Title: Anamorphic cosmology

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Abstract: <p>I will present a novel approach to explain the smoothness and flatness of the universe on large scales and the generation of a nearly scale-invariant spectrum of adiabatic density perturbations.</p>

An introduction to anamorphic cosmology

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arXiv: very soon

Why anamorphic cosmology?

Inflationary theory has some serious problems ...

- inflation makes the big-bang initial conditions problem exponentially worse;

  Penrose 1987, Gibbons/Turok 2008, Berezhiani/Trodden 2015

- implies eternal inflation that leads to a multiverse of outcomes;

  Steinhardt 1983, Vilenkin 1983

- the simplest textbook models are observationally disfavored

  AI/Steinhardt/Loeb 2013, 2014

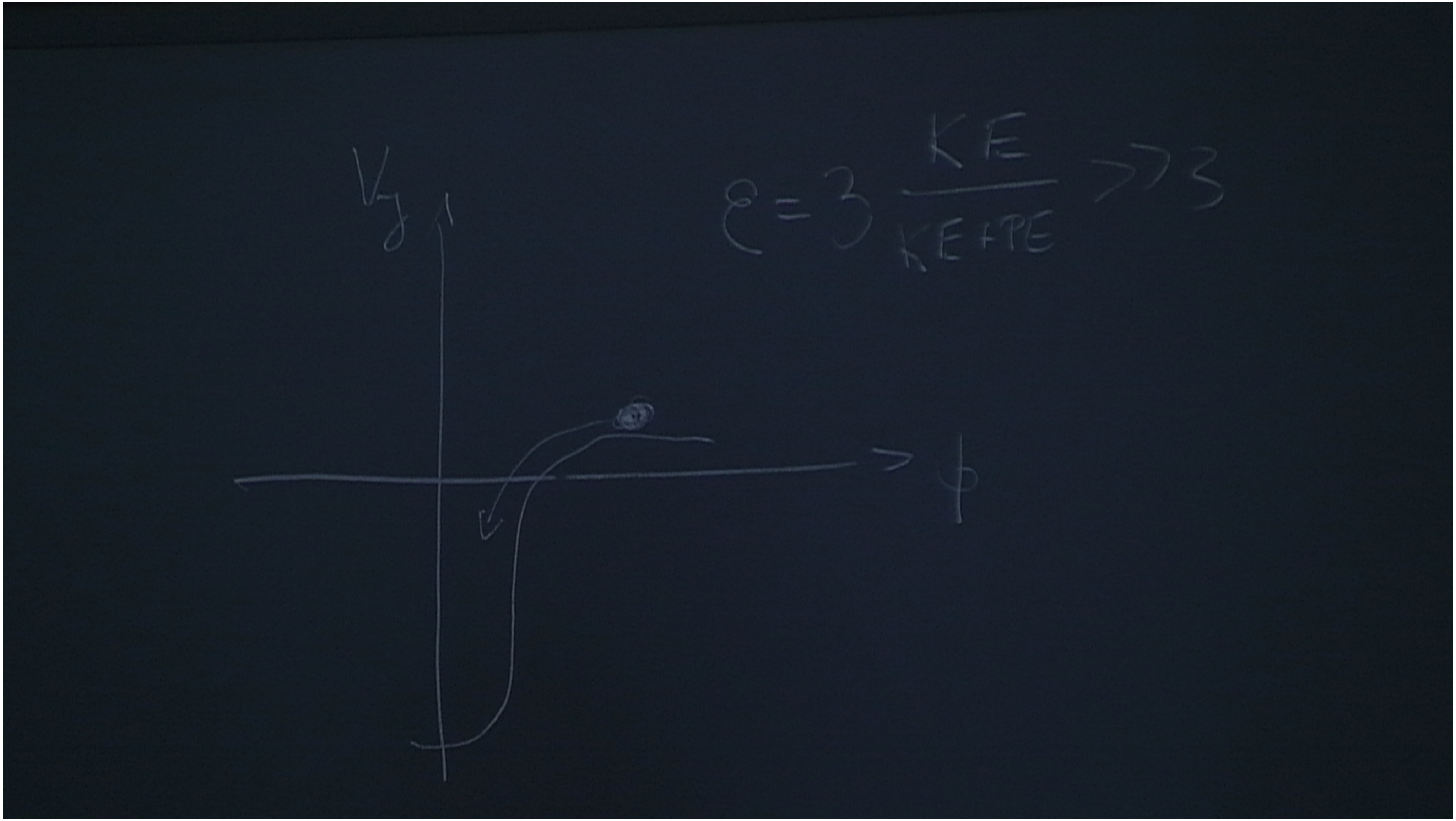
Why anamorphic cosmology?

