# The mechanism of domain walls and strings formation in the early Universe

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# Introduction

- Inflationary models with several fields could contain complicated potentials.
- These potentials may have several minima and saddle points (e.g. mexican hat, landscape, ...)
- Such conditions can lead to the formation of topologically non-trivial structures — solitons[1]
- These non-trivial structures may lead to formation of PBH[2]

[1] JCAP 04 (2018) 042
[2] JETP 92 (2001) 921

# Numerical simulation

Lagrangian density of two real scalar fields:

$$\mathcal{L} = \frac{1}{2} g_{\mu\nu}(\partial_\mu \varphi \partial_\nu \varphi + \partial_\mu \chi \partial_\nu \chi) - \mathcal{V}(\varphi, \chi)$$

Equations of motion:

$$\begin{cases} \varphi_{tt} - 3H\varphi_t - \varphi_{xx} - \varphi_{yy} = -\frac{\partial \mathcal{V}}{\partial \varphi}, \\ \chi_{tt} - 3H\chi_t - \chi_{xx} - \chi_{yy} = -\frac{\partial \mathcal{V}}{\partial \chi}. \end{cases}$$

Boundary conditions:

$$-\infty \le x \le \infty, -\infty \le y \le \infty$$

$$\begin{cases} \varphi_x(\pm\infty, y, t) = 0, \\ \varphi_y(x, \pm\infty, t) = 0. \end{cases} \qquad \begin{cases} \chi_x(\pm\infty, y, t) = 0, \\ \chi_y(x, \pm\infty, t) = 0. \end{cases}$$

Initial conditions:

$$\begin{cases} \varphi(x, y, 0) = \mathcal{R}\cos\Theta + l_1, \\ \chi(x, y, 0) = \mathcal{R}\sin\Theta + l_2, \\ \varphi_t(x, y, 0) = 0, \\ \chi_t(x, y, 0) = 0, \end{cases} \qquad \begin{cases} \mathcal{R}(r) = \dfrac{\mathcal{R}_0}{\cosh \frac{r_0}{r}}, \\ \Theta = \theta. \end{cases}$$

$\mathcal{R}_0$, $l_1$, $l_2$, $r_0$ — parameters.

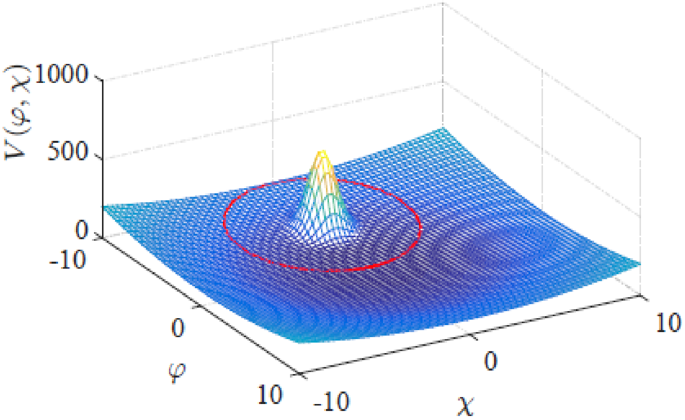
# Model 1

$$\mathcal{V} = d(\varphi^2 + \chi^2) + a \exp\left[-b(\varphi - \varphi_0)^2 - c(\chi - \chi_0)^2\right]$$

Parameters: $a$, $d$, $b$, $c$, $\varphi_0 = -5$, $\chi_0 = 0$[3].
With these parameter values potential have local maximum at $\varphi = -5$, $\chi = 0$.

