Dark Matter in the Coming Decade:
Complementary Paths to Discovery and Beyond

Snowmass 2013 Cosmic Frontier Working Group 4: Dark Matter Complementarity*

I. INTRODUCTION

Dark matter is six times as prevalent as normal matter in the Universe, but its identity is unknown. Dark matter is a grand challenge for fundamental physics and astronomy. Its mere existence implies that our inventory of the basic building blocks of nature is incomplete, and uncertainty about its properties clouds all attempts to understand how the universe evolved to its present state and how it will evolve in the future. At the same time, the field of dark matter will be transformed in the coming decade. This prospect has drawn many new researchers to the field, which is now characterized by an extraordinary diversity of approaches unified by the common goal of discovering the identity of dark matter.

As we will discuss, a compelling solution to the dark matter problem requires synergistic progress along many lines of inquiry. Our primary conclusion is that the diversity of possible dark matter candidates requires a balanced program based on four pillars: direct detection experiments that look for dark matter interacting in the lab, indirect detection experiments that connect lab signals to dark matter in the galactic halos, collider experiments that elucidate the particle properties of dark matter, and astrophysical probes that determine how dark matter has shaped the evolution of large-scale structures in the Universe.

In this Report we summarize the many dark matter searches currently being pursued in each of these four approaches. The essential features of broad classes of experiments are described, each with their own strengths and weaknesses. The goal of this Report is not to prioritize individual experiments, but rather to highlight the complementarity of the four general approaches that are required to sustain a vital dark matter research program. Complementarity also exists on many other levels,of course; in particular, complementarity *within* each approach is also important, but will be addressed by the Snowmass Cosmic Frontier subgroups that focus on each approach.

In Sec. II we briefly summarize what is known about dark matter and some of the leading particle candidates. In Sec. III, we discuss four broad categories of search strategies and summarize the current status of experiments in each area. We then turn to the complementarity of these approaches in Sec. IV. Conclusions are collected in Sec. V. The Appendix contains tables listing current and planned experiments and some of their key properties.

II. EVIDENCE AND CANDIDATES

Dark matter was first postulated in its modern form in the 1930s to explain the anomalously large velocities of galaxies in the Coma cluster [1]. Evidence for dark matter has grown steadily since then from data from galactic rotation curves [2–4], weak [5] and strong [6] lensing, hot gas in clusters [7], the Bullet Cluster [8], Big Bang nucleosynthesis (BBN) [9], further constraints from large scale structure [10], distant supernovae [11, 12], and the cosmic microwave background (CMB) [13]. Together, these data now provide overwhelming evidence that dark matter is 6 times as prevalent as normal matter and accounts for about 23% of the energy density of the Universe.

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Unfortunately, all of this evidence for dark matter derives from its gravitational pull on visible matter. This does little to shed light on the identity of dark matter, since all particles interact universally through gravity. To make progress, dark matter must be detected through non-gravitational interactions. There are many possibilities.

In the case of weakly-interacting massive particles (WIMPs), dark matter particles are produced in the hot early Universe and then annihilate in pairs. Those that survive to the present are known as "thermal relics." Such particles are generically predicted in models of physics beyond the standard model, including models with supersymmetry or extra spatial dimensions. Remarkably, if these particles interact through the weak interactions of the standard model, the resulting thermal relic density is $\Omega_X \sim \mathcal{O}(0.1)$, just right to be dark matter. This coincidence, the "WIMP miracle," provides strong motivation for dark matter with masses from 10 GeV to 1 TeV and weak interactions with visible particles.

An alternative possibility is asymmetric dark matter. In this case, there is a slight excess of dark particles over dark anti-particles in the early Universe. These annihilate until only the slight excess of dark particles remains. In many models, the dark matter asymmetry is related to the normal matter–anti-matter asymmetry, and one expects the number of dark matter particles to be similar to the number of protons. Since dark matter is 6 times as prevalent as normal matter, this scenario then predicts dark matter particles with mass $\sim 1 - 10$ GeV.

There are several other important dark matter candidates. Axions are strongly motivated by a severe problem of the standard model: the theory of the strong interactions naturally predicts large CP violating effects that have not been observed. Axions would resolve this problem elegantly by suppressing CP violation to experimentally allowed levels. Sterile neutrinos are required to explain neutrino masses, and for certain ranges of masses and interaction strengths, they may be dark matter. Alternatively, dark matter may be in a so-called hidden sector, which has its own set of matter particles and forces, through which the dark matter interacts with other currently unknown particles.

