Simulation of soliton foam formation in 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
- Such conditions can lead to the formation of topologically non-trivial structures — solitons

Model and numerical simulation

Lagrangian density:

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

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

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

Model and numerical simulation

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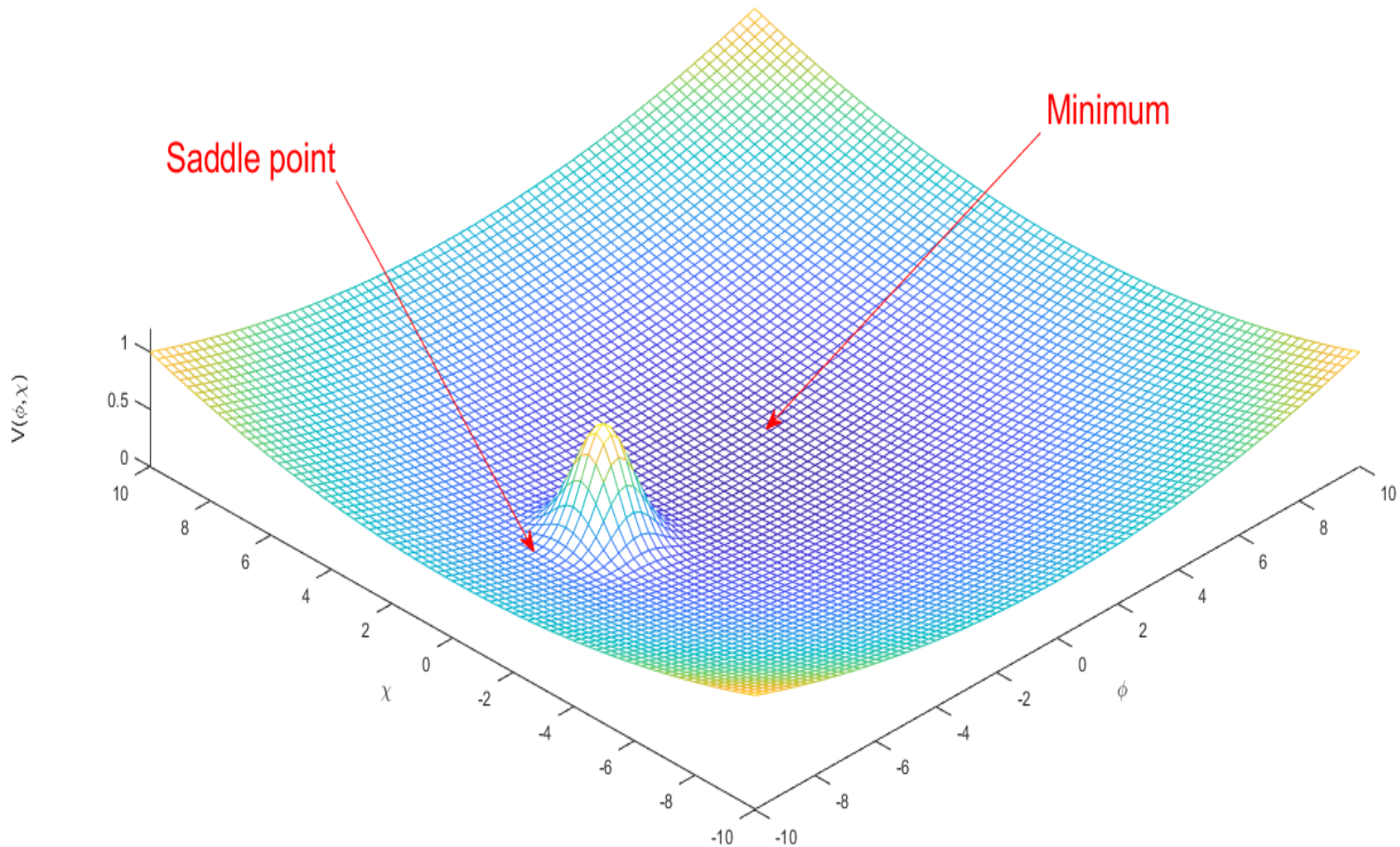
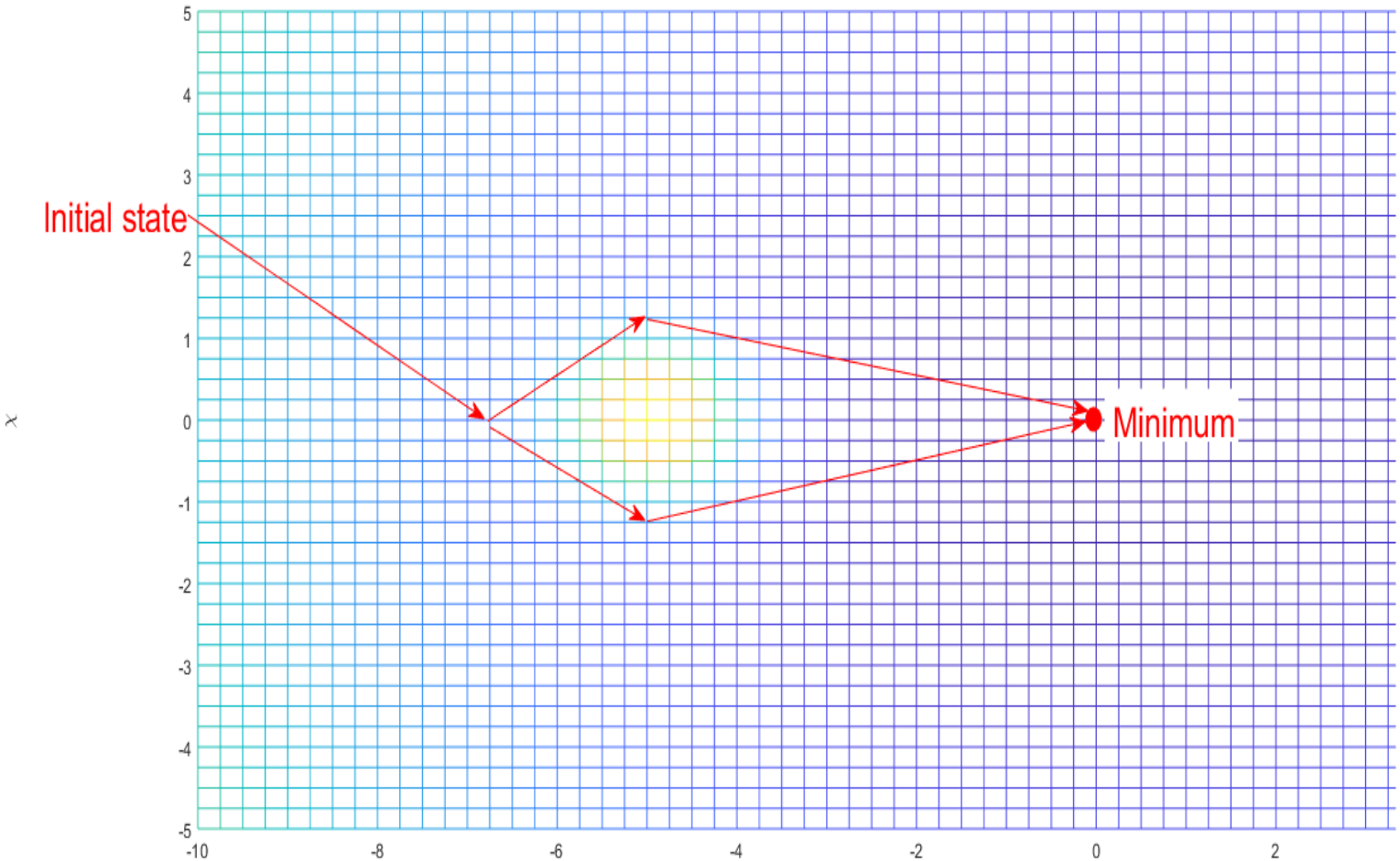


