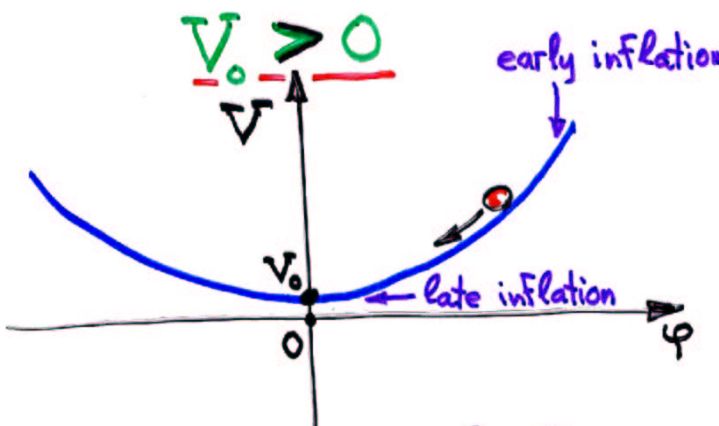


Supergravity, Dark Energy, and the Fate of the Universe

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M. Shmakova hep-th/0208156

R. Kallosh, A.L. hep-th/0208157

$$V(\varphi) = \frac{m^2 \varphi^2}{2} + V_0$$


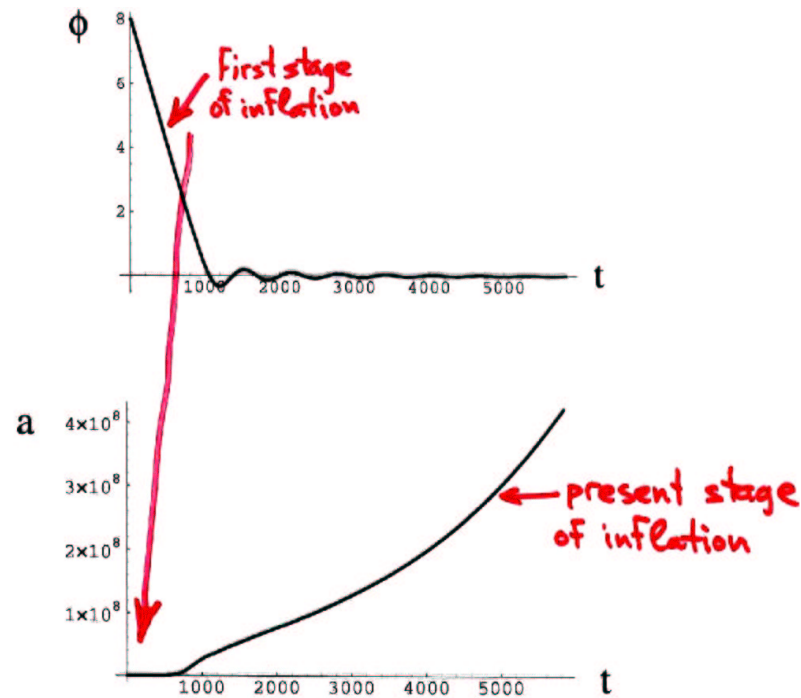
$M_P = 1$

$$H^2 = \frac{1}{3} \left(\dot{\varphi}^2 + \frac{m^2 \varphi^2}{2} \right) + \frac{V_0}{3}$$

$m=1$

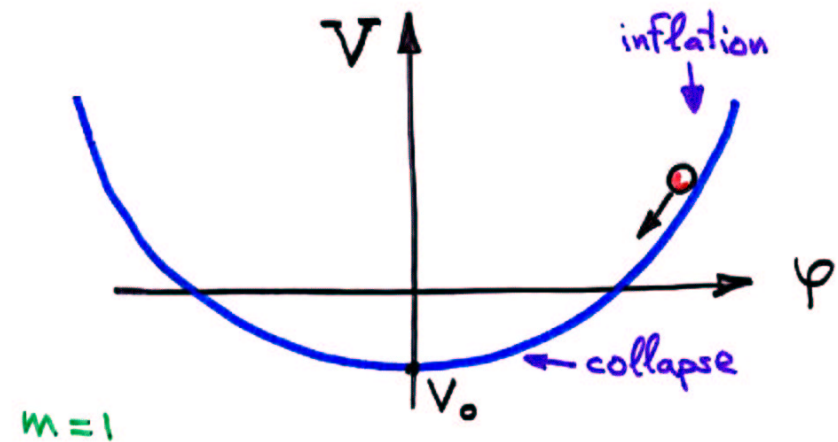
$$\dot{\varphi}^2 + \varphi^2 - 6H^2 = -2V_0$$

