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SMR.1508 - 39

SUMMER SCHOOL ON PARTICLE PHYSICS

16 June - 4 July 2003

EKPYROTIC UNIVERSE

Special Lecture - Part 1

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Ekpyrotic Universe

Khoury, Ovrut, Steinhardt, Turok

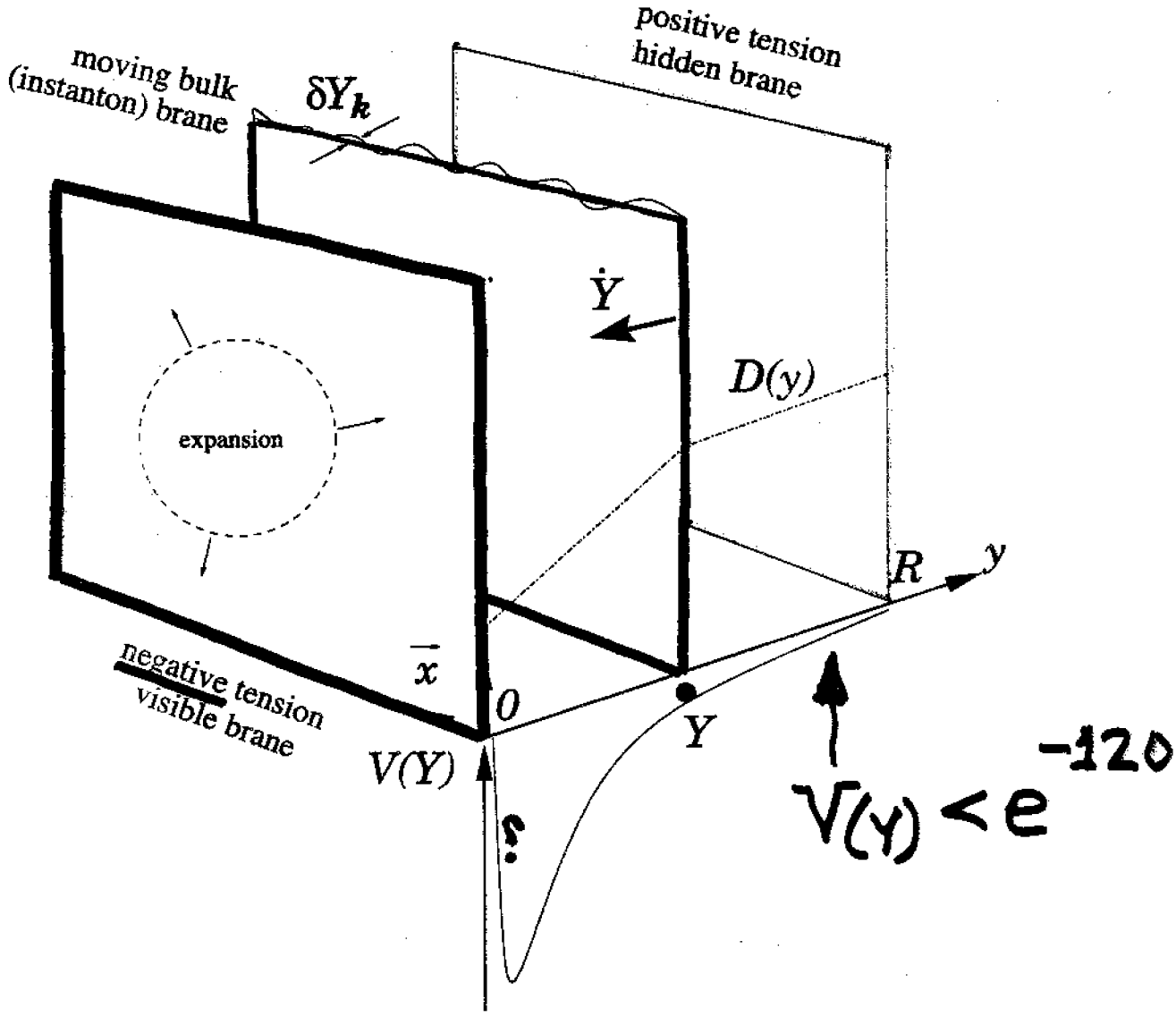


Figure 1:

Sketch of the ekpyrotic scenario. We live on a brane with negative energy density. Big bang happens when the bulk brane hits our brane. The bulk brane has potential energy $V(Y)$ which is postulated to have a very specific form: It is negative everywhere except our brane, and its absolute value decreases exponentially at large Y. An important feature of this scenario is that the volume of space controlled by metric $D(Y)$ decreases near our brane, which makes the spectrum of perturbations blue.

