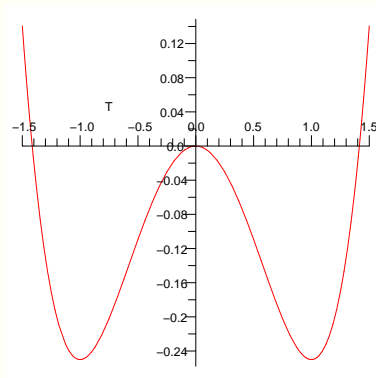**Tachyon EOM looks very simple:** $\mathcal{F}T = T^p$

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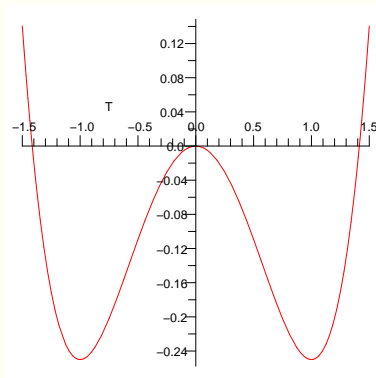

Tachyon potential (odd p)

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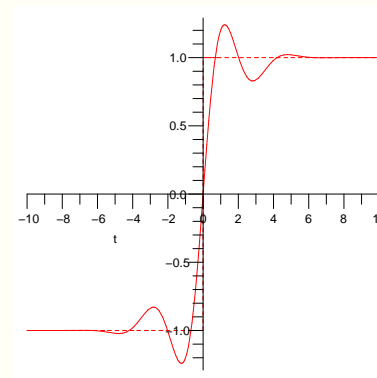
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Tachyon potential (odd p)   **Rolling solution**

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

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

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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

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Coupling to Dilaton

$$S = \int dx \sqrt{-g} \left(\frac{e^{-\Phi}}{2\kappa^2} \left(R + \partial_\mu \Phi \partial^\mu \Phi - g_u U(\Phi) \right) + \frac{e^{-\Phi/2}}{g_4^2} \left(-\frac{g^{\mu\nu}}{2} \partial_\mu T \partial_\nu T + \frac{T^2}{2\alpha'} - \frac{\widehat{V(\tilde{T})}}{\alpha'} \right) \right)$$

where $\hat{\tilde{\varphi}} = \varphi$.

Perform a linearization around the tachyon vacuum and take constant dilaton.

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

Λ can be non-zero only if both tachyon and dilaton are in the game.

Cosmological model

Take SFT motivated non-local operator $\mathcal{F} = (\alpha' \Box_g + 1)e^{\beta \alpha' \Box_g}$.

Consider $V''(1) = 1$, so that the whole potential $\frac{\psi^2}{2} - \frac{V''(1)}{2}\psi^2$ has zero second derivative in the minimum.

It is a special case when string scales disappear.

Corrections to a background solution without tachyon is an oscillating function

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

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

One finds $\omega^2 = \frac{\sigma^2 H_0^2}{1+\beta}$ for $\beta \neq -1$ and $\omega^2 \approx \frac{\sigma^2 H_0^2}{1+\beta}$ for $\beta \neq -1$

Taking $\beta = -0.95$ and $\sigma = 1.1$ out of SFT we get
a period of oscillations of order 1 **Gyr**.

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Perturbations

We take a standard procedure and write down perturbation equations in gauge invariant variables.

We get a system of two coupled linear but non-local equations on the Bardeen potential Φ and ζ which is a gauge invariant perturbation of the scalar field ψ.

The complexity of the equations is mainly determined by the background solution chosen but in any case a help of numeric methods is inevitable.

It is possible to show that thanks to non-local operators entering the equations perturbations do not grow despite the fact that phantom phase exists during the evolution.

A.K., Vernov, almost completed work

The latter behavior is different from the canonical local scalar field models where growing modes exist in some regimes (for some domains of the wavenumber k).

Summary

- Non-local action with a general operator $\mathcal{F}$ is analyzed and a its linearization near a non-perturbative vacuum is studied.

- It is shown that tachyon scalar field coupled to a dilaton generates crossing of the phantom divide in the cosmological constant background. This crossing is periodic.

- Period of oscillations is intriguingly close to oscillations in the distribution of quasar spectra reported to be $(0.15 - 0.65)$ **Gyr**

  Ryabinkov, Kaminker, Varshalovich, 2007

- Perturbations are briefly reviewed and it is argued that linear perturbation do not grow.

Thank you!