

Gravitational Waves and Electroweak Phase Transition in a Singlet–Doublet Scalar Extension of the Standard Model

Abstract:

We investigate the nature of the electroweak phase transition (EWPT) in a scalar extension of the Standard Model featuring an additional scalar doublet and a scalar singlet fields. Such extensions are well motivated as minimal frameworks capable of modifying the Higgs sector and potentially triggering a strong first-order electroweak phase transition, a necessary ingredient for explaining baryogenesis and producing observable stochastic gravitational-wave backgrounds

This study highlights the potential of singlet–doublet scalar extensions of the Standard Model as testable scenarios connecting early-universe phase transitions with gravitational-wave astronomy and collider phenomenology.

Outline:

1. Model Construction
 - Define Standard Model extended with a scalar doublet and a scalar singlet.
 - Write down the scalar potential and interaction terms.
2. Vacuum Structure
 - Determine zero-temperature vacuum configurations.
 - Analyze stability and symmetry breaking patterns.
3. Finite-Temperature Effective Potential
 - Include thermal corrections to the scalar potential.
 - Study how the vacuum evolves with temperature.
4. Electroweak Phase Transition
 - Determine whether the transition is first-order.
 - Compute critical temperature and nucleation temperature.
5. Phase Transition Parameters
 - Calculate strength of the transition.
 - Compute inverse duration parameter.
6. Gravitational Waves
 - Compute gravitational wave spectrum from the phase transition.
 - Compare results with LISA and other detectors.
7. Parameter Scan
 - Explore model parameter space.
 - Identify regions consistent with theoretical and experimental constraints.
8. Conclusion
 - Summarize physical implications and detectability prospects.

References:

- 1- ATLAS collaboration, Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC, Phys. Lett. B 716 (2012) 1 [1207.7214].
- 2- CMS collaboration, Observation of a New Boson at a Mass of 125 GeV with the CMS Experiment at the LHC, Phys. Lett. B 716 (2012) 30 [1207.7235].
- 3- D. Curtin, P. Meade and C.-T. Yu, Testing Electroweak Baryogenesis with Future Colliders, JHEP 11 (2014) 127 [1409.0005].
- 4- C. Caprini et al., Detecting gravitational waves from cosmological phase transitions with

LISA: an update, JCAP 03 (2020) 024 [1910.13125].

5- P.B. Arnold and O. Espinosa, The Effective potential and first order phase transitions: Beyond leading-order, Phys. Rev. D 47 (1993) 3546 [hep-ph/9212235].

6- O. Gould and T.V.I. Tenkanen, On the perturbative expansion at high temperature and implications for cosmological phase transitions, JHEP 06 (2021) 069 [2104.04399].

7- P. Athron, C. Balazs, A. Fowlie, L. Morris, G. White and Y. Zhang, How arbitrary are perturbative calculations of the electroweak phase transition?, JHEP 01 (2023) 050 [2208.01319].