1) We live on a negative tension brane

Ekpyrosis

2) There is no cosmological singularity, much better than Pre-Big Bang

3) We do not need inflation ("superluminal expansion) to solve all major cosmological problems.

1) Disagrees with standard HW phenomenology

2) Instead of Big Bang → Big Crunch

Original solution of 4d and 5d equations is incorrect

3) Require <u>Fine tuning</u> of initial conditions with accuracy better than 10^{-60}.

Much worse than the standard homogeneity problem.

Ekpyrotic/cyclic

Predictions:
(kind of)

1. ~~Blue~~ Red density perturbations

   Exactly as in inflation

2. Grav. waves with amplitude sharply falling at large λ

   Cannot detect with Planck, LIGO and LISA

If grav. waves are found with Planck, it will disprove ekpyrotic/cyclic

If they are not found, it will mean nothing since 50% of infationary models predict very small GW

Thus, all observations planned now can only disprove ekpyrotic/cyclic scenario. No obvious way to prove it...

Problems

1. Singularity problem is not solved.

2. Theory of density perturbations is problematic

Lyth 2001
Brandenberger, Finelli
Hwang 2001

3. Brane stabilization is absent

4. Potential is Fine-tuned; one needs $V(\varphi) \gg M_p^4$. Not related to string theory.

5. 5d brane cosmology?

Rasanen 2001

6. Can it be cyclic?

No cycles in the original model

7. Homogeneity, huge size and entropy are required for consistency of the scenario. It is quite different from a solution of these problems in usual inflation.

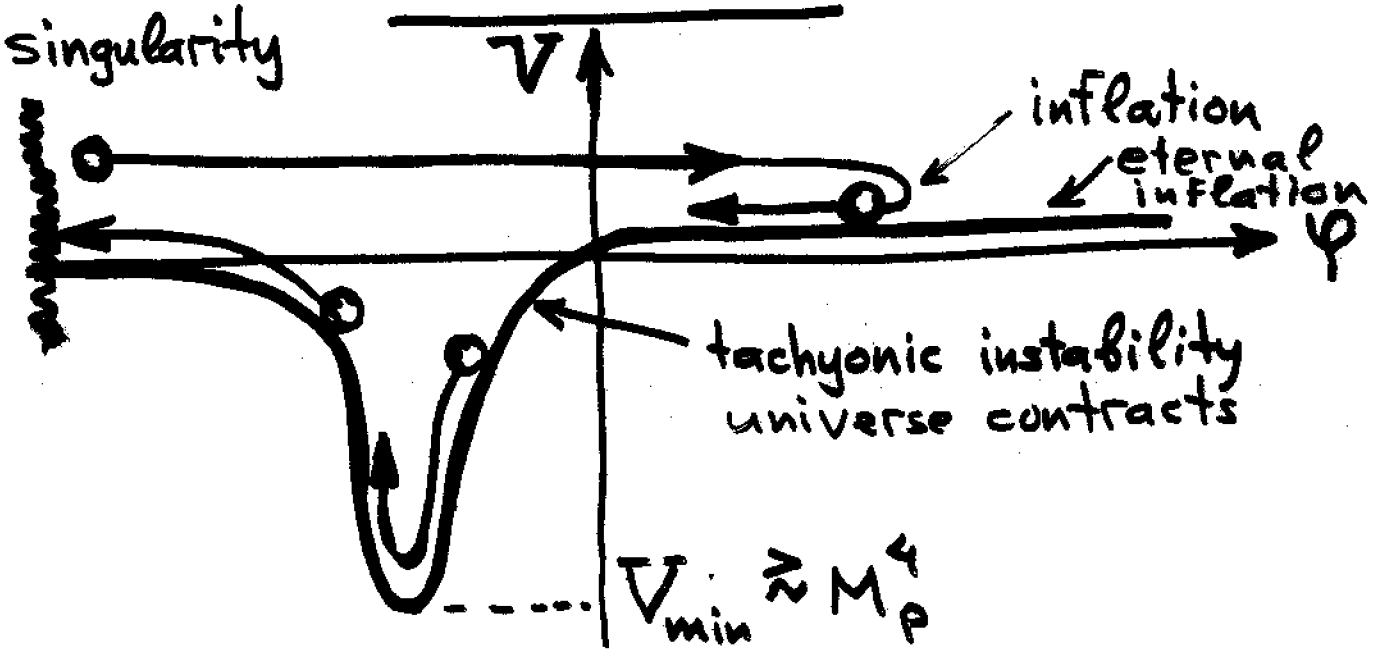
And, after all, a stage of "superluminal expansion" (i.e. inflation) must occur before the singularity in order to make the universe homogeneous

