The Standard Model is not simple or minimal. Has many different kinds of dynamics. Why not the dark sector?

Question: is dark matter just a single, simple, collisionless particle? Or possibly multiple states, possibly interacting and even forming dark structures? How could we know?

Ockham’s razor???
Gravitational Probes of Particle Physics Properties

Direct detection, indirect detection, and collider production of the particles that make up DM rely on interactions much stronger than gravity. Require relatively strong interactions between dark and ordinary matter. What if DM talks mostly to itself? Detect through alterations in gravitational interaction with ordinary matter?

“SIDM” (Self-interacting dark matter) as example:

Bullet Cluster

halo shapes: Peter, Bullock, Rocha, Kaplinghat, 2012

allow 0.1 barn/GeV: huge interaction
Exploring Novel Models of Interacting Dark Matter

Dark matter constitutes 85% of the matter in the universe, about which we know very little except that it interacts through gravity. The full range of particle physics possibilities for interactions in the dark sector has only recently begun to be explored. Well-known constraints on the interactions of dark matter particles with other dark matter particles arise from halo shapes [1–3] and the Bullet Cluster [4,5]. These constrain the cross section–to–mass ratio $\sigma/m < \sim 1\text{ barn}/\text{GeV}$. By the standards of particle physics, this cross section is very large! It is approximately the same cross section that characterizes scattering of atomic nuclei, for instance. Thus, dark matter could be a strongly interacting particle—for instance, around stat ego faco in finning a gauge theory—with no direct tension with astrophysical observations.

In fact, as the PI and his collaborators observed recently [6, 7], there is even more room than this. The halo shape and Bullet Cluster bounds have traditionally been derived assuming that all of the dark matter has the same cross section for self-interactions. One might motivate this assumption by minimality or by Ockham's razor. On the other hand, given the complexity of the Standard Model of particle physics, with its three separate gauge groups, three families of particles, and large number of different couplings and emergent low-energy phenomena, it is very reasonable to suspect that dark matter is part of a complex, interacting dark sector. The failure to date of searches for the simplest theoretically preferred neutralino dark matter candidates is another reason to consider a more complex dark sector. Such a picture has motivated a great deal of recent activity in particle physics and astrophysics (for some selected examples, see refs. [8–15]). If it turns out that dark matter is more than one kind of particle, it could well be the case that a subdominant fraction of dark matter exhibits cross sections that are much stronger than those allowed by the halo shape or Bullet Cluster constraints. This dark matter could even be distributed in a very different manner than the typical halo dark matter.

**Figure 1: Cooling processes for Double-Disk Dark Matter.** Left: dark bremsstrahlung. Two oppositely charged dark matter particles, $e_d$ and $p_d$, scatter through a dark photon $\gamma_d$ and radiate another dark photon. Right: dark Compton scattering. We have in mind inverse Compton scattering, when a soft dark CMB photon is scattered to higher energies and the dark electron loses kinetic energy.

The PI and collaborators recently proposed “Double-Disk Dark Matter,” or DDDM, as a relatively simple instantiation of the idea that even if most dark matter is cold and can form a dark disk dark accretion disks around astrophysical objects? (Fischler and collaborators) dark acoustic oscillations (Cyr-Racine and collaborators)

**Partially Interacting Dark Matter**

Idea: if only a fraction of all DM has an interaction, constraints can become dramatically weaker. But also potentially get new signals. (J. Fan, A. Katz, MR, L. Randall 2013)

e.g. dissipation of energy through dark U(1) gauge interaction (more generally, DM coupled to dark radiation)

can form a dark disk dark accretion disks around astrophysical objects? (Fischler and collaborators) dark acoustic oscillations (Cyr-Racine and collaborators)
Partially Interacting Dark Matter

Idea: if only a fraction of all DM has an interaction, constraints can become dramatically weaker. But also potentially get new signals. (J. Fan, A. Katz, MR, L. Randall 2013)

e.g. dissipation of energy through dark U(1) gauge interaction (more generally, DM coupled to dark radiation)

can form a dark disk
dark accretion disks around astrophysical objects
dark acoustic oscillations
Partially Interacting Dark Matter

Idea: if only a \textbf{fraction} of all DM has an interaction, constraints can become dramatically weaker. But also potentially get \textbf{new signals}.

(J. Fan, A. Katz, MR, L. Randall 2013)

e.g. \textbf{dissipation of energy} through \textbf{dark U(1) gauge interaction} (more generally, DM coupled to dark radiation)

can form a dark disk
dark accretion disks around astrophysical objects
dark acoustic oscillations
Partially Interacting Dark Matter

“Well-motivated” models built to solve specific problems, like supersymmetry, may turn out to be true but so far are coming up empty in data.

Useful to think about more general possibilities, motivated or not: what can dark matter do? Leave no stone unturned; make sure we don’t overlook signals.

- e.g. stellar kinematics (RAVE, APOGEE, Gaia, …)
- Not just dissipation: we should explore general outcomes of DM effective field theories

If “MOND phenomenology” (Tully-Fisher, etc) isn’t just emergent property of CDM, maybe it’s related to some DM interaction?

New DM interactions more theoretically reasonable than “modified gravity”: let’s explore all the options!