Gravitational Waves from Grand Unified Theories and Extended Theories of Gravity

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Contents

Sinchon GW Group

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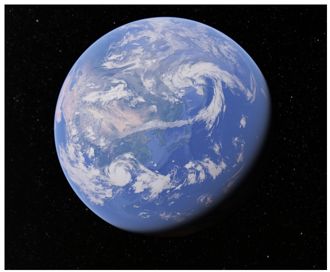
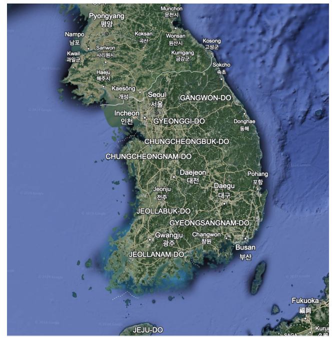
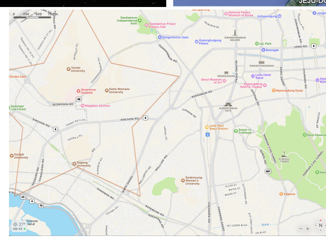






Goals

- Phase Transitions in Realistic GUT models
- GW signals in extended theories of gravity

Phase Transitions in Realistic GUT models

+50 years of Grand Unified Theories

- Georgi, Glasgow 1974, SU(5)
- 1980 Plethora of models and phenomenology
- 1990 Matching to MSSM fields developed
- 1990-2000: Computation of 2-loops beta functions, matching at EW Scale developed
- 2004-2010: Computation of Higgs Observables, development of tools for probing SUSY at the LHC J. Ellis, K. Olive, L V-S, et al.
- 2010: Adding of running above, use of supergravity (More realistic models)
- 2013: Code developments (full RGE loops)
- 2014+: Of course no hints at the LHC
- 2017: Lattice calculation reduced to 10% uncertainty in hadronic parameters: crucial for proton decay limits
- 2019: Refinements in the theory and precision in calculations for PD J. Ellis, K. Olive, L V-S, et al. Eur.Phys.J.C 80 (2020) 4, 332 aX: 1912.04888
- 2020-2024: Contrasting with flavor observables and EDMs Kaneta, N. Nagata, K A. Olive, M. Pospelov, L V-S JHEP 03 (2023) 250 aX: 2303.02822
- Richness of possible GW signals: topolgical defects, phase transitions

Kibble, Lazarides, Shafi. "Strings in SO(10)". Phys. Lett. B 113 (1982)

Dunsky, et al. Phys.Rev.D 106 (2022) 7, 075030 aX: 2111.08750

EJ Chun & L. V-S. Phys.Rev.D 106 (2022) 3, 035008 aX: 2112.14483

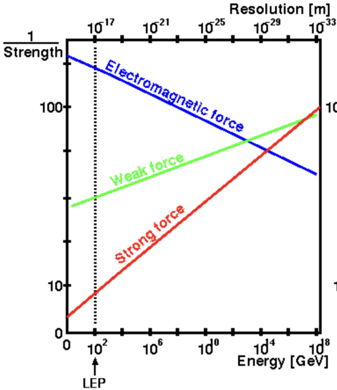
Unification of fundamental forces

It is well known that unification of couplings is not achieved only with the SM

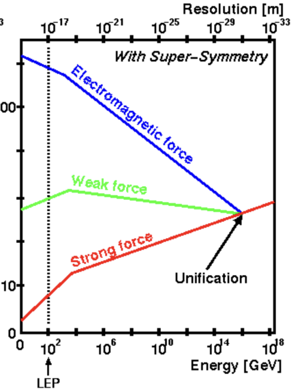
But supersymmetric theories can achieve unification

Lesser known is the fact that both non-supersymmetric theories and supersymmetric theories can achieve unification in two steps