Thus, cyclic scenario is not an alternative to inflation, it is a rather complicated version of inflationary cosmolog

In fact, it is eternal inflation

A.L.

Main idea



$$\frac{\delta\rho}{\rho} \sim \frac{\sqrt{-V}}{M_p^2} \xi^4 \cdot 10^{-5} \qquad \xi \ll 1$$

(if the derivation is correct, see Lyth 2001, Brandenberger, Finelli, Hwang 2001 .....)

One needs

$$|V_{min}| \gg M_p^4 \quad (!)$$

The universe is homogeneous because of inflation. In ekpyrotic scenario the main point was that „superluminal expansion" (inflation) is no longer needed.

Independently of that,
m changes within time $\sim m^{-1} \sim 1$
From 0 to $m \sim 1$ and back to 0.

Nonadiabatic process,
creates scalar particles with

$$\rho \approx 1$$ (in units of Planck density)

Thus the scenario does not work unless the kinetic energy of the field φ after it rolls out from the minimum is greater than $10^{12} M_p^4$ (!!!)

Creation of nonrelativistic matter may improve the situation, but that is an additional „epicycle", requiring a specific interaction of matter with φ.

The field must roll to $\varphi > 1$, only then inflation can begin.

One can show that on the way from -33 to $+1$ radiation will dominate unless its original contribution is smaller than 10^{-12}.

Meanwhile after the singularity one expects radiation contribution $O(1)$.

If radiation dominates, scalar field never reaches $\varphi > 1$, inflation never begins $\longrightarrow$ no inflationary cycles