Hyperboloid in terms of
coordinates $(\varphi, \dot{\varphi}, H)$



Evolution of the scalar field and the scale factor in the model with $V(\phi) = \frac{m^2}{2}\phi^2 + V_0$ with $V_0 > 0$.

$$V(\phi) = \frac{m^2}{2}\phi^2 + V_0 \quad \underline{V_0 < 0}$$

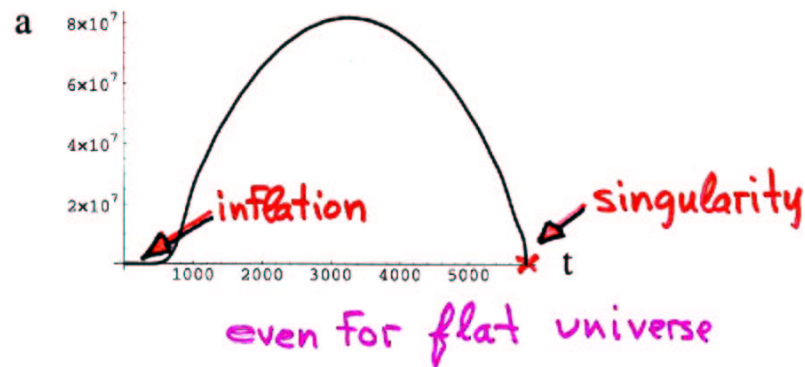
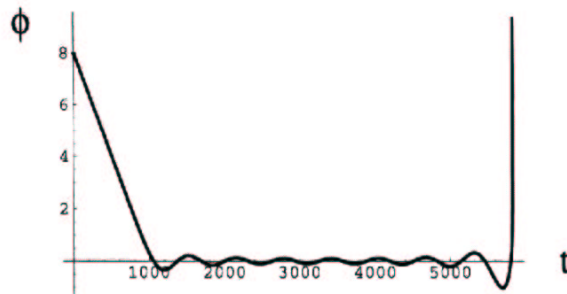


$$\dot{\phi}^2 + \phi^2 - 6H^2 = -2V_0$$

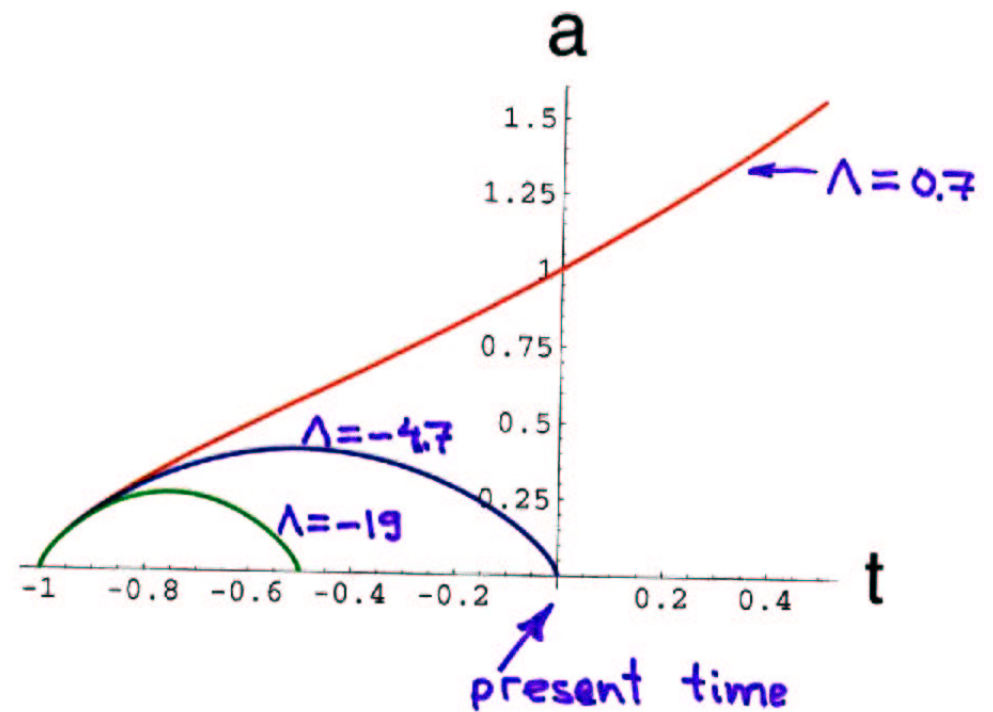
Hyperboloid in terms of $(\dot{\phi}, \phi, H)$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{\dot{\phi}^2}{2} + V(\phi) \geq 0$$

At $\frac{\dot{\phi}^2}{2} + V = 0$ the universe stops and then it collapses



Evolution of the scalar field and the scale factor in the model with $V(\phi) = \frac{m^2}{2}\phi^2 + V_0$ with $V_0 < 0$.



