Leptogenesis and low energy phases

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Abstract. In this work we analyze the relevance of the different low energy phases for the CP asymmetry of the Universe. To this end, we develop a parametrization of the see-saw mechanism in terms of low energy data that will allow us to study leptogenesis from a bottom-up perspective. We find that the relevant phases for leptogenesis depend on the particular scenario, and we classify the different possibilities in connection to lepton flavour violation. We find that the phase that would be measured at the neutrino factory is relevant for leptogenesis over much of the parameter space where this phase can be measured.

1. Introduction

After the discovery of neutrino oscillations, leptogenesis [1] stands as one of the most appealing explanations for the observed baryon asymmetry of the Universe. It relies on the see-saw mechanism, that assumes that there exist three right handed neutrinos with Majorana masses in the range $\sim 10^{10} - 10^{15}$ GeV, that couple to the left-handed neutrinos through Yukawa couplings. These simple assumptions, that can be naturally accommodated in a GUT theory, are enough to explain the smallness of neutrino masses. It is also remarkable that the decay of the right-handed neutrinos in the early Universe can also generate the observed baryon asymmetry. This is the so-called leptogenesis scenario.

To generate a lepton asymmetry three conditions have to be satisfied in the early Universe: deviation from thermal equilibrium, C and CP violation, and lepton number violation. This lepton asymmetry would be eventually reprocessed into the observed baryon asymmetry by sphaleron processes. The successes of the hot Big Bang theory indicate that there were processes out of thermal equilibrium in the early Universe. On the other hand, it is believed that neutrinos are Majorana particles and have lepton number interactions, although the experiments on neutrinoless double-beta decay have not confirmed this. Finally, no indication has been found so far for CP violation in the leptonic sector. For this reason, a lot of effort is being bestowed in the design of a neutrino factory, that could possibly measure the leptonic version of the CKM phase. Therefore, it is interesting to study the interplay between the CP violation that would be observed at low energies at the neutrino factory, and the CP violation that appears at high energies and that could be responsible for the baryon asymmetry.

2. The top-down vs. the bottom-up approach

The lepton asymmetry is generated through the decay rate difference of right-handed neutrinos into lepton and Higgs doublets, and their conjugate counterparts. These processes occur at very high energies and are not directly testable by experiments, so it is not straight-forward to make predictions about leptogenesis. However, these Yukawa couplings and right-handed masses leave an imprint at low energies that can be exploited to obtain information about the theory at high energies. Clearly, the neutrino masses, the mixing angles and the phases of the MNS matrix depend on the neutrino Yukawa couplings and the right handed neutrino masses. However, this information is not enough to reconstruct the whole theory, since the high energy theory has 18 parameters (12 real parameters and 6 phases), while the neutrino mass matrix only has nine (three masses, three mixing angles and three CP violating phases).

Fortunately there is a second window onto the high energy physics, namely radiative corrections. In a supersymmetric theory, neutrino Yukawa couplings affect the renormalization group evolution of the slepton mass matrix. Therefore, if we were able to measure the slepton mass matrix at low energies and we knew its structure at high energies, we would be able to disentangle the effects of the neutrino Yukawa couplings and obtain additional information about them. As a matter of fact, *the information encoded in radiative corrections is enough to reconstruct the complete theory* [2]. Of course one has to know which is the theory at high energies, and this relies on theoretical assumptions. However, a common assumption in the literature is to assume that the slepton mass matrix at high energies is proportional to the identity. This assumption is motivated both by phenomenological reasons (for instance, the non observation of rare lepton decays) as well as theoretical reasons (this is what one obtains in several well motivated supersymmetry breaking scenarios, such as minimal supergravity). If this is the case, neutrino Yukawa couplings spoil the diagonal form and this will give rise to clear signatures that could be measured with low energy experiments. For example, the off-diagonal entries in the Yukawa couplings would give rise to flavour violating entries in the slepton mass matrix, that would in turn induce rare processes like $\mu \to e\gamma$. Therefore, the observation of these processes would give additional information about the Yukawa couplings. Also, at tree level the three sneutrino masses are degenerate, and this degeneracy is lifted by radiative corrections. This non-degeneracy could also be measured and could provide further information about the see-saw mechanism. Although the possibility of reconstructing the high energy theory just from low energy data is very attractive, in practice is not attainable [2]. Nevertheless, this parametrization opens the possibility of studying leptogenesis from a bottom-up perspective and provides a natural set up to address the interplay between leptogenesis and low energy phases.

