TAsP: Theoretical Astroparticle Physics

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Main scientific activities and achievements during the year 2019.

Axion Physics:

We have contributed to the writeup of the Conceptual Design Report of the KLASH (KLoe magnet for Axion SearcH) experiment at the Laboratori Nazionali di Frascati (LNF) [1]. The idea of this experiment has been stimulated by the availability of the large volume superconducting magnet, with a moderate magnetic field of 0.6 T, used in the KLOE detector at the DAFNE collider. The main conclusion drawn from this report is the possibility to build and put in operation at LNF in 2-3 years a large haloscope with the sensitivity to KSVZ axions in the low mass range between 0.2 and 1 μeV, complementary to that of other experiments. The responsibility of TAsP-LNF was that of writing the theoretical part with all the details of the KLASH physics case.

The strongest upper bounds on the axion mass come from astrophysical observations like the neutrino burst duration of SN1987A, which depends on the axion couplings to nucleons, or the white-dwarf cooling rates and red-giant evolution, which involve the axion-electron coupling. It has been recently argued that in variants of DFSZ models with generation-dependent Peccei-Quinn charges an approximate axion-nucleon decoupling can occur, strongly relaxing the SN1987A bound. However, as in standard DFSZ models, the axion remains in general coupled to electrons, unless an ad hoc cancellation is engineered. In Ref.[2] we have shown that axion-electron decoupling can be implemented without extra tunings in DFSZ-like models with three Higgs doublets. Remarkably, the numerical value of the quark mass ratio $m_u/m_d \sim 1/2$, is crucial to open up this possibility.

In Ref. [3] we have investigated to what extent a generic, generation-dependent U(1) symmetry acting on the quark Yukawa operators can reduce the number of free parameters by forcing some entries in the Yukawa matrices to vanish. The maximal reduction compatible with CP violation yields nine real parameters and one phase, which matches the number of physical observables, implying that such models have no free parameters. We derive a set of results, the most important of which is that the U(1) symmetries that generate the Yukawa textures all have a QCD anomaly, and hence are Peccei-Quinn symmetries, reinforcing the idea of a possible connection between the quark flavour puzzle and the axion solution to the strong CP problem. Intriguingly, in some cases the contributions to the QCD anomaly of two generations cancels out, and this opens the possibility that the axion coupling to nucleons could be strongly suppressed. Flavour-violating axion couplings to quarks are completely fixed, up to the axion decay constant, providing a non-trivial complementarity between low-energy flavour-violating processes and standard axion searches.

Neutrino Mass Models:

The flavour neutrino puzzle is often addressed by considering neutrino mass matrices m with a certain number of vanishing entries ($m_{ij} = 0$ for some values of the indices), since a reduction in the number of free parameters increases the predictive power. Symmetries that can enforce textures zero can also enforce a more general type of conditions. In this case the neutrino mass matrix can have all entries non-vanishing with no reduction in its predictive power. In Ref. [4] we have classified all generation-dependent U(1) symmetries which, in the presence of two leptonic Higgs doublets, can reduce the number of independent high-energy parameters of type-I seesaw to the

minimum number compatible with non-vanishing neutrino mixings and CP violation. These symmetries are broken above the scale where the effective operator is generated and can thus remain covert, in the sense that no explicit evidence of the symmetry can be read off the neutrino mass matrix, and different symmetries can give rise to the same low-energy structure. We have found that only two cases are viable: one yields a structure with two zero-textures already considered in the literature, the other has no zero-textures and has never been considered before. It predicts normal ordering, a lightest neutrino mass $\sim 10\,\mathrm{meV}$, a Dirac phase $\delta \sim 3\pi/2$ and definite values for the Majorana phases.

Publications

1 KLASH Conceptual design report,
D. Alesini et. al.
arXiv:1911.02427

2 Axion-electron decoupling in nucleophobic axion models,
Fredrik Björkeroth (Frascati), Luca Di Luzio (INFN, Pisa & Pisa U.), Federico Mescia (ICC, Barcelona U.), Enrico Nardi (Frascati), Paolo Panci (INFN, Pisa & Pisa U. & CERN & Gran Sasso), Robert Ziegler (CERN).
Published in Phys.Rev. D101 (2020) no.3, 035027.

3 $U(1)$ flavour symmetries as Peccei-Quinn symmetries,
Fredrik Bjorkeroth (Frascati), Luca Di Luzio (Durham U., IPPP & Durham U.), Federico Mescia (ICC, Barcelona U.), Enrico Nardi (Frascati).
Published in JHEP 1902 (2019) 133.

4 Covert symmetries in the neutrino mass matrix,
Fredrik Björkeroth (Frascati), Luca Di Luzio (INFN, Pisa & Pisa U.), Federico Mescia (Barcelona U., ECM & ICC, Barcelona U.), Enrico Nardi (Frascati)
(arXiv:1910.00576) Published in JHEP 2002 (2020) 066.