

Exploring the Degree of Freedom Beyond Standard Model via Primordial Black Hole Evaporation with Memory Burden Effect



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1. Abstract

In this study, we investigate the impact of additional degrees of freedom (DoF) from supersymmetry (SUSY) particles and the memory burden effect (MBE) on the evaporation process of PBHs. By analyzing how these factors influence the PBH lifetime, we aim to provide insights into potential new physics and constraints on early universe phase transitions.

2. Motivation

- Investigate the hypothesis of the Memory Burden Effect (MBE);
- Probe beyond the Standard Model (SM) degrees of freedom (DoF);
- Potentially support the model of a dark first-order phase transition (FOPT), which could be one of the models capable of producing such light primordial black holes (PBHs);

3. What is "Memory Burden Effect"?

The back-reaction of emission on the quantum state of the black hole causes the information stored in the event horizon to resist its decay,

$$\frac{dM_{PBH}^{MBE}}{dt} = \frac{1}{S(M_{PBH})^k} \frac{dM_{PBH}}{dt} \quad (1a), \quad \frac{dM_{PBH}}{dt} = -\frac{\mathcal{G}g_{SM}}{30720\pi G^2 M_{PBH}^2} \quad (1b) \quad (1)$$

The entropy suppresses evaporation, thereby extending the black hole's lifetime.

\mathcal{G} Gray body factor

g_{SM} DoF of particles belong to SM

M_{PBH} Mass of PBH

G Gravitational constant

$S(M_{PBH})$ Entropy of PBH, $S(M_{PBH}) = 4\pi G M_{PBH}^2$

4. Method

- We use BlackHawk[2][3] to calculate the evolution of PBHs and their particle spectra.
- We take into account MBE.
- Additional degrees of freedom (DoF) are included based on SUSY.
- The transition from a cusped to a core density profile requires energy, which we assume comes from interactions between neutrinos and DM particles.

5. Hawking radiation spectrum (PBH spectrum & neutrino spectrum)

The current age of the universe is approximately $\approx 6.6 \times 10^{41} \text{ GeV}^{-1}$

