Broad area of research (July 2024 PhD)

Topic: Baryogenesis with first order phase transitions and gravitational wave signatures

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The present universe has around 5% visible matter dominantly composed of baryons with negligible trace of antibaryons. The observed baryon asymmetry is often quantified in terms of the baryon-to-photon density ratio, $\eta = \frac{n_{\rm B} - n_{\bar{\rm B}}}{n_\gamma}$, where n_x ($x = {\rm B}, \bar{\rm B}, \gamma$) is the number density of the corresponding species x. The observed value of η at the present epoch is of the order of $\sim 10^{-10}$ [1]. This excess is in agreement with cosmic microwave background (CMB) observations as well as big bang nucleosynthesis (BBN) predictions for light nuclei abundance. As the universe is expected to begin in a symmetric manner and any initial asymmetry is likely to be diluted by the period of inflationary expansion, the observed excess of matter over antimatter gives rise to a longstanding puzzle [2]. Now, to generate a nonzero matter-antimatter asymmetry within an initially symmetric Universe, one has to satisfy three necessary conditions known as the Sakharov's conditions. These are baryon number violation, C and CP violation and departure from thermal equilibrium. There exist several popular mechanisms for generating the baryon asymmetry such as grand unified theory (GUT) baryogenesis, electroweak baryogenesis, Affleck-Dine baryogenesis and baryogenesis via leptogenesis. While GUT baryogenesis scale is typically required to be very heavy, in conflict with the CMB upper limit on inflationary scale, electroweak baryogenesis requires new particles around the TeV scale tightly constrained by collider data and new sources of CP violation constrained by limits on electric dipole moments of neutron, electron. On the other hand, Affleck-Dine baryogenesis and leptogenesis are typically high scale phenomena making direct experimental probe difficult.

In view of these, it is important to devise alternate search strategies to probe different baryogenesis models which can be out of reach from direct search experiments. In particular, precision CMB experiments like CMB-S4, SPT-3G have the potential to probe some of scenarios having either new relativistic degrees of freedom or late decay of long-lived particles. Another promising alternative is to look for stochastic gravitational wave (GW) signatures of different baryogenesis models [3, 4]. This is particularly promising in the light of ongoing LIGO-Virgo-KAGRA experiments as well as several planned GW experiments in the future. Secondly, it is important to look for new ways of solving the problem of baryon asymmetry. This requires new model building which may not only open up novel detection prospects but may also solve other puzzles like the origin of dark matter, neutrino mass, cosmic inflation. Such model building is also relevant in the light of null results at the collider experiments for popular models originally motivated from the naturalness criteria.

The research problem to be floated for a prospective PhD student admitted via regular mode in July 2024 will be related to exploration of baryogenesis or leptogenesis scenarios involving first order phase transition [5] having gravitational wave signatures. The basic topics necessary for such a problem are quantum field theory, standard model of particle physics and finite-temperature field theory [6]. Calculations will be of both analytical and numerical types.

References

[1] N. Aganim *et al.* [Planck Collaboration], Planck 2018 results. VI. Cosmological parameters, Astron. Astrophys. **641**, A6 (2020).

[2] D. Bodeker, W. Buchmuller, Baryogenesis from the weak scale to the grand unification scale, Rev. Mod. Phys. 93 (2021) 3, 035004

[3] C. Caprini *et al.*, Science with the space-based interferometer eLISA. II: gravitational waves from cosmological phase transitions, JCAP 04 (2016) 001.

[4] D. Borah *et al.*, JHEP 11 (2022) 136; Phys.Rev.D 108 (2023) 9, L091701; Phys. Rev. D 109 (2024) 095034.

[5] A. Mazumdar, G. White, Rept. Prog. Phys. 82 (2019) 7, 076901; M. B. Hindmarsh *et al.*, SciPost Phys. Lect. Notes 24 (2021) 1.

[6] M. Quiros, Finite Temperature Field Theory and Phase Transitions, arxiv:hep-ph/9901312.