Flat universe, Λ CDM

Λ is in units of $\rho_0 = 10^{-29} \text{ g/cm}^3$

Consequences

1) Inflation predicts that we cannot live in AdS space:

$$H^2 \pm \frac{k}{a^2} = \frac{8}{3}$$

inflation $a^2 \rightarrow \infty$

$$H^2 = \frac{8}{3}$$

g must be positive

2) Theories with $V(\varphi)$ Bounded from below at $V_{\min} < 0$ are as bad as the theories unbounded from below

A.L. hep-th/0110195

Felder, Frolov, Kofman, A.L.

Supergravity,

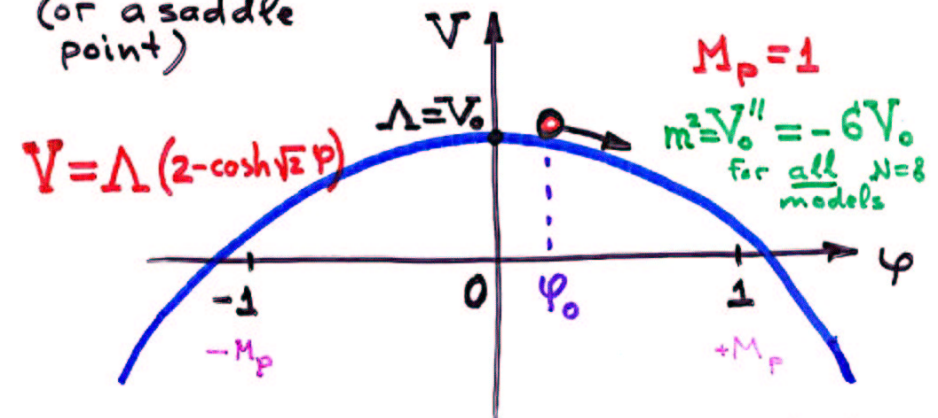
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0208157

Supernova,

And the future of the universe

Kallosh, Prokushkin, Shmakova, A.L.
2001, 2002

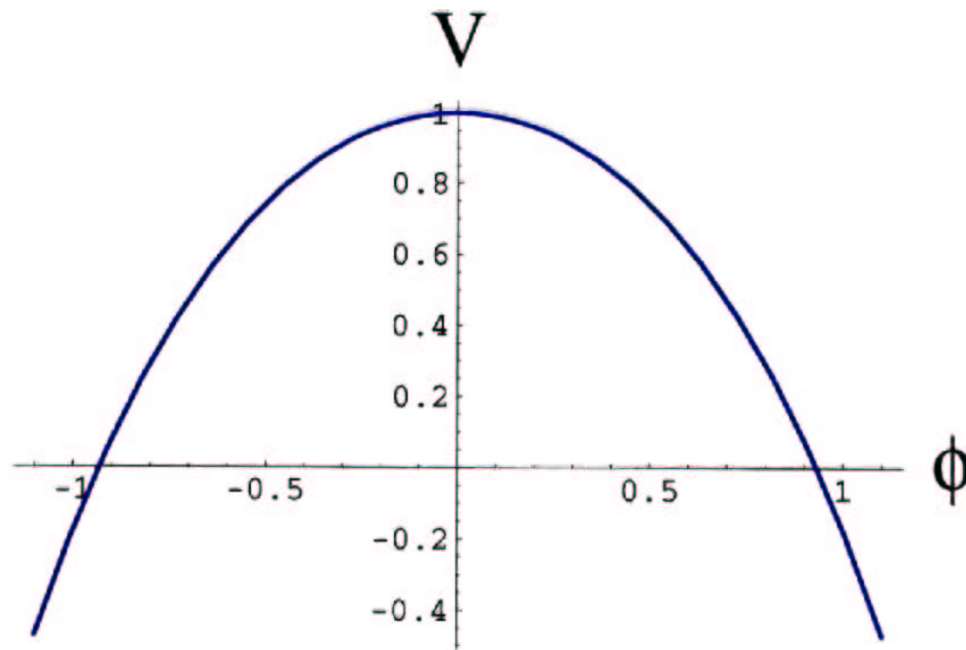
It is possible to obtain dS space in $N=8$ supergravity, but in all known examples it corresponds to a maximum of $V(\varphi)$, (or a saddle point)