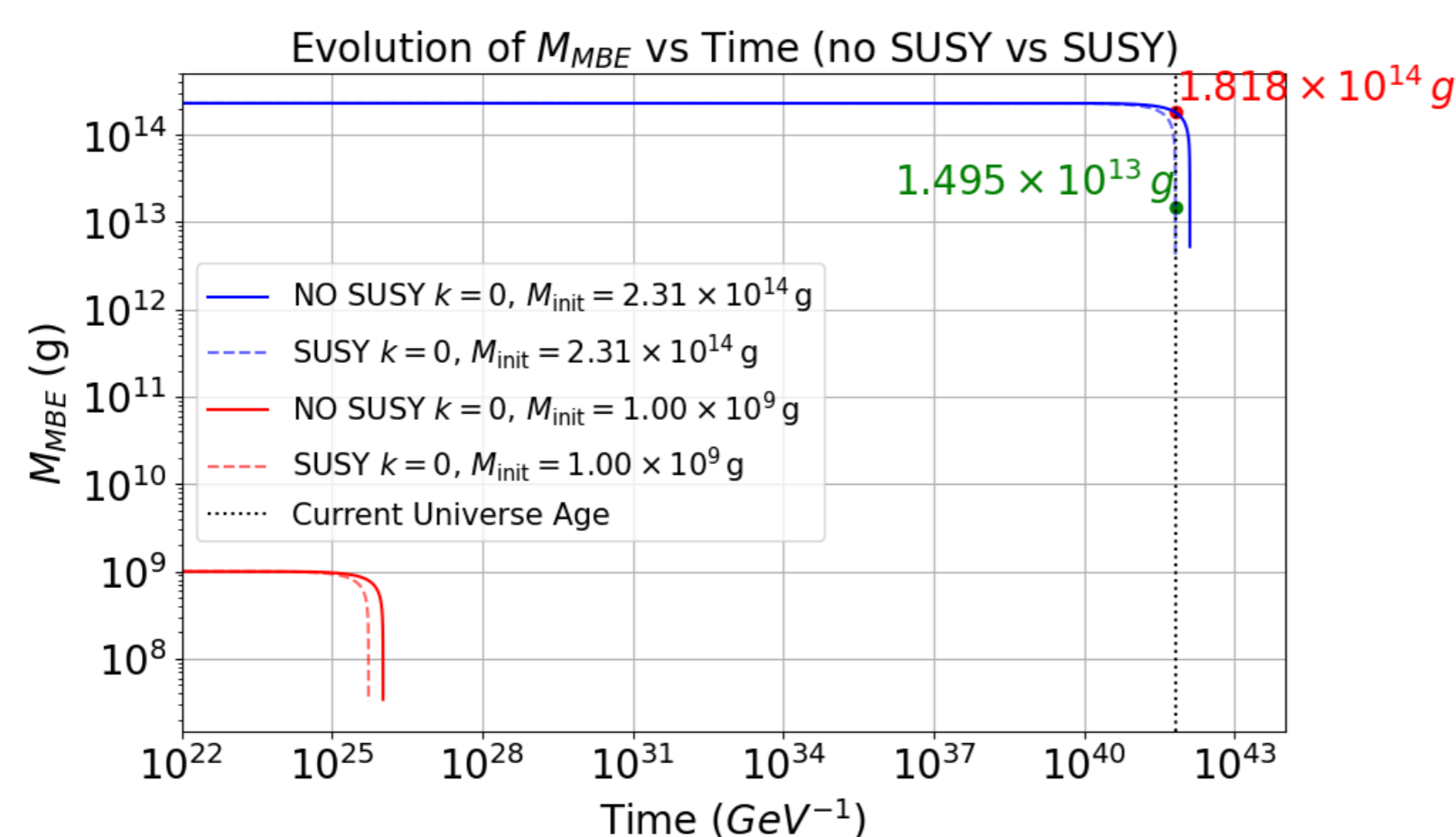


Figure 1: Mass evolution of a PBH without MBE, with its mass today being $1.818 \times 10^{14} \text{ g}$. If SUSY particles contribute additional degrees of freedom (DoF = 200) [1], the final mass is smaller. Without MBE, PBHs with insufficient initial mass cannot survive until the present.

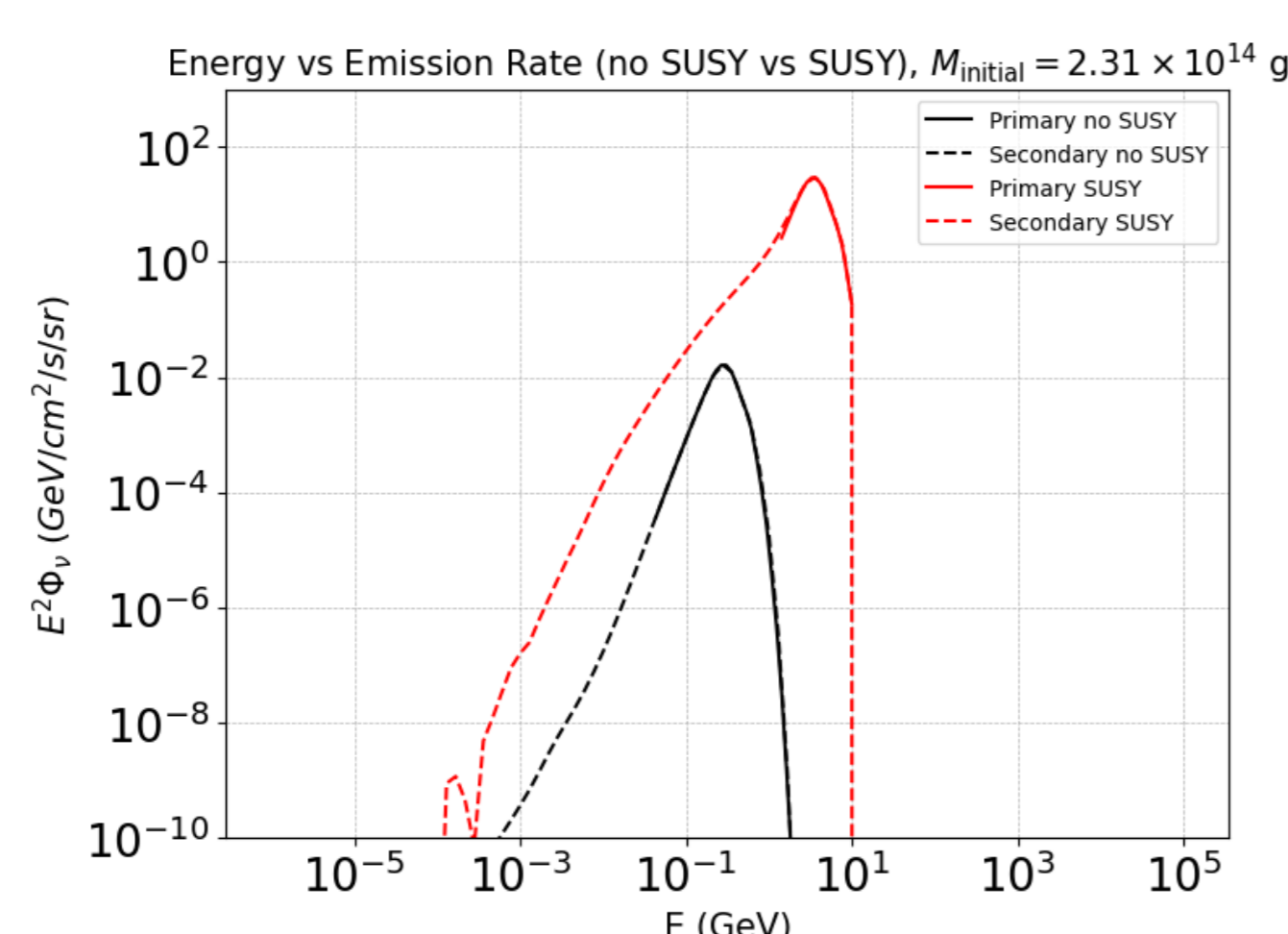


Figure 2: The neutrino spectrum indicates the evaporation of PBH in the current universe.

6. Spectra with MBE

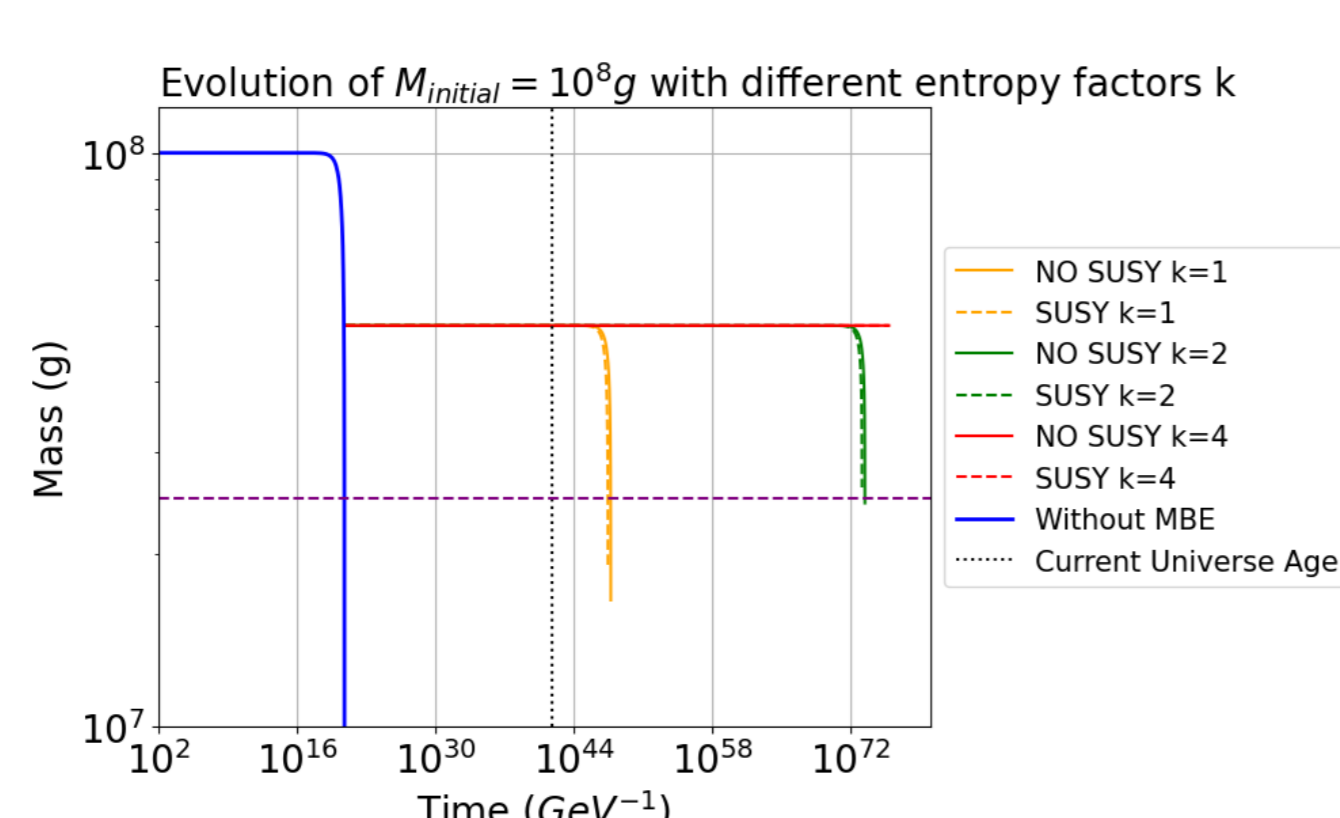


Figure 3: Mass evolution of a PBH with MBE.

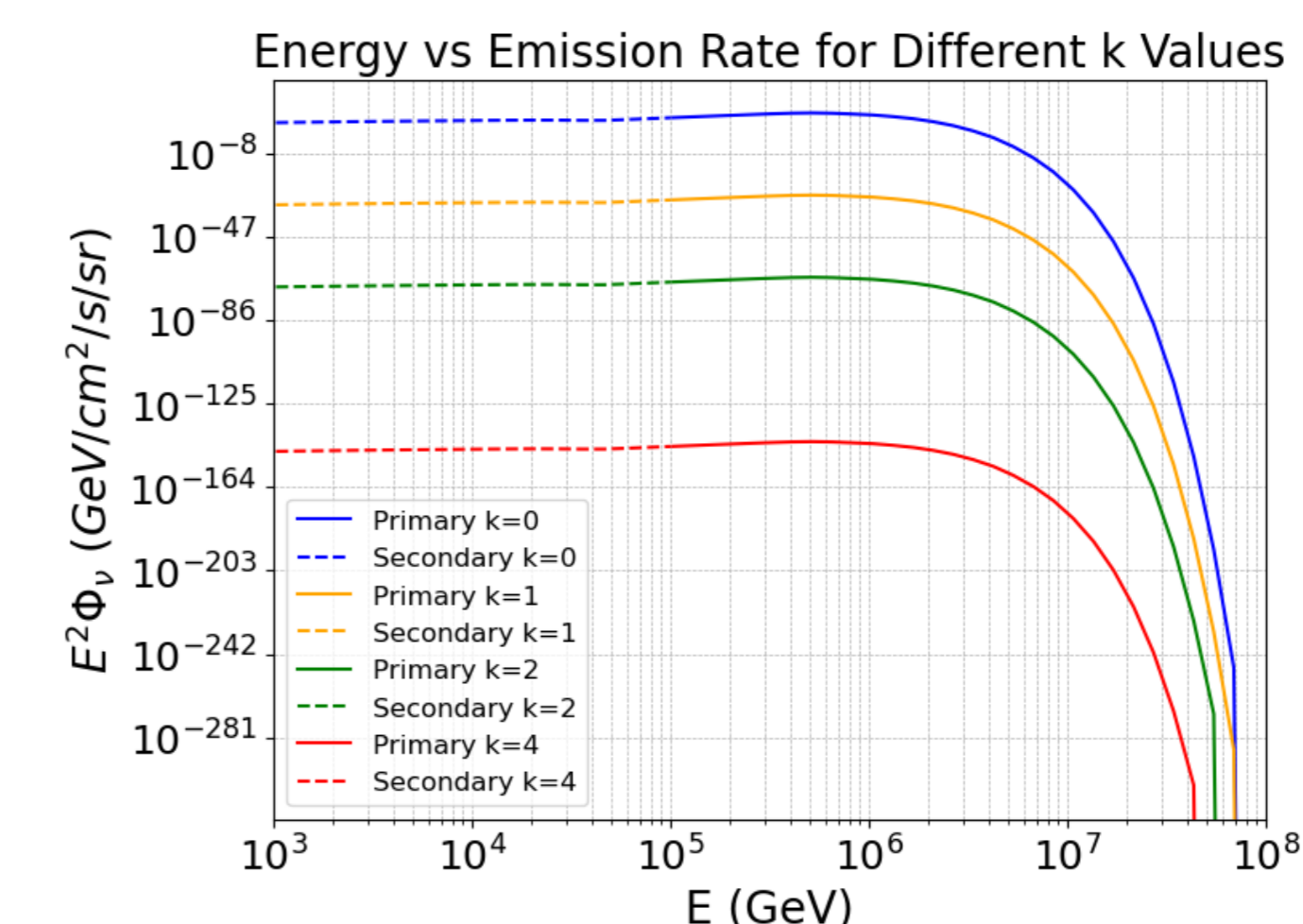


Figure 4: Neutrino spectra with different entropy factors.

7. Interaction with Dark Matter(DM) Particles

Similar to Heston et al's work [5], we assume the neutrinos which generated by PBHs interact with DM Particles among the DM halos of dwarf galaxies (DGs).

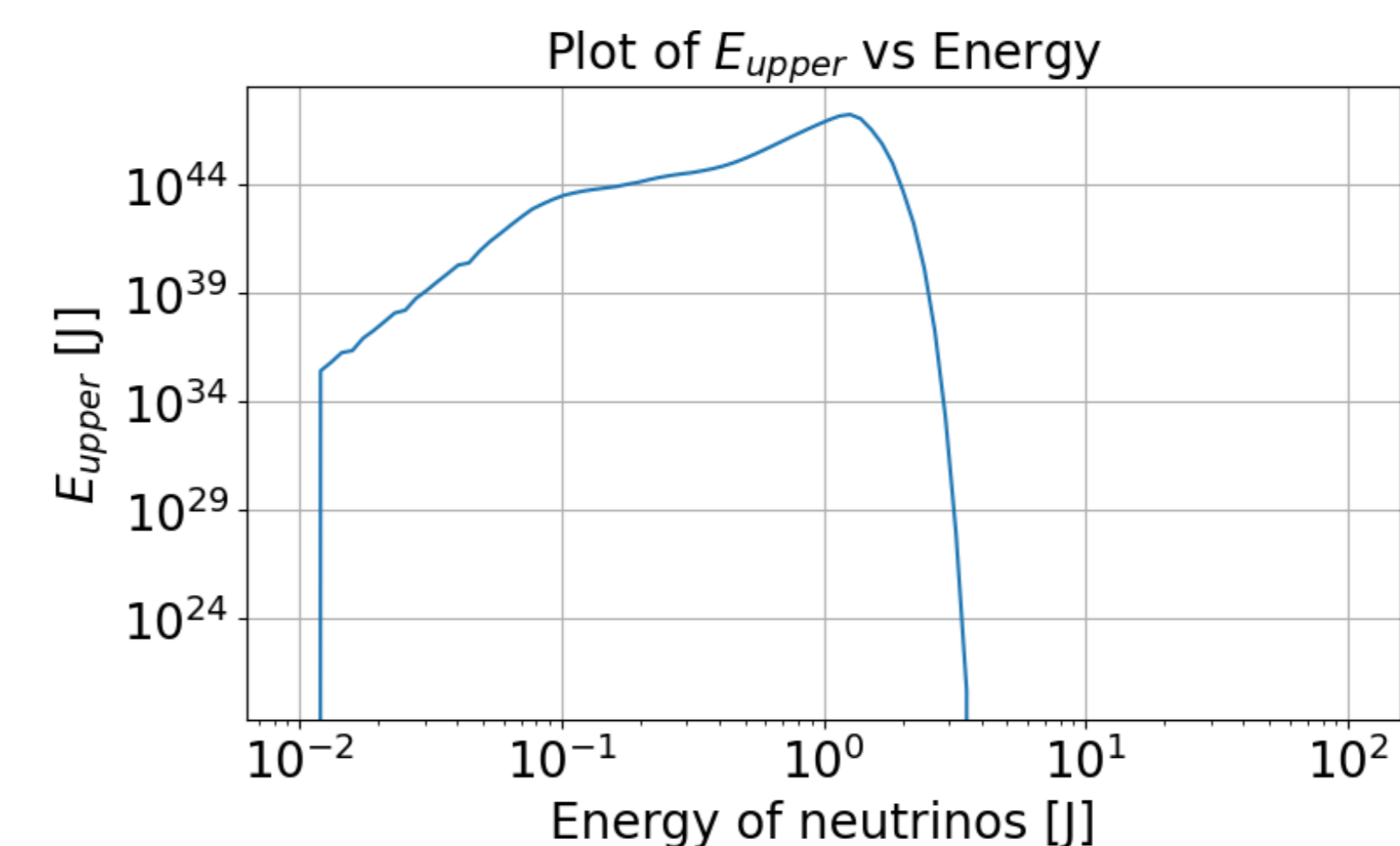


Figure 5: Neutrinos from PBHs interacting with DM particles provide the energy distribution corresponding to the NFW profile.

8. Future work

- Correlated gravitational waves generated from bubble collisions during a first-order phase transition (FOPT).

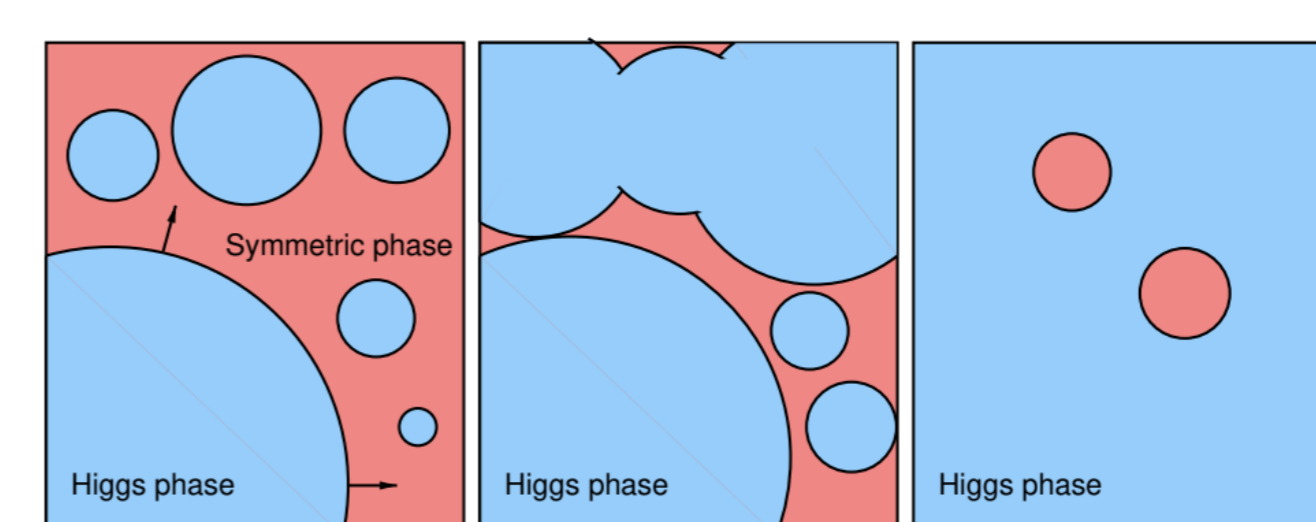


Figure 6: Due to thermal fluctuations, bubbles of the Higgs stable ground state form and expand into metastable regions [6].

- Prediction of ultra-high-energy neutrino flux observations.

9. Conclusion

- If MBE exists, it is possible that light PBHs ($M_{PBH}^{MBE} \leq 10^{15} \text{ g}$) exist, which can only be produced by FOPT in all currently known models.[4]
- We consider a scenario where both the SM and SUSY contribute additional DoF, leading to a shorter-than-expected lifetime for PBHs. However, PBHs could still survive in the present universe if MBE mechanisms extend their lifetime.

Referências

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