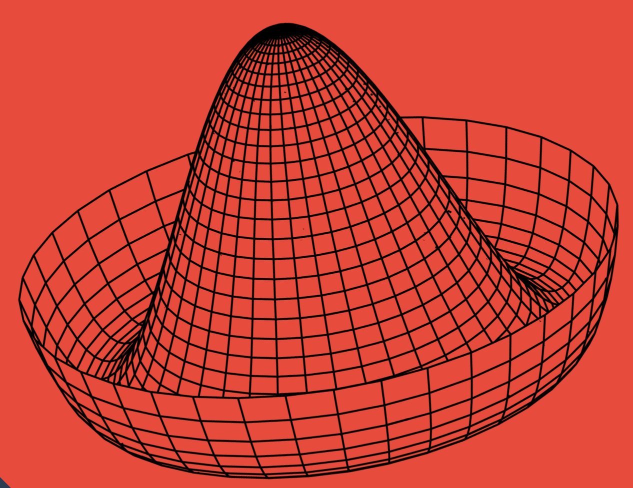
Stochastic Gravitational Wave Background Resulting from Higgs Field Inhomogeneities



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Motivation and Hypothesis

Questions

- How do gravitational waves (GW) emitted from the Higgs field reveal the nature of our cosmological history?
- Are these GW detectable?

Hypothesis

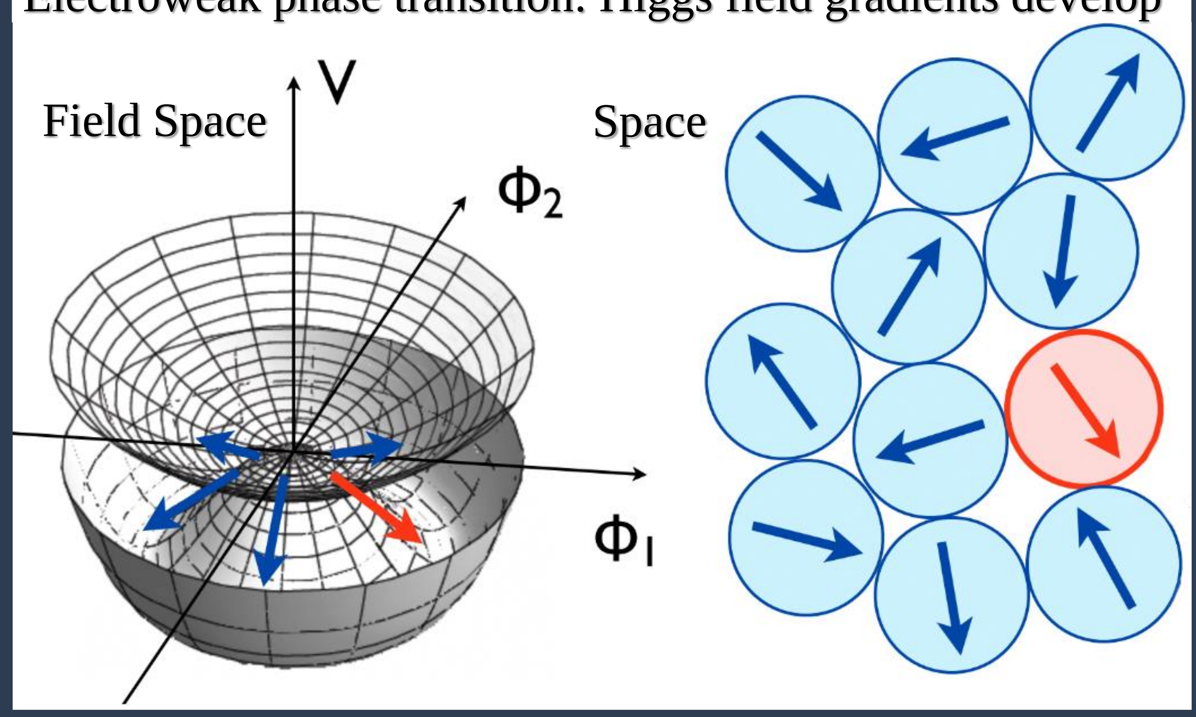
Given the sensitivities of contemporary GW detectors, the stochastic gravitational wave background from the Higgs field remains undetectable because of the small Higgs field vacuum expectation value (VEV).

Introduction and Background

Due to thermal fluctuations in the early universe (~0.1 ns), the Higgs potential fell in a variable manner in different regions of space, as depicted in Figure I. When these regions come into causal contact, the disparity in the Higgs VEV creates a tension gradient in the field which must be resolved, so this energy is dissipated in the form of GW. This phenomenon occurs with self-ordering scalar fields (SOSF), one of which is the Higgs field.

