Title: Accelerating Universe from Cubic String Field Theory

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Abstract:

Accelerating Universe from String Field Theory

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CTC

Novel Theories of the Early Universe, March 6, 2008

Motivation / Introduction

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A. Sen, JHEP, 04 (2002) 048
G.W. Gibbons, Phys. Lett. B 537 (2002) 1,
Class. Quant. Grav. 20 (2003) S321

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J.E. Lidsey, Phys. Rev.D, 2007
L.J., Phys. Rev.D, 2007
N. Barnaby, J.M. Cline, JCAP, 2007; arXiv: 0802.3218

Model / Minkowski case

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$$S = \int d^4x \left(\frac{m_p^2}{2} R + \frac{1}{2}\phi \Box_g \phi + \frac{1}{2}\phi^2 - \frac{\lambda}{3}\Phi^3 - \Lambda' \right)$$

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where $\lambda = \frac{3^{9/2}}{2^6} \approx 2.19$, $\Lambda' = (6\lambda^2)^{-1}$, ϕ is a dimensionless scalar field, $\Phi = e^{k\Box_g}\phi$, $k = \frac{\ln\lambda}{3} \approx 0.26$, $m_p^2 = g_4 \frac{M_p^2}{M_s^2}$ and $\Box_g = \frac{1}{\sqrt{-g}}\partial_\mu\sqrt{-g}g^{\mu\nu}\partial_\nu$.

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Equation of motion

$$(\Box + 1)e^{-2k\Box}\Phi = \lambda\Phi^2$$

For spatially homogeneous configurations $\Box_g = -\partial^2$.

Stress Tensor

Stress Tensor

Definition

$$T_{\alpha\beta}(x) = \frac{2}{\sqrt{-g}} \frac{\delta S}{\delta g^{\alpha\beta}}$$

The stress tensor takes the form

$$T_{\alpha\beta}(x) = -g_{\alpha\beta} \left(\frac{1}{2}\phi^2 - \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{\lambda}{3}\Phi^3 - \Lambda' \right) - \partial_\alpha \phi \partial_\beta \phi$$

$$-g_{\alpha\beta}\, k \int_0^1 d\rho \left[(e^{k\rho\Box}\lambda\Phi^2)(\Box e^{-k\rho\Box}\Phi) + (\partial_\mu e^{k\rho\Box}\lambda\Phi^2)(\partial^\mu e^{-k\rho\Box}\Phi) \right]$$

$$+2k \int_0^1 d\rho \, (\partial_\alpha e^{k\rho\Box}\lambda\Phi^2)(\partial_\beta e^{-k\rho\Box}\Phi).$$

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$$+2k\int_0^1 d\rho\,(\partial_\alpha e^{k\rho\Box}\lambda\Phi^2)(\partial_\beta e^{-k\rho\Box}\Phi).$$

Note that here and below integration over ρ understand as limit of the following regularization

$$\int_0^1 d\rho f(\rho) = \lim_{\epsilon_1\to+0}\lim_{\epsilon_2\to+0}\int_{\epsilon_1}^{1-\epsilon_2} d\rho f(\rho).$$

Energy

Energy

The Energy is defined as $E(t) = T^{00}$ and for our model have the form

$$\mathcal{E} = \mathcal{E}_k + \mathcal{E}_p + \Lambda' + \mathcal{E}_{nl1} + \mathcal{E}_{nl2}$$

$$\mathcal{E}_k = \frac{1}{2}(\partial\phi)^2, \quad \mathcal{E}_p = -\frac{1}{2}\phi^2 + \frac{\lambda}{3}\Phi^3$$

$$\mathcal{E}_{nl1} = k\int_0^1 d\rho \left(e^{k\rho\Box}\lambda\Phi^2\right)\left(-\Box e^{-k\rho\Box}\Phi\right),$$

$$\mathcal{E}_{nl2} = -k\int_0^1 d\rho \left(\partial e^{k\rho\Box}\lambda\Phi^2\right)\left(\partial e^{-k\rho\Box}\Phi\right).$$

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$$\mathcal{E}_{nl2} = -k\int_0^1 d\rho \left(\partial e^{k\rho\Box}\lambda\Phi^2\right)\left(\partial e^{-k\rho\Box}\Phi\right).$$

To avoid calculation of $e^{k\rho\Box}$ term which is much harder to compute than $e^{-k\rho\Box}$ $(k > 0)$ as computation of the former results in an ill-posed problem we will use the following representation for nonlocal energy terms E_{nl_1} and E_{nl_2} on the equation of motion for the scalar field

$$\mathcal{E}_{nl1} = k\int_0^1 d\rho \left((\Box + 1)e^{-(2-\rho)k\Box}\Phi\right)\left(-\Box e^{-k\rho\Box}\Phi\right),$$

$$\mathcal{E}_{nl2} = -k\int_0^1 d\rho \left(\partial(\Box + 1)e^{-(2-\rho)k\Box}\Phi\right)\left(\partial e^{-k\rho\Box}\Phi\right).$$

Energy Conservation Theorem / Minkowski case

Energy Conservation Theorem / Minkowski case

Claim.
The Energy

$$E = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}\phi^2 + \frac{\lambda}{3}\Phi^3 + \Lambda' + k\int_0^1 d\rho\ ((-\xi^2\partial^2 + 1)e^{(2-\rho)k\partial^2}\Phi)\overleftrightarrow{\partial}(\partial e^{k\rho\partial^2}\Phi),$$

is conserved on the solutions of equation of motion

$$(-\partial^2 + 1)e^{2k\partial^2}\Phi = \lambda\Phi^2$$

where $A\overleftrightarrow{\partial}B = A\partial B - B\partial A$.

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$$(-\partial^2 + 1)e^{2k\partial^2}\Phi = \lambda\Phi^2$$

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Proof.

$$\frac{dE(t)}{dt} = \xi^2(\partial\phi)\partial^2\phi - \phi\partial\phi + \Phi^3\partial\Phi + k\int_0^1 d\rho((-\xi^2\partial^2 + 1)e^{(2-\rho)k\partial^2}\Phi)\overleftrightarrow{\partial^2}(\partial e^{k\rho\partial^2}\Phi).$$

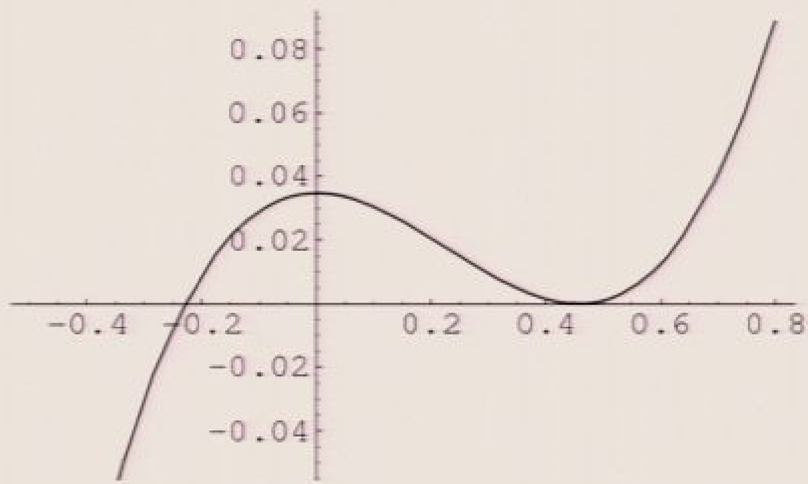
Using following identity

$$\int_0^1 d\rho(e^{\rho\partial^2}\varphi)\overleftrightarrow{\partial^2}(e^{(1-\rho)\partial^2}\phi) = \varphi\overleftrightarrow{e^{\partial^2}}\phi,$$

equation of motion and field Φ definition, we have

$$\frac{dE(t)}{dt} = \xi^2(\partial\phi)\partial^2\phi - \phi\partial\phi + \Phi^3\partial\Phi - \partial\Phi\overleftrightarrow{e^{k\partial^2}}((-\xi^2+1)e^{k\partial^2}\Phi) = \partial\Phi\left[\Phi^3 - (-\xi^2\partial^2 + 1)e^{2k\partial^2}\Phi\right] = 0$$

Rolling tachyon solution



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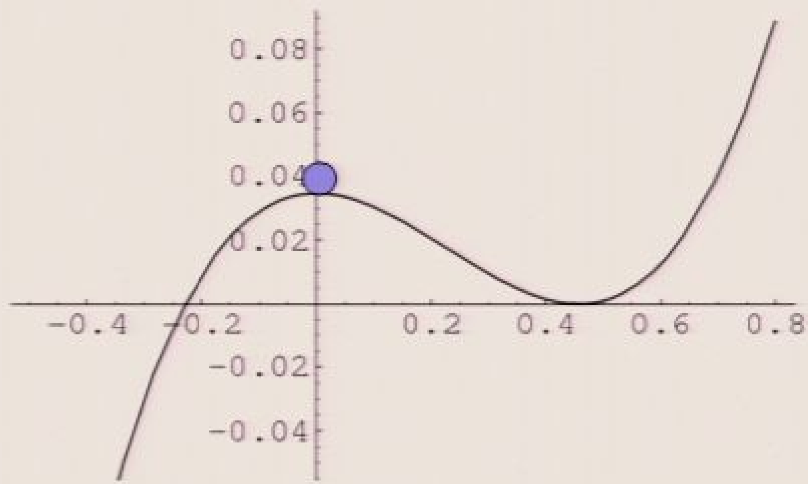