3. Leptogenesis from the bottom-up

In this talk we will concentrate in the step of leptogenesis that is most closely related to neutrino physics, namely the CP asymmetry. Using a bottom-up approach we were able to reformulate leptogenesis in terms of low energy data: neutrino and sneutrino masses, mixing angles and CP violating phases [3]. We found that the CP asymmetry generated in the decay of the lightest right-handed neutrino depends on five phases: the three phases in the MNS matrix and two combinations of phases in the sneutrino mass matrix. We also found that leptogenesis does not depend on a single phase, but instead on combinations of them, being the particular combination rather model dependent.

We have been able to classify all the possible different scenarios in terms of low energy observables, and identify the relevant phases for leptogenesis in each scenario.

The different scenarios can be classified essentially depending on the rates of rare lepton decays, like $\mu \to e\gamma$ and $\tau \to e\gamma$ (the asymmetry produced in the decay of the lightest right-handed neutrino is not very sensitive to $\tau \to \mu\gamma$). Here, we report the main results (for details, see [3]) and concentrate on the phases that have better prospects to be measured experimentally: the "neutrino factory phase" (the ν-fact phase) and the "neutrinoless double-beta decay phase" (the $(\beta\beta)_{0\nu}$-decay phase):

- **Vanishing rates.** In this case, leptogenesis depends exclusively on the phases that appear in the MNS matrix, and furthermore, depends only on phase differences. We find that the $(\beta\beta)_{0\nu}$-decay phase is always important, whereas the ν-fact phase is relevant when the CHOOZ angle is $\gtrsim 0.01$ (for the hierarchy of light neutrino masses 0.01:0.1:1). It is interesting to note that for these values of the CHOOZ angle, the neutrino factory should be able to observe CP violation.
- **Small rates.** Now all the five phases become relevant, although this number can be reduced in particular limits. If all the mixing angles in the sneutrino sector are smaller than the CHOOZ angle, then the ν-fact phase is relevant for leptogenesis. Otherwise, if one mixing angle in the sneutrino sector is larger, the ν-fact phase becomes irrelevant. As before, the $(\beta\beta)_{0\nu}$-decay is always important.
- **Large rates.** In this case, the ν-fact phase is essentially irrelevant, whereas the $(\beta\beta)_{0\nu}$-decay phase is still important. However, leptogenesis depends not only on the $(\beta\beta)_{0\nu}$-decay phase, but also on some other phases associated to sneutrino physics that have little prospects to be measured.

4. Conclusions

We have developed a bottom-up parametrization of the see-saw mechanism that has allowed us to formulate leptogenesis just in terms of low energy observables: neutrino masses and mixing angles, branching ratios for rare lepton decays, sneutrino masses, etc., and phases that could be in principle measured at low energies. We have classified the possible scenarios by the rates for the rare lepton processes and we have identified the relevant low energy phases for leptogenesis in each scenario. We have found that the "neutrinoless double-beta decay phase" is always important for leptogenesis, whereas the "neutrino factory phase" is important over much of the parameter space where the neutrino factory can measure CP violation (as long as the rates for the rare lepton decays are not too large). Also, we have found that leptogenesis depends on combinations of phases rather than on a single phase. Therefore, even if we could measure CP violation at the neutrino factory, little could be said about leptogenesis. However, and since one does not expect cancellations among the different phases, the observation of CP violation at the neutrino factory would give further support to leptogenesis as the actual mechanism to generate the observed baryon asymmetry in the Universe.

References

[1] See the contribution by Michael Plümacher to these proceedings for a nice review of leptogenesis.
[2] S. Davidson and A. Ibarra, JHEP **0109** (2201) 013.
[3] S. Davidson and A. Ibarra, hep-ph/0206304.