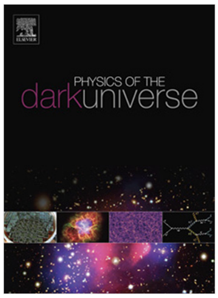
Accepted Manuscript



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PII: S2212-6864(18)30025-6
DOI: https://doi.org/10.1016/j.dark.2018.04.003
Reference: DARK 207

To appear in: *Physics of the Dark Universe*

Received date : 29 January 2017
Accepted date : 6 April 2018

SLAC–PUB–16190, MITP/14-104, SCIPP 15/01

Perturbative Unitarity Constraints on Charged/Colored Portals

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Dark matter that was once in thermal equilibrium with the Standard Model is generally prohibited from obtaining all of its mass from the electroweak or QCD phase transitions. This implies a new scale of physics and mediator particles needed to facilitate dark matter annihilations. In this work, we consider scenarios where thermal dark matter annihilates via scalar mediators that are colored and/or electrically charged. We show how partial wave unitarity places upper bounds on the masses and couplings on both the dark matter and mediators. To do this, we employ effective field theories with dark matter as well as three flavors of sleptons or squarks with minimum flavor violation. For Dirac (Majorana) dark matter that annihilates via mediators charged as left-handed sleptons, we find an upper bound around 45 TeV (7 TeV) for both the mediator and dark matter masses, respectively. These bounds vary as the square root of the number of colors times the number of flavors involved. Therefore the bounds diminish by root two for right handed selectrons. The bounds increase by root three and root six for right and left handed squarks, respectively. Finally, because of the interest in natural models, we also focus on an effective field theory with only stops. We find an upper bound around 32 TeV (5 TeV) for both the Dirac (Majorana) dark matter and stop masses. In comparison to traditional naturalness arguments, the stop bound gives a firmer, alternative expectation on when new physics will appear. Similar to naturalness, all of the bounds quoted above are valid outside of a defined fine-tuned regions where the dark matter can co-annihilate. The bounds in this region of parameter space can exceed the well-known bounds from Griest and Kamionkowski [1]. We briefly describe the impact on planned and existing direct detection experiments and colliders.

I. INTRODUCTION

Understanding the nature of dark matter is one of the most pressing, unresolved problems in particle physics. Dark matter is needed to understand structure formation, the observed galactic rotation curves [2–4] and the acoustic peaks in the cosmic microwave background [5]. Moreover, the dark matter relic abundance is measured to be [5]

$$h^2\,\Omega_c = 0.1199 \pm 0.0027. \tag{1}$$

A compelling argument for the origin of this abundance is to assume dark matter was once in thermal contact with the baryon-photon plasma during the early universe. Since all known forms of matter in the universe were once in thermal equilibrium, this type of dark matter is theoretically persuasive. In this scenario, the measured relic abundance is controlled by dark matter annihilations into Standard Model (SM) particles. Because of constraints from the observed large scale structure in the universe, dark matter must be stable and non-relativistic (cold) when departing thermal equilibrium [3].

The Standard Model (SM) alone cannot account for the missing matter in the universe [6]. Current experimental constraints, however, provide some guidance on the structure of the underlying theory. For example, the lack of large missing energy signatures at the Large Hadron Collider (LHC) [7–17] and other colliders [18–25] suggests that the dark matter is either heavy or has very small couplings with the SM so that it is not produced in high-energy collisions. Additionally, direct detection experiments [26–28], updated precision electroweak constraints, and precision Z-pole experiments [29–31] all severely constrain the direct coupling of dark matter to the SM Higgs and/or Z bosons. These constraints all imply that dark matter cannot obtain all of its mass from the SM Higgs alone [30]. Mediator-facilitated interactions help to evade current experimental constraints by partially decoupling the dark matter from the SM. Should these scenarios be realized in nature, the discovery of the mediator particles would be an important step in understanding the nature of dark matter. It is therefore crucial to place bounds on the masses and couplings of these mediators. The most popular ways for dark matter to annihilate via a mediator particle are through scalars that are colored or charged, the Higgs boson [32], or via a new neutral gauge boson. Some of us explored the perturbative unitarity constraints on the Higgs [33–35] and the gauge portals [36]. In this work we focus on constraining scenarios where fermionic dark matter annihilates via charged or colored scalars.

In supersymmetric (SUSY) models, the charged and colored scalars are sleptons and squarks, respectively. We employ an effective field theory including these particles as a benchmark in our analysis. In addition, because of