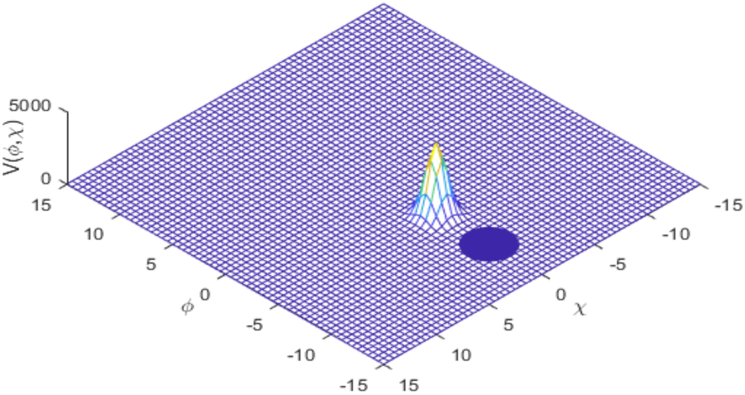
[3] hereinafter all values in Hubble units

# Model 1



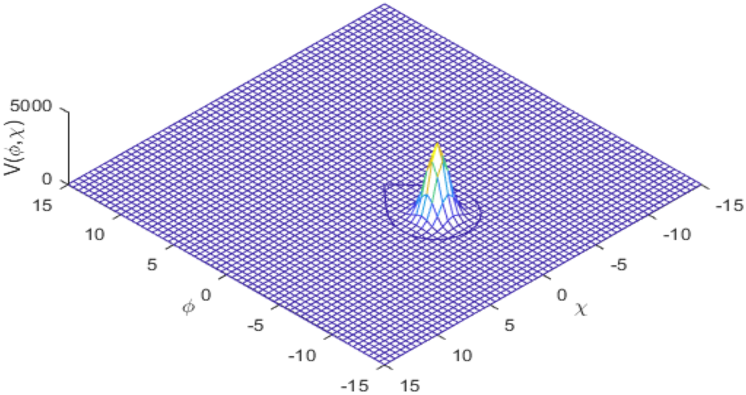
# Model 1

Initial condition with parameter values: $\mathcal{R}_0 = 2$, $d = 0.05$, $a = 5000$, $l_1 = -10$, $l_2 = 0$, $b = 1$, $c = 1$, $\varphi_0 = -5$, $\chi_0 = 0$, $r_0 = 1$



