TAsP: Theoretical Astroparticle Physics

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Main scientific activities and achievements of the IS TAsP during the year 2021.

Axion Physics:

Exact accidental U(1) symmetries for the axion.
Explaining the origin of the Peccei-Quinn (PQ) symmetry that solves the strong CP problem is an open issue, as is also the mechanism that ensures that this symmetry is respected by effective operators up to a rather large dimension. In Ref. [1] we have shown how a certain type of gauge groups can automatically yield a perturbatively *exact* PQ symmetry and solve these problems.

Selective enhancement of the QCD axion couplings.
In most models the strength of the axion coupling to standard model fields is proportional to its mass. In Ref. [2] we have put forth a type of constructions in which this theoretical constraint is evaded: the axion coupling to photons, nucleons or leptons can be enhanced selectively without increasing the axion mass.

Stellar Evolution confronts Axion Models.
Axion production from astrophysical bodies is a topic in continuous development, because of theoretical progress in the estimate of stellar emission rates and, especially, because of improved stellar observations. In Ref. [3] we have carried out a comprehensive analysis of the most informative astrophysics data, revisiting the bounds on axion couplings to photons, nucleons and electrons, reassessing the significance of various hints of anomalous stellar energy losses, and confronting the performance of various theoretical constructions in accounting for these hints.

Flavor-violating Higgs decays and stellar cooling anomalies in axion models.
In Ref. [4] a class of DFSZ-like models for the QCD axion that can address observed anomalies in stellar cooling has been studied. We have shown that large parts of the parameter space that allow to explain the anomalies will be tested by the next generation of axion helioscopes such as IAXO.

Physics of the dark sectors and of dark matter:

Invisible decays of axion-like particles: constraints and prospects,
In Ref. [5] we have studied the phenomenology of an Axion-like particle (ALP) portal when the ALP mainly decays invisibly, while its interaction with the standard model sector proceeds essentially via its coupling to electrons and/or photons. We have re-analysed existing limits from various collider and beam dump experiments, including in particular ALP production via $e^{\pm}$ interactions in addition to the usual production through ALP-photon coupling. We have also illustrated the prospects for ALP searches at the positron fixed-target experiment PADME, and the future reach of an upgraded experimental setup.

Light dark matter searches with positrons
In Ref. [6] we have discussed two complementary strategies to search for light dark matter (LDM) exploiting the positron beam possibly available in the future at Jefferson Laboratory. Thanks to the high intensity and the high energy of the CEBAF (Continuous Electron Beam Accelerator Facility) beam, and relying on a novel LDM production mechanism via positron annihilation on target atomic electrons, the proposed strategies will allow the exploration explore new regions in the LDM parameters space, thoroughly probing the LDM hypothesis as well as more general hidden sector scenarios.

Dark Photon bounds in the dark EFT.
Using the framework of dark effective field theory, in Ref. [7] we have studied how robust are the current experimental bounds on dark photons that interact with ordinary photons via a kinetic mixing with the hypercharge field strength tensor, focussing in particular on the possible existence of a dark dipole interaction between the Standard Model leptons and the dark photon.

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. [8] 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.

Probing light vector mediators with coherent scattering at future facilities.
Future experiments for Coherent Elastic Neutrino Nucleus Scattering measurements may be powerful tools in probing light new physics. In Ref. [9] we have studyed the sensitivity on light Z' mediators of two proposed experiments: a directional low pressure Time Projection Chamber detector, νBDX-DRIFT, that will utilise neutrinos produced at the Long Baseline Neutrino Facility, and several possible experiments to be installed at the European Spallation Source. We have shown that these experiments have the potential to test unexplored regions that, in some case, could explain the anomalous magnetic moment of the muon or peculiar spectral features in the cosmic neutrino spectrum observed by IceCube.

Theory of Dirac Dark Matter.
In Ref. [10] we have studied a simple theory predicting the existence of a Dirac dark matter candidate from gauge anomaly cancellation. In this theory, a spontaneous breaking of local baryon number at the low scale can be a viable possibility. We have shown that the constraint from the dark matter relic abundance implies an upper bound on the theory of a few tens of TeV. Correlation between the dark matter constraints and the prediction for the electric dipole moment (EDM) of the electron have been also studied.

Dark Energy, Cosmology and the Hubble tension.

Direct detection of dark energy.
In Ref. [11] we have explored the prospects for direct detection of dark energy by current and upcoming terrestrial dark matter direct detection experiments. If dark energy is driven by a new light degree of freedom coupled to matter and photons then dark energy quanta can be produced in the Sun, and can then free-stream towards Earth where they can interact with Standard Model particles in direct detection experiments. We speculate on the tantalising possibility that the XENON1T electron recoils excess may represent the first direct detection of dark energy.

Review of solutions to the Hubble tension.
The ΛCDM model provides a good fit to cosmological data, but with the improvement in the accuracy of observations, discrepancies among key cosmological parameters of the model have emerged. The most statistically significant tension is the 4-6σ disagreement between predictions of the Hubble constant H_0 by early time probes with the ΛCDM model, and a number of late time, model-independent determinations from local measurements of distances and redshifts. In Ref. [12] we have presented a thorough review of the problem, including a discussion of recent H_0 estimates and a summary of the proposed theoretical solutions.

Publications

1 Exact accidental U(1) symmetries for the axion,
L. Darmé and E. Nardi,
Published in: Phys. Rev. D **103**, no.1, 015034 (2021).

2 Selective enhancement of the QCD axion couplings,
L. Darmé, L. Di Luzio, M. Giannotti and E. Nardi,
Published in: Phys. Rev. D **103**, no.1, 015034 (2021).

3 Stellar Evolution confronts Axion Models,
L. Di Luzio, M. Fedele, M. Giannotti, F. Mescia and E. Nardi,
[arXiv:2109.10368 [hep-ph]], Published in JCAP 02 (2022) 035.

4 Flavor-violating Higgs decays and stellar cooling anomalies in axion models,
M. Badziak, G. Grilli di Cortona, M. Tabet, R. Ziegler,
Published in: JHEP 10 (2021) 181.

5 Invisible decays of axion-like particles: constraints and prospects,
L. Darmé, F. Giacchino, E. Nardi, M. Raggi
Published in JHEP 06 (2021) 009.

6 Light dark matter searches with positrons,
M. Battaglieri et al.
Published in Eur.Phys.J.A 57 (2021) 8, 253.

7 Dark photon bounds in the dark EFT,
D. Barducci, E. Bertuzzo, G. Grilli di Cortona, G. M. Salla,
[arXiv:2109.04852 [hep-ph]].

8 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,
[arXiv:2112.09139 [hep-ph]].

9 Probing light vector mediators with coherent scattering at future facilities,
E. Bertuzzo, G. Grilli di Cortona, L. Magno D. Ramos,
[arXiv:2112.04020 [hep-ph]].

10 Theory of Dirac Dark Matter: Higgs Decays and EDMs,
P. Fileviez Perez, A. D. Plascencia,
[arXiv:2112.02103 [hep-ph]].

11 Direct detection of dark energy: The XENON1T excess and future prospects,
S. Vagnozzi, L. Visinelli, P. Brax, A.-C. Davis, J. Sakstein,
Published in Phys. Rev. D 104 (2021) 6, 063023.

12 In the realm of the Hubble tension – a review of solutions,
E. Di Valentino, O. Mena, S. Pan, L. Visinelli, Weiqiang Yang,
Published in Class. Quant. Grav. 38 (2021) 15, 153001.