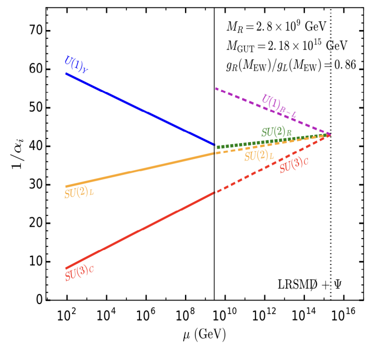
SM



SUSY



NON-SUSY intermediate scale



L. V-S et. al. Phys.Rev.D 106 (2022) 8, 083012, aX: 2206.06667

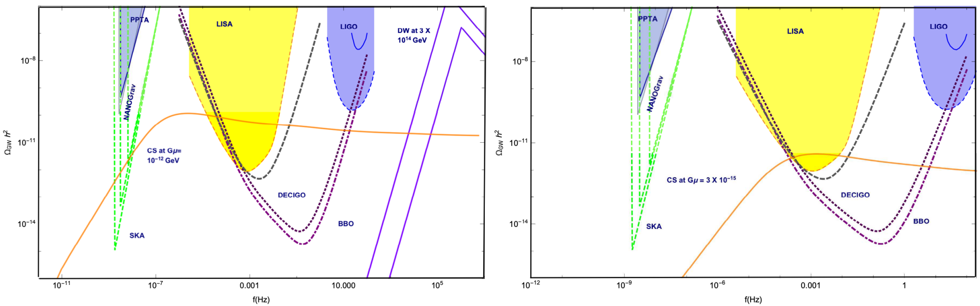
Why two-step group breaking is interesting?

Plenty of appearance of topological defects and phase transitions

Monopoles, Cosmic Strings ↓ **DomainWalls** ↓ **Cosmic Strings** ↓

$$G_{SO(10)} \xrightarrow[\mathbf{210}]{} SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{(B-L)} \times \mathbf{D} \xrightarrow[\mathbf{45}]{} SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{(B-L)} \xrightarrow[\mathbf{126}]{} G_{SM} \times \mathbb{Z}_2 \xrightarrow[\mathbf{10}]{} SU(3)_C \times U(1)_Y \times \mathbb{Z}_2$$

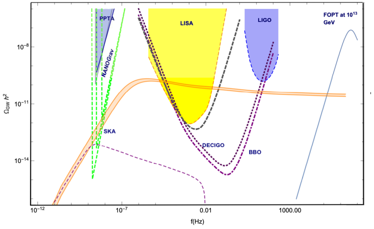
↑ $M_{GUT} \sim 10^{16}$ GeV ↑ **Inflation** $\sim 10^{13}$ **GeV**



EJ Chun & L. V-S. Phys.Rev.D 106 (2022) 3, 035008 aX: 2112.14483

Challenges

- Apart from Cosmic Strings, other effects are out of reach of present experiments
- GUT breaking requires a multifield analysis, particularly difficult for studying First Order Phase Transitions

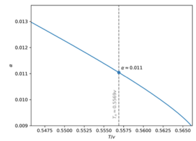


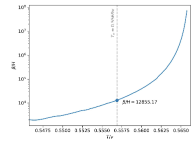
Why bother?

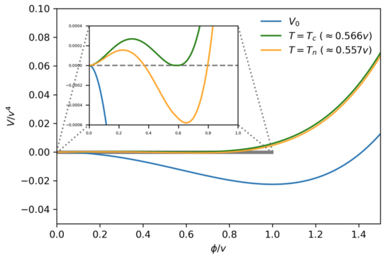
- Realistic models that passed all constraints on proton decay, LHC limits, EDMs are worth to study to see if they have a GW signal

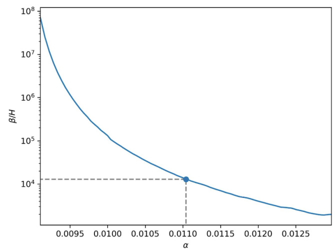
EXAMPLE

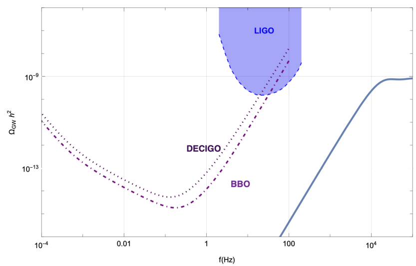
- VEV: $v = 10^{15}$ GeV
- D.O.F of particles: (scalar, gauge boson, fermion) =(1+1, 3, 4)
- coupling constants
  - scalar self-coupling: λ = 0.09
  - gauge coupling: $g = 1$
  - Yukawa coupling: $y = 1$