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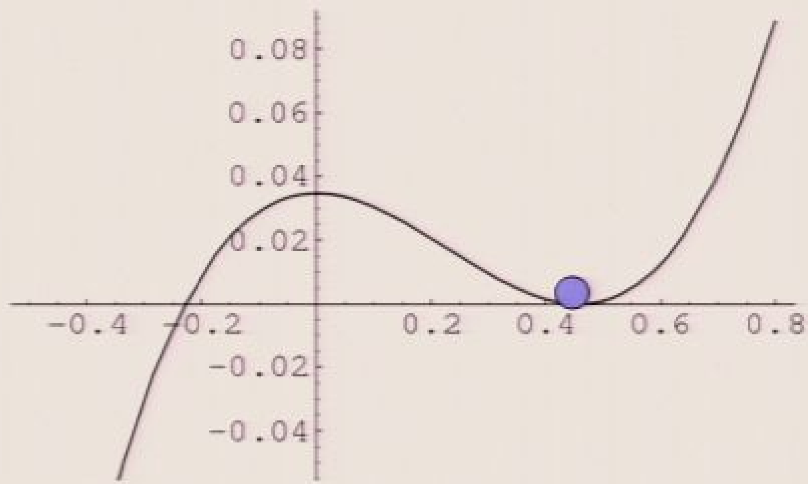
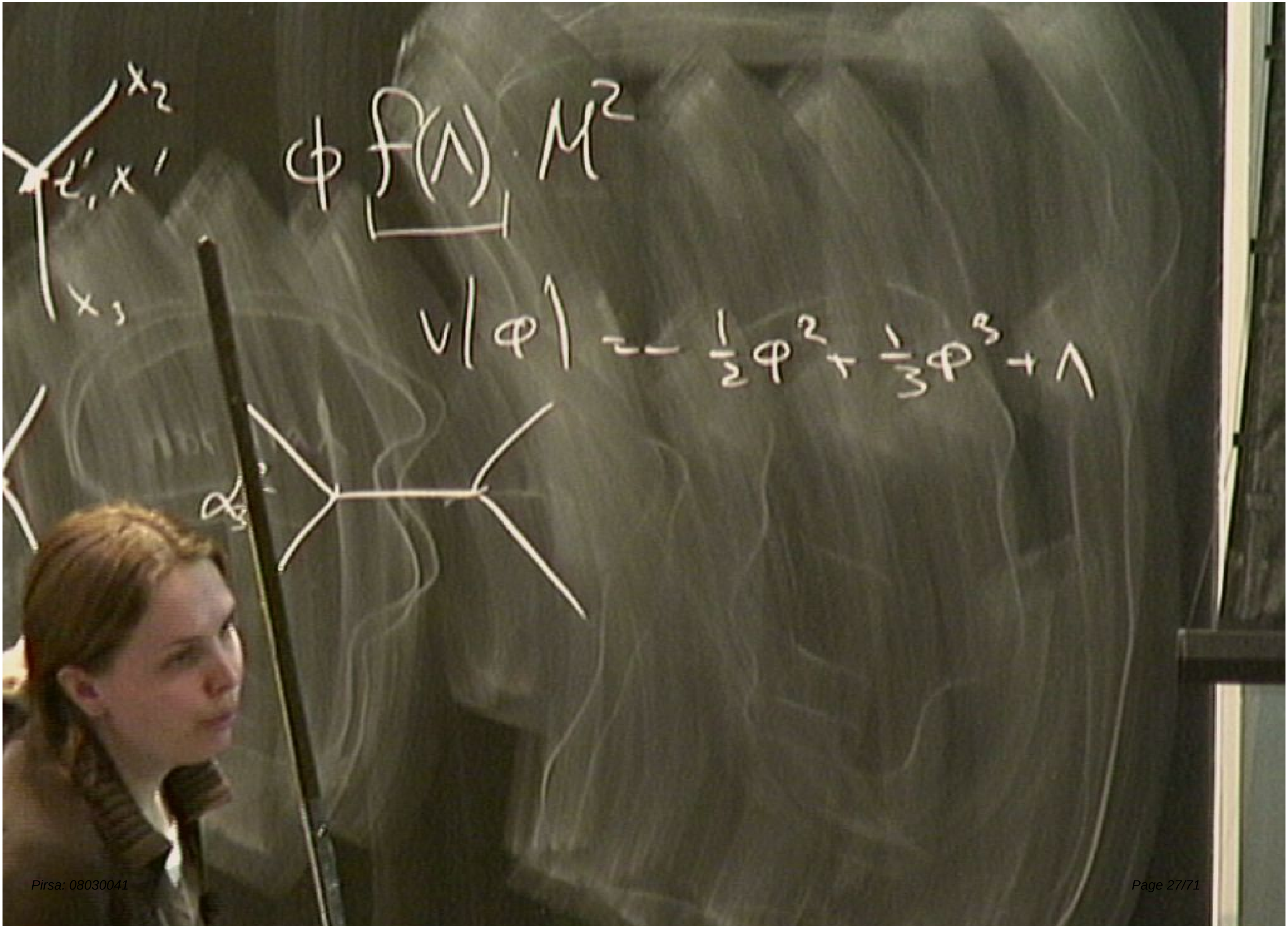
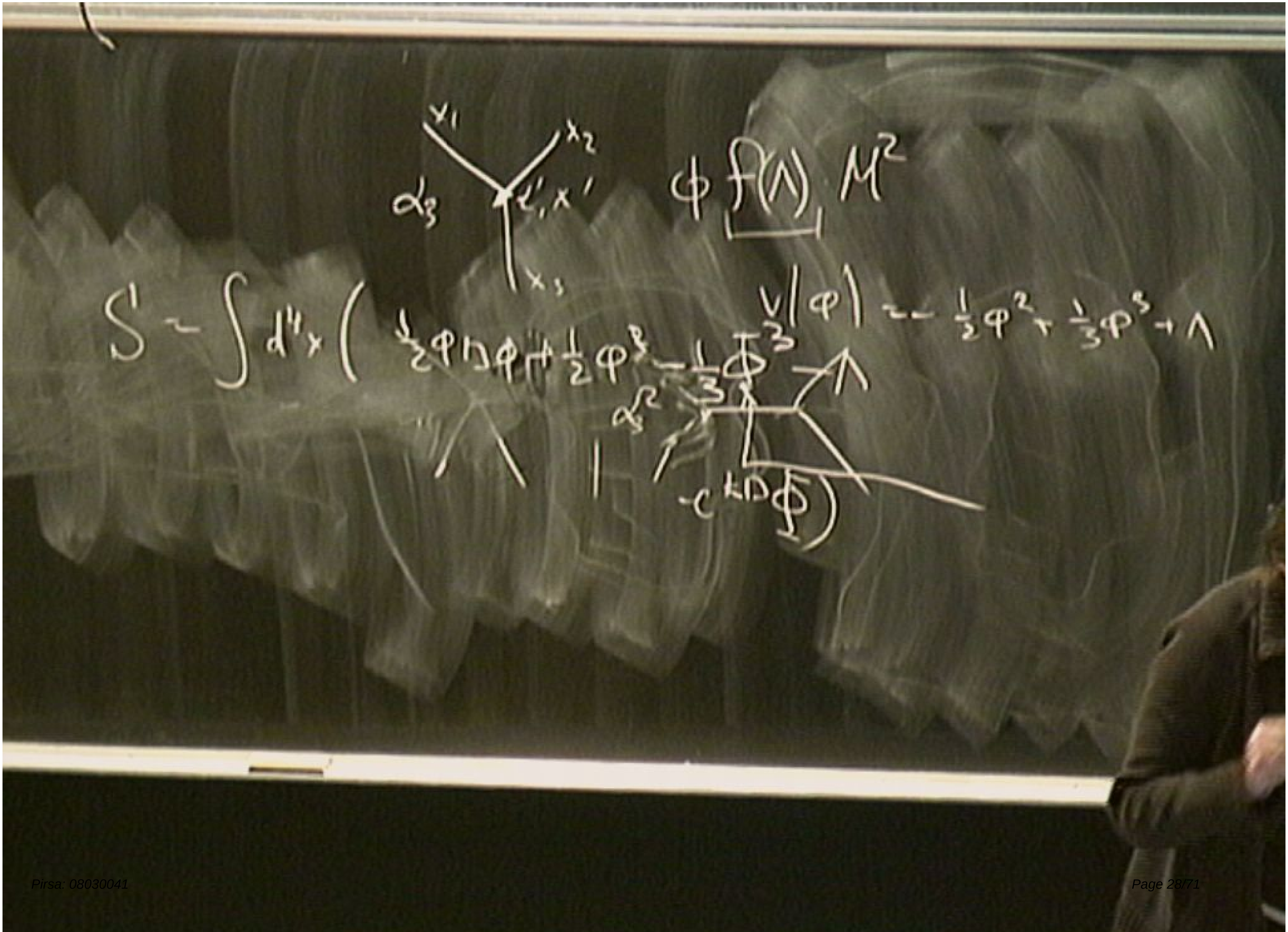



x2
t', x'
x3
φ f(Λ) M2
V(φ) = − 1/2 φ2 + 1/3 φ3 + Λ


x1
x2
α3
t', x'
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S' = ∫ d⁴x (½ φ□φ + ½ φ² − ⅓ φ³ − Λ
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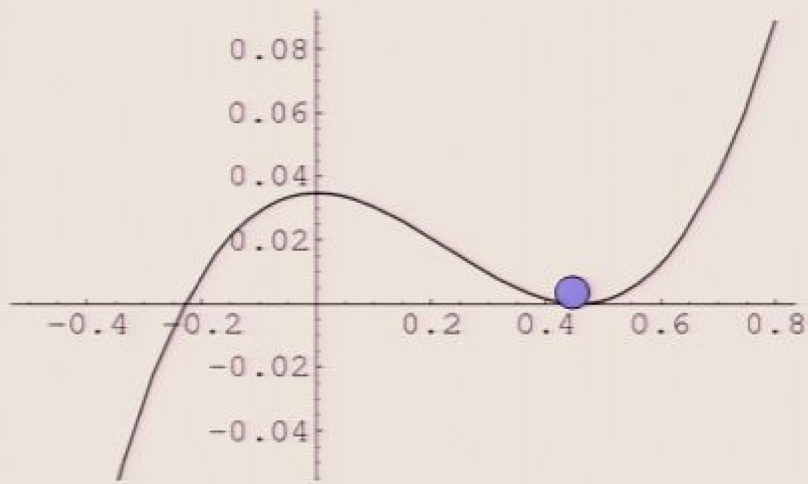
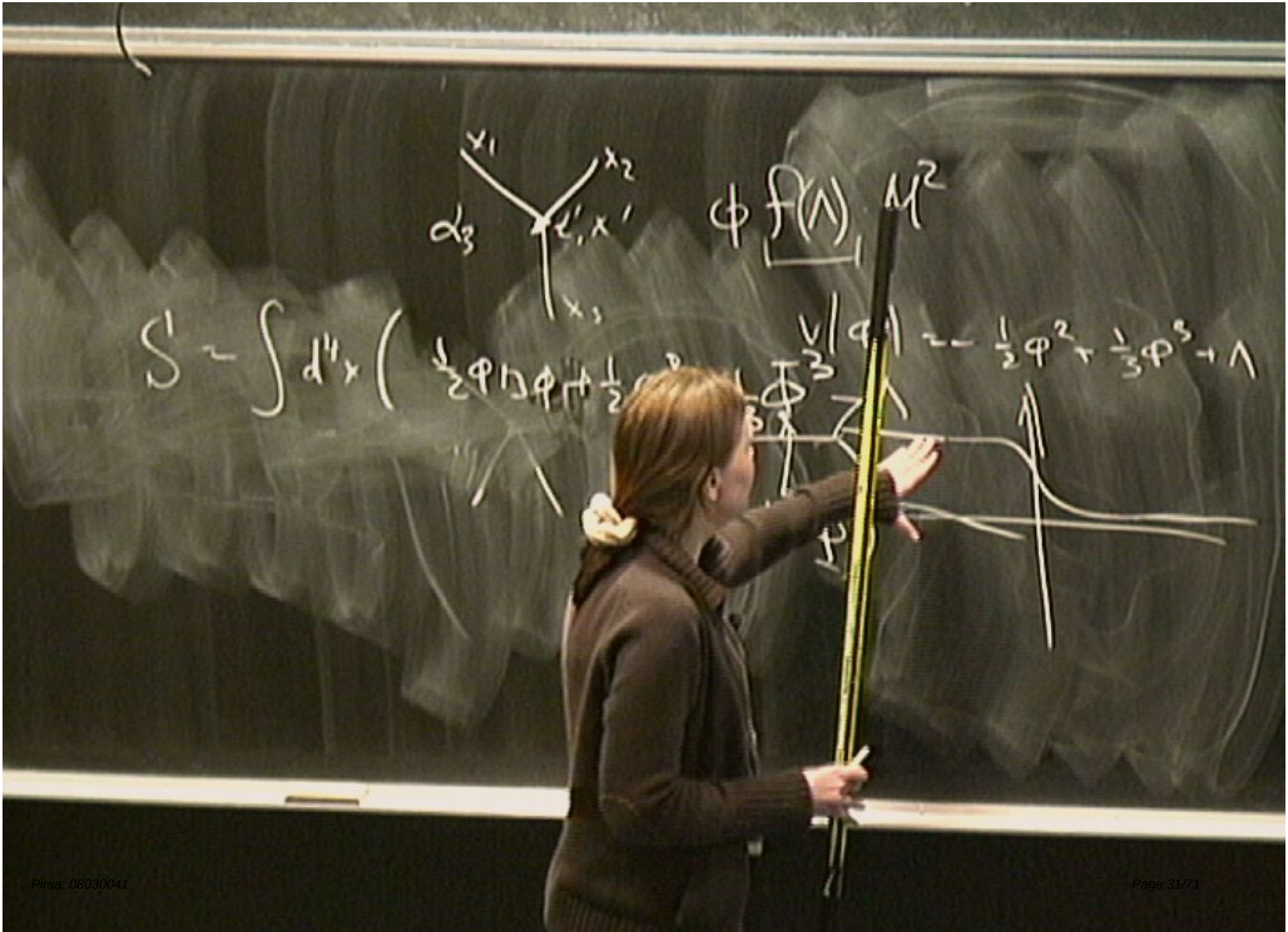
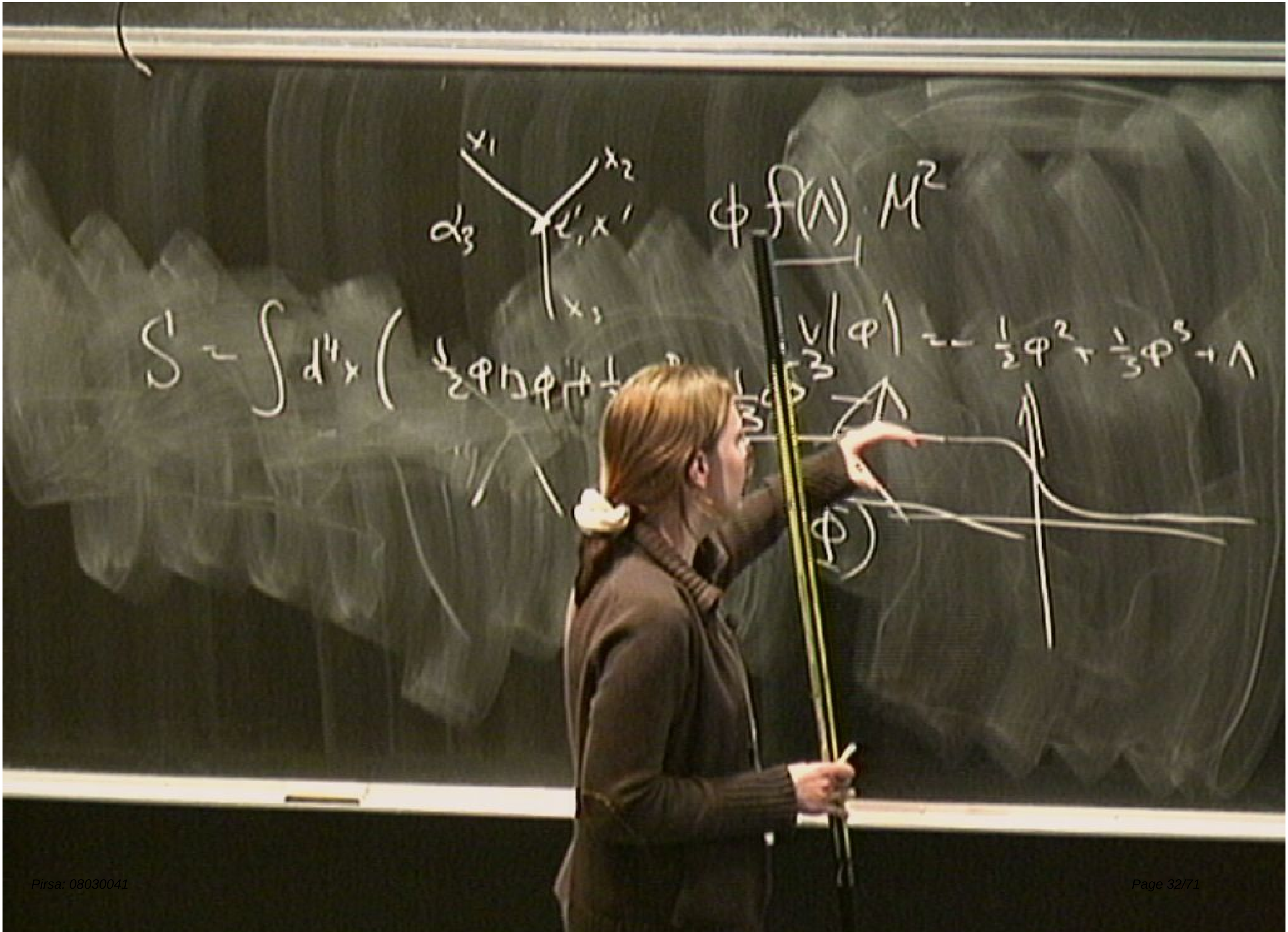
α3²
−c(□φ)

