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The Physics of the Dark Photon

A Primer

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Preface

New Particles Beyond the Standard Model have always been thought to be charged under at least some of the same gauge interactions of ordinary particles. Although this assumption has driven the theoretical speculations, as well as the experimental searches of the last 50 years, it has also been increasingly challenged by the negative results of all these searches—and the mounting frustration for the failure to discover any of these hypothetical new particles.

As the hope of a breakthrough along these lines is waning, interest in a *dark sector*—dark because not charged under the Standard Model gauge groups—is growing: Maybe no new particles have been seen simply because they do not interact through the Standard Model gauge interactions.

The dark sector can be simple or have a complex structure with many states—some of which can be dark matter candidates.

If the dark and the visible sectors were to interact only gravitationally—which they cannot avoid—there would be little hope of observing in the laboratory particles belonging to the dark sector. A similar problem exists for dark matter: Although its presence is motivated by gravitational physics, it is searched mostly through its putative weak interactions—as in the direct- and indirect-detection searches of a weakly interacting massive particle. For the same reason, we must pin our hopes on assuming that dark and ordinary sectors also interact through a *portal*—as the current terminology has it—that is, through a sallow glimmer, in a manner that, though feeble, is (at least in principle) experimentally accessible.

The portal may take various forms that can be classified by the type and dimension of its operators. The best motivated and most studied cases contain relevant operators taking different forms depending on the spin of the mediator: *Vector* (spin 1), *Neutrino* (spin 1/2), *Higgs* (scalar) and *Axion* (pseudo-scalar).

Among these possible portals, the vector portal is the one where the interaction takes place because of the kinetic mixing between one dark and one visible Abelian gauge boson (nonAbelian gauge bosons do not mix). The visible photon is taken to be the boson of the $U(1)$ gauge group of electromagnetism—or, above the electroweak symmetry-breaking scale, of the hyper-charge—while the *dark photon* comes to be identified as the boson of an extra $U(1)$ symmetry.

The concept of a portal—which at first blush might seem rather harmless—actually represents a radical departure from what is the main conceptual outcome of our study of particle physics, namely, the gauge principle and idea that all interactions must be described by a gauge theory. The portal, and the new interactions that it brings into the picture, adds a significant exception to this principle. Among the possible portals, the vector case deviates the least from the gauge principle as it only introduces a mixing for the gauge bosons while the interaction to matter remains of the gauge type (albeit with an un-quantized charge). Instead, the other kinds of portal imply a manifest new violation to the gauge principle, the other's being the notable case of the Yukawa and self-interactions of the Higgs boson—which are themselves, exactly because of their not being gauge interactions, the least understood part of the Standard Model.

There is an additional and important reason to study the dark sector in general, and the dark photon in particular: The main motivation in introducing new-physics scenarios is to use them as a foil for the Standard Model in mapping possible experimental discrepancies. In the absence of clearly identified new states, the many parameters, for instance, of the supersymmetric extensions to the Standard Model or even of the effective field theory approach to physics beyond the Standard Model, are working against their usefulness. Instead, each dark sector can be reduced to few parameters—to wit, just two in the case of the dark photon—in terms of which the possible discrepancies with respect to the Standard Model are more effectively mapped in the experimental searches and the potential discovery more discernible.

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[1]Website: https://automeris.io/WebPlotDigitizer.

[2]Website: https://gitlab.com/philten/darkcast.

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