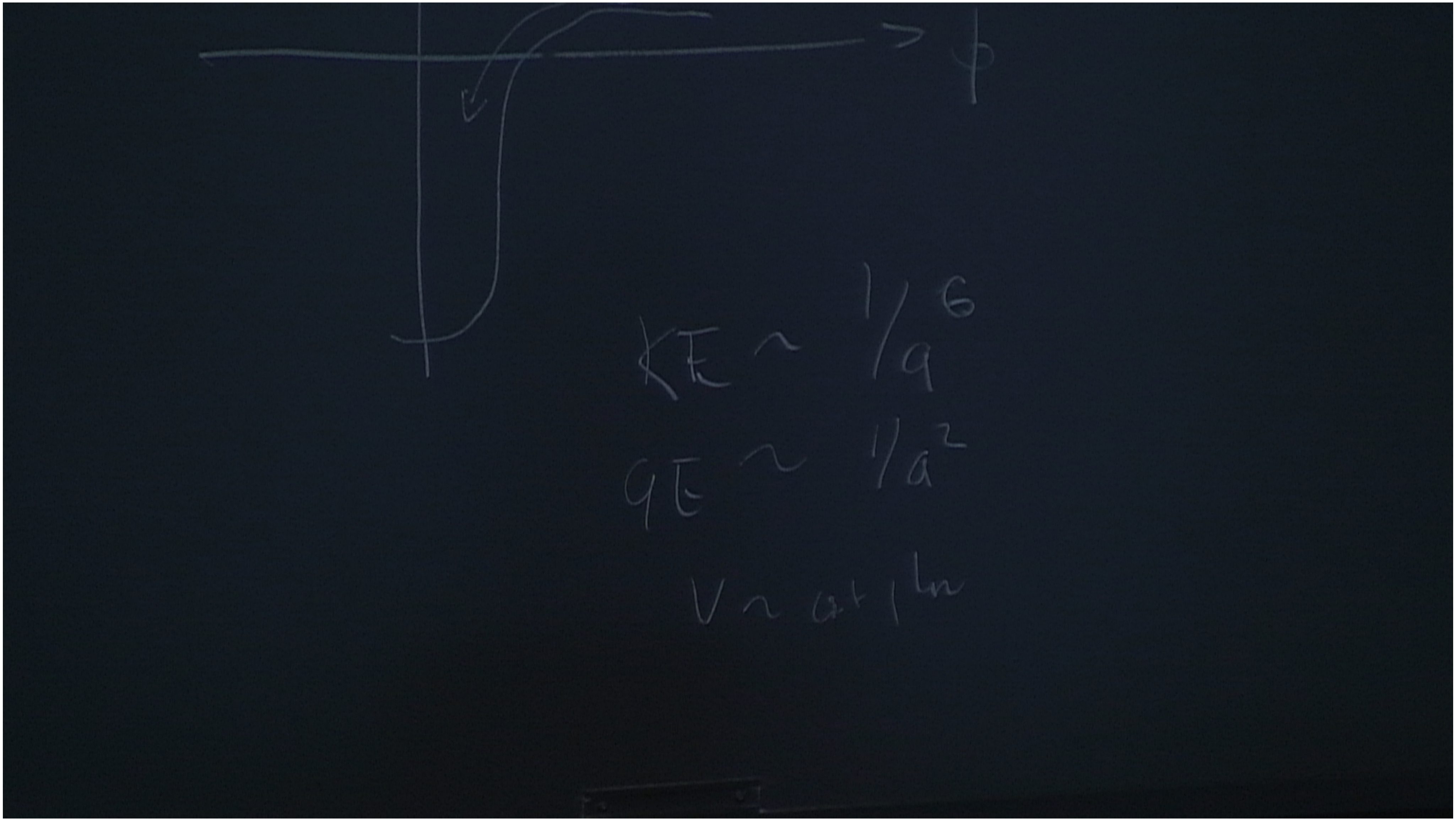
Ekpyrotic/cyclic theory solves these problems ...