Rolling tachyon solution






x1
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$\phi\, f(\Lambda)\ M^2$
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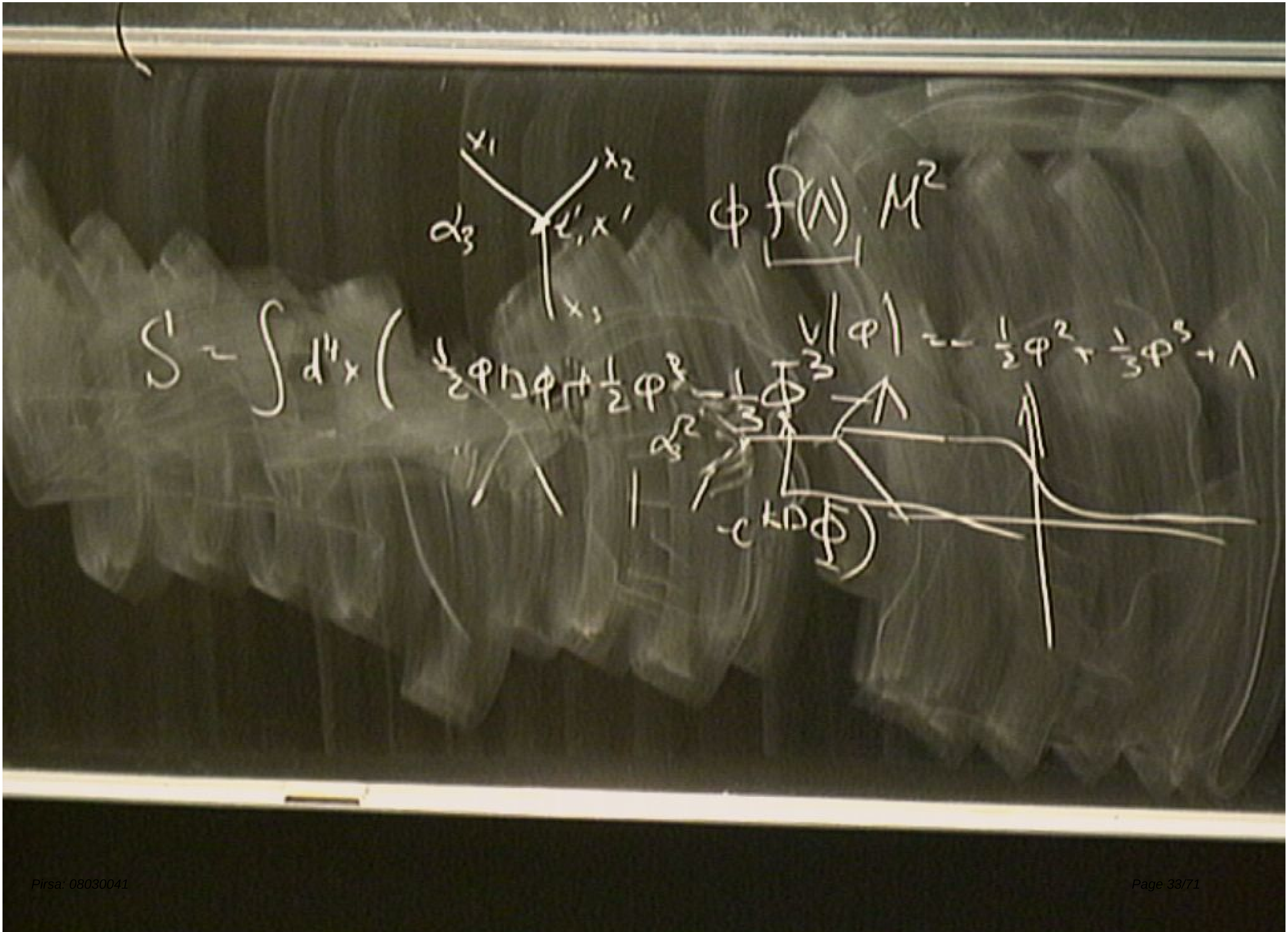
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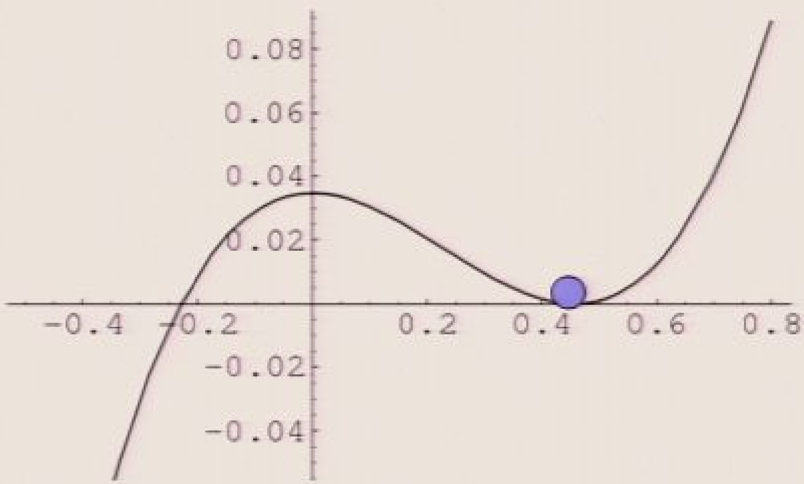
Rolling tachyon solution

$$E(\phi = 0) = \Lambda'$$



Coupling to the gravity / FRW case

$$S = \int d^4x \sqrt{-g} \left(\frac{m_p^2}{2} R + \frac{1}{2} \phi \Box_g \phi + \frac{1}{2} \phi^2 - \frac{\lambda}{3} \Phi^3 - \Lambda' \right)$$

$$\Box_g = -\partial^2 - 3H(t)\partial = -\mathcal{D}_{\rm H}^2.$$

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Scalar field and Friedmann equations:

$$(-\mathcal{D}_{\mathrm{H}}^2 + 1) e^{2k\mathcal{D}_{\mathrm{H}}^2}\Phi = \lambda\Phi^2, \quad \mathcal{D}_{\mathrm{H}}^2 = \partial_t^2 + 3H(t)\partial_t,$$

$$3H^2 = \frac{1}{m_p^2}\,\mathcal{E}, \quad 3H^2 + 2\dot{H} = -\frac{1}{m_p^2}\,\mathcal{P},$$

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$$\mathcal{E}_{nl1}=k\int_0^1 d\rho\left((-\mathcal{D}_{\mathrm{H}}^2+1)e^{(2-\rho)k\mathcal{D}_{\mathrm{H}}^2}\Phi\right)\left(\mathcal{D}_{\mathrm{H}}^2e^{k\rho\mathcal{D}_{\mathrm{H}}^2}\Phi\right),$$

$$\mathcal{E}_{nl2}=-k\int_0^1 d\rho\left(\partial(-\mathcal{D}_{\mathrm{H}}^2+1)e^{(2-\rho)k\mathcal{D}_{\mathrm{H}}^2}\Phi\right)\left(\partial e^{k\rho\mathcal{D}_{\mathrm{H}}^2}\Phi\right).$$

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Do we have the rolling tachyon solution in this case?

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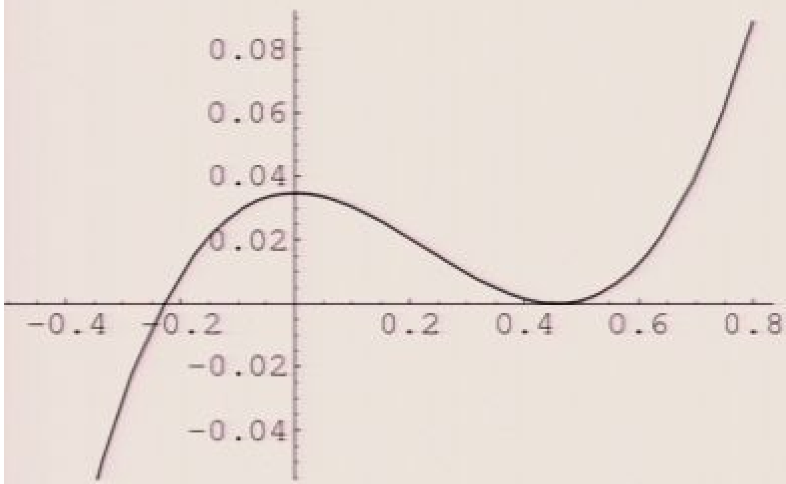

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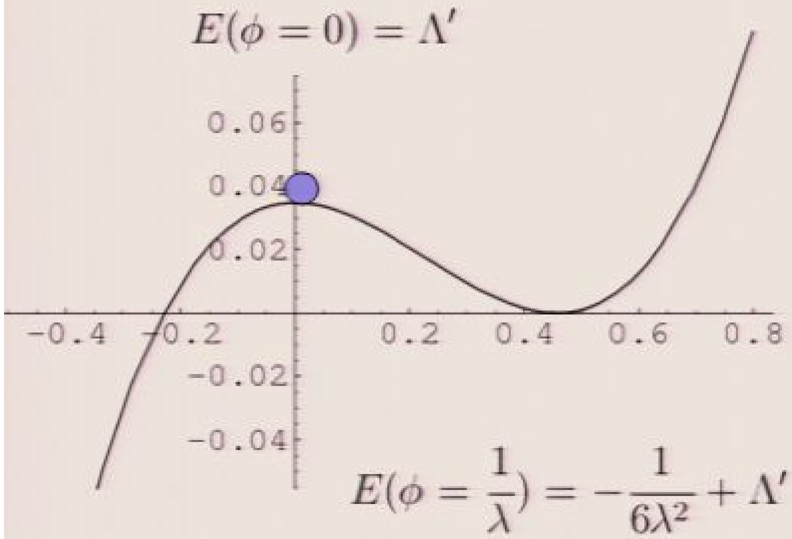

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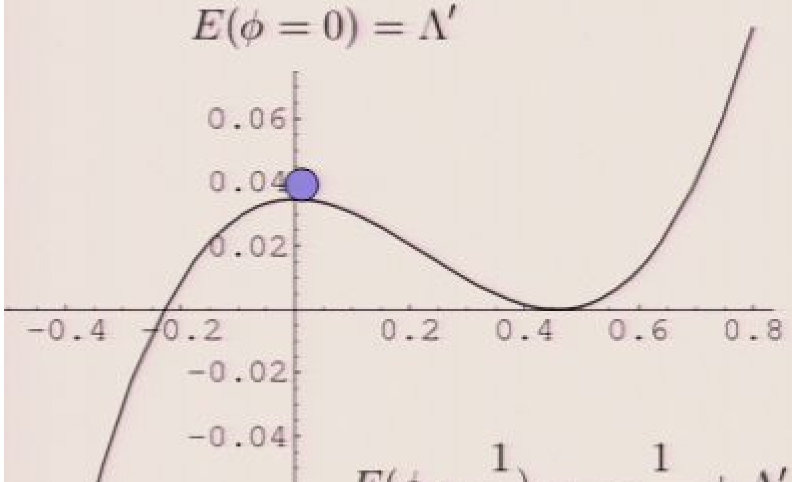
$$E(\phi = 0) = \Lambda'$$



$$E(\phi = \frac{1}{\lambda}) = -\frac{1}{6\lambda^2} + \Lambda'$$

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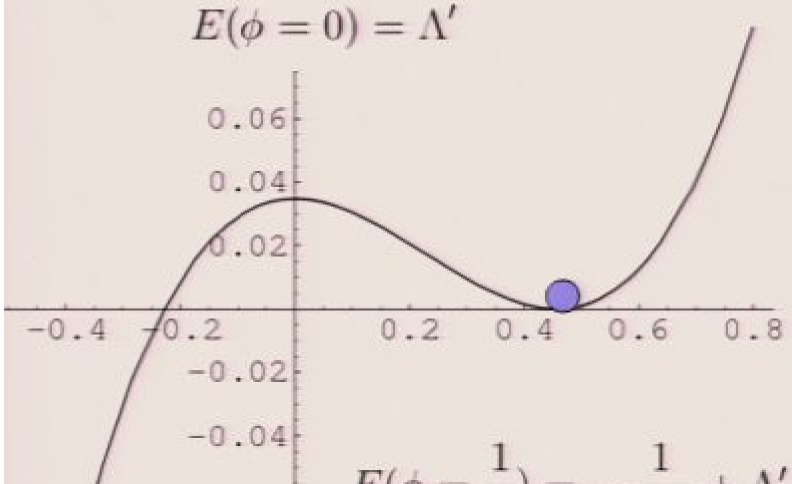