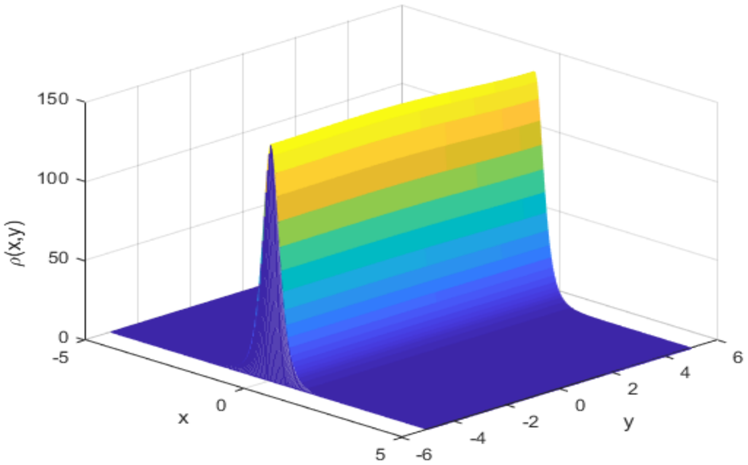
# Model 1

## Final state



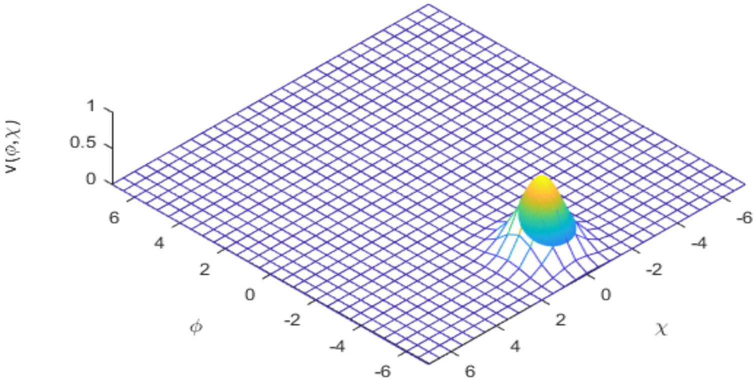
# Model 1: energy density

Final state



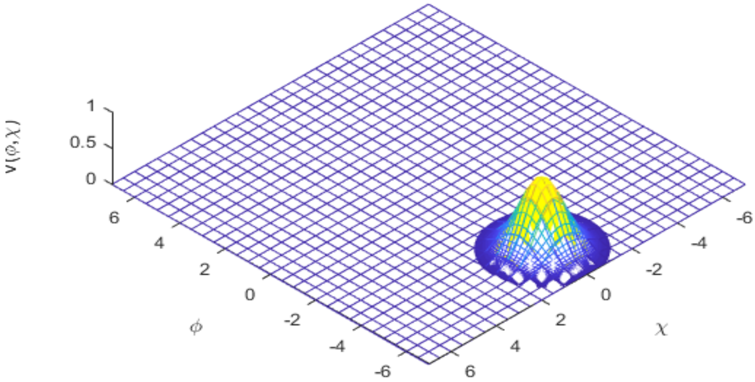
# Model 2

Initial condition with parameter values: $\mathcal{R}_0 = 0.1$, $d = 5 \cdot 10^{-7}$, $a = 1$, $l_1 = -5.05$, $l_2 = 0$, $b = 1$, $c = 1$, $\varphi_0 = -5$, $\chi_0 = 0$, $r_0 = 1$



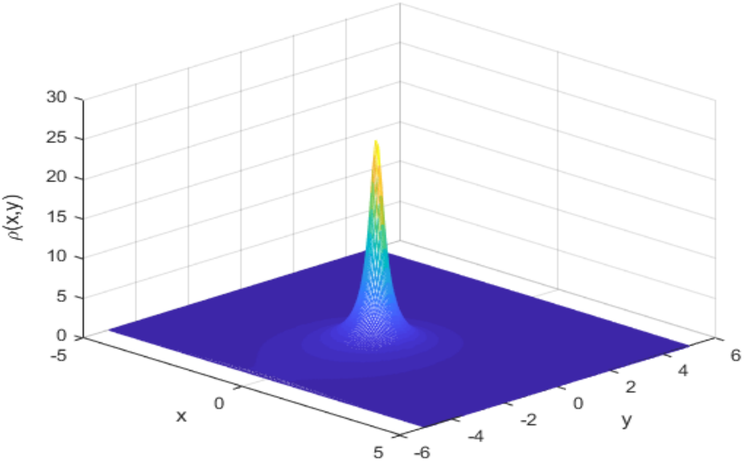
# Model 2

## Final state



# Model 2: energy density

Final state



# Model 3

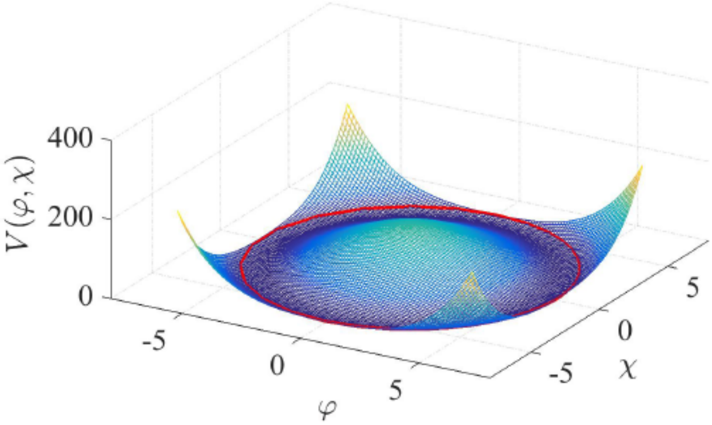
Potential[4]:

$$\mathcal{V} = \lambda\left(\varphi^2 + \chi^2 - \frac{g^2}{2}\right)^2 + \Lambda\left(1 - \frac{\varphi}{\sqrt{\varphi^2 + \chi^2}}\right),$$

Parameters: $g = 1$, $\lambda = 1$, $\Lambda = 5 \cdot 10^{-13}$.