$$3H^2 = \frac{\rho_m}{a^3} + \frac{\rho_r}{a^4} + \frac{\sigma^2}{a^6} - \frac{k}{a^2} + \frac{\rho}{a^{2\varepsilon}}$$

with $\varepsilon = 3/2\,(w+1) > 3$,
$w = p/\varrho$

- has no initial conditions problem;


$\varepsilon = 3\,\frac{KE}{KE+PE} \gg 3$
ϕ


φ
KE ~ 1/a6
GE ~ 1/a2

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- has no initial conditions problem;
- no multiverse;
- simplest ekpyrotic models consistent with current observations (Levy/AI/Steinhardt 2015)

... but full-blown theory of bounce is missing;

and it is important to explore other alternatives anyway!

Essentials of anamorphic cosmology

scalar-tensor theory:

$$S = \int d^4x\sqrt{-g}\left(\frac{1}{2}M^2_{Pl}(\phi)R - \frac{1}{2}k(\phi)(\partial_\mu\phi)^2 - V(\phi)\right) + S_m$$

Essentials of anamorphic cosmology

scalar-tensor theory:

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}M_{Pl}^2(\phi)R - \frac{1}{2}k(\phi)(\partial_\mu\phi)^2 - V(\phi)\right] + S_m$$

$$S_m = \int m\, ds$$

FRW metric: $ds^2 = -dt^2 + a^2(t)\, dx_i dx^i$ -> frame invariants

$$\Theta_{Pl} \equiv \left(H + \frac{\dot{M}_{Pl}}{M_{Pl}}\right) / M_{Pl}\,, \quad \Theta_m \equiv \left(H + \frac{\dot{m}}{m}\right) / M_{Pl}$$

	Jordan frame	Einstein frame
metric	$g_{\mu\nu}$	$f(\phi)\, g_{\mu\nu}$
scale factor	a_J	$a_E = a_J \sqrt{f}$
M_{Pl}	$\sqrt{f}$	1
test-particle mass	m_J = constant	$m_E = m_J / \sqrt{f}$