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$$\partial^2\Phi = -\frac{\Phi - \lambda\Phi^2}{(2k-1)} - 3H\partial\Phi$$

$$V(\Phi) = \frac{-\frac{1}{2}\Phi^2 + \frac{\lambda}{3}\Phi^3}{(1-2k)}$$

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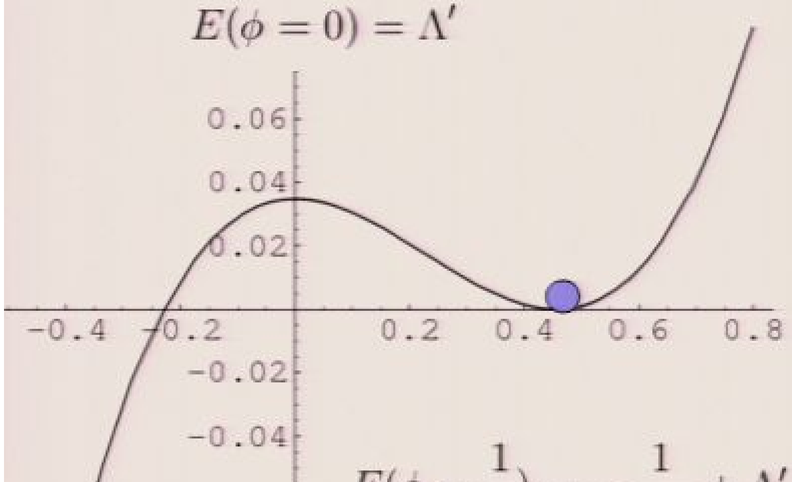

$$E(\phi = \frac{1}{\lambda}) = -\frac{1}{6\lambda^2} + \Lambda'$$

$$H(\phi = \frac{1}{\lambda}) = \sqrt{\frac{-\frac{1}{6\lambda^2} + \Lambda'}{3m_p^2}} = 0$$

Do we have the rolling tachyon solution in this case?

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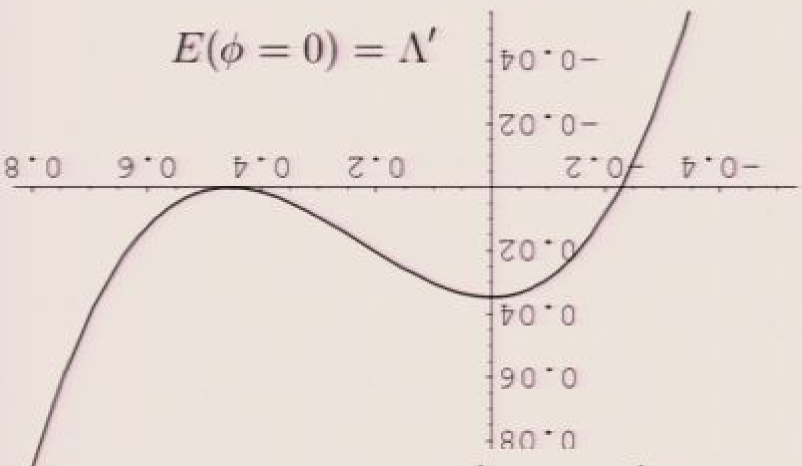

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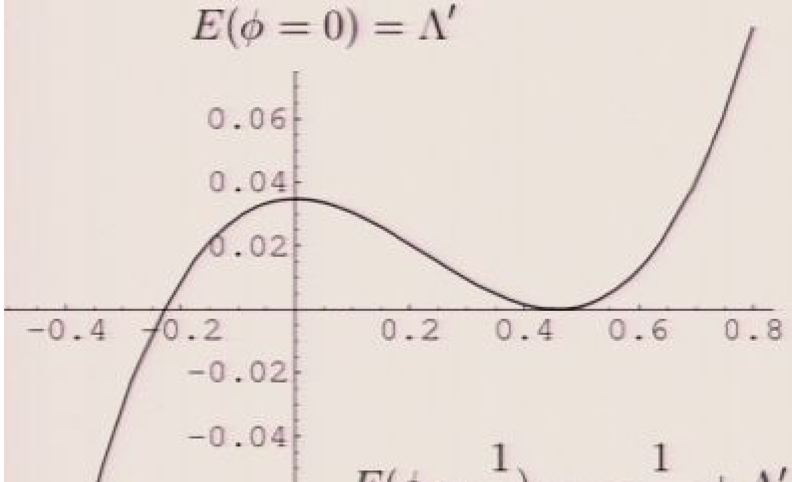

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Do we have the rolling tachyon solution in this case?

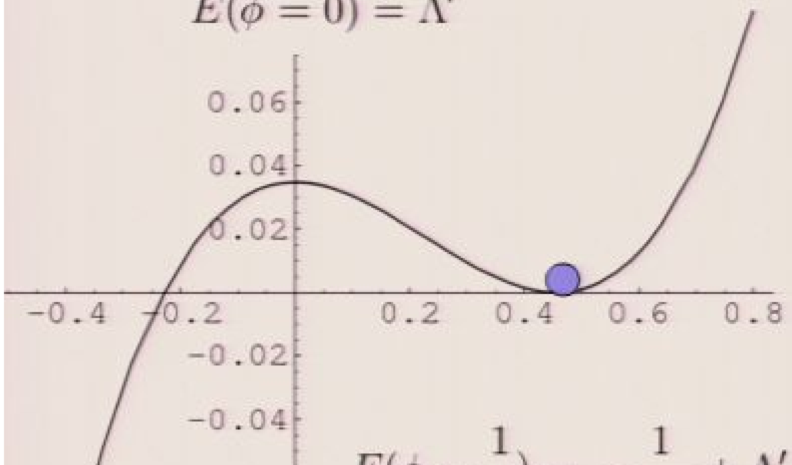
$$(-\mathcal{D}_{\mathrm{H}}^2 + 1)e^{2k\mathcal{D}_{\mathrm{H}}^2}\Phi = \lambda\Phi^2, \quad \mathcal{D}_{\mathrm{H}}^2 = \partial_t^2 + 3H(t)\partial_t$$

$$H(\phi = 0) = \sqrt{\frac{\Lambda'}{3m_p^2}}$$

$$\partial^2\Phi = -\frac{\Phi - \lambda\Phi^2}{(2k-1)} - 3H\partial\Phi$$

$$E(\phi = 0) = \Lambda'$$

$$V(\Phi) = \frac{-\frac{1}{2}\Phi^2 + \frac{\lambda}{3}\Phi^3}{(1-2k)}$$



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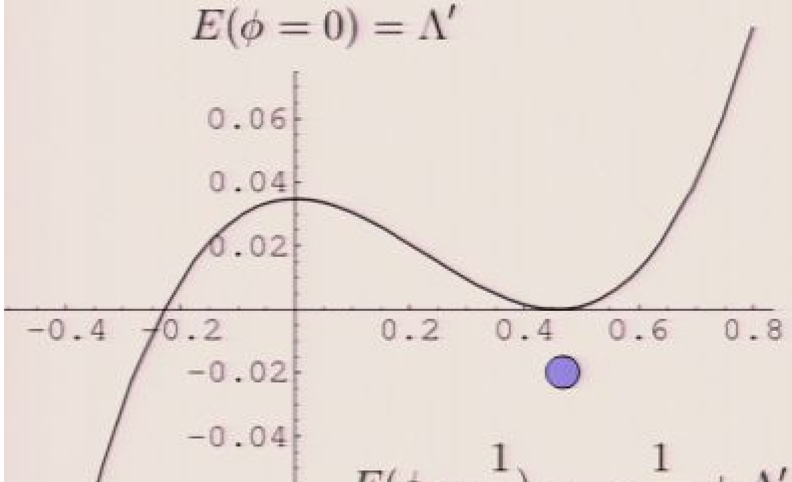

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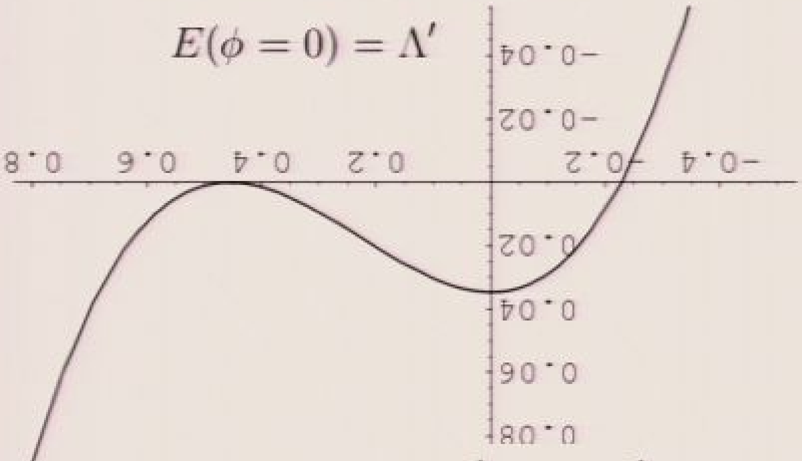

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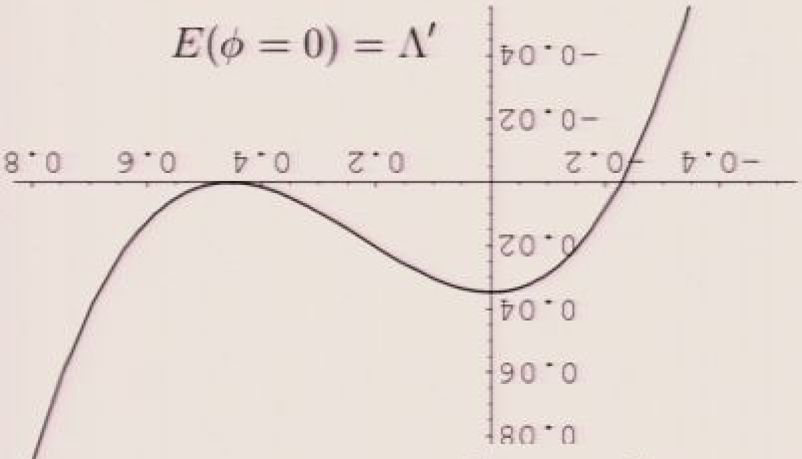

