Higgs domain walls in the thermal background

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Motivation

1. The quantitative study of the renormalisation group improved (RG improved) effective potential of the Standard Model (SM) has revealed existence of two families of minima.
2. It is possible that in the early Universe the Higgs field acquired fluctuations large enough to overcome the potential barrier and each of two vacua was randomly selected in each patch of the Universe.
3. The result of this process was a network of cosmological domain walls.
4. After reheating the early Universe was very hot and dense and it was better described that time by the thermal state with temperature T, than by the vacuum state.
5. The dynamics of Higgs domain walls in the background of this thermal state could be different than in the vacuum state.

What are domain walls?

- Domain walls (DWs) are sheet-like topological defects.
- A potential with two (or more) local minima is necessary for the existence of DWs.
- Cosmological DWs could be produced in the early Universe during spontaneous symmetry breaking.
- DWs are formed at boundaries of regions (domains) where symmetry breaking field has different vacuum expectation values (VEVs).
- Cosmological domain walls form networks whose dynamics is non-linear.
- Evolution of these structures can be investigated in numerical simulations.

Higgs field's fluctuations in the early Universe

Fluctuations of the Higgs field's strength could be produced during inflations. Distribution of the produced fluctuations is nearly gaussian with the standard deviation σ_I equal to:

$$\sigma_I \sim \frac{\sqrt{N} H_I}{2\pi},$$

where H_I is value of the Hubble parameter and N is number of e-folds.

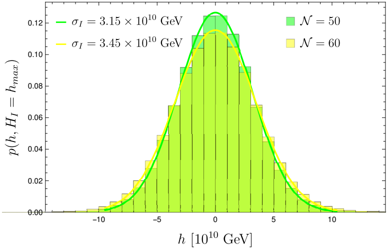

Figure: Distribution of the Higgs field strength values after inflation lasting $\mathcal{N} = 50$ or $\mathcal{N} = 60$ e-folds.

Properties of the Higgs domain wall

Higgs domain walls are configurations of the expectation value of the Higgs field which interpolates between minima of the effective scalar potential.
The knowledge of the position of the local maximum h_{max} is needed in the lattice simulations.

- The value of h_{max} determines the significant range of parameters for the initialization of simulations.
- h_{max} is used in numerical simulations for detection of domain walls.

Position of the local maximum

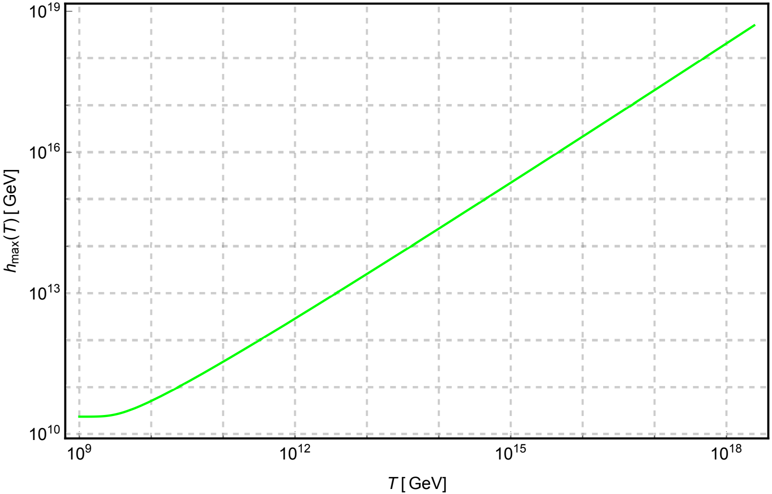

Figure: The position h_{max} of the local maximum separating two minima of the RG improved effective potential as a function of the temperature of thermal bath T.

Bounds on the standard deviation σ

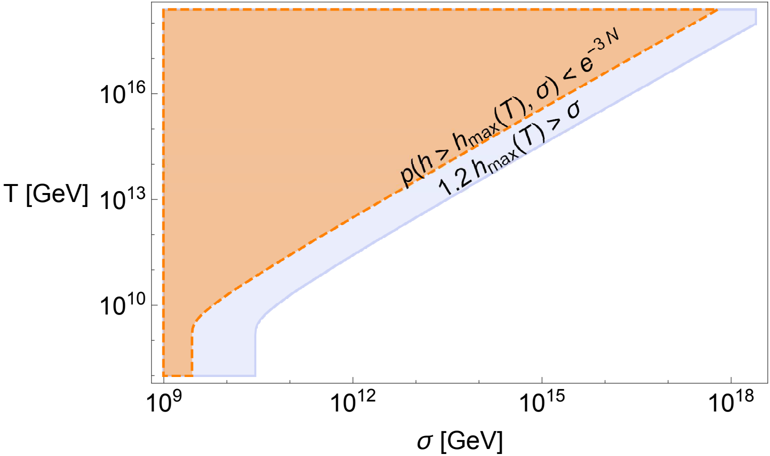

Figure: Maximal value of the standard deviation σ_I of initial distribution for given temperature T.

Bounds on the reheating temperature T_{RH}

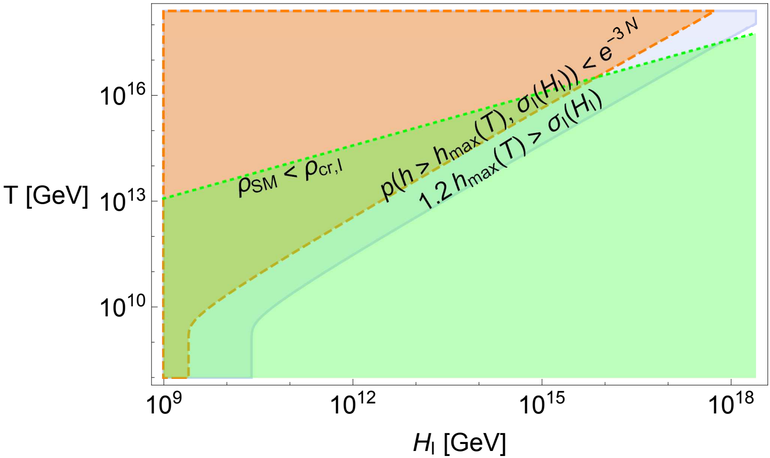

Figure: Maximal value of the reheating temperature from inflation with Hubble parameter value H_I.

Evolution in the thermal background

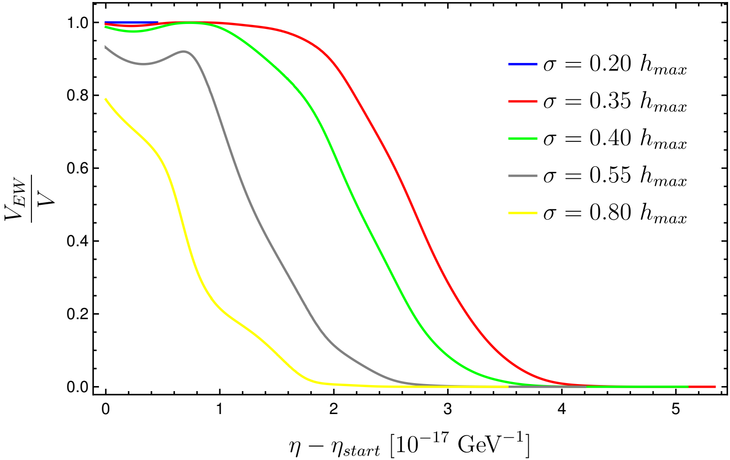

Figure: The fraction $\frac{V_{EW}}{V}$ as a function of conformal time η for values of standard deviation σ of initialization distribution.

Bounds from the evolution of Higgs domain walls

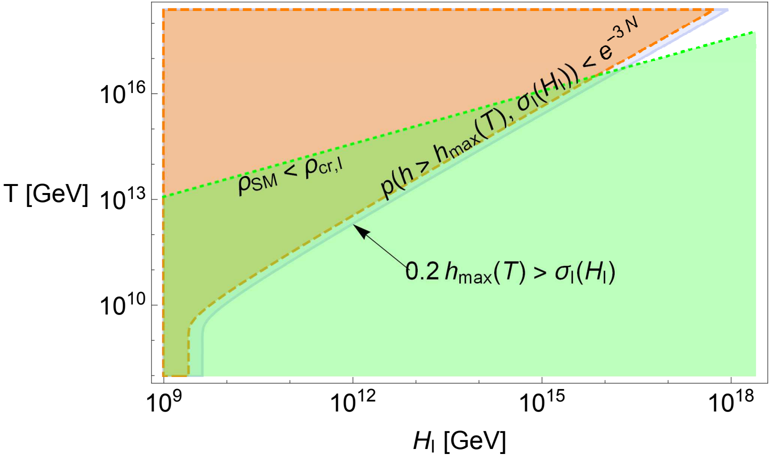

Figure: Bounds on inflationary models from the evolution of Higgs domain walls.

Summary

1. Thermal corrections to the effective potential stabilize the Higgs field by enlarging the basing of attraction of EWSB vacuum.
2. Higgs domain walls in the thermal background are highly unstable.
3. Gravitational waves produced by decaying Higgs domain walls are too weak to be detected in the planned detectors.

Thank you for your attention.

Networks of cosmological domain walls could have twofold topologies: finite bubbles of one vacuum in a sea of the other or an infinite networks spreading through whole Universe.

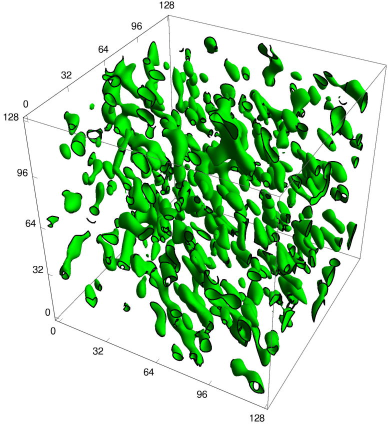

Figure: Network of domain walls formed by bubbles of finite volume.

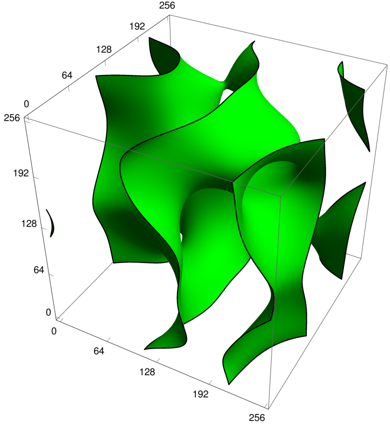

Figure: An example of the infinite network of domain walls.

The problem of cosmological domain walls

- Networks of domain walls have an effective equation of state $\rho = \omega p$ with $-2/3 < \omega < -1/3$ (with negative pressure), so long lived domain walls will dominate the Universe.
- Measurements of the CMB radiation exclude domain walls with the energy scale $> 1\ \mathrm{MeV}$ (Zel'dovich bound[1]) during the recombination.
- Measurements of the expansion of the Universe disfavour domain walls as a main component of the Dark Energy.
- SM domain walls are consistent with the present experimental data only if they decay fast enough.

[1] Ya. B. Zeldovich, I. Yu. Kobzarev, and L. B. Okun. "Cosmological Consequences of the Spontaneous Breakdown of Discrete Symmetry". In: *Zh. Eksp. Teor. Fiz.* 67 (1974). [Sov. Phys. JETP40,1(1974)], pp. 3–11.

Width of Higgs domain walls

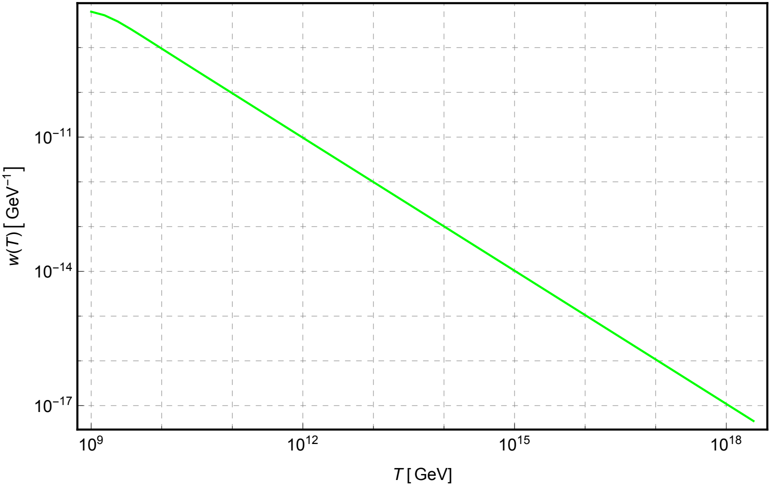

Figure: The width of domain walls w as a function of the temperature T.

About our simulation

- We modeled the Higgs field with a positive, real scalar ϕ.
- The evolution of ϕ is given by EOM:

$$\frac{\partial^2\phi}{\partial\eta^2} + \frac{\alpha}{\eta}\left(\frac{d\ln a}{d\ln\eta}\right)\frac{\partial\phi}{\partial\eta} - \Delta\phi = -a^{\beta}\frac{\partial V}{\partial\phi},$$

  with a potential $V(\phi)$ equal to the RG improved potential of the SM Higgs $V_{\mathrm{SM}}(|h|)$.
- The PRS algorithm[2] (with $\alpha = 3$, $\beta = 0$) was used.
- We used the optimization of a time step[3].
- Our simulations were run on a lattice of the size 512^3.

[2] William H. Press, Barbara S. Ryden, and David N. Spergel. "Dynamical Evolution of Domain Walls in an Expanding Universe". In: *Astrophys. J.* 347 (1989), pp. 590–604. DOI: 10.1086/168151.

[3] Z. Lalak, S. Lola, and P. Magnowski. "Dynamics of domain walls for split and runaway potentials". In: *Phys. Rev.* D78 (2008), p. 085020. DOI: 10.1103/PhysRevD.78.085020. arXiv: 0710.1233 [hep-ph].