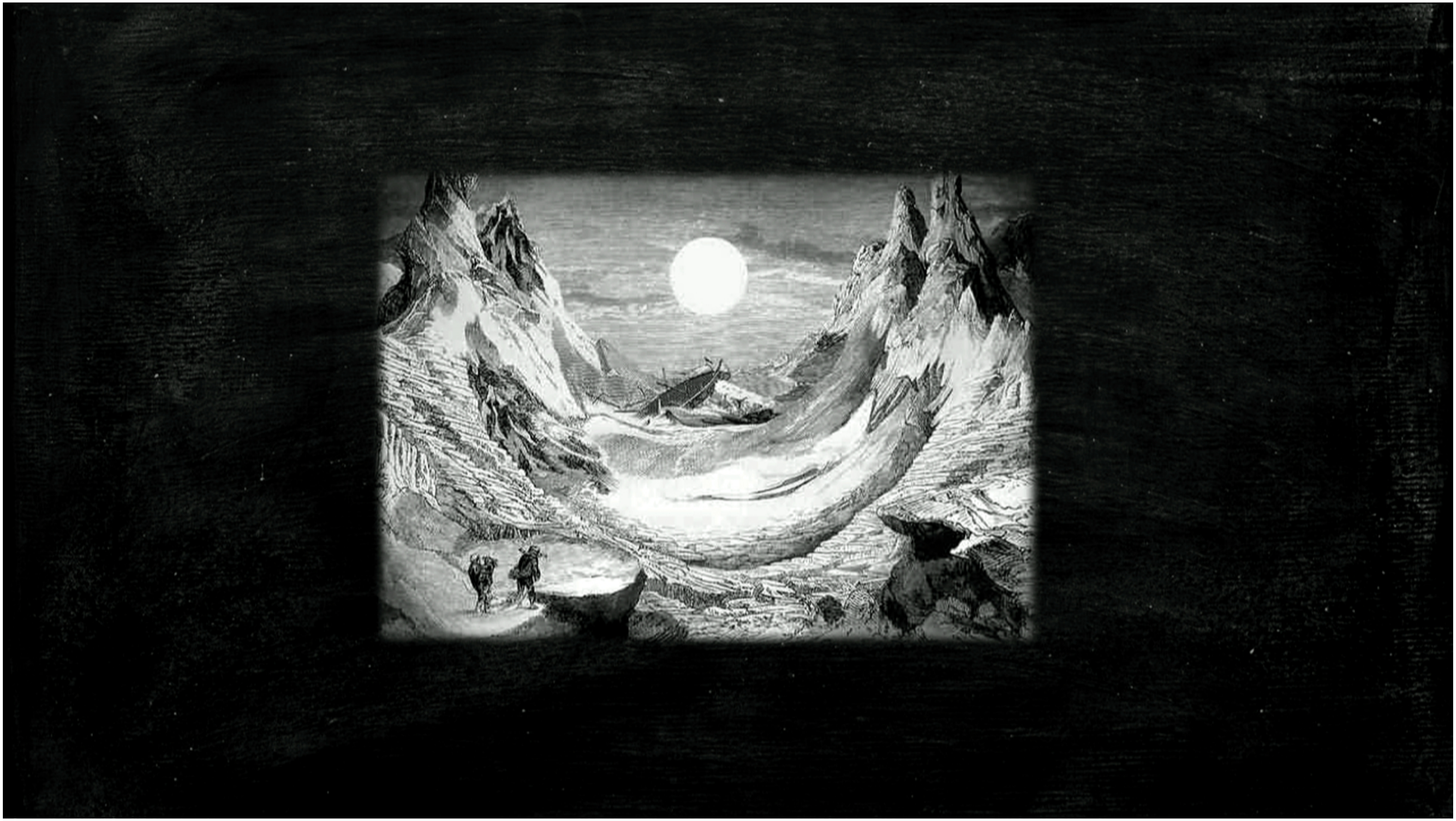
$$\Theta_{Pl} = \frac{1}{\sqrt{f}}\left(\frac{\dot{a}_J}{a_J} + \frac{\left(\sqrt{f}\right)^{\cdot}_J}{\sqrt{f}}\right) = \frac{d\ln(a_J\sqrt{f})}{\sqrt{f}dt_J} = \frac{d\ln(a_E)}{dt_E} = H_E\,/M_{Pl}$$