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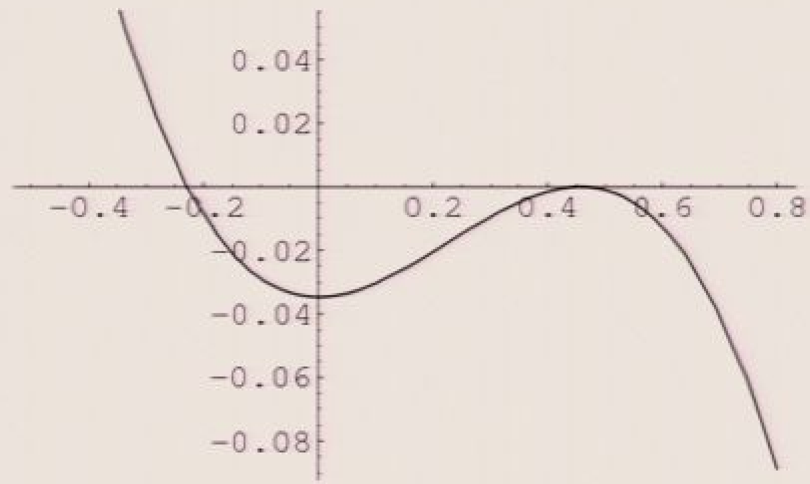
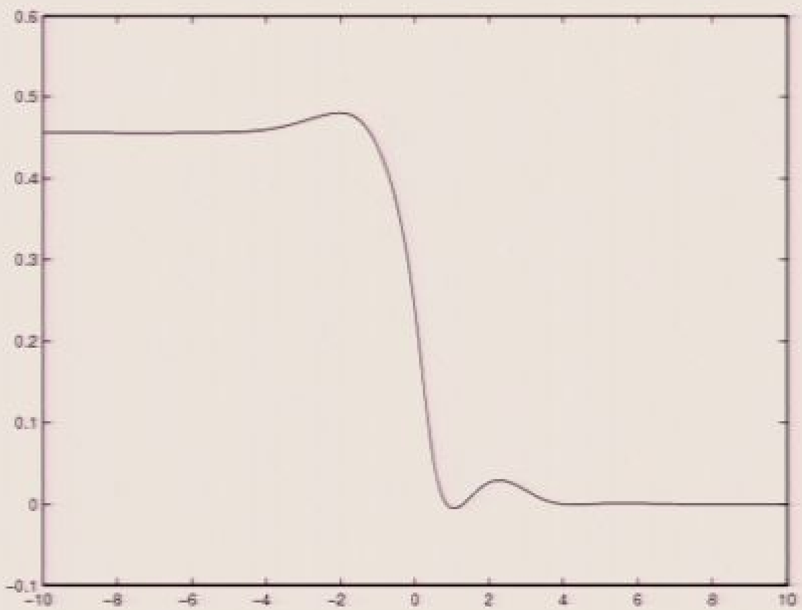
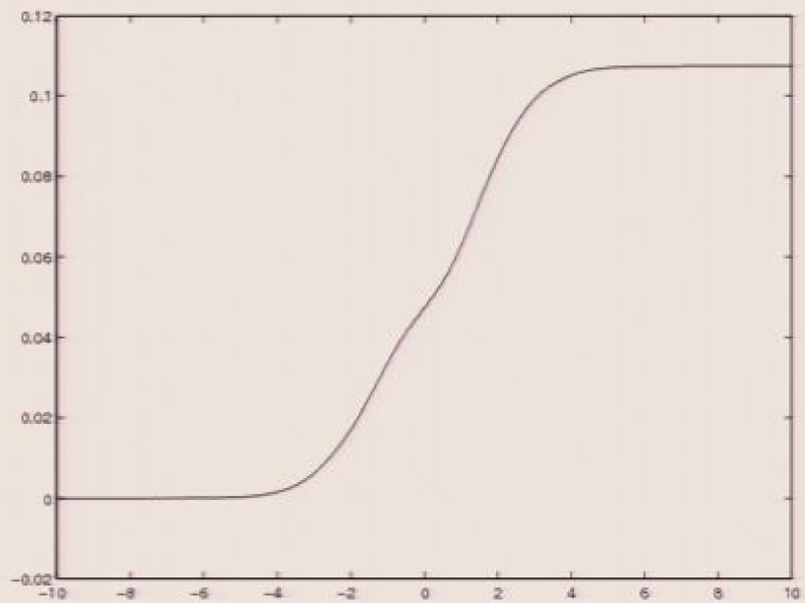
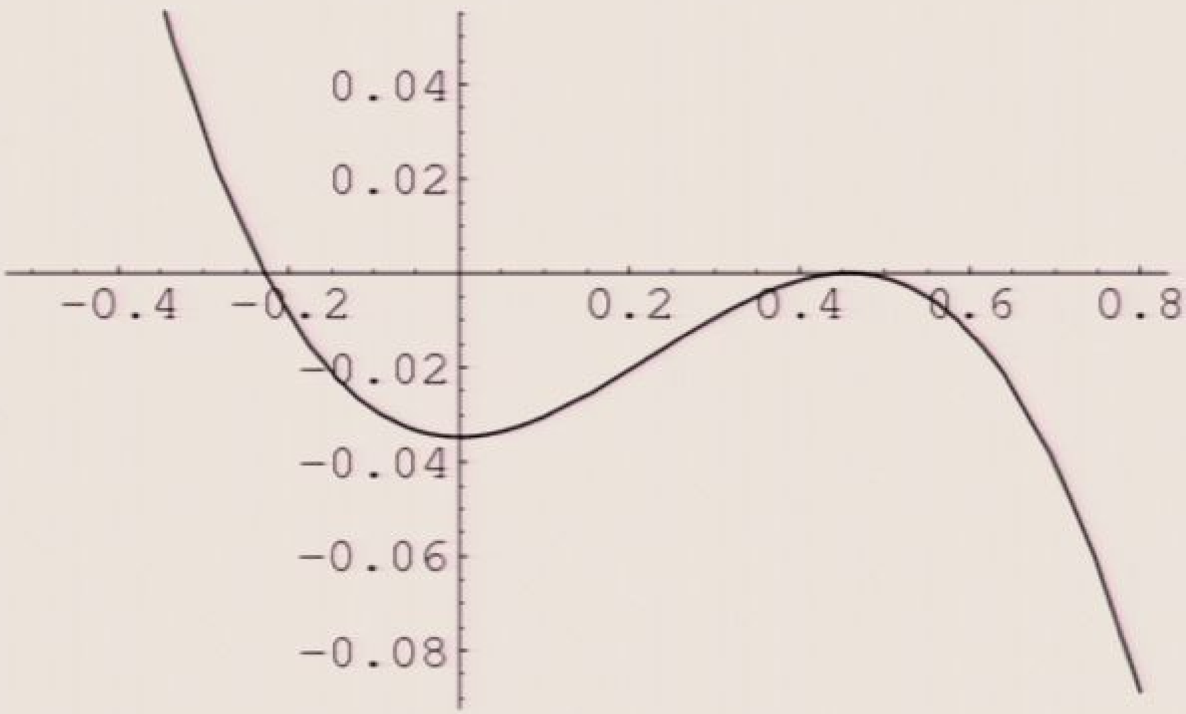


Numerical solutions





Dynamics of the scalar field for different parameters of the system



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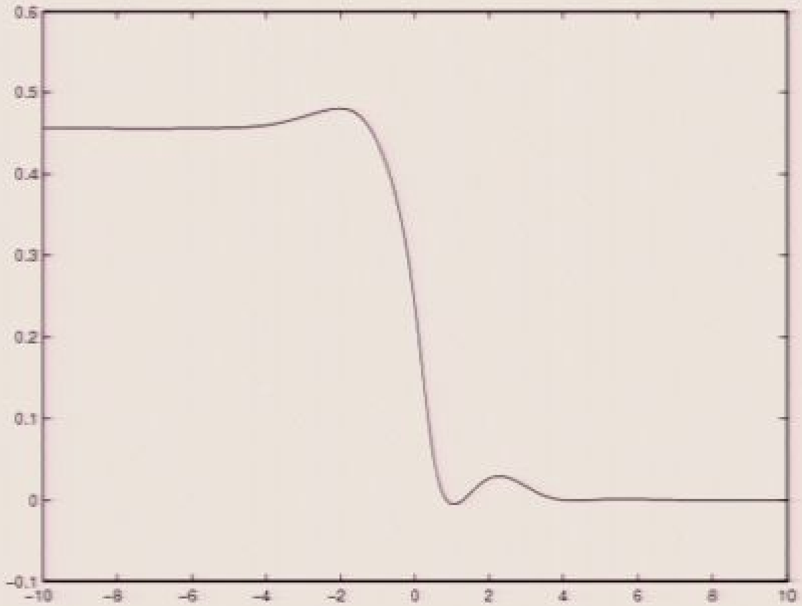

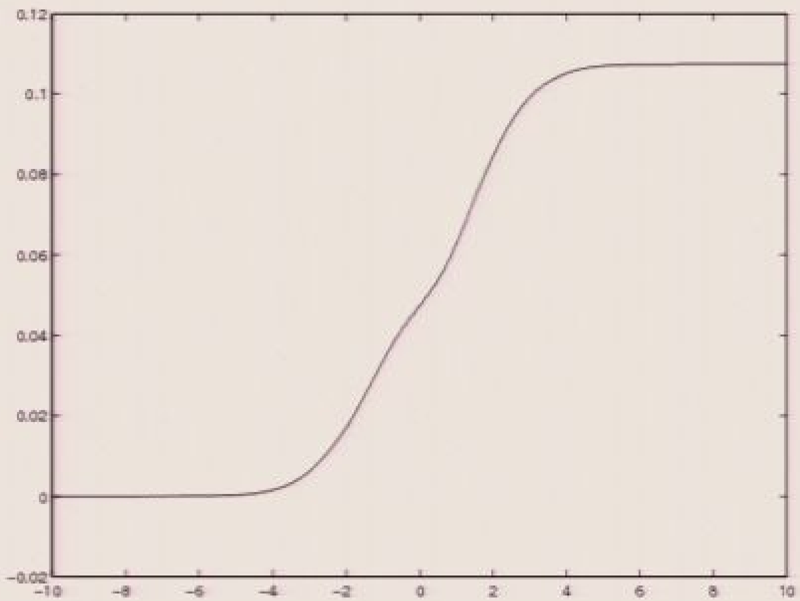

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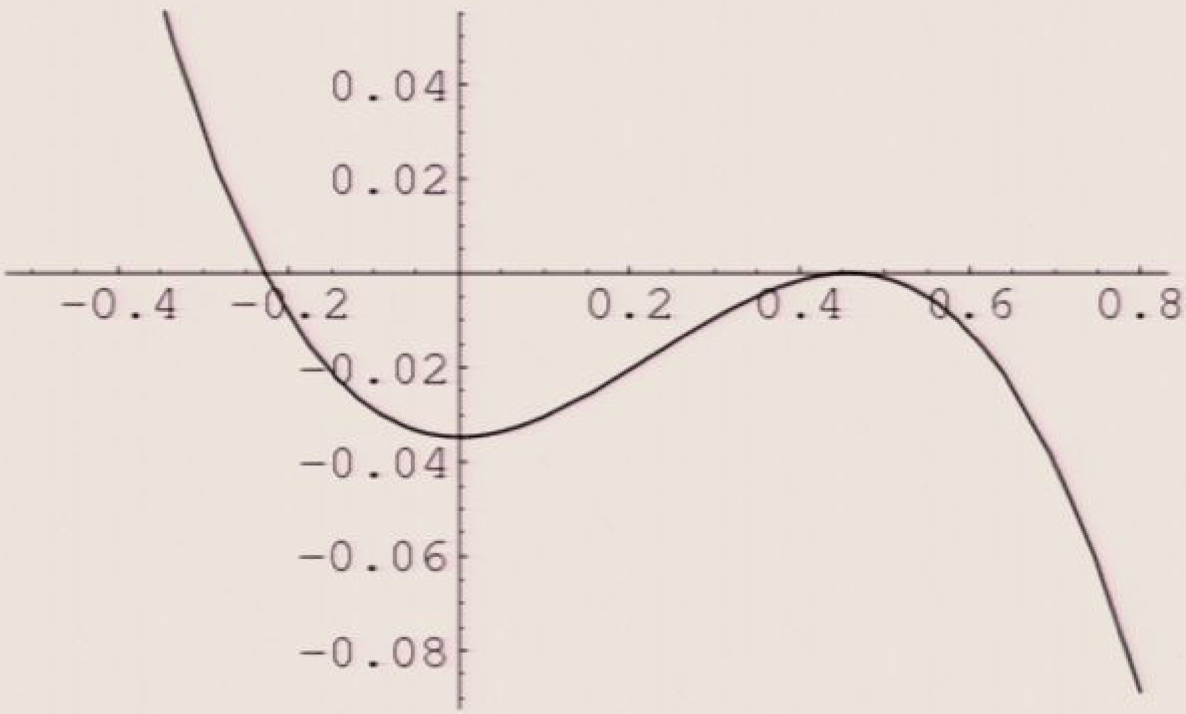