In all known examples $m^2(\varphi)$ is quantized in units of H^2

$$m^2 = 0, \pm 2, \pm 3, \pm 4, \pm 6 H^2$$

Why? (+ \rightarrow for $N=2$ SUGRA, Van Proeyen, Fre, Trigiante)



Potential in $N=8$ SUGRA

$$V''(0) = -2V(0)$$

$$m^2 = -6H_0^2$$

Let us assume that $N=8$ describes a hidden sector of the theory with $V_0 \sim 10^{-120} M_P^4$

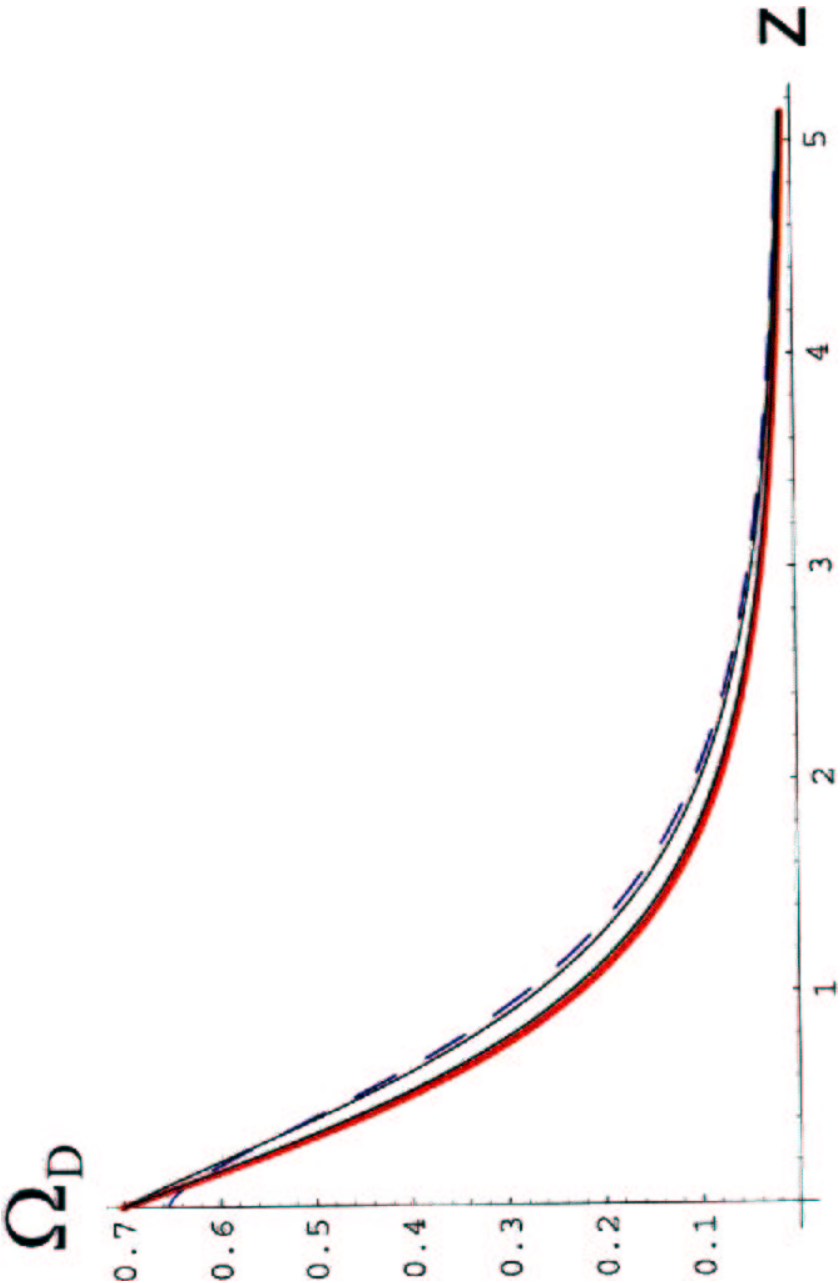
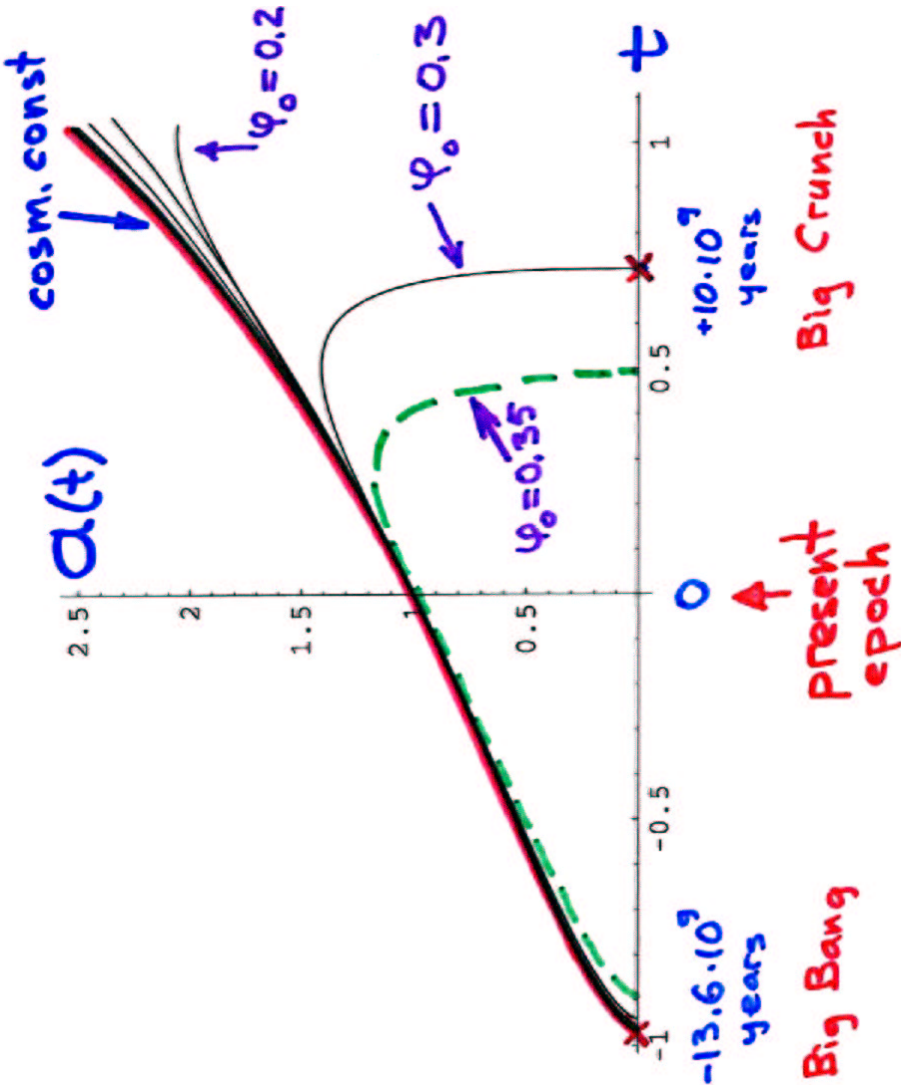
present value of the "cosmological constant"