Model and numerical simulation



Model and numerical simulation

Equations of motion in expanding Universe:

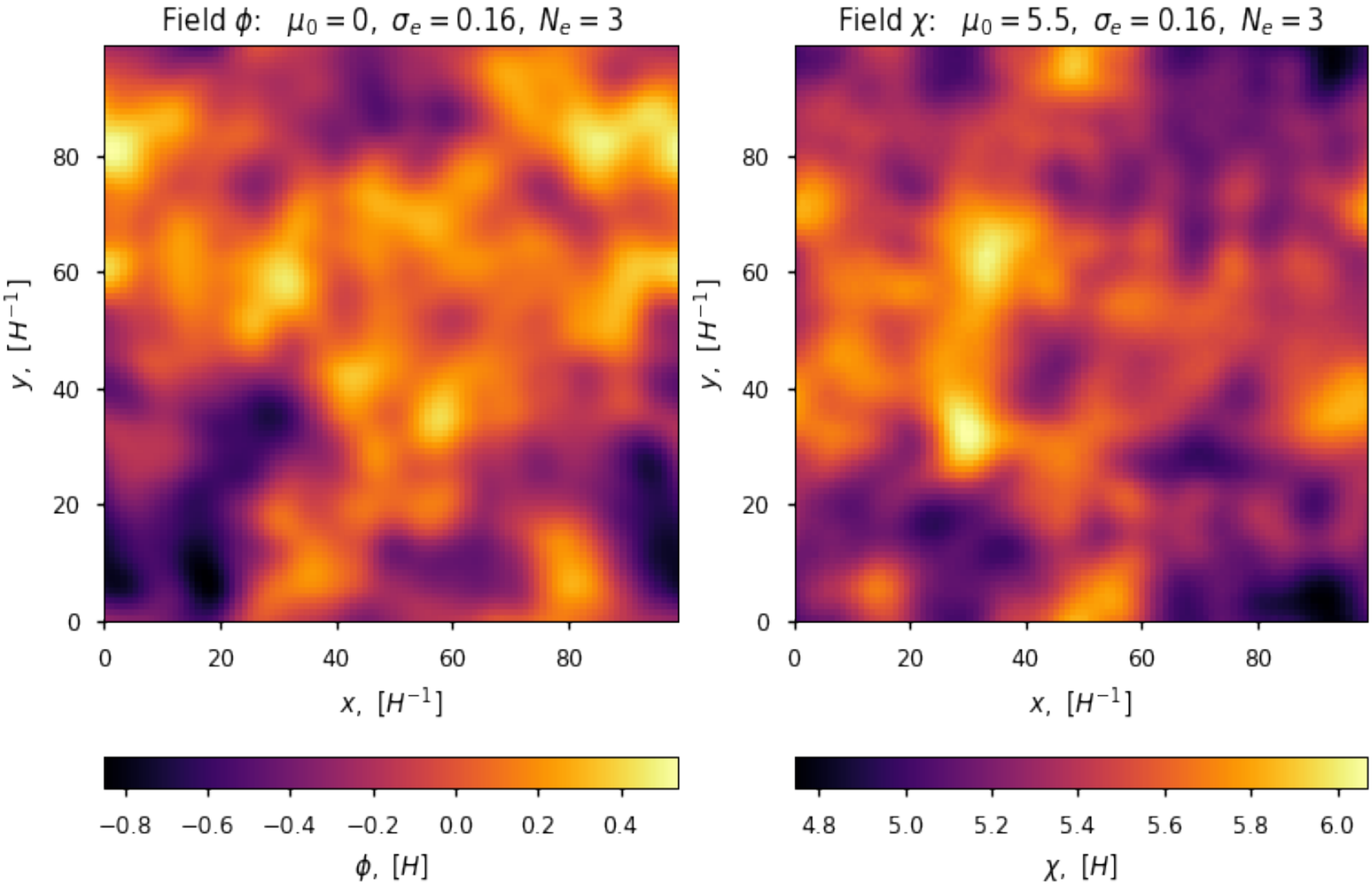
$$\ddot{\Phi} + 3Ha\dot{\Phi} - \nabla^2\Phi = -a^2\frac{\partial V}{\partial \Phi},$$

a —scale factor, H — Hubble parameter, $\Phi = [\varphi, \chi]$

Initial conditions

- Random Gaussian noise generated pixel by pixel, with zero mean.
- The noise is smoothed out by convolution with a Gaussian whose width is equal to the size of the horizon.
- Calculation performed several times to simulate the evolution of the initial conditions over several e-folds.