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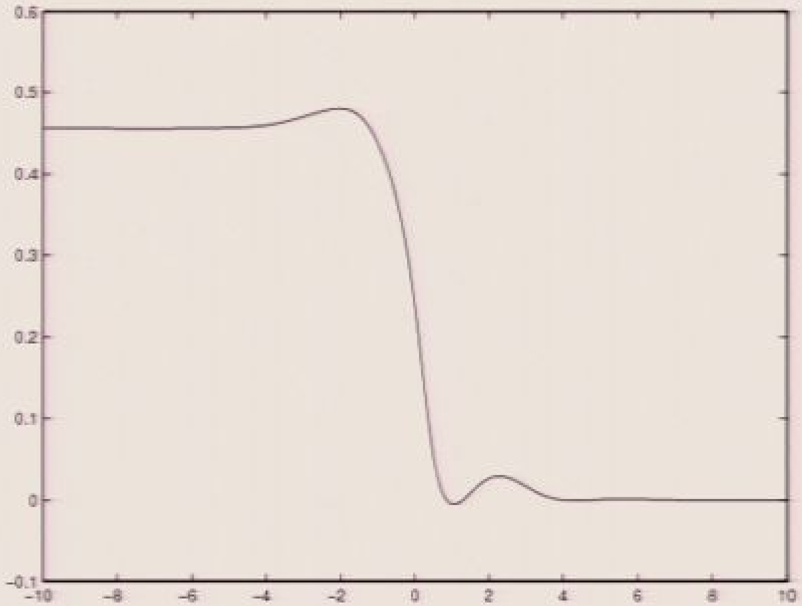
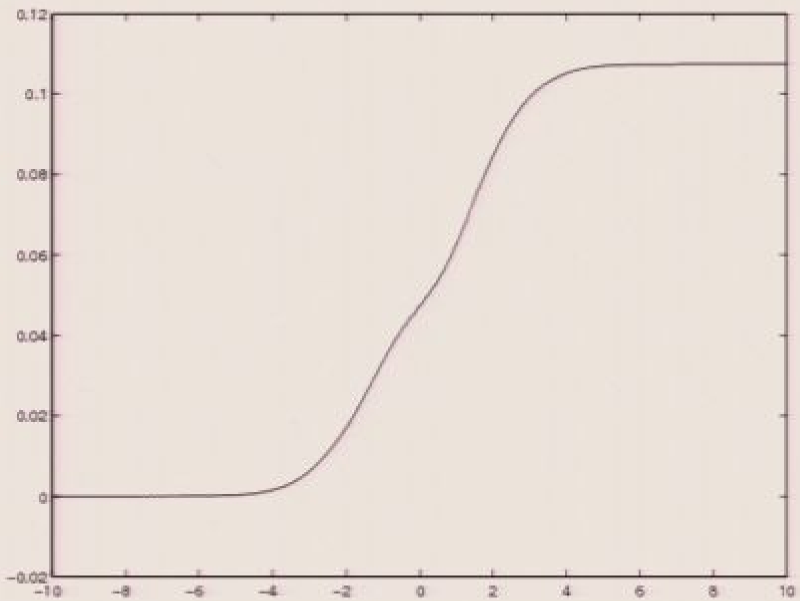
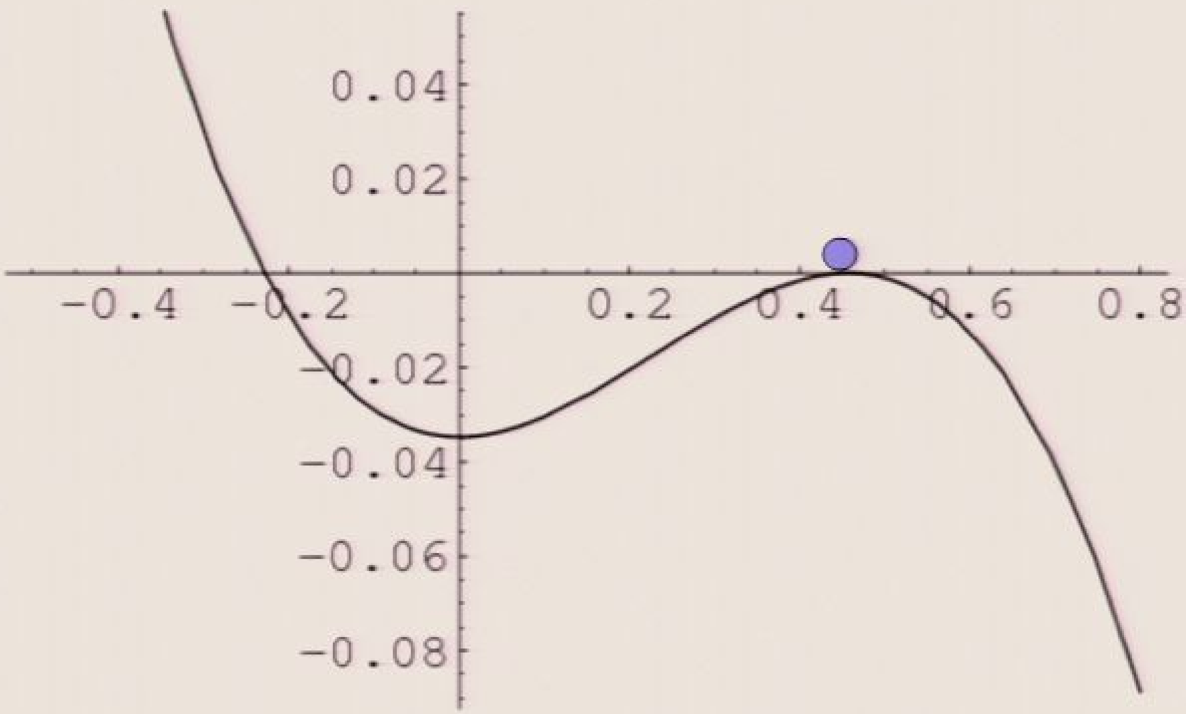
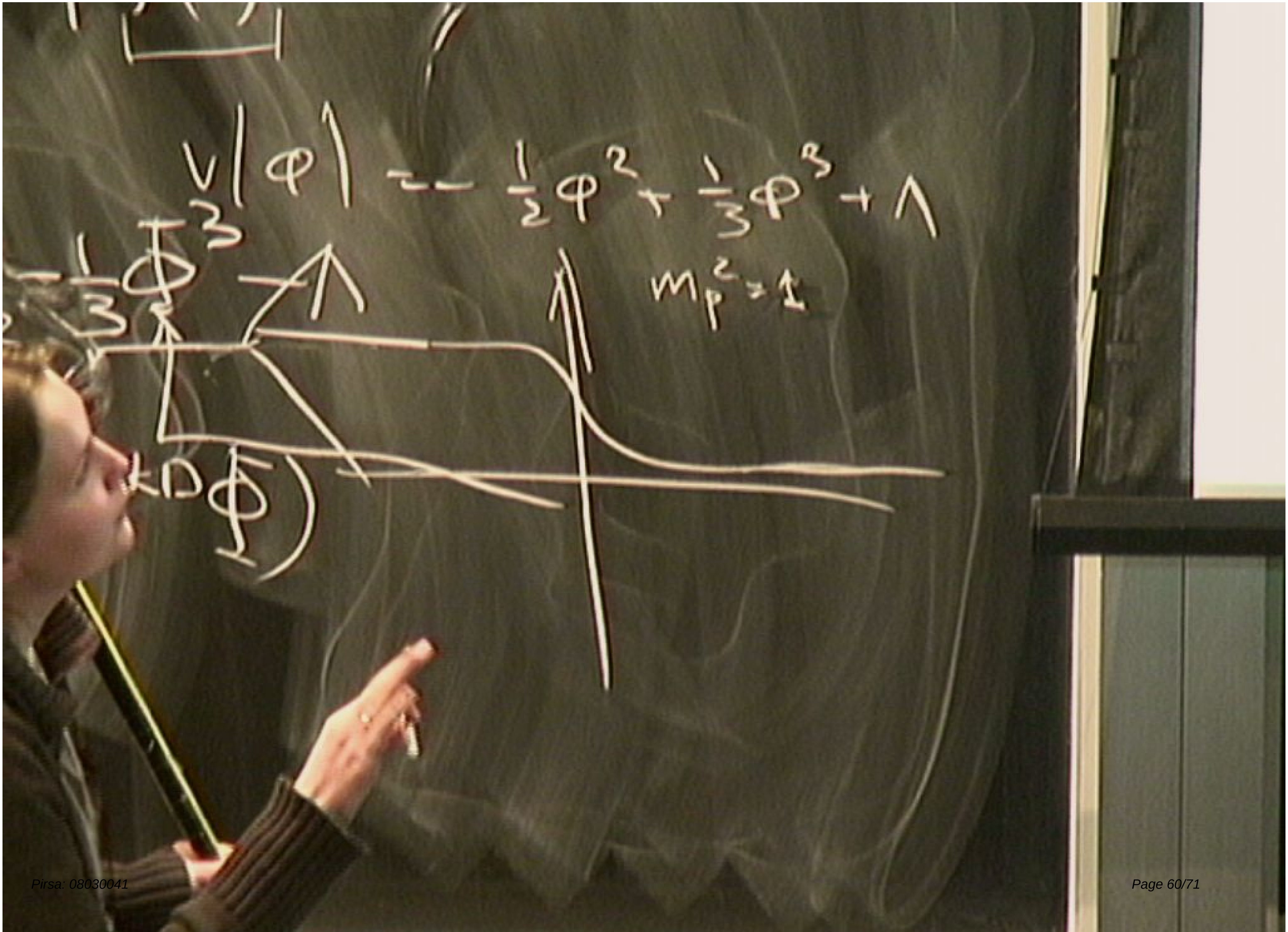


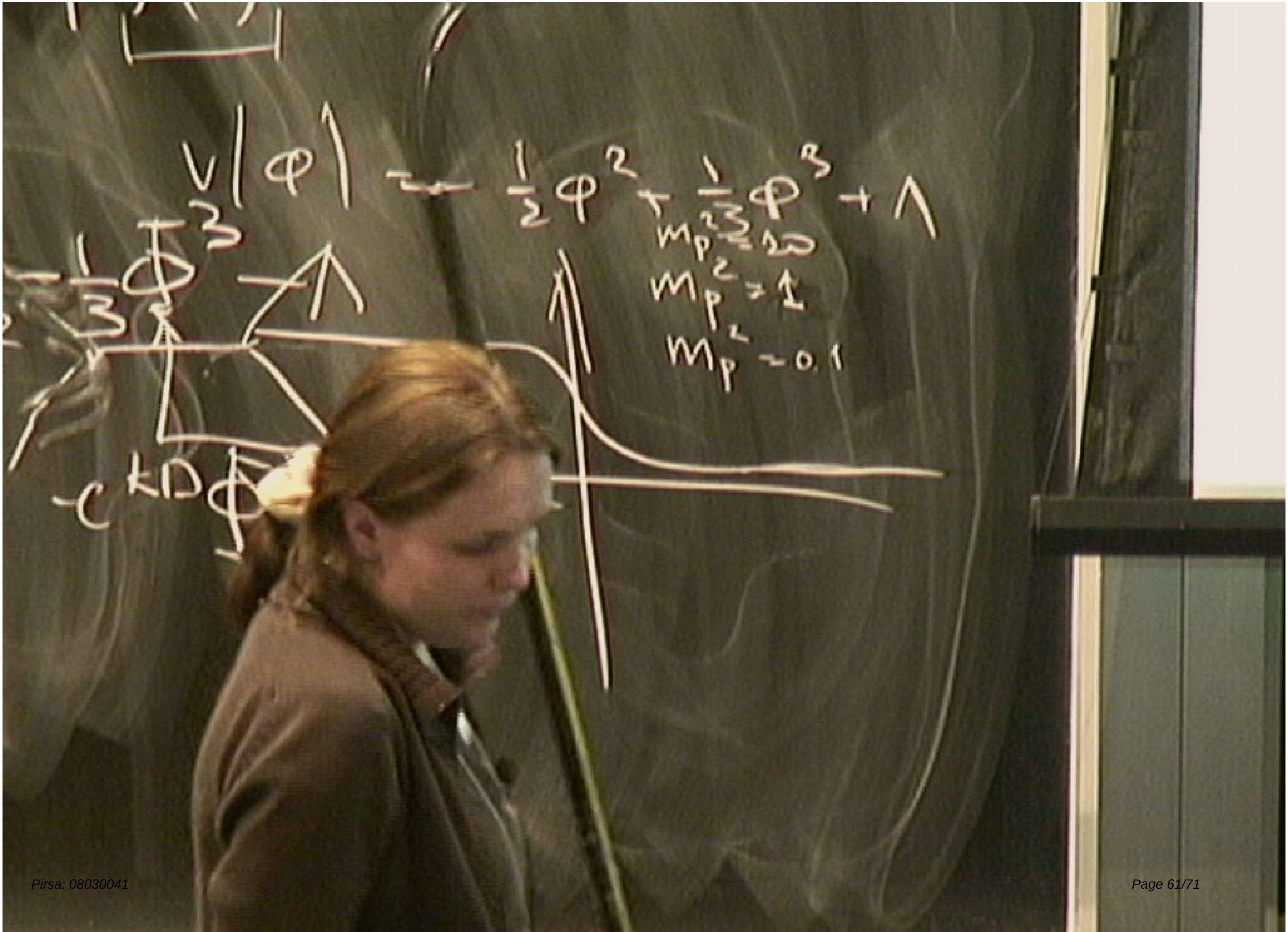


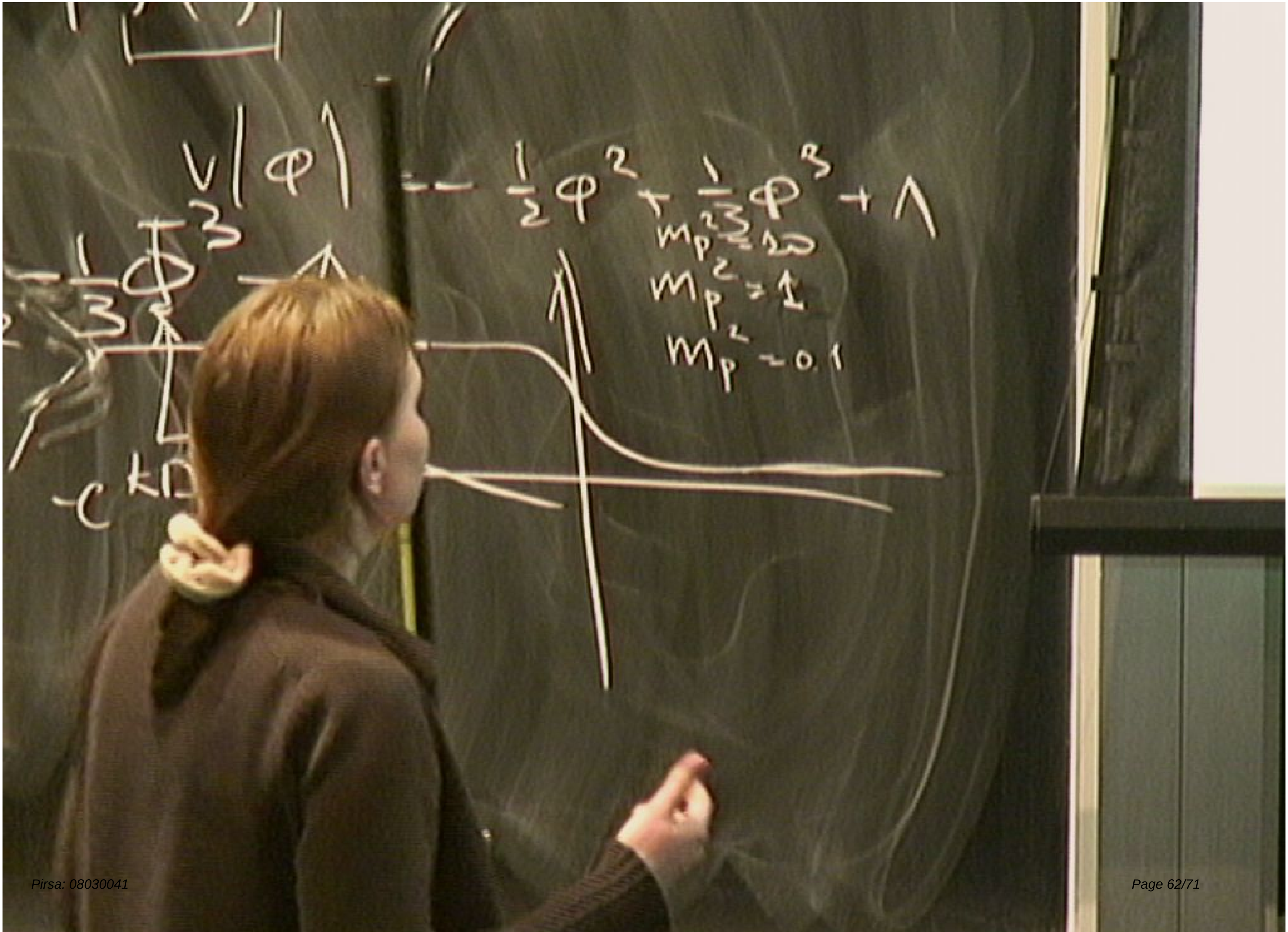
Dynamics of the scalar field for different parameters of the system