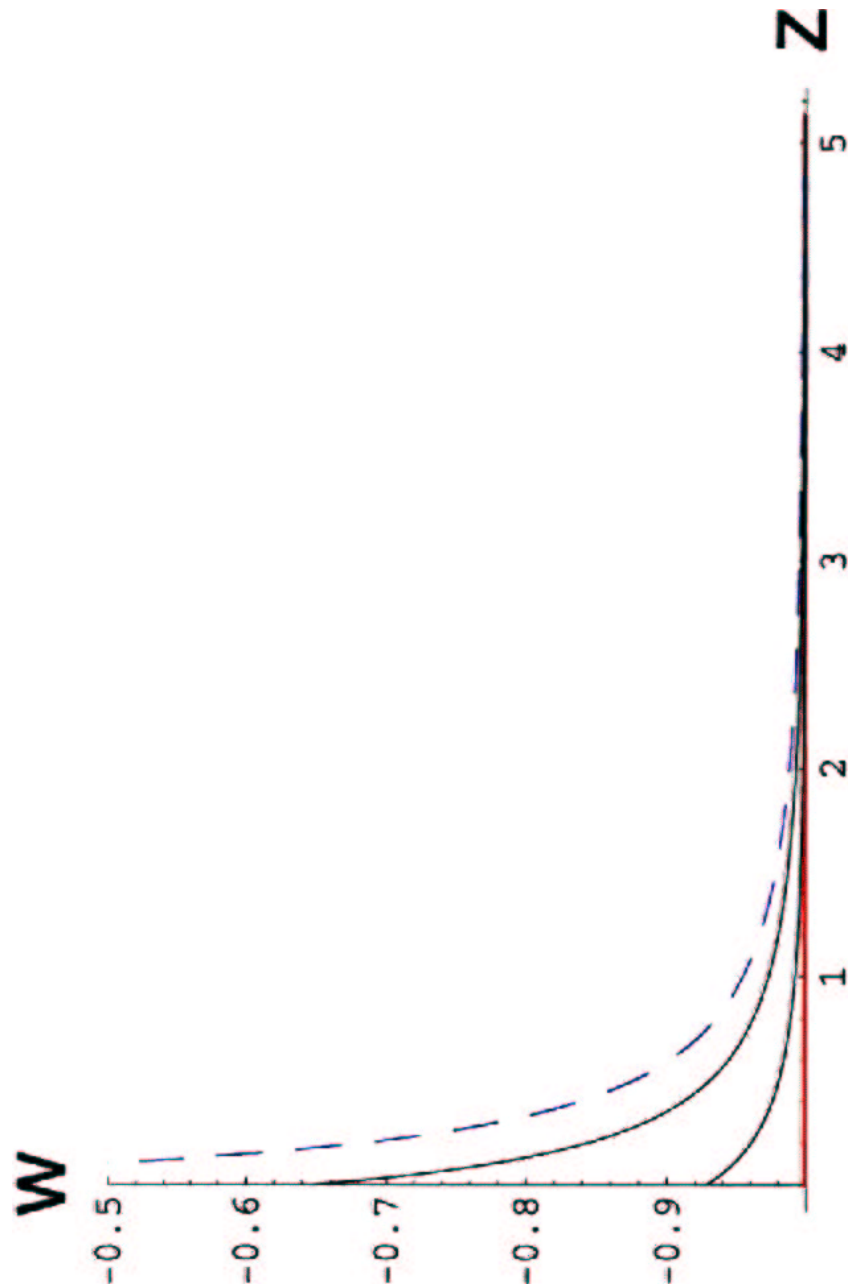
$$\text{Then } |m| = \sqrt{6} H \sim 10^{-60} M_P$$