Although these dark matter candidates differ in important ways, in each case, they have non-gravitational interactions through which they may be detected. The non-gravitational interactions may be with any of the known particles or, as noted above for hidden sector dark matter, with other currently unknown particles. These possibilities are shown in Fig. 1, where the particles are grouped into four categories: nuclear matter; leptons; photons and other bosons; and other as-yet unknown particles. Dark matter may interact with one type of particle, or it may interact with several.

A complete research program in dark matter therefore requires a diverse set of experiments that together probe all possible types of couplings. At present, the experiments may be grouped into the following four categories:

- *Direct Detection.* Dark matter scatters off a detector, producing a detectable signal. Prime examples are the detection of WIMPs through scattering off nuclei and the detection of axions through their interaction with photons in a magnetic field.
- *Indirect Detection.* Pairs of dark matter particles annihilate producing high-energy particles (anti-matter, neutrinos, or photons). Alternatively, dark matter may be metastable, and its decay may produce the same high-energy particles.
- *Particle Colliders.* Particle colliders, such as the Large Hadron Collider (LHC) and proposed future lepton colliders, produce dark matter particles, which pass through the detector, but are discovered as an excess of events with missing energy or momentum.
- *Astrophysical Probes.* The particle properties of dark matter are constrained through its impact on astrophysical observables. Examples include reduced central dark matter densities in galaxies and distortions in dark matter halo shapes from dark matter self-interactions.

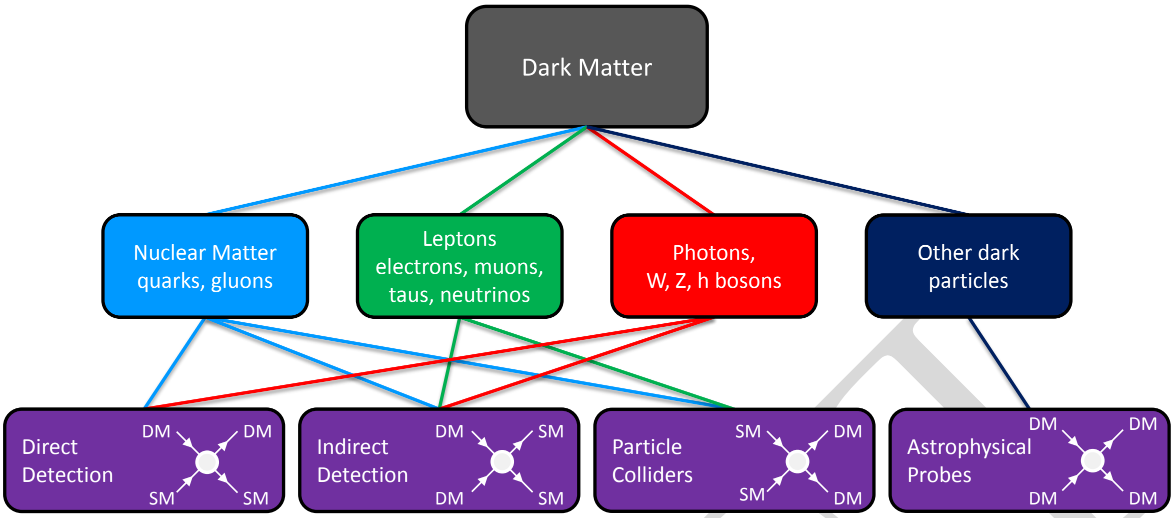

FIG. 1: Dark matter may have non-gravitational interactions with one or more of four categories of particles: nuclear matter, leptons, photons and other bosons, and other dark particles. These interactions may then be probed by four complementary approaches: direct detection, indirect detection, particle colliders, and astrophysical probes. The diagrams give example reactions of dark matter (DM) with standard model particles (SM) for each experimental approach.

These search strategies are shown in Fig. 1 and are connected to the particle interactions they most stringently probe. In the next Section, we briefly describe these four approaches and summarize their current status.

