TAsP: Theoretical Astroparticle Physics

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Main scientific activities and achievements of the IS TAsP during the year 2022.

Axion Physics:

Renormalization group effects in astrophobic axion models.
In certain axion models it is possible to suppress simultaneously both the axion couplings to nucleons and electrons, realising the so-called astrophobic axion scenarios, wherein the tight bounds from SN1987A and from stellar evolution of red giants and white dwarfs are greatly relaxed. So far, however, the conditions for realising astrophobia have only been set out in tree-level analyses. In Ref.[1] we have studied whether these conditions can still be consistently implemented once renormalization group effects are included in the running of axion couplings. Astrophobia keeps holding, albeit within fairly different parameter space regions, and we have provide analytical insights into this result.

The axion flavour connection.
A local flavour symmetry acting on the quarks of the Standard Model can automatically give rise to an accidental global $U(1)$ which remains preserved from sources of explicit breaking up to a large operator dimension, while it gets spontaneously broken together with the flavour symmetry. Such non-fundamental symmetries are often endowed with a mixed QCD anomaly, so that the strong CP problem is automatically solved via the axion mechanism. In Ref. [2] we have illustrated the general features required to realise this scenario, and we have discussed a simple construction based on the flavour group $SU(3)SU(2)U(1)_F$ to illustrate how mass hierarchies can arise while ensuring at the same time a high quality Peccei-Quinn symmetry.

Physics of dark sectors and of dark matter:

The muon g-2 anomaly confronts indirect new physics effects.
The 4.2σ discrepancy between the SM prediction for the muon anomalous magnetic moment a_μ and the experimental result is accompanied by other anomalies. A crucial input for the prediction is the hadronic vacuum polarization $a_\mu^{\rm HVP}$ inferred from $\sigma_{\rm had} = \sigma(e^+e^- \to \text{hadrons})$ data. However, the two most accurate determinations of $\sigma_{\rm had}$ from KLOE and BaBar disagree by $3\,\sigma$. Additionally, the combined data-driven result disagrees with the most precise lattice determination of $a_\mu^{\rm HVP}$ by $2.1\,\sigma$. In Ref. [3] we have shown that all these discrepancies can be accounted for by the direct and indirect effects of a new boson produced resonantly around the KLOE centre of mass energy, and decaying promptly, yielding e^+e^- and $\mu^+\mu^-$ pairs in the final state.

A GeV-scale new physics explanation of the $(\mathbf{g-2})_\mu$ window discrepancy.
Recent lattice determinations of the hadronic vacuum polarization contribution to the muon anomalous magnetic moment $a_\mu^{\rm HVP}$ indicate an exacerbation of the discrepancy with the data driven dispersive method at the level of $\sim 4.5\sigma$. This disagreement could be due to some process beyond the standard model affecting the determination of a_μ from $e^+e^- \to$hadrons data within a certain energy range. In Ref. [4] we have studied how the theoretical construction put forth in Ref. [3] performs in the short, intermediate and long distance windows. We have found that, in agreement with lattice indications, the dominant effects are confined to the low and intermediate energy windows, while the high energy window remains largely unaffected.

Probing light mediators at the MUonE experiment.
The MUonE experiment, that aims to provide a precise measurement of the hadronic vacuum polarization contribution to the muon g-2 via elastic muon-electron scattering, has also the potential to explore the parameter space of light new physics. In Ref. [5] we have demonstrated that, by exploiting the process $\mu^- N \to \mu^- N X$, where N is the target nucleus and X is a new physics light mediator, MUonE can be sensitive to new regions of parameter space for sub-GeV dark photons, and can also probe the parameter space of axion-like particles for different assumptions of the couplings to electrons, muons and photons.

Resonant search for the X17 boson at PADME.
In Ref. [6] we have discussed the experimental reach of the Frascati PADME experiment in searching for new light bosons via their resonant production in positron annihilation on fixed target atomic electrons. We have shown that a scan in the mass range around 17 MeV will thoroughly probe the particle physics interpretation of the anomaly observed by the ATOMKI nuclear physics experiment. In particular, for the case of a spin-1 boson, the viable parameter space can be fully covered in a few months of data taking.