It will take the field about 10^{10} years to fall down, depending on its initial value ϕ_0

Note: Typical time to fall $t_{\text{fall}} \sim m^{-1}$. Age of the universe $t_{\text{now}} \sim H^{-1}$. Since $m \sim H$, the time t_{fall} remaining until the global collapse is similar to the present age of the universe.

We have 10^{10} years to think about it...





easily extended to a large class of $N = 1$ supergravity models.

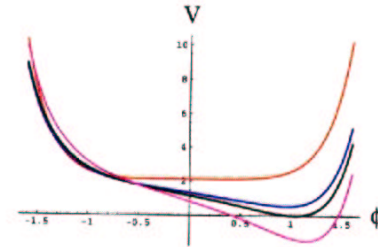


FIG. 8. Polonyi field potential for $\beta = 0$ (symmetric potential with a minimum at $V > 0$), $\beta = 0.2$ (minimum at $V > 0$), $\beta = 2 - \sqrt{3}$ (minimum at $V = 0$), and $\beta = 0.4$ (minimum at $V < 0$). In all of these cases $|V''| = O(|V|)$ for $|\phi| \lesssim 1$. The potential is shown in units of m^2 ; the field is shown in units of M_P . Potentials with $\beta < 0$ can be obtained by the change $\phi \rightarrow -\phi$.

In particular, Polonyi model with $|\beta| < 2 - \sqrt{3} \approx 0.268$ leads to asymptotically de Sitter universe, just like in $N = 2$ model of Ref. [20]. The fine-tuned model with $|\beta| = 2 - \sqrt{3}$ asymptotically leads to Minkowski space. Meanwhile all models with $2 - \sqrt{3} < |\beta|$ lead to a collapsing universe. However, just like the $N = 8$ model, the $N = 1$ models with $2 - \sqrt{3} < |\beta| \lesssim 0.5$ can describe dark energy in an accelerating universe, see Figs. 9 - 12. These figures show the results of calculations where we for definiteness took the initial value of the field ϕ equal to $\phi_0 = -1$.

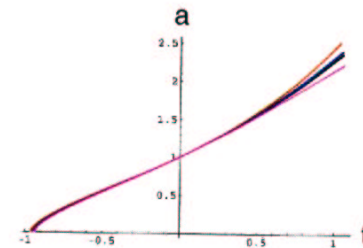


FIG. 9. The scale factor $a(t)$ for the Polonyi field potential. At large t the upper curve corresponds to $\beta = 0$, the next one - to $\beta = 0.2$, then $\beta = 2 - \sqrt{3}$, and $\beta = 0.4$.

Simplest $N=1$ Polonyi model
 $K = z z^*$ $W = \mu^2 (z + \beta)$

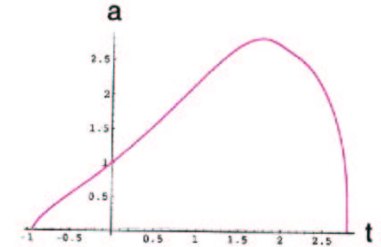


FIG. 10. The future of the universe in the Polonyi model for $\beta = 0.4$ and $\phi_0 = -1$. The present time corresponds to $t = 0$. The universe in this regime would accelerate for the next 20 billion years, but then eventually collapse. In the models with $\beta > 0.4$ the collapse occurs much earlier.

