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Direct surface-based simulation of primordial black hole clusters formation via collapse of non-spherical domain walls

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One possible mechanism for the formation of primordial black holes (PBHs) is the collapse of domain walls. Previous theoretical models considered PBH formation in the spherical approximation, whereas full field-theoretic simulations of non-spherical domain walls clusters are too computationally demanding to accumulate sufficient statistics.

In this work, we derive the equations of motion of a domain wall in the thin-wall approximation and propose a numerical method for evolving the wall surface using triangular mesh algorithms. For prescribed field configurations of a cluster, the method yields the differential mass spectrum of the resulting PBHs.

Based on a Monte Carlo ensemble, we obtain $dN/dM \propto M^{-\alpha}$ with $\alpha = 2.31^{+0.01}_{-0.02}$, significantly larger than the theoretical value $\alpha \approx 1.75$ for spherical-wall collapse, indicating a larger fraction of low-mass PBHs. This deviation is presumably due to the fragmentation of walls with complex geometry, which is absent in the spherical approximation.

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