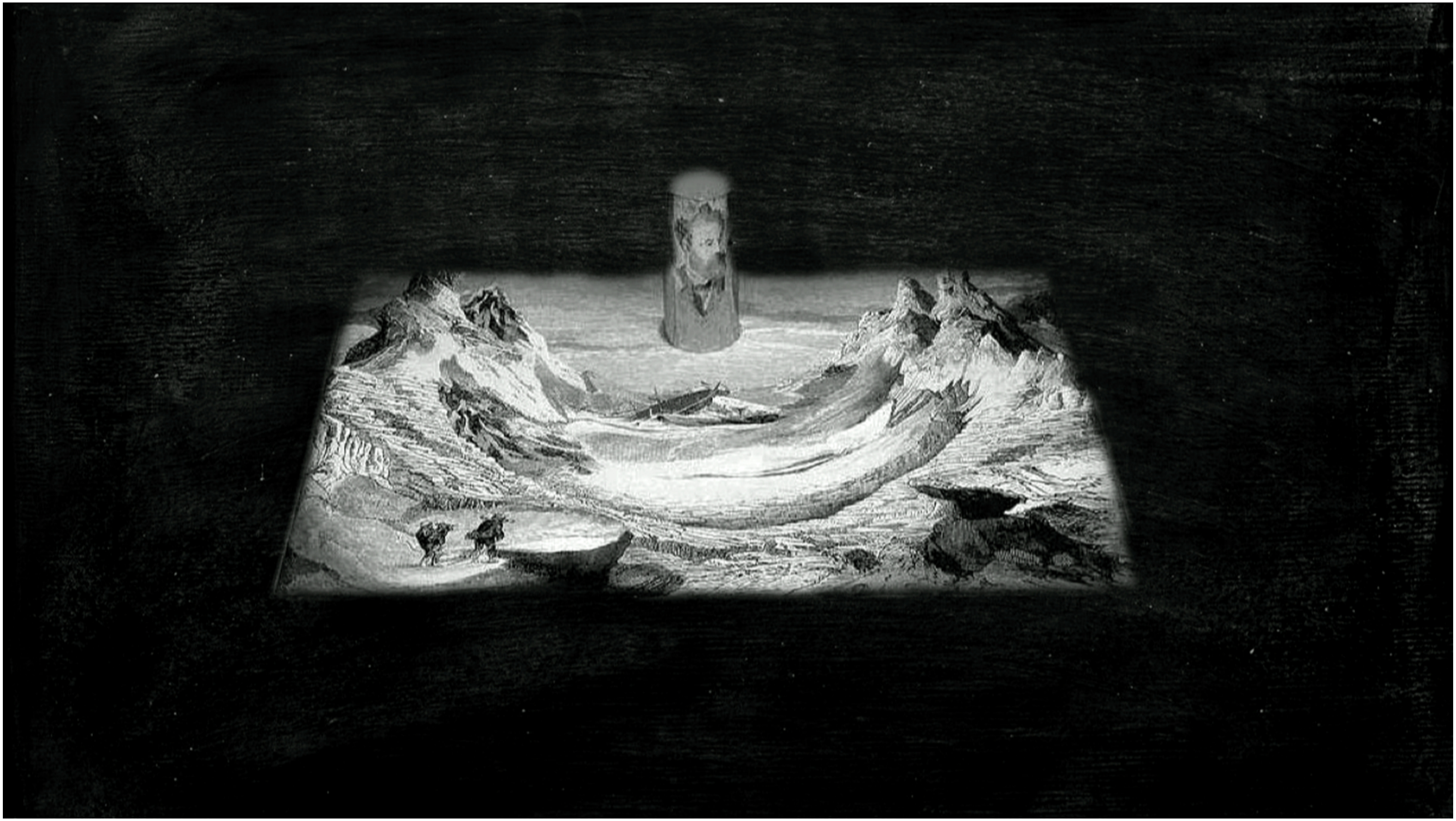
$$\Theta_m = \left(\frac{\dot{a}_E}{a_E} + \frac{\dot{m}_E}{m_E}\right) = \frac{d\ln(a_E\,/\,\sqrt{f})}{\sqrt{f}dt_J} = H_J\,/\,M_{Pl}$$

	inflation	ekpyrosis	
$\theta_m\ M_{Pl}(\phi)$	$H_E > 0$	$H_E < 0$	$H_J < 0$
background	expands	contracts	contracts
$\theta_{Pl}\ M_{Pl}(\phi)$	$H_E > 0$	$H_E < 0$	$H_E > 0$
curvature perturbations	grow	decay	grow

	inflation	ekpyrosis	
θ_m $M_{Pl}(\phi)$	$H_E > 0$	$H_E < 0$	$H_J < 0$
background	expands	contracts	contracts
θ_{Pl} $M_{Pl}(\phi)$	$H_E > 0$	$H_E < 0$	$H_E > 0$
curvature perturbations	grow	decay	grow

θ_m bounce!





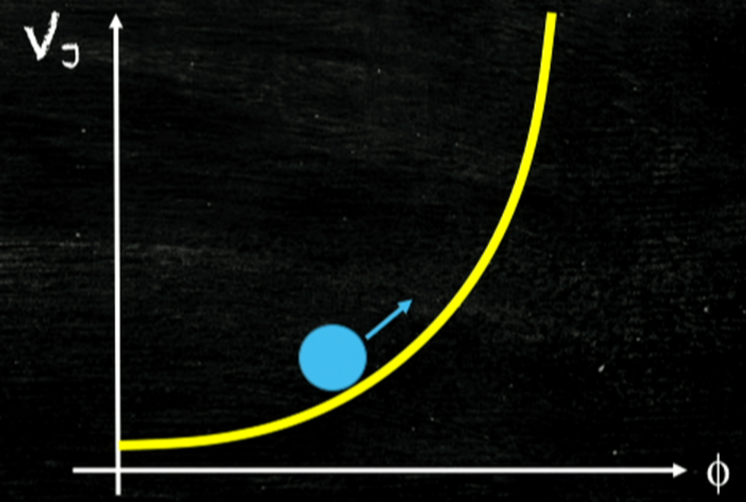
Field picture

$$\mathcal{L}_{Jordan} = \frac{1}{2} M^2_{Pl}(\phi) R - \frac{1}{2} k(\phi)(\partial_\mu \phi)^2 - V(\phi)$$