III. THE FOUR PILLARS OF DARK MATTER DETECTION

A. Direct Detection

Dark matter permeates the whole Universe, and its local density on Earth is known to be 10^{-24} g/cm^3 to within a factor of 2. This creates the opportunity to detect dark matter particles *directly* as they pass through and scatter off normal matter. Such events are extremely rare, and so the direct detection approach requires sensitive detectors with exquisite background rejection. The expected signals depend on the nature of the dark matter particles and their interactions. For a list of current and planned experiments, see Table I.

In the case of WIMPs, direct searches are extremely promising. Experimental techniques include detectors that record ionization, scintillation light, and phonons. The most sensitive of the detectors employ multiple techniques, and the interplay of each is used to discriminate against backgrounds. Depending on the target material, experiments can be sensitive to (a combination of) spin-dependent and spin-independent WIMP interactions with matter. The sensitivity of the current generation of detectors for spin-independent cross sections for scattering off protons is approaching $\sigma_{\rm SI}^p \sim 10^{-45}$ cm^2 for WIMP masses of ~ 100 GeV, with orders of magnitude improvement expected in the coming decade. For asymmetric dark matter with masses $\sim$ GeV, the reduced recoil energy is challenging to detect, but there has been significant progress in designing experiments with low threshold energies.

Axions also have strong prospects for direct detection. Cosmological and astrophysical constraints restrict the allowed axion mass range to be between 1 μeV and 1 meV. In a static magnetic field, there is a small probability for cosmologically-produced axions to be converted by virtual photons to real microwave photons by the Primakoff effect. This would produce a monochromatic signal with a line width of $dE/E \sim 10^{-6}$. The ADMX experiment, for example, consists of a high-Q microwave cavity tunable over GHz frequencies to search for this effect. After its present upgrade, ADMX will be sensitive to models with axion mass $\sim \mu$eV, which is the favored mass range if axions are a significant component of dark matter.

B. Indirect Detection

In contrast to direct detection experiments, indirect detection efforts do not aim to detect dark matter particles themselves. Instead, they attempt to detect the standard model particles that are produced in their annihilations or decays. Signals for indirect detection experiments include gamma-rays, neutrinos, and cosmic rays (including positrons, electrons, anti-protons, and anti-deuterons), as well as radio and X-ray emission. Many types of detectors and telescopes have been designed and deployed with these goals in mind, ranging from space- and ground-based gamma-ray telescopes and cosmic ray detectors, to large underground, under-ice, and underwater neutrino telescopes. Current and planned indirect search experiments are listed in Table II.

Motivating the existing and planned indirect detection efforts is the characteristic annihilation cross section of WIMP thermal relics. Although the precise value of this cross section depends on a number of model-dependent features, WIMP candidates that annihilate to the correct relic density to be dark matter typically have cross sections (multiplied by the relative velocity of the annihilating WIMPs) of $\sigma_{\rm th} v \sim 3 \times 10^{-26}$ cm^3/s.

Excitingly, indirect detection experiments have started to reach the level of sensitivity required to discover WIMPs with this annihilation cross section. Current constraints from the Fermi Gamma-Ray Space Telescope's observations of dwarf galaxies and the Galactic Center, in particular, have begun to exclude some thermal WIMP models. Constraints from the cosmic ray anti-proton spectrum as measured by AMS are also starting to constrain such models. Furthermore, results from the Planck experiment are expected to constrain the rate of dark matter annihilations that took place during the era of recombination, on the order of 100,000 years after the Big Bang. The kilometer-scale neutrino telescope IceCube also has the indirect detection of dark matter as a major science goal. In contrast to other indirect searches, neutrino telescopes are most sensitive to WIMPs that annihilate in the core of the Sun. Current constraints from IceCube data have begun to exclude otherwise viable WIMP models.

Indirect searches are not limited to dark matter in the form of WIMPs. Sterile neutrinos, for example, are predicted to decay, leading to potentially observable X-ray spectral lines. Other decaying dark matter particles can also be constrained by indirect detection experiments.

C. Particle Colliders

Dark matter may also be produced in high-energy particle collisions. For example, if dark matter has substantial couplings to nuclear matter, it can be produced through proton-proton collisions at the Large Hadron Collider (LHC). Once produced, dark matter particles will likely pass through detectors without a trace, but their production may be inferred from an imbalance in the visible momentum, just as in the case of neutrinos. Searches for dark matter at the LHC are therefore typified by missing momentum, and can be categorized by the nature of the visible particles that accompany the dark matter production. Because backgrounds are typically smaller for larger values of missing momentum, collider searches tend to be most effective for low-mass dark matter particles, which are more easily produced with high momentum.

