Dark Photons, Kinetic Mixing and UV Scenarios

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The lack of any clear signal so far for WIMPs or axions has led to an ever-widening set of ideas for what dark matter (DM) can be and how it may be experimentally discovered; these scenarios generally require the existence of new forces [1]. One such possibility which has gotten much recent attention is the kinetic mixing (KM)/vector boson portal [2], which allows for a Standard Model (SM)-singlet thermal relic in the sub-GeV mass range. At low energy scales, the essential physics of this model is adequately described by only four basic parameters: the dark matter and dark photon (DP) masses, m_{DM}, m_{DP}, which are required to have similar values, the dark gauge coupling, g_D, and the strength of the KM, $\epsilon \sim 10^{-(3-4)}$. These parameters are not only constrained by accelerator and direct detection experiments but also by, *e.g.*, the CMB, yet parameter space regions yielding the observed DM relic density are easily found. The relatively simple features of this scenario remain mysterious and raise many questions, *e.g.*, why are the DM and DP masses necessarily so similar, what are the details of the mechanism that generates the small value of ϵ, what prevents sizable mixing of the SM and dark Higgs (which generates the DP mass) that would produce an invisible width for the SM Higgs exceeding experimental bounds and do other new gauge interactions and fields exist as part of the dark sector? These and other related questions can only be addressed by examining the origins of the various components of this simple model within the context of a more complete theory.

There are multiple paths for the construction of more UV-complete and phenomenologically interesting models based this low-energy theory. We have begun model building in two different directions to address the questions above (as well as others) and plan to continue this effort as part of the Snowmass process. Both of the approaches so far considered link the DP model, which is active at the $\sim$ GeV scale, to new physics at the (multi-)TeV scale in the form of new fermions/scalars and gauge bosons with exotic properties which can be probed at the LHC and at other possible future colliders. The associated phenomenology is quite rich at multiple scales but the studies performed so far are only rather preliminary.

As one example, in the simplest realization, ϵ can be generated at the one-loop level by sets of TeV-scale vector-like fermions, generically called portal matter (PM), carrying both SM hypercharge as well as a dark charge [3,4]. Once produced, depending on their SM quantum numbers, the VLF will decay by mixing into a SM quark or lepton plus a long-lived DP or dark Higgs leading to MET or boosted lepton-jets rather than the conventional LHC search final state of a SM quark plus a Higgs or vector boson. The production properties of these new VLF states can also differ substantially from the more familiar models, for instance by the existence of additional t-channel exchanges not present in the VLF models currently searched for at the LHC. Usually associated with these PM fields are a set of new TeV-scale gauge bosons which link the PM to the SM fields and which have production and decay properties atypical of most models of new gauge bosons, *e.g.* large branching fractions into SM fermions plus boosted DPs or MET. More UV-complete realizations of a PM setup, meanwhile, may introduce still more interesting phenomenological consequences; for example, one might imagine potential relationships between these VLFs and SM flavor physics.

The second direction we have begun to explore employs ideas from models of both flat and warped extra dimensions (ED) to address some of the questions above as well as others that are not addressed via

PM alone [5,6,7]. As an example, the experimentally constrained dark-SM Higgs mixing can be suppressed, or removed entirely, via the choice of dark Higgs localization and/or 5-D boundary conditions. 5-D boundary conditions can even remove the need for a dark Higgs from the model entirely. ED can not only lead to new tensor structures for the DP-DM interaction absent in the 4-D analog model, but they also naturally lead to Kaluza-Klein (KK) excitations of (at the very least) the dark sector fields that extend upwards to and beyond the TeV scale. These KK excitations may appear as a series of new fermions and gauge bosons in both fixed target and collider experiments. The physics of these DP KK states in particular can be employed to open new paths for light Dirac fermion DM annihilation consistent with the CMB which are not allowed in 4-D, *e.g.*, via the interference/resonance structure of the amplitude. As in the case of PM, the studies of ED UV-completions are currently in preliminary stages.

Our plan [8] for Snowmass is to extend both of these ideas into new directions, leading to new signatures in both low-energy and collider experiments, and to come up with new possibilities for UV-completions with phenomenological implications not considered in current models and searches.

References

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