Rationale

We live in a peculiar epoch of Elementary Particle Physics: on one hand we have a theory (the Standard Model of strong and electroweak interactions) that works astonishingly well, being able to agree with data at an unprecedented level of accuracy. On the other hand, we know it cannot be the whole story, given the well known unsatisfying arbitrariness built in it and its incomplete description of the fundamental interactions. This notorious fact has given the way to a number of “Beyond the SM” constructions (SuperSymmetry, Technicolor, Grand Unification and, recently, Extra space Dimensions and Little Higgs theories) that still wait for confirmation or disproof. On the experimental side, a very successful era of precision experiments (mainly at Lep and the Tevatron) has almost come to an end, leaving us with no serious surprise or hint of discrepancy, while the next step (the LHC above all) still belongs to the future (fortunately: next and concrete).

Something vaguely similar is going on in the restricted realm of Neutrino Physics: in the latest years, experiment after experiment, every piece of evidence is finding its place in a beautiful picture, but several fundamental questions are still open. While the present generation of incredibly successful underground, reactor and accelerator experiments is almost over, the next generation (LBL, mega-ton detectors, neutrino factories...) is still at the level of development or even of imagination.

How to overcome, then, the theoretical impasse and the experimental await? One of the possible answers is: turning one’s eyes to the stars and the cosmo.

Although, of course, less under control than table-top or accelerator experiments, stars (core-collapse Supernovæ in particular) and the Early Universe (whose image is imprinted in the deep space that we observe today) are powerful laboratories for particle physics, and often come with features that make them complementary or even more useful than the traditional means of probing the microscopic world.

The subject of this thesis fits in such a picture: focussing on the issue of the possible existence of sterile neutrinos, I discuss the constraints and the possible signals of their presence that come from the physics of Supernovæ and of the Early Universe.

In the first Chapter I substantiate the link between the search for New Physics and the use of supernovæ and cosmological processes. This Chapter has the character of an introductory general overview, which consists of four parts: The Standard Model and why to go beyond, “Standard” neutrino physics and why to go beyond, The role of Supernovæ, The role of the Early Universe. Each of these parts can be essentially read in an independent way from the others (or even skipped by the learned reader). The specific work of this thesis builds up on this general background and knowledge, to which I will occasionally refer in the subsequent Chapters.

In the second Chapter, based on ref.[1], I focus on the case of a single (4D) sterile neutrino. After the presentation of the adopted four neutrino formalism, I describe the derivation of bounds and signals on its mixing parameters with the active neutrinos, considering BBN, LSS, CMB and supernovæ. Including the consolidated mixing of active neutrinos among themselves in all these contexts can lead to outputs quite different from those in the literature and to new features. As a result, I present plots of the combined excluded regions in the space of the mixing parameters.

In the third Chapter, based on refs.[2, 3], I move to the case of an infinite tower of sterile neutrinos motivated by Extra Dimensions. After the description of the 5D setup, I discuss the model of modified evolution developed for the SN inner core, first qualitatively and then in detail. I show that a careful study of the SN physics can allow a relaxation of the previous bounds in the literature by several orders of magnitude, giving also rise to an interesting modified phenomenology. For the three cases of electron, muon and tau neutrinos mixed with the extra dimensional states, I present the possible signatures of extra dimensional states in the neutrino signal from the next SN.