Dynamics of the scalar field for different parameters of the system




V(φ) = -1/2 φ^2 + 1/3 φ^3 + Λ
m_p^2 = 1


V(φ) = - 1/2 φ^2 + 1/3 φ^3 + Λ
m_p^2 = 10
m_p^2 = 1
m_p^2 = 0.1


V(φ) = - 1/2 φ² + 1/3 φ³ + Λ
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m_p² = 1
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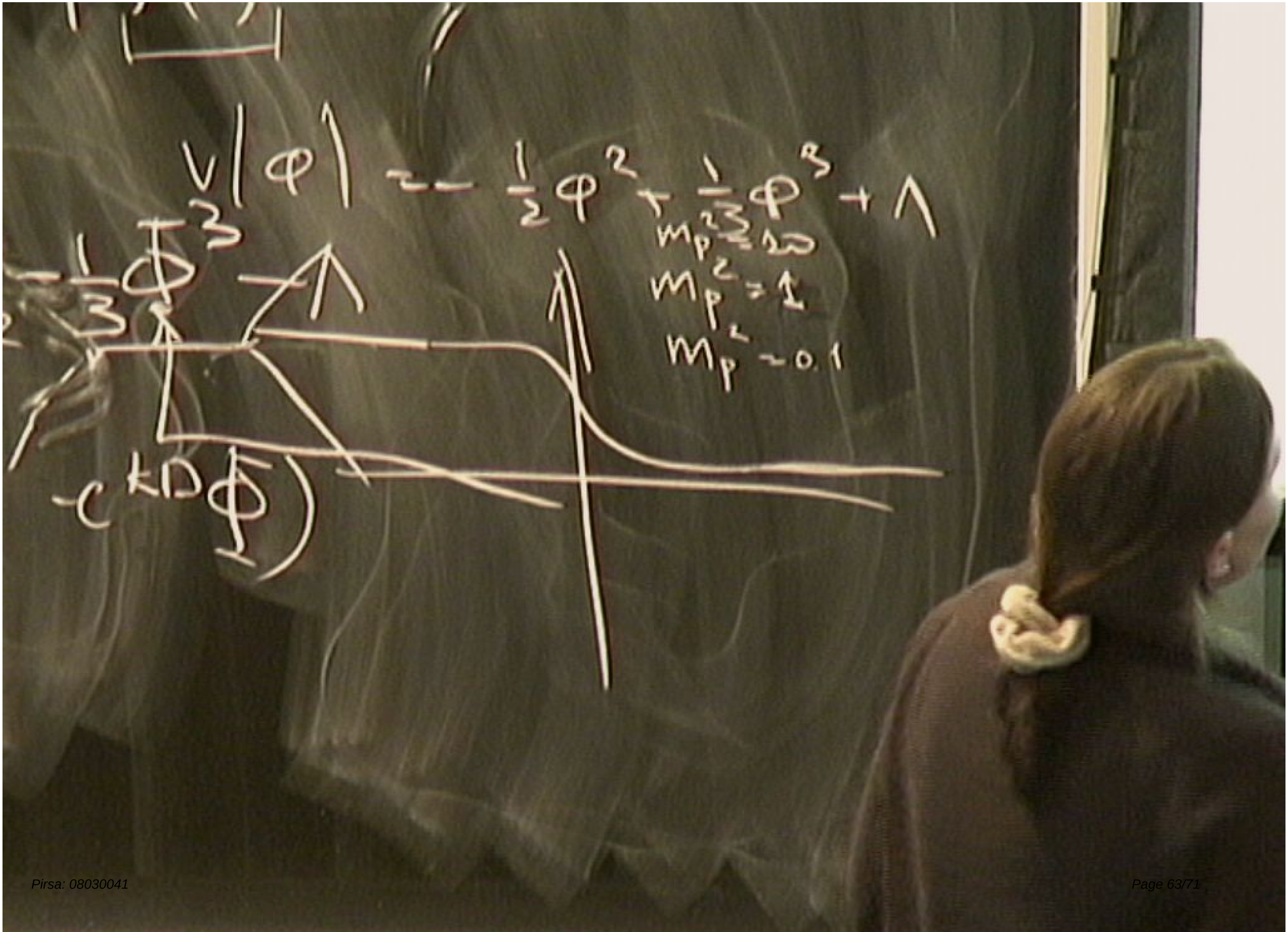
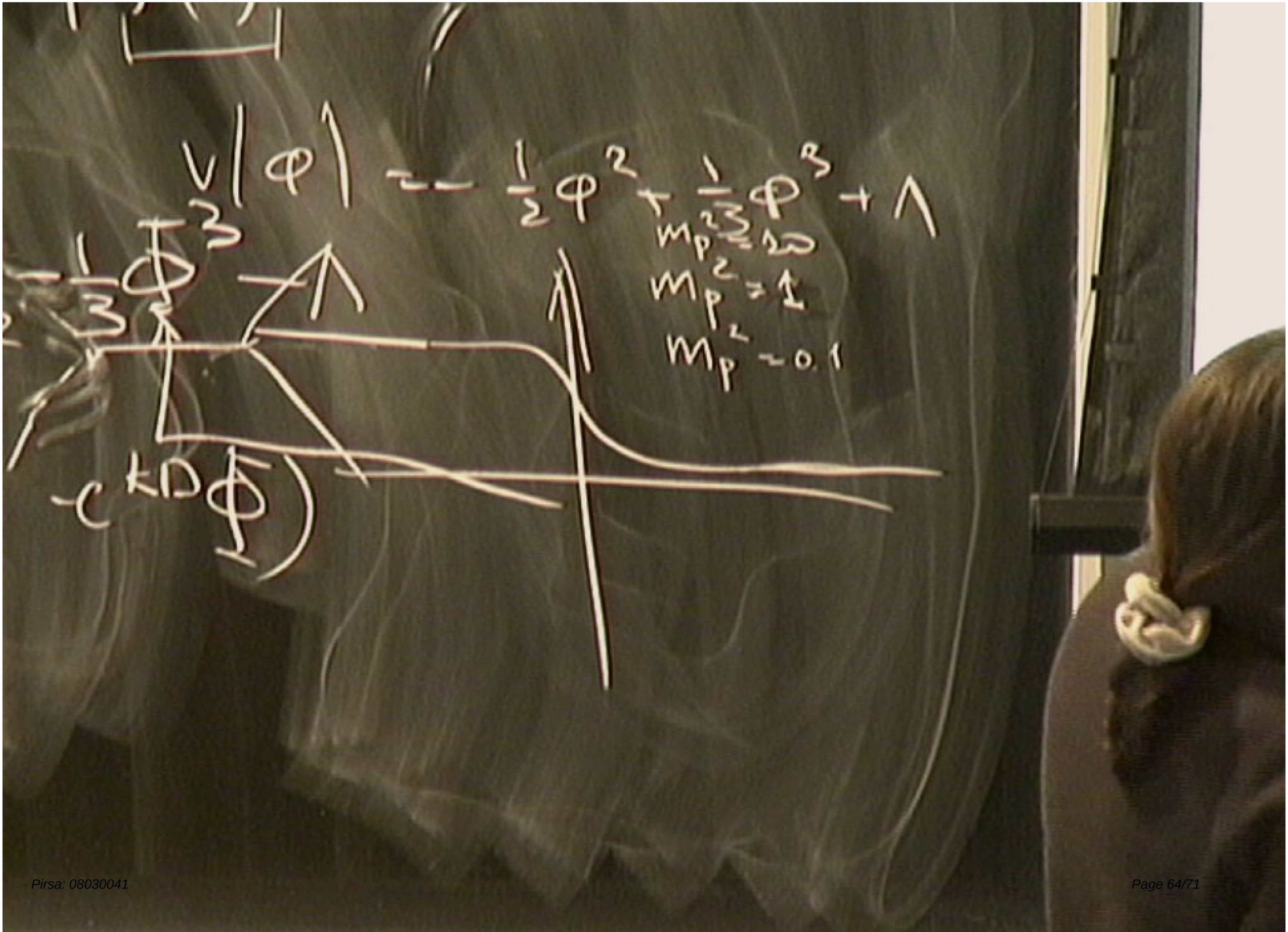

V(φ) = -1/2 φ² + 1/3 φ³ + Λ
m_p² = 1
m_p² = 0.1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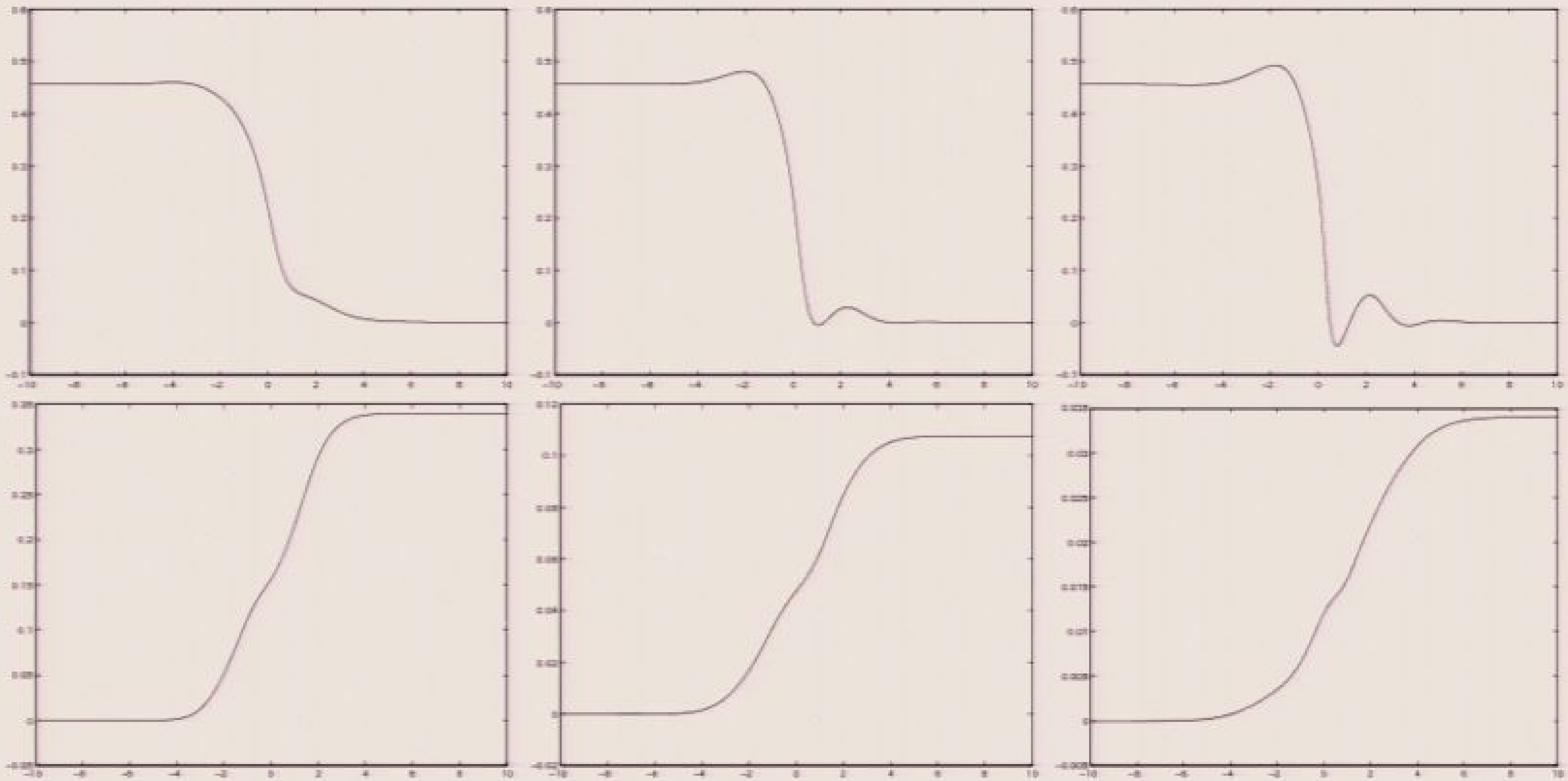
Numerical solutions for different parameters of the system