There are two primary mechanisms by which the LHC could hope to produce dark matter together with hadronic jets. In the first, two strongly-interacting parent particles of the dark matter theory are produced, and each one subsequently decays into the dark matter and standard model particles, resulting in missing momentum plus two or more jets of hadrons. Since the production relies on the strong force, the rate of production is specified by the color charge, mass, and spin of the parent particles and is typically rather insensitive to the mass of the dark matter itself. Current null results from LHC searches for the supersymmetric partners of quarks exclude such particles with masses less than ~ 1.5 TeV.

A second production mechanism produces the dark matter directly together with additional radiation from the initial quarks or gluons participating in the reaction, resulting in missing momentum recoiling against a single "mono-jet." Since this process does not rely as explicitly on the existence of additional colored particles which decay into dark matter, it is somewhat less sensitive to the details of the specific theory and places bounds directly in the parameter space of the dark matter mass and interaction strength. However, one does need to posit a specific form of the interaction between the dark matter with quarks or gluons. For electroweak-sized couplings and specific choices of the interaction structure, these searches exclude dark matter masses below about 500 GeV.

High energy lepton colliders may produce dark matter through analogous processes, such as production of dark matter along with a photon radiated from the initial leptons. For electroweak-sized couplings of dark matter to electrons, LEP excluded dark matter masses below about 90 GeV. A future high-energy lepton collider could conceivably discover dark matter particles with masses up to roughly half the collision energy, *e.g.*, 500 GeV for a 1 TeV ILC. For a list of current and proposed future colliders, see Table III.

D. Astrophysical Probes

Dark matter particle properties may also be constrained through their effects on astrophysical and cosmological observables. Of particular interest are its effects on structure formation, including the census and internal structure of galactic halos.

The majority of dark matter candidates that are being searched for through direct detection or at colliders are astrophysically categorized as cold and collisionless dark matter (CDM). To make predictions for cosmological structure formation in these models, one does not require any parameter beyond the usual cosmological parameters. On large scales, these predictions are in amazing agreement with cosmological data [14]. However, in the central parts of galaxies and clusters of galaxies, the observed density of dark matter is often lower than predicted by dark-matter-only simulations.

The least massive galaxies that are well-measured are the satellites of the Milky Way, and their central densities are smaller than expected, with evidence for constant density cores in a couple of satellites [15, 16]. High-resolution observations of spiral galaxies close to the Milky Way also show evidence for constant density cores [17–21]. At the high-mass end, recent work has shown that the observed densities are lower than simple CDM predictions even in giant clusters of galaxies [22]. Constant density cores in dark matter halos are in conflict with the simplest CDM predictions, but feedback from supernovae may change those predictions [23]. It is worth keeping in mind that there is a lot of scatter in the properties of the cores and solutions to the above deviations must also explain the diversity. Both dark matter physics and feedback may be required to explain these deviations fully.

On the theory side, many currently viable models have either warm dark matter (WDM) or strongly self-interacting dark matter (SIDM) as opposed to CDM (cold collisionless dark matter).

Phenomenologically, WDM and SIDM distinguish themselves from CDM by changing the number and internal structure of dark matter halos, which are the building blocks of structure formation wherein gas condenses and stars form. The biggest difference in WDM is the dramatically reduced number of low-mass dark matter halos. The mass-scale below which this suppression happens is directly related to the "warmth," which in turn is related to the one or more parameters of the model — for example, mass of a sterile neutrino dark matter [24–27] or mass of the unstable neutralino in supersymmetric models where the gravitino is the lightest supersymmetric particle [28, 29]. In addition, in WDM cosmology the central density of dark matter halos is also reduced, especially for smaller mass halos, but this is comparatively a more subtle effect.

In comparison, the primary effect of SIDM is to reduce the central density of dark matter halos and create constant density cores, while the effect on the census of low-mass halos is much more subtle [30]. The self-interaction cross sections over mass (of the dark matter particle) required to produce observable effects in dark matter halos are in the $0.1 - 1$ cm^2/g range [31–36], with larger cross sections being ruled out by measured dark matter densities, observations of shapes of dark matter halos and the Bullet Cluster [37, 38]. Cross sections significantly below this range are irrelevant for structure formation. Large cross sections of this magnitude are easily produced in hidden sector dark matter models through the exchange of a light gauge boson and this interaction can also endow the dark matter particle with the right relic density through a hidden sector analogue of the WIMP miracle [39–41].

