Gravitational Wave Signal of the Dark Matter Triggered Phase Transition

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Motivation

Strongly first order electroweak phase transition (EWPT) is a necessary ingredient for the explanation of the baryon asymmetry of the universe via the electroweak baryogenesis mechanism. Its signature at the LHC is di-Higgs in various channels, but no hint has been observed up-to-now. With the discovery of the gravitational wave (GW) at the LIGO, it opens a new window for detecting EWPT, which is the stochastic GW background generated during bubble nucleation in the space-based interferometer.

The SM Higgs itself is too heavy to give rise to a first order EWPT, so new Higgs interaction is needed. The Higgs portal is a well-motivated scenario for triggering the first order EWPT, since it may kill two birds with one stone. In this case the EWPT will be two-step and the barrier between the electroweak broken and symmetric phases arises naturally at the tree-level. In this poster, we show the GW signal arisen from this kind of EWPT.

Thermal History of the EWPT

T

- T_1: The first step PT takes place and the DM get non-zero VEV
- T_C: The temperature where the EW broken and symmetric phases become degenerate
- T_n: The bubble nucleation temperature
- T_D: The temperature where the EW broken phase fills the universe.

Sources of the GW from EWPT

① Bubble collisions; Calculated using envelope approximation

② Sound wave: Percolation produces bulk motion in the fluid in the form of sound wave

③ MHD turbulence: Percolation can induce Magnetohydrodynamic turbulence in the plasma since the plasma is fully ionized.

Key formulae

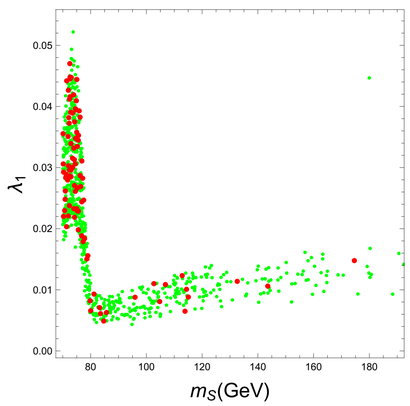
$$\rho_{GW}(\eta) = \frac{< \dot{h}_{ij}(x)\dot{h}_{ij}(x) >}{8\pi G a(\eta)^2} \qquad T_{ab}(x,\tau) = (\rho + p)\frac{v_a(x,\tau)\, v_b(x,\tau)}{1 - v^2(x,\tau)}$$

Results

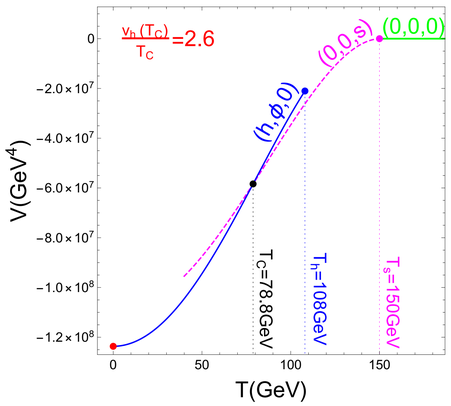
To get the bubble nucleation temperature, bubble profile and the tunneling rate, which are necessary for the calculation of GW spectra, one needs to solve the O(3)-Euclidean equation of motion for background fields:

$$\frac{d^2\phi_i}{dr^2} + \frac{2}{r}\frac{d\phi_i}{dr} = \bar{V}'(\vec{\phi})$$

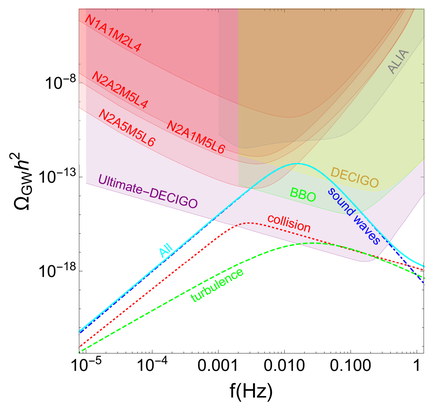
Here $\bar{V}'$ is derivative of the effective potential with respect to various background fields. These equations can be solved numerically with the shooting method.



Scattering plot in the DM's mass-coupling plane for a large enough DM relic density, strongly first order EWPT and negligible direct detection cross section.



Evolution of the effective potential at the two minima in *s* (blue) and *(h, ϕ)* (magenta dashed) directions as *T* drops from right to the left.



Spectra of GW generated during the first order EWPT as a function of frequency from thee sources, The color shaded regions are sensitivities of eLISA, ALIA, BBO and DECIGO

Conclusions

The stochastic GW signal arisen during EWPT in the space-based interferometer is an important complementation to collider searches of the first order EWPT. In this poster we explored the detail of EWPT triggered by the Higgs portal. We exemplified, using one representative benchmark point, the discovery possibility of the EWPT with the generated GW signals during the second step EWPT and found that the GW signals can be detected by the LISA in the configuration N2A5M5L6, BBO, DECIGO and Ultimate- DECIGO.

Relevant paper

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