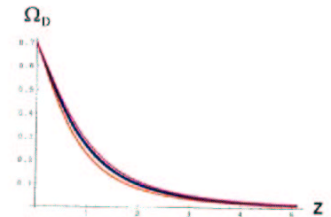


FIG. 11. The values of Ω_D for the Polonyi field potential as a function of redshift z . The lower (horizontal) curve corresponds to $\beta = 0$, the next one - to $\beta = 0.2$, then $\beta = 2 - \sqrt{3}$, and $\beta = 0.4$.

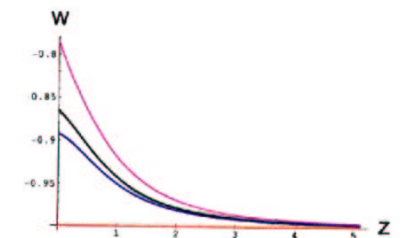
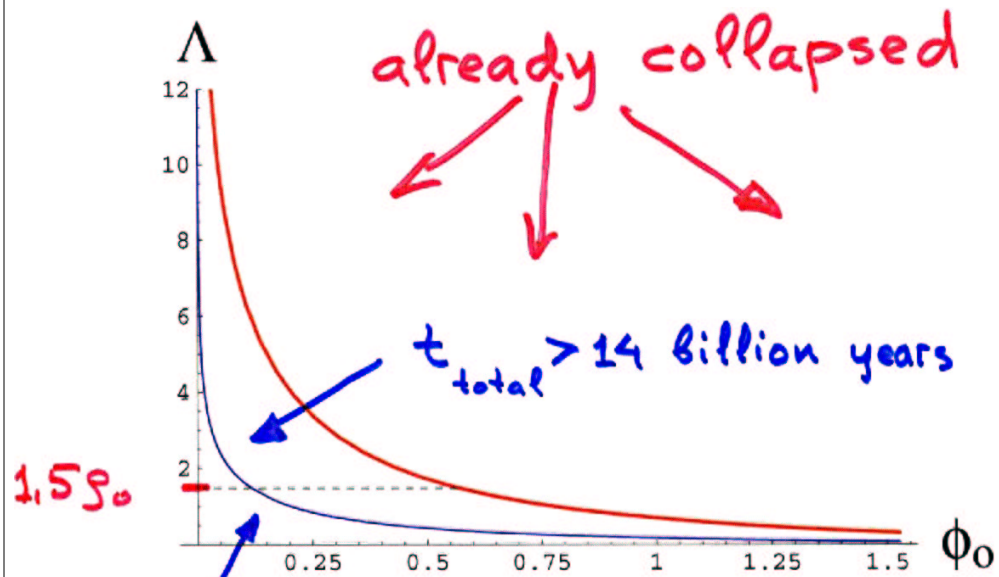


FIG. 12. The values of w for the Polonyi field potential as a function of redshift z . The lower (horizontal) curve corresponds to $\beta = 0$, the next one - to $\beta = 0.2$, then $\beta = 2 - \sqrt{3}$, and $\beta = 0.4$.