In addition to structure formation, non-gravitational interactions of dark matter could impact a variety of other astrophysical phenomena. For example, axions and light sterile neutrinos (in general light hidden sector particles) may affect the cooling of compact objects (stars, neutron stars, white dwarfs, supernovae), which leads to stringent constraints on their properties. While dark matter physics may have imprinted tell-tale astrophysical signatures (in compact objects or structure formation), it will be hard to unambiguously identify such signatures as non-gravitational interactions of dark matter. The complementarity with direct, indirect or collider searches is an essential part of this endeavor.

IV. COMPLEMENTARITY

A. Basic Features

As evident from the brief descriptions in Sec. III, every experimental approach provides useful information for every dark matter scenario. At the same time, each approach is subject to different systematic uncertainties and no approach will illuminate all aspects of dark matter. In detail, what is learned from each approach is highly scenario-dependent.

At a qualitative level, the complementarity may be illustrated by the following observations that follow from basic features of each approach:

- *Direct Detection* is perhaps the most straightforward detection method, with excellent prospects for improved sensitivity in the coming decade and for discovering WIMPs. The approach requires careful control of low-energy backgrounds, and is relatively insensitive to dark matter that couples to leptons only, or to WIMP-like dark matter with mass ~ 1 GeV or below.
- *Indirect Detection* is sensitive to dark matter interactions with all standard model particles, directly probes the annihilation process suggested by the WIMP miracle, and experimental sensitivities are expected to improve greatly on several fronts in the coming decade. Discovery through indirect detection requires understanding astrophysical backgrounds and the signal strength is subject to uncertainties in halo profiles. Indirect detection signals are suppressed

if dark matter annihilation is insignificant now, for example, as in the case of asymmetric dark matter.

- *Particle Colliders* provide the opportunity to study dark matter in a highly-controlled laboratory environment, may be used to precisely constrain many dark matter particle properties, and are sensitive to the broad range of masses favored for WIMPs. Hadron colliders are relatively insensitive to dark matter that interacts only with leptons, and colliders are unable to distinguish missing momentum signals produced by a particle with lifetime $\sim 10^{-7}$ s from one with lifetime $\gtrsim 10^{17}$ s, as required for dark matter.
- *Astrophysical Probes* are unique probes of the "warmth" of dark matter and hidden dark matter properties, such as its self-interaction strength, and they directly measure the effects of dark matter properties on large-scale structure in the Universe. Astrophysical probes are typically unable to distinguish various forms of CDM from each other or make other precision measurements of the particle properties of dark matter.

B. Model-Independent Examples

The qualitative features outlined above may be illustrated in a simple and fairly model-independent setting by considering dark matter that interacts with standard model particles through four-particle contact interactions, which represent the exchange of very heavy particles.

To do this, we may choose representative couplings of a spin-1/2 dark matter particle χ with quarks q, gluons g, and leptons ℓ given by

$$\frac{1}{M_q^2}\,\bar{\chi}\gamma^\mu\gamma_5\chi\sum_q\bar{q}\gamma_\mu\gamma_5 q+\frac{\alpha_S}{M_g^3}\,\bar{\chi}\chi G^{a\mu\nu}G^a_{\mu\nu}+\frac{1}{M_\ell^2}\,\bar{\chi}\gamma^\mu\chi\sum_\ell\bar{\ell}\gamma_\mu\ell\ . \tag{1}$$

The interactions with quarks mediate spin-dependent direct signals, whereas those with gluons mediate spin-independent direct signals. The coefficients M_q, M_g, and M_ℓ characterize the strength of the interaction with the respective SM particle, and in this representative example should be chosen such that the annihilation cross section into all three channels provides the correct relic density of dark matter. The values of the three interaction strengths together with the mass of the dark matter particle m_χ completely defines this theory and allows one to predict the rate of both spin-dependent and spin-independent direct scattering, the annihilation cross section into quarks, gluons, and leptons, and the production rate of dark matter at colliders.

Each class of dark matter search outlined in Sec. III is sensitive to some range of the interaction strengths for a given dark matter mass. Therefore, they are all implicitly putting a bound on the annihilation cross section into a particular channel. Since the annihilation cross section predicts the dark matter relic density, the reach of any experiment