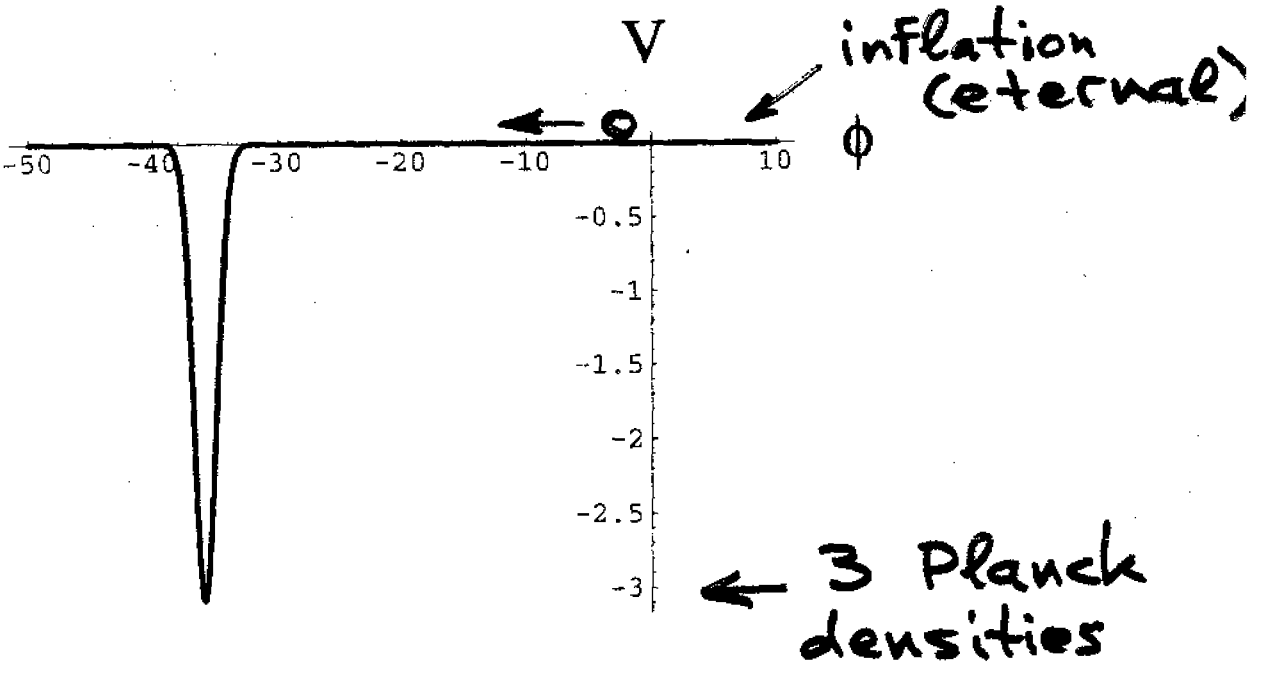
No cycles in cyclic scenario

Scalar potential $V(\phi)$ in the cyclic scenario:

Steinhardt, Turok astro-ph/0112537

$$V(\phi) = V_0\,(1 - e^{-c\phi})\,e^{-e^{-\gamma\phi}}, \quad V_0 = 10^{-120}, \quad c = 10, \quad \gamma \approx 0.1226$$

fine tuning better than 1%

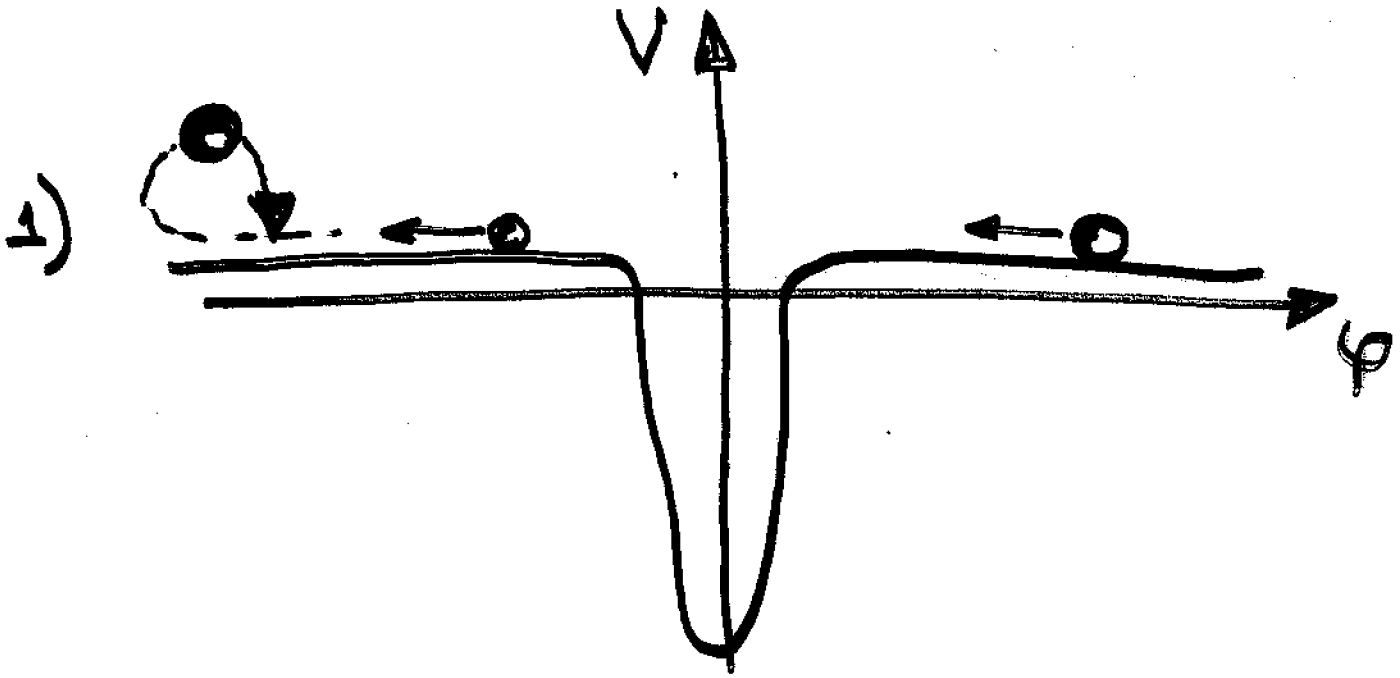


Kinetic energy of the scalar field ϕ when it reaches the minimum of $V(\phi)$ is $\sim 10^2\ M_p^4$.