Thus, even the very simplest models based on $N =$

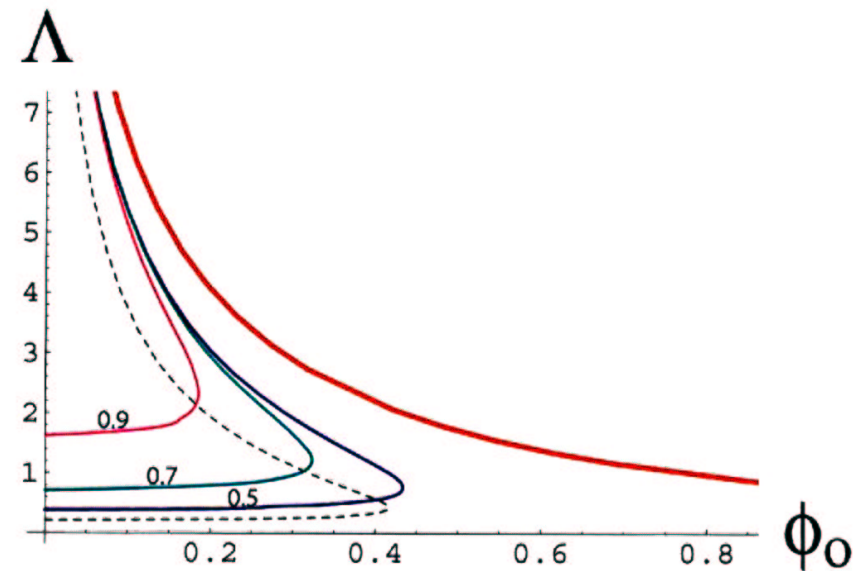


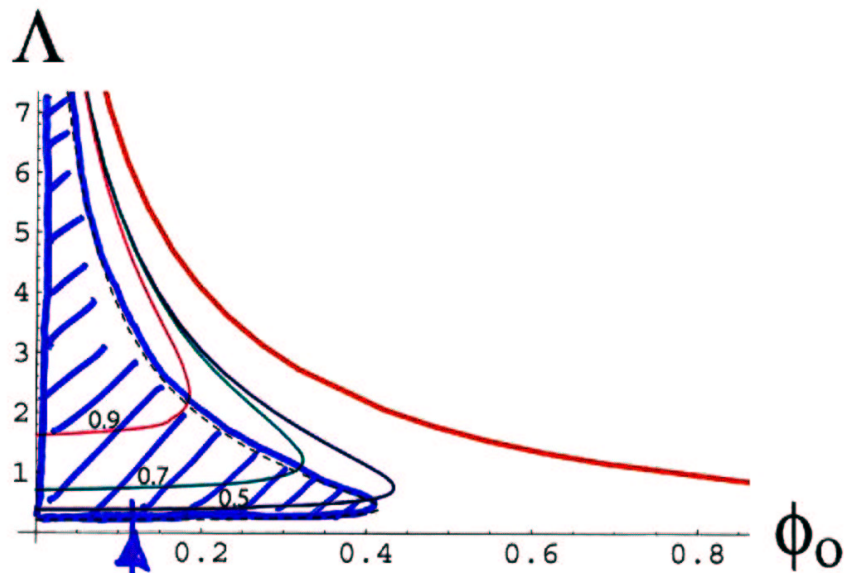
$t_{\text{total}} > 28$ billion years
 (the universe collapses
 at $t > 14$ billion years
 from now)

----- divides all (Λ, ϕ_0)
 into two parts of equal area

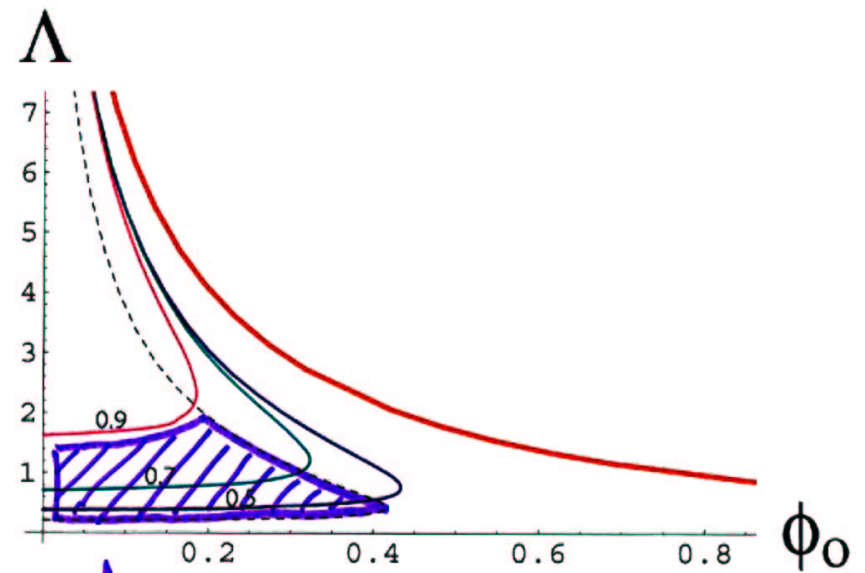
Expect $\Lambda = 0(g_0)$

$\Lambda \sim 1.5 g_0$





accelerating universe
 $P \approx 35\%$



accelerating universe
 with $0.5 < \Omega_D < 0.9$
 $P \approx 10\%$

Thus, $N=8$ supergravity may help us to solve the cosmological constant problem ($\Lambda = 0(p_0) \sim 10^{-120} M_{\text{P}}^4$) and the coincidence problem (the universe now is accelerating with probability 35%, and $0.5 < \Omega_D < 0.9$ with probability 10%)

The bad news is that $N=8$ SUGRA suggests that our universe is going to collapse within 10-20 billion years

The good news is that we still have some time to check whether this is really going to happen.

Observational
cosmology is not about
finding w , Ω_D or $\frac{\Delta T}{T}$

It is about finding
our future