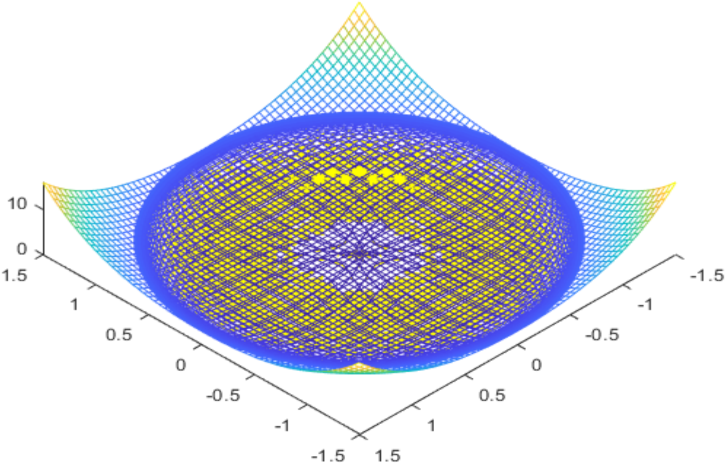
[4] Phys. Rev. D 56 (1997) 6155

# Model 3



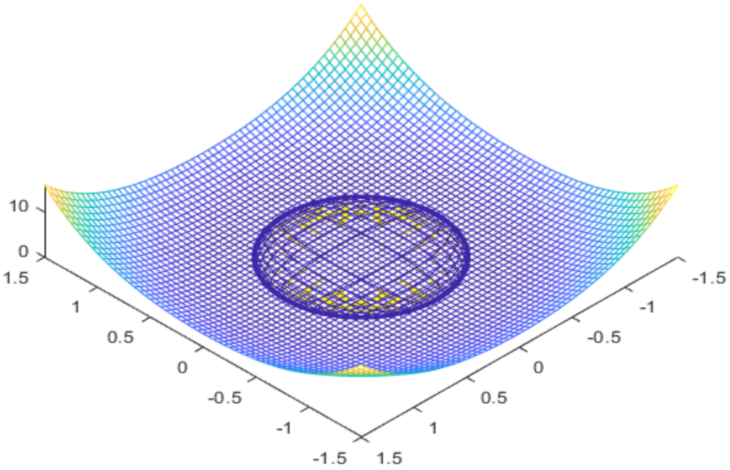
# Model 3

Initial condition with parameter values: $\mathcal{R}_0 = 2$, $l_1 = 0$, $l_2 = 0$, $r_0 = 1$



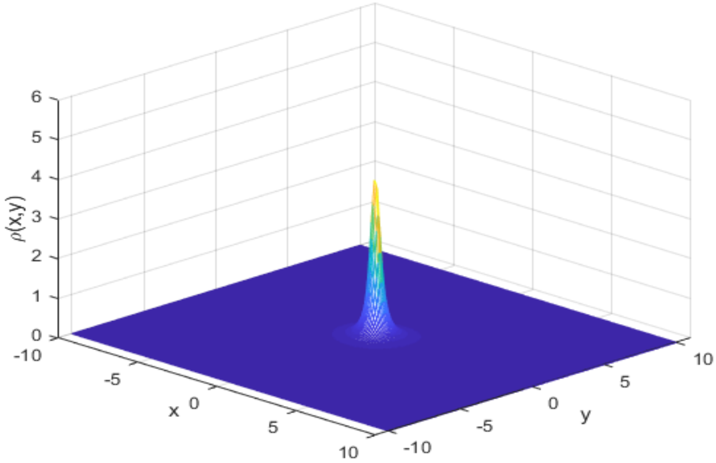
# Model 3

## Final state



# Model 3: energy density

Final state



# Conclusion

- The field configurations corresponding to the domain wall and string were obtained
- It was shown that during the evolution of the system, different variants of the solitons are possible, depending on the initial conditions and potential parameters
- If inflation model contains saddle point potential, the formation of solitons should be checked.