$M^2_{Pl}(\phi) = f(\phi) > 0;$

$k(\phi) < 0;$

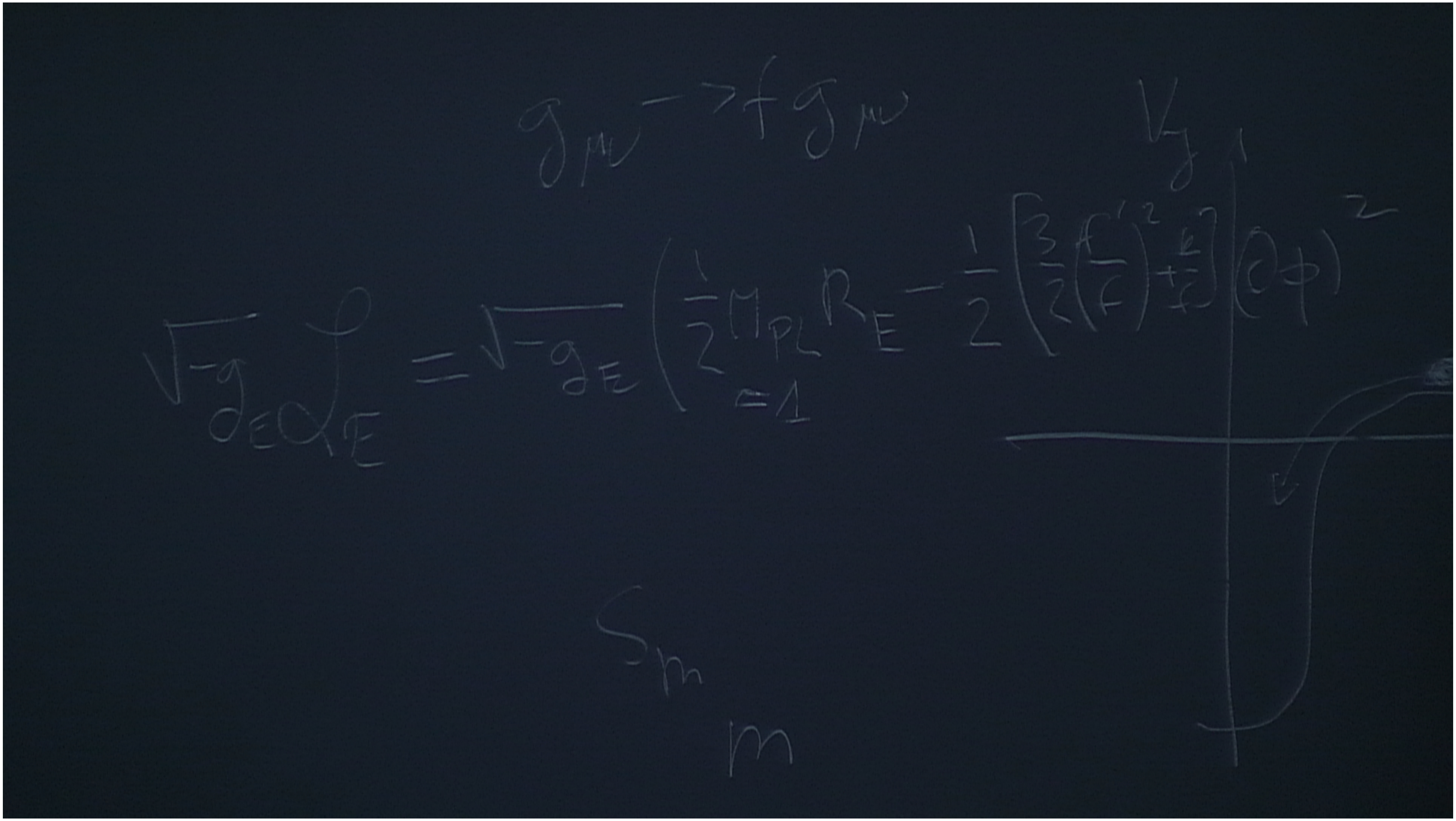
$V(\phi) > 0$



Background

Friedmann equation:

$$H_J^2 + H_J \frac{f_{,\phi}}{f}\dot{\phi}_J = \frac{1}{3f}\left(\frac{1}{2}k(\phi)\dot{\phi}_J^2 + V_J(\phi)\right) - \frac{\kappa}{a_J^2} + \frac{\sigma^2}{f^2 a_J^6}$$


gμν → f gμν
V
√-gE ℒE = √-gE (½ MPL RE − ½ [3/2 (f′/f)² + k/f] (∂φ)²
= 1
Sm
m

Background

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$$H_J^2 + H_J \frac{f_{,\phi}}{f}\dot{\phi}_J = \frac{1}{3f}\left(\frac{1}{2}k(\phi)\dot{\phi}_J^2 + V_J(\phi)\right) - \frac{\kappa}{a_J^2} + \frac{\sigma^2}{f^2 a_J^6}$$

$\sim 1/a_J^{2\varepsilon_{eff}}$

$\sim 1/a_J^{2(3-\beta)}$,

$\beta > 2$ if $\Theta_{PL} > 0$

Background

Friedmann equation:

$$H_J^2 + H_J \frac{f_{,\phi}}{f}\dot{\phi}_J = \underbrace{\frac{1}{3f}\left(\frac{1}{2}k(\phi)\dot{\phi}_J^2 + V_J(\phi)\right)}_{\sim 1/a_J^{2\varepsilon_{eff}}} - \frac{\kappa}{a_J^2} + \underbrace{\frac{\sigma^2}{f^2 a_J^6}}_{\sim 1/a_J^{2(3-\beta)}}$$

$\sim 1/a_J^{2(3-\beta)}$, $\beta > 2$ if $\Theta_{PL} > 0$

smoothing + flattening: $1 < \varepsilon_{eff}$

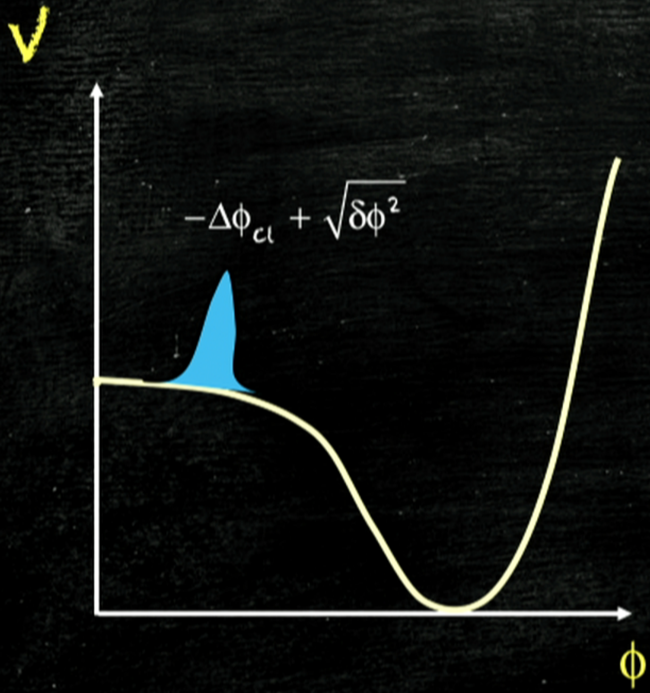
Perturbations

perturbed metric: $ds^2 = -dt^2 + a(t)e^{2\zeta(t,x^i)}dx^i dx_i$

action for curvature perturbations:

$$S_{2,s} \sim \frac{1}{2}\int d\eta d^3x\, a_J^2 f(\phi)\left[\left(\zeta_{,\eta}\right)^2 - \left(\partial_k \zeta\right)^2\right], d\eta = a_J dt$$

No multiverse



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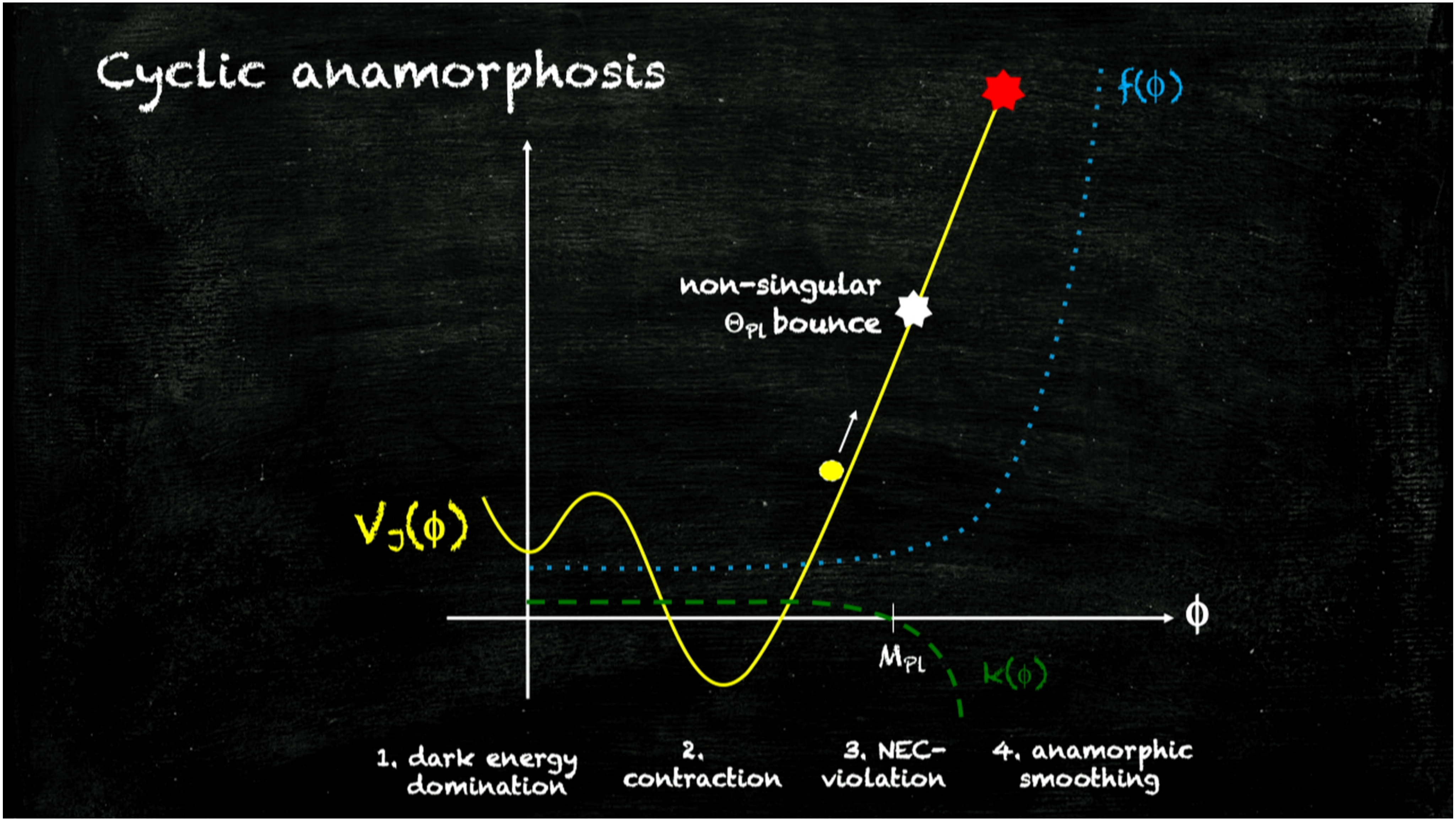

Cyclic anamorphosis
f(ϕ)
non-singular
Θ_Pl bounce
V_J(ϕ)
ϕ
M_Pl
k(ϕ)
1. dark energy domination
2. contraction
3. NEC-violation
4. anamorphic smoothing