Abstract of the thesis

Dark matter as a laboratory for new ideas in physics beyond the Standard Model

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One of the most puzzling features of our Universe is that for each atom of ordinary matter, there are five others that are invisible. The nature of this so-called dark matter (DM) remains mysterious and efforts to detect it are one the most significant lines of research in modern physics. This thesis is dedicated to studying various popular candidates for particle DM, focusing on models and phenomena that can be related to other puzzles of the Standard Model (SM) and that will be tested in experiments in the near-future.

We first present the theoretical and observational foundations of the Standard Cosmological Model (ΛCDM). Within this model, the DM problem is presented and other viewpoints on this issue - mainly from astrophysics and particle physics - are discussed. We then discuss the production mechanism of thermal DM, which represents a broad class of DM candidates often predicted by well-motivated extensions of the SM. In fact, most of the DM candidates discussed in this thesis belong to this type. We also discuss in detail the experimental program devoted to the search for such particles, among them the celebrated Weakly Interacting Massive Particles (WIMPs), which could be naturally related to the electroweak scale of the SM, as shown by the numerical coincidence called *WIMP miracle*. However, current searches for electroweak scale WIMPs yielded null results, which motivates exploring other possibilities. Among them are beyond the SM scenarios involving light, sub-GeV new particles which naturally extend the *WIMP miracle*, and can be naturally related to other problems of the SM. In particular, realistic models of this type often include unstable particles, which are generally long-lived. Such particles are of particular interest from the point of view of particle physics and cosmology, and at the same time they are perfect target for the emerging forward physics experiments, like FASER, that will soon take data at the LHC. We study the prospects of such scenarios involving (i) renormalizable SM interactions with new scalar or vector mediators and (ii) non-standard neutrino interactions, finding great prospects in each case. We then discuss the prospects of indirect detection searches for heavy, $m_{\rm DM} > 100\text{GeV}$, supersymmetric WIMP DM comprised of the lightest neutralino at Cherenkov light telescopes. We find great potential for such searches to almost completely cover the key benchmark of thermal DM annihilation cross section, which is challenging in other detection strategies. Next, we study the relatively unexplored complementarity between indirect detection, intensity frontier searches, and CMB radiation surveys that allow to constrain long-lived particles within a rich dark sector model. We find, for example, that the resulting non-local effects in indirect detection significantly differ from the signal associated with WIMPs annihilations, potentially affecting the usual detection strategies. Finally, we discuss a new mechanism for producing self-interacting DM from late decays of pseudo-WIMP taking place after the recombination. Among other things, we find that such a mechanism can solve the small-scale problems of ΛCDM, while partially alleviating the so-called Hubble tension in broad region of parameter space of the model, and resolving the XENON-1T electron recoil anomaly for a particular realization of the mechanism. Lastly, we summarize the obtained results described in this thesis in a broader context.