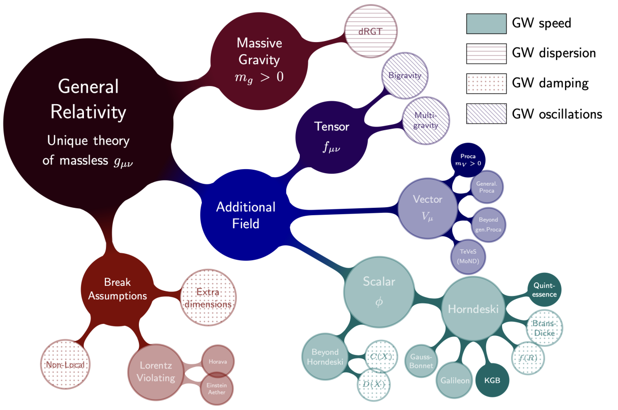








GW signals in extended theories of gravity



Plot Credit: Ezquiaga, Zumalacárregui 1807.09241

GW from particle physics processes

FOPT

SM plasma: Physical processes ranging from microscopic particle collisions to macroscopic hydrodynamic fluctuations induce gravitational waves in any plasma in thermal equilibrium [1504.02569, 2004.11392, J. Ghiglieri, M. Laine, et. al.].

For the largest wavelengths the emission rate is proportional to the shear viscosity, $\eta(T, \hat{k})$, of the plasma. In the Standard Model at $T > 160$ GeV, the shear viscosity is dominated by the most weakly interacting particles, right-handed leptons, and is relatively large.
The evolution of the density of the GW is simply given by

$$(\partial_t + 4H)\rho(t)_{\mathrm{GW}} = 4\frac{T^4}{\overline{M}_{\mathrm{P}}^2}\int \frac{d^3k}{(2\pi)^3}\eta(T,k),$$

All the information of the plasma is encoded in $\eta(T, k)$.

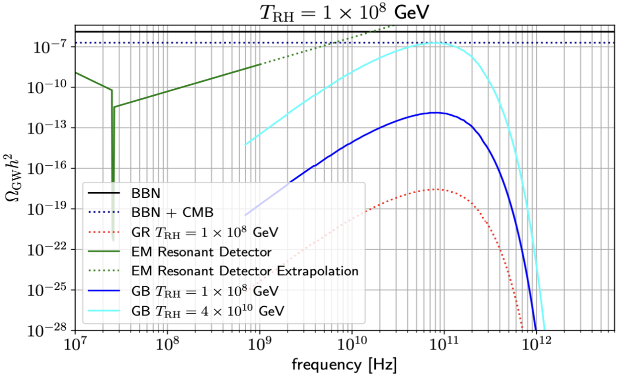
The basic behaviour is controlled by how big $\rho_{\rm Tot.}$ increases or decreases with respect to the radiation density, as it can be seen by looking at the temperature dependence on

$$\frac{\Omega_{\rm GW}(f)h^2}{\Omega_{\gamma_0}h^2} \approx \Omega_\gamma \frac{\lambda}{\overline{M}_{\rm P}} \int_{T_{\rm end}}^{T_{\rm in}} dT \left(\frac{g_{*0}}{g*(T)}\right)^{4/3} T^2\,\hat{k}^3 \frac{\eta(T,\hat{k})}{\sqrt{\rho_{\rm Tot.}}} ,$$

and remembering $\rho_{\rm rad.} \propto T^4$.

The peak frequency has only a minor dependence on the temperature and therefore it does not change much

In GR $f_{\rm Peak} \approx 74$ GHz.



Biswas, Kar, Lee[3], Scopel, Lin, L V-S, JCAP 09 (2024) 007 aX: 2405.15998

Interest on the Workshop

- Update me on latest FOPT refined determination of GW parameters
- Talk to people doing data analysis of stochastic waves
- Experimental ideas and prospects for experiments above the MHz region