ϕ

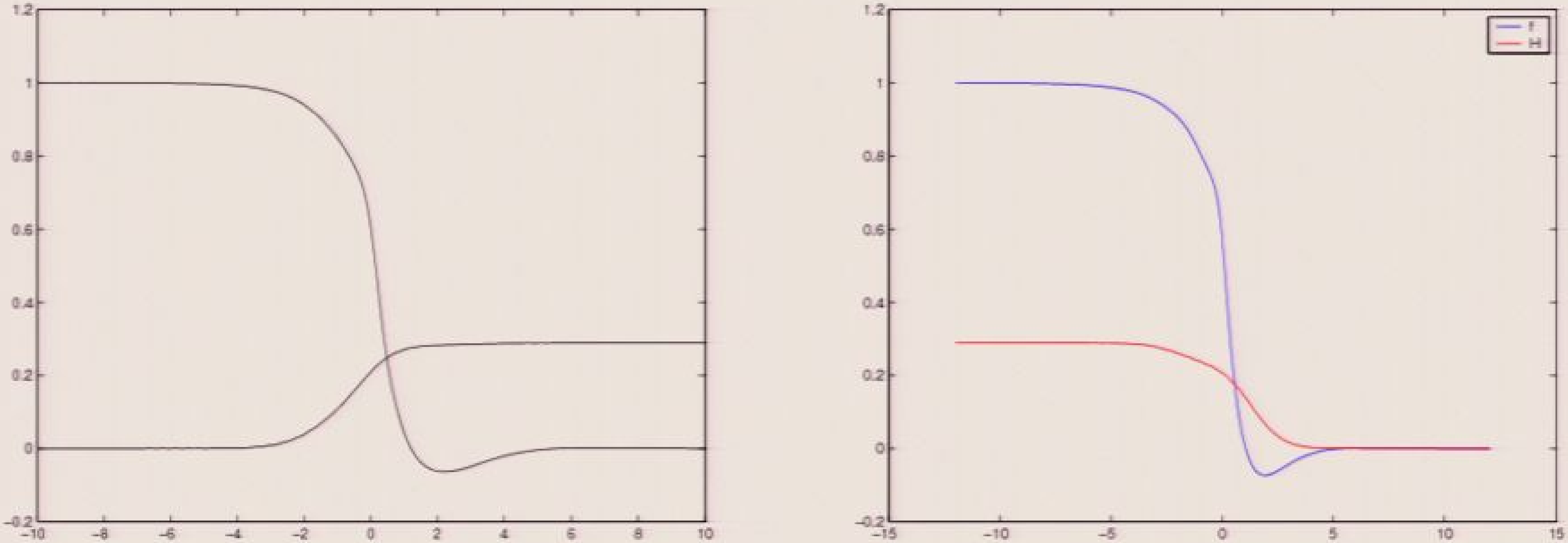
H



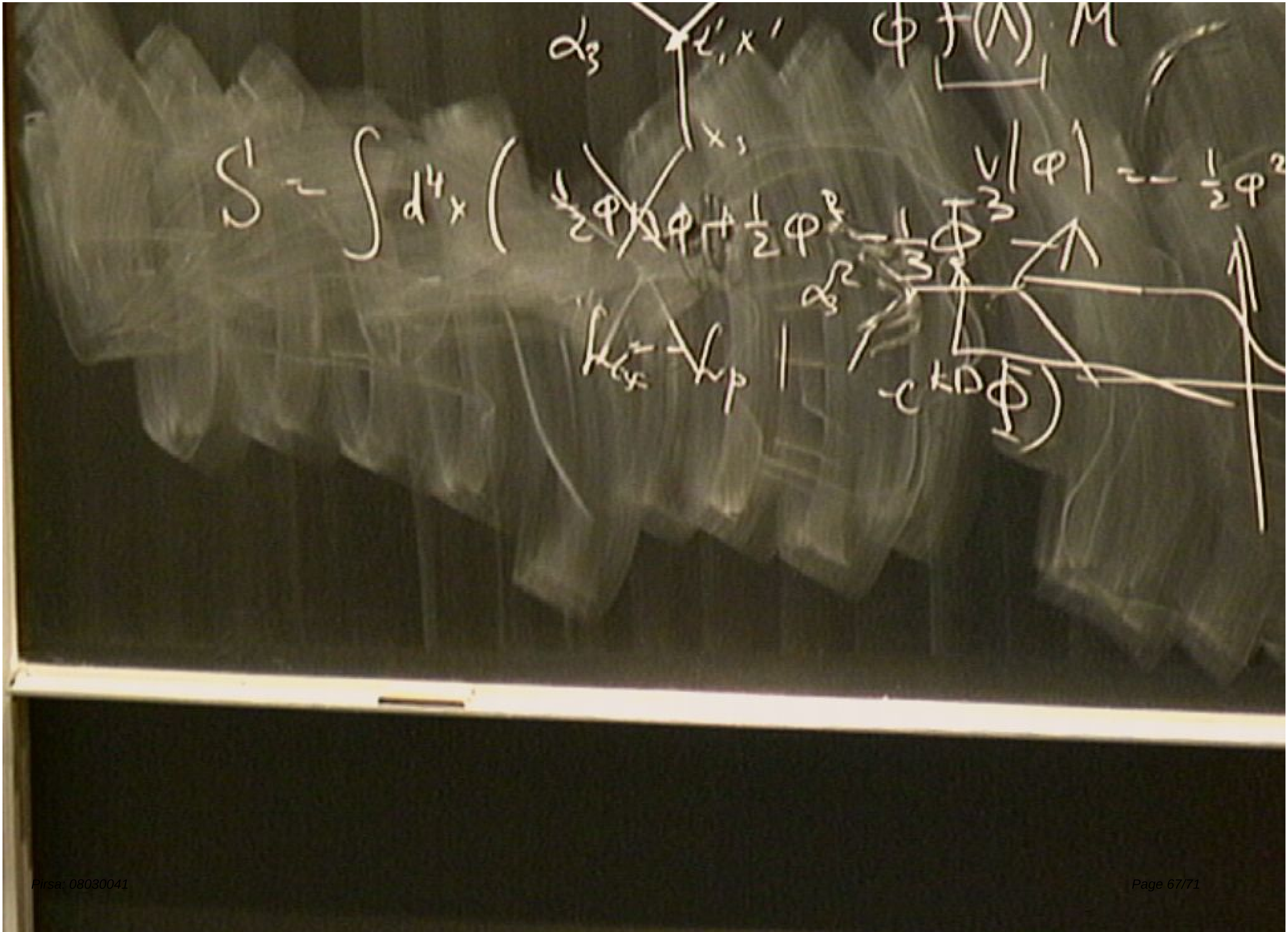
$m_p^2 = 0.1.$ $m_p^2 = 1.$ $m_p^2 = 10.$

N. Barnaby, T. Biswas, J.M. Cline, JHEP, 2007N. Barnaby, J.M. Cline, JCAP, 2007; arXiv: 0802.3218
L.J. (in prep.), D. Mulryne (in prep)

Particular case / P-adic Nonlocal Cosmological Model



$$S = \int d^4x \sqrt{-g} \left(\frac{m_p^2}{2} R \pm L \right)$$


S' = ∫ d⁴x (
V(φ) = − ½ φ²

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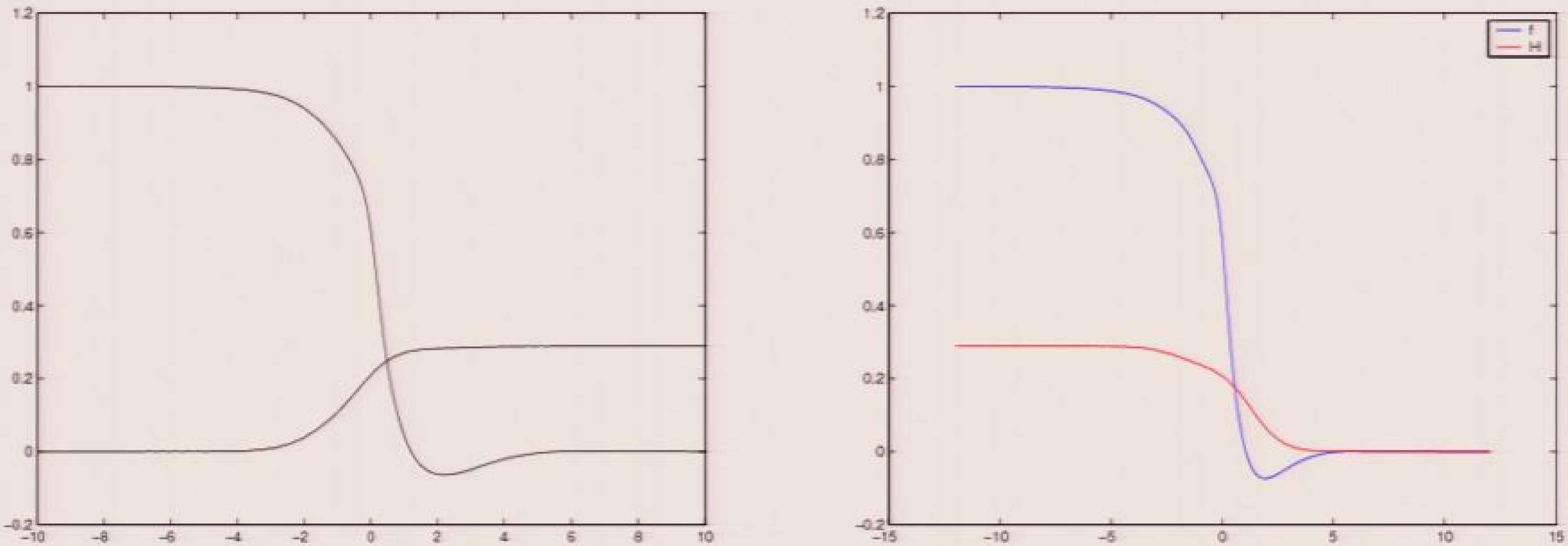

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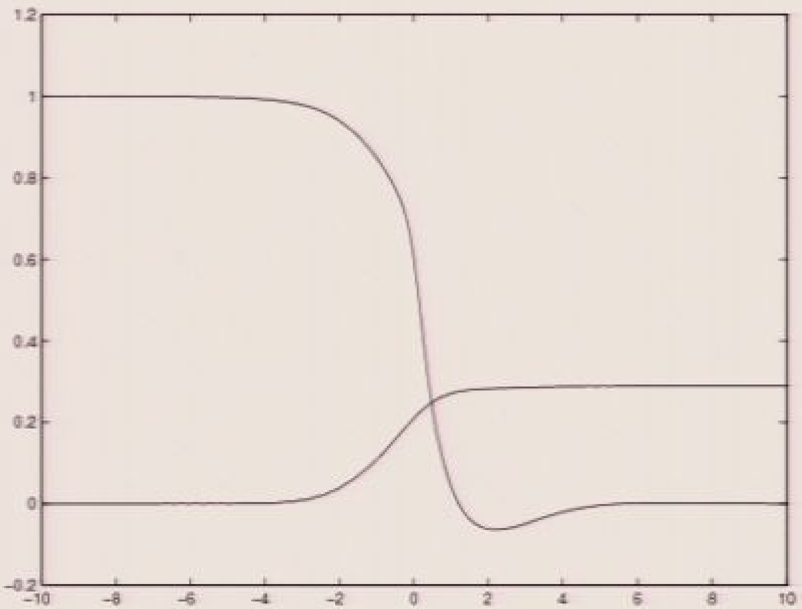

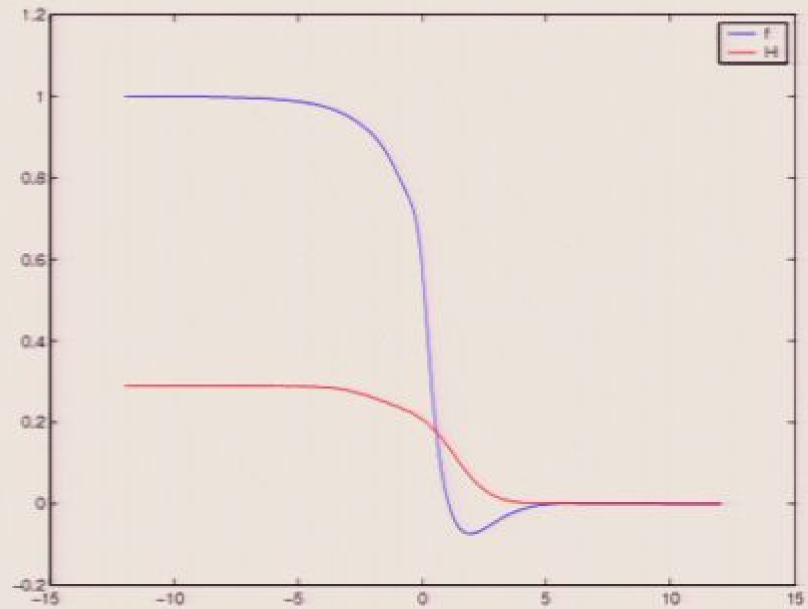

$$S = \int d^4x \sqrt{-g} \left(\frac{m_p^2}{2} R \pm L \right)$$

Conclusions / Further Directions

- Dynamics of the tachyon scalar field in Witten's open string filed theory is considered in the Friedmann-Robertson-Walker background.

- The new rolling tachyon solution interpolating between perturbative and non-perturbative vacua is presented. It is shown that this solution leads to the cosmic acceleration.

- To consider perturbations in such a nonlocal models.

Thank you for the attention!