Charged dark matter in supersymmetric twin Higgs models.
Supersymmetric Twin Higgs models ameliorate the fine-tuning of the electroweak scale originating from the heavy scalar top partners required by the non-discovery of them at the Large Hadron Collider. If the Lightest Supersymmetric Particle resides in the twin sector, it may play the role of dark matter even if it is charged under twin gauge interactions. In In Ref. [7] we have shown that the twin stau is a viable candidate for charged dark matter, even if the twin electromagnetic gauge symmetry is unbroken, with thermal relic abundance that naturally matches the observed dark matter abundance. Twin stau dark matter can be observed in future direct detection experiments such as LUX-ZEPLIN.

On the W-mass and New Higgs Bosons.
In Ref. [8] we have discussed the prediction of the W boson mass in a simple extension of the Standard Model with a real scalar triplet. A shift in the W mass as reported by the CDF II collaboration can naturally be accommodated by the model without modifying the Standard Model value for the Z mass. We have discussed the main implications and the properties of the new Higgs bosons.

Two-Higgs-doublet model and quark-lepton unification.
In Ref. [9] we have studied the Two-Higgs-Doublet Model predicted in the minimal theory for quark-lepton unification that can describe physics at the low scale. We have discussed the relations among the different decay widths of the new Higgs bosons and we have studyed their phenomenology at the Large Hadron Collider. As a result of matter unification, this theory predicts a correlation between the decay widths of the heavy Higgs bosons into tau leptons and bottom quarks.

Enhancing $B_s \to e^+e^-$ to an observable level in the two-Higgs-doublet model.
As a result of the helicity suppression effect, within the Standard Model the rare decay channel $B_s \to e^+e^-$ has a decay probability which is five orders of magnitude below current experimental limits. Thus, any observation of this channel within the current or forthcoming experiments will give unambiguous evidence of Physics Beyond the Standard Model. In Ref. [10] we have presented for the first time a New Physics scenario in which the branching fraction for $B_s \to e^+e^-$ is enhanced up to values which saturate the current experimental bounds. Furthermore, we have demonstrated how this scenario can arise from a UV-complete theory of quark-lepton unification that can live at a low scale.

Publications

1 Renormalization group effects in astrophobic axion models,
L. Di Luzio, F. Mescia, E. Nardi and S. Okawa,
Published in: Phys. Rev. D **106**, no.5, 055016 (2022).

2 The axion flavour connection,
L. Darmé, E. Nardi and C. Smarra,
Published in: JHEP 02 (2023) 201.

3 The muon g-2 anomaly confronts new physics in $e^{\pm}$ and $\mu^{\pm}$ final states scattering,
L. Darmé, G. Grilli di Cortona, E. Nardi,
Published in: JHEP 06 (2022) 122.

4 The $(g-2)_\mu$ window discrepancy: a GeV-scale new physics explanation,
L. Darmé, G. Grilli di Cortona, E. Nardi,
[arXiv:2212.03877[hep-ph]].

5 Probing light mediators at the MUonE experiment,
G. Grilli di Cortona and E. Nardi,
Published in: Phys. Rev. D **105**, no.11, L111701 (2022).

6 Resonant search for the X17 boson at PADME,
L. Darmé, M. Mancini, E. Nardi and M. Raggi,
Published in: Phys. Rev. D **106**, no.11, 115036 (2022).

7 Charged Dark Matter in Supersymmetric Twin Higgs models,
M. Badziak, G. Grilli di Cortona, K. Harigaya, M. Łukawski,
Published in: JHEP 10 (2022) 057.

8 On the W mass and new Higgs bosons,
P. Fileviez Perez, H.H. Patel and A.D. Plascencia,
Published in: Phys. Lett. B 833 (2022) 137371.

9 Two-Higgs-doublet model and quark-lepton unification,
P. Fileviez Perez, E. Golias and A.D. Plascencia,
Published in: JHEP 08 (2022) 293.

10 Enhancing $B_s \to e^+e^-$ to an observable level in the two-Higgs-doublet model,
M. Black, A.D. Plascencia, G. Tetlalmatzi-Xolocotzi,
Published in: Phys. Rev. D **107** (2023) 3, 035013.