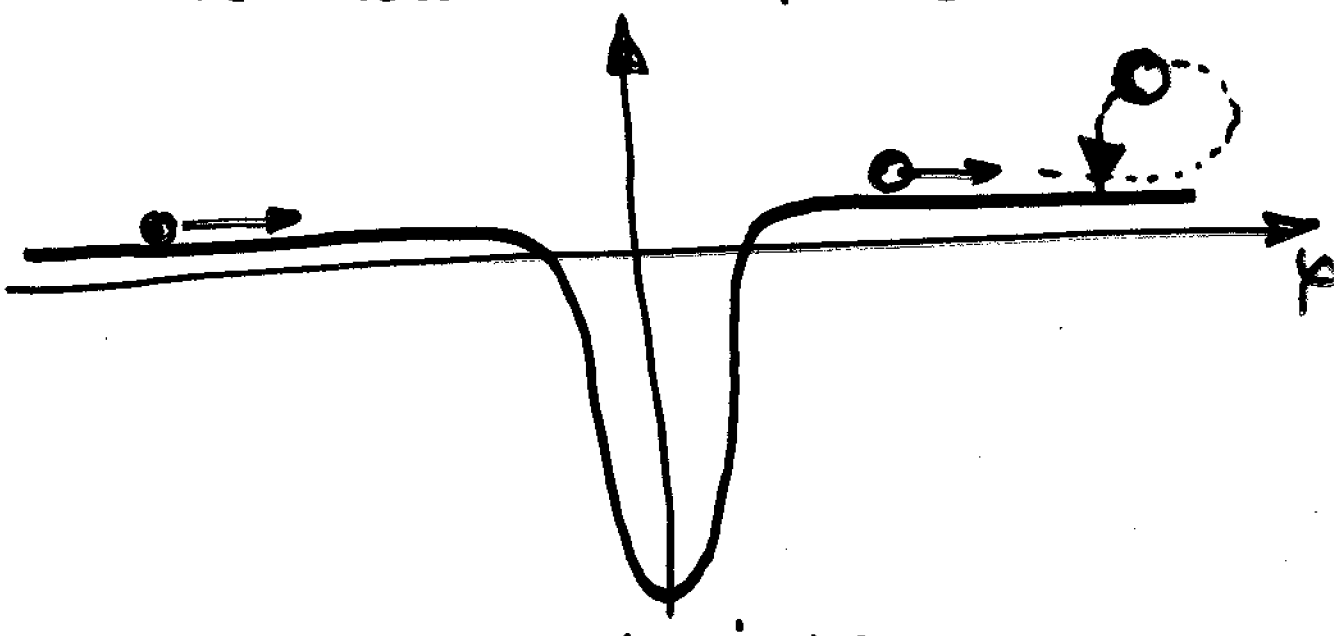
When the field approaches $\phi \sim -39$, where the effective potential becomes flat, the kinetic energy of the field ϕ becomes $\sim 10^6\ M_p^4$, i.e. a million times greater than the Planck density.

Can we improve the cyclic scenario?

Sure, just make several new alterations:



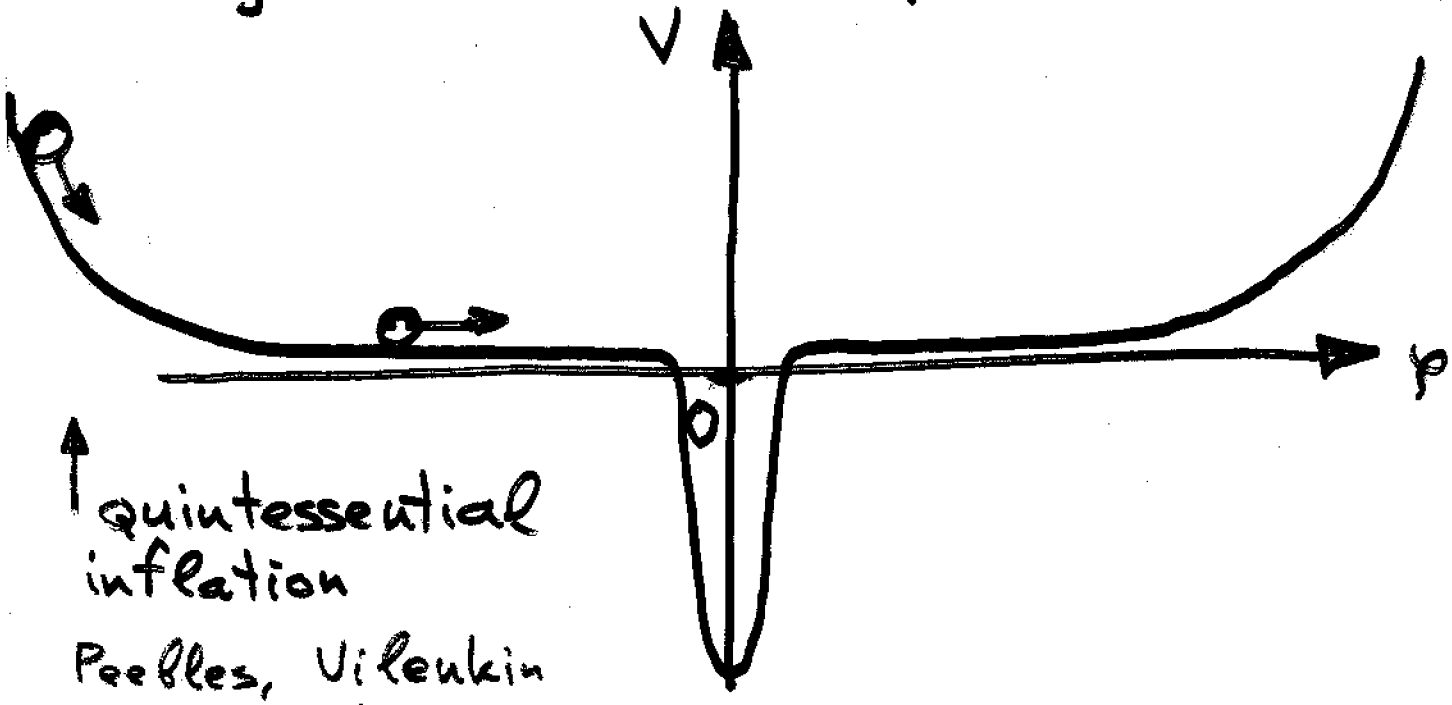
We are now at $\varphi < 0$



DOUBLE CYCLING

But we still have the singularity problem, and we still need to live with density perturbations produced before the singularity...

Let us pay for insurance to get singularity protection:



quintessential inflation

Peebles, Vilenkin
Felder, Kofman, A.L.

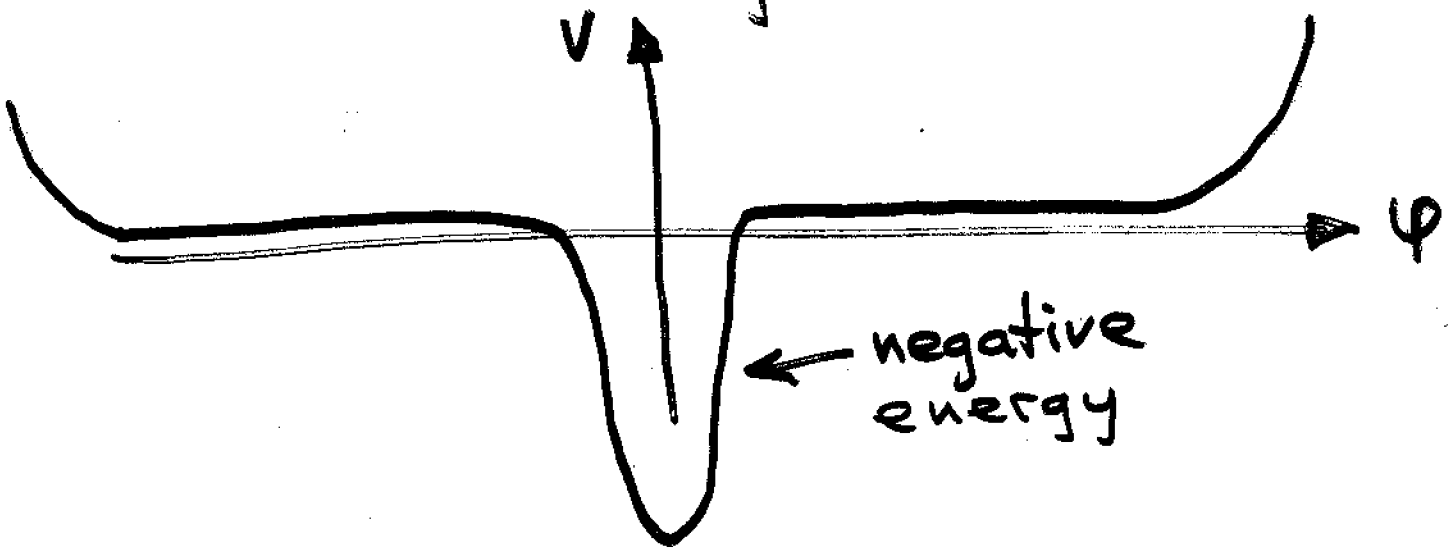
Inflationary density perturbations produced after the singularity.

Gravitational or instant (p)reheating after inflation.

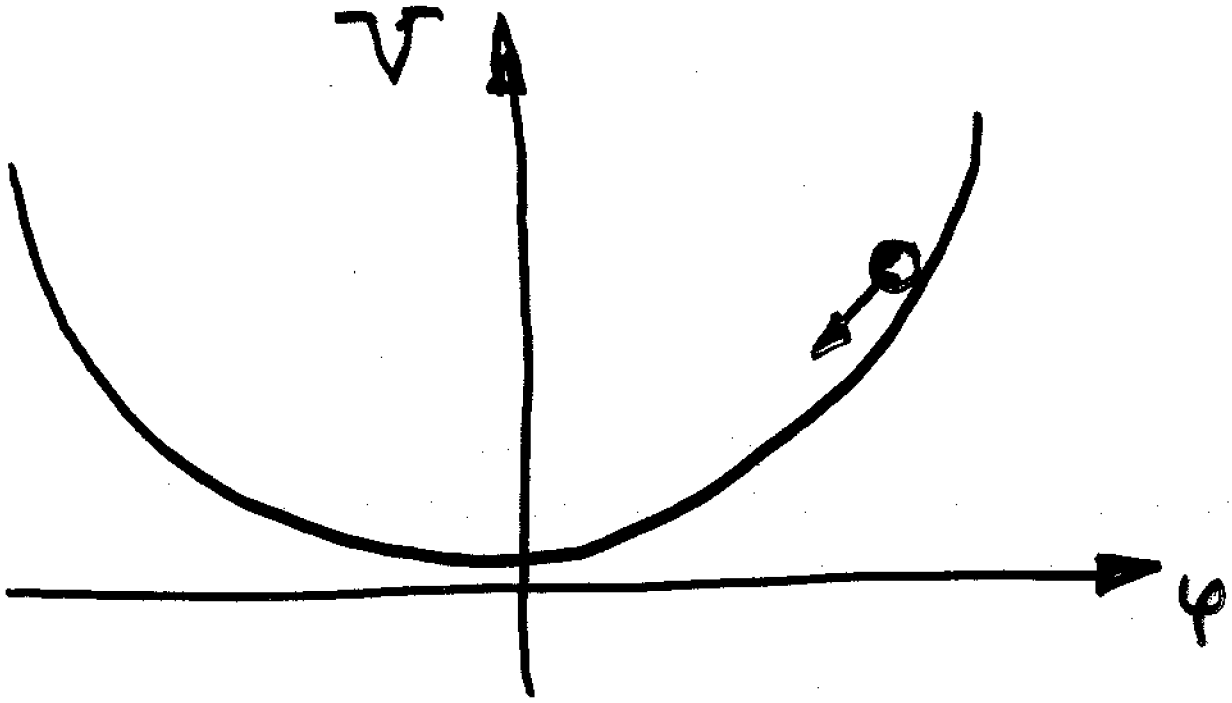
And then – a new cycle...

But we still need to pass through the singularity, though now nothing depends on it, and we need to use unconventional reheating...

What is the cause of our suffering?



Let us cut the damn thing!



After getting rid of all epicycles, we return back to our simple harmonic oscillator model...