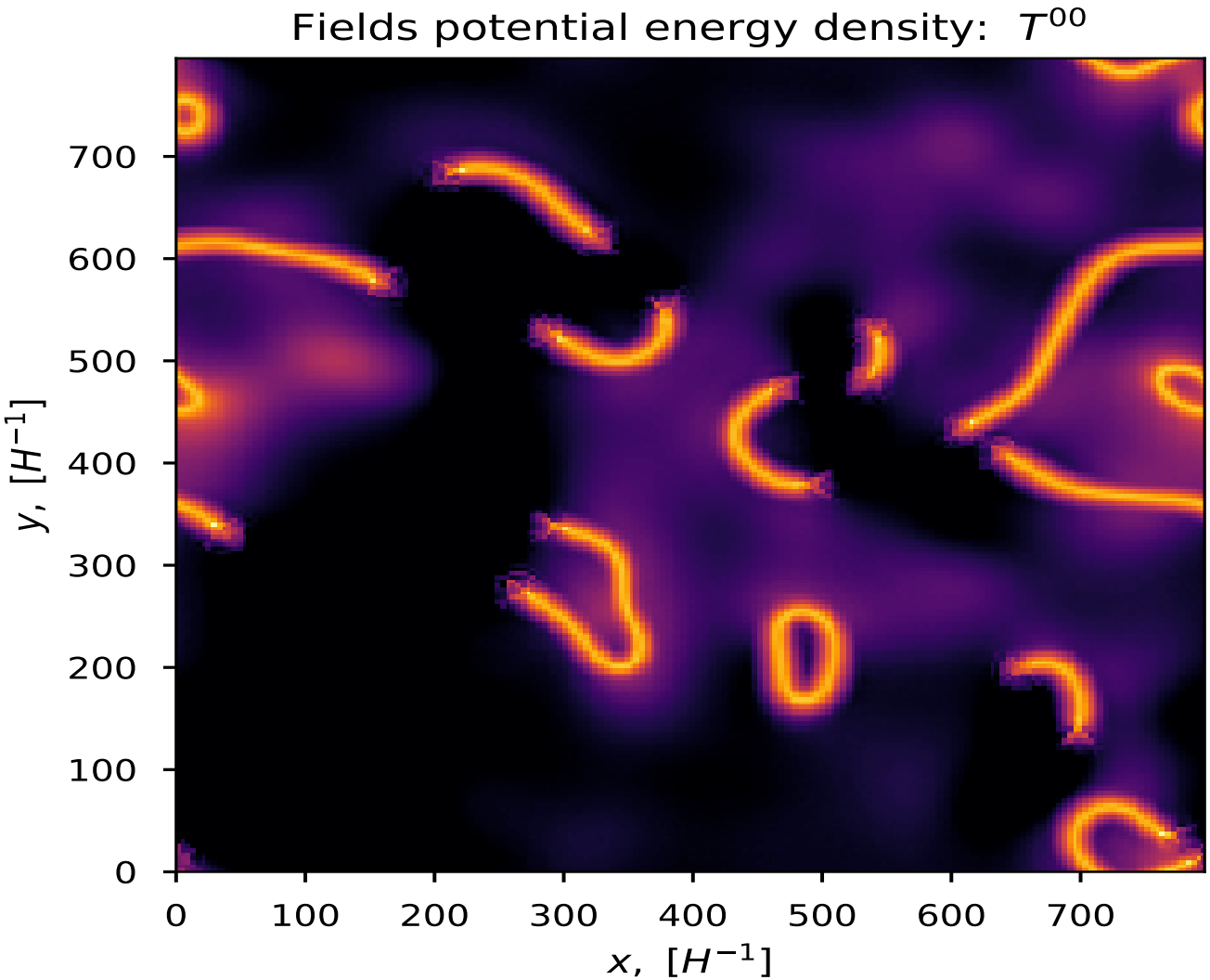
Initial conditions



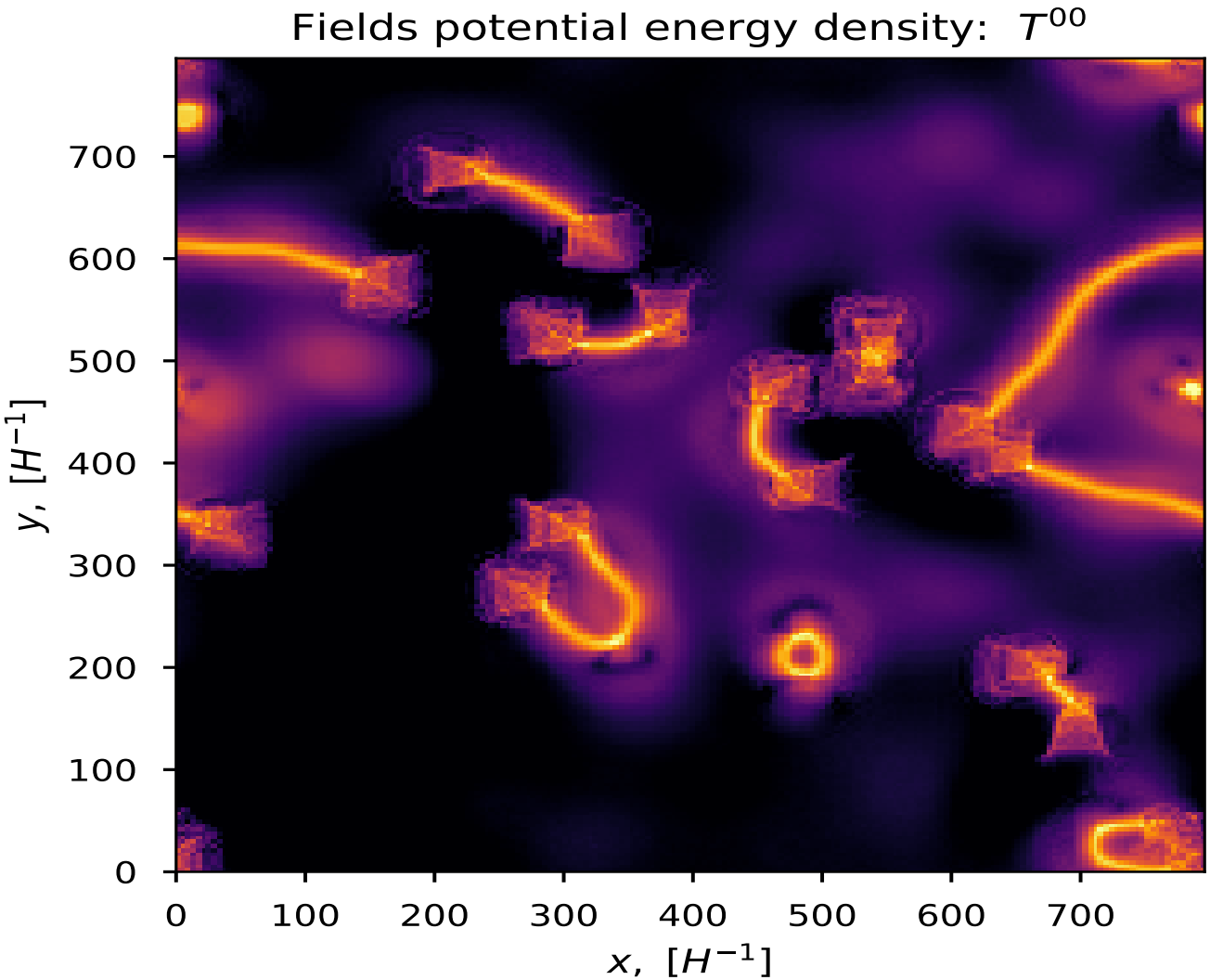
Calculation

- The evolution of the initial field configuration is calculated numerically.
- Dependence of the Hubble parameter and the scale factor on time in Starobinsky's inflation model are also calculated.

Results


Fields potential energy density: T^{00}
700
600
500
400
300
200
100
0
y, $[H^{-1}]$
0
100
200
300
400
500
600
700
x, $[H^{-1}]$

Results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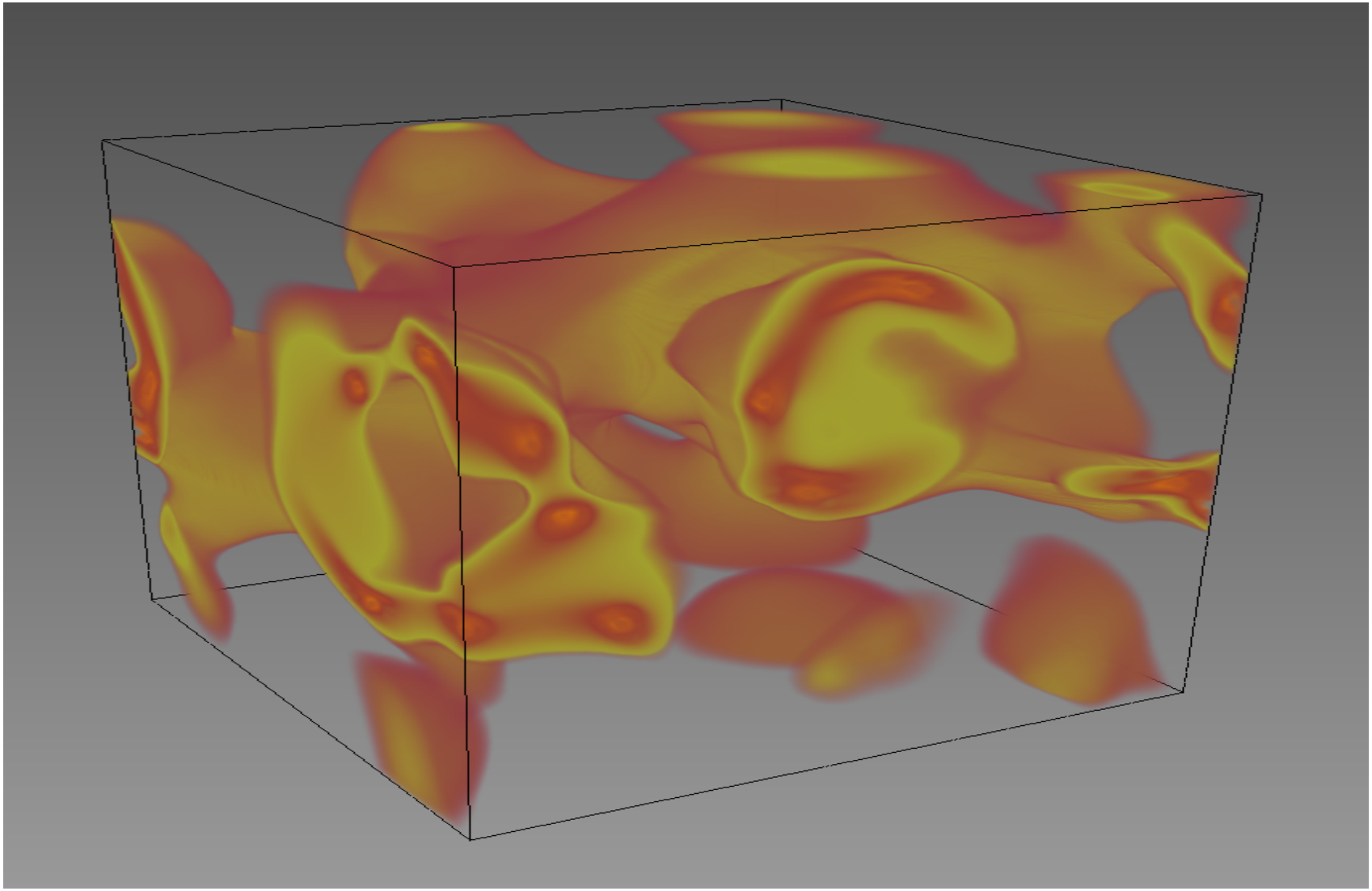

Conclusion

- Similar soliton structures can appear in any model with at least one local peak.
- Realistic initial conditions lead to the appearance of a composite soliton structure — soliton foam.
- The collapse of emerging solitons may be the mechanism for the formation of PBH