Figure I [3]

Electroweak phase transition: Higgs field gradients develop



Methods

We first assess what previous research has accomplished. The scale invariant GW energy density was recently derived and is displayed below.

$$h_0^2\Omega^{(0)}_{\rm GW}(f) \simeq \frac{650}{N}\, h_0^2\Omega^{(0)}_{\rm rad}\left(\frac{v}{M_{\rm Pl}}\right)^4$$

where v is the VEV of the SOSF, N is the number of scalar field components, M_{Pl} is the Planck mass, and $h_o^2\Omega^{(0)}_{rad} \sim 4*10^{-5}$ [2]. We extend the calculation above utilizing mathematical software and hand calculations. This leads to the spectra in Figure II and Figure III. The diagram below displays the project workflow.

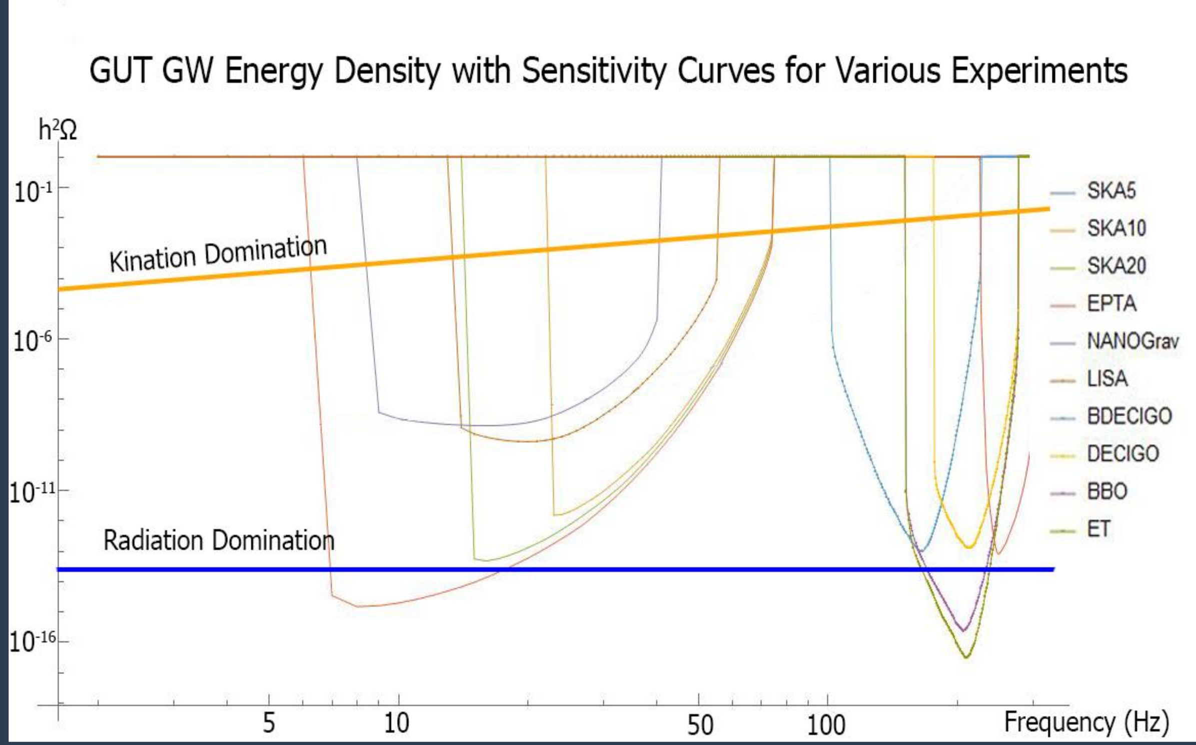
Project Workflow

Utilize previous work
- Generic SOSF GW emissions during the radiation dominated era
- GW from cosmic strings

Extend calculations
- Use Mathematica and MATLAB to create spectra
- Consider theoretical eras, various VEV, time at which modified era ends

Overlay sensitivities
- Sensitivities from PLI Dataset [1]
- Imported into MATLAB/Mathematica

Figure II



Results

Discovering the early universe through GW

Our model allows for the adjustment of three parameters: the VEV of the SOSF v, the rate at which the scale factor grows n, and the time at which the early theoretical era ends t_Δ.

We modeled the Grand Unified Theory (GUT) scale VEV, 10ˆ16 GeV, in Figure II. Interestingly, it is already feasible to confirm a kination or radiation dominated era with a GUT phase transition. The matter dominated era curve tends toward negative infinity as the frequency increases, and thus is not visible.

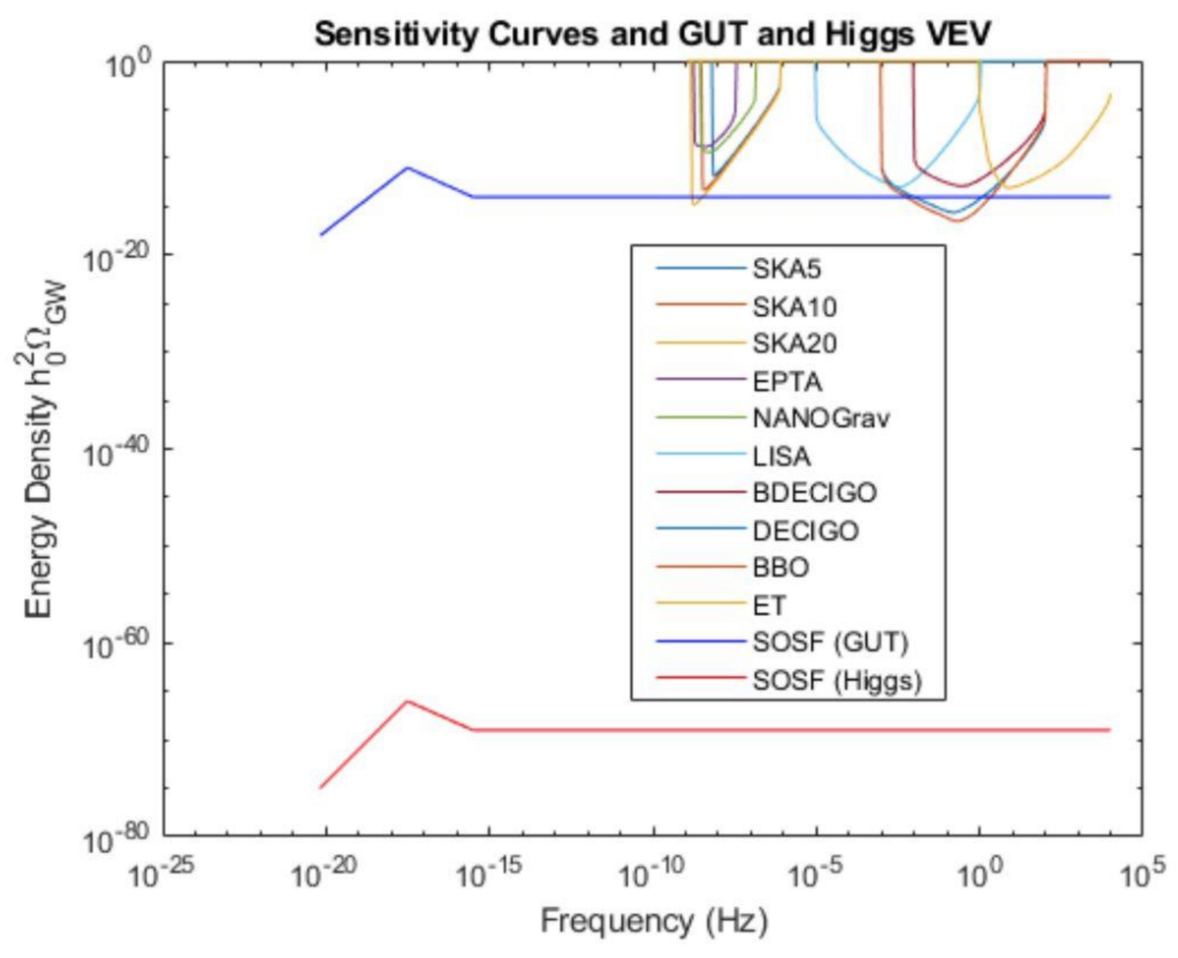
Current GW Detectability Restrictions

From Figure III, we can see that

- GW emitted from the Higgs field are extremely weak and undetectable
- A kination dominated era is not enough to make the Higgs curve rise and suggest detectability
  - This is due to a finite limit on the exponential term of the scale factor in the large n case

Thus, the only resolution would be to drastically increase GW detector sensitivities, which given the scale at which this needs to occur, appears unreasonable.

Figure III



Conclusions

Summary

We calculated the GW energy density spectrum resulting from the relaxation of the Higgs field in multiple eras of the universe. Our spectrum was manipulable and could be modified to simulate theoretical and known dominant energy densities in the universe, as well as the time these eras ended and the VEV of the field we wanted to investigate. The diagram below summarizes the consequences of our research.

Summary of Research Results

Goal: Create GW energy density spectrum

Product: Manipulable spectrum, three free parameters (era type, era duration, VEV)

Result 1: GW from Higgs field are undetectable

Result 2: New physics like GUT symmetry breaking can be tested

Result 3: Theoretical cosmic history can be tested

We ultimately found that while GW from the Higgs field are undetectable, constraints can be placed on new physics such as GUT symmetry breaking and a kination dominated era, and in certain conditions, GW associated with these phenomena can be registered by current detectors.

References

[1] Breitbach et al, hep-ph/1811.11175
[2] Figueroa et al, hep-ph/2007.03337
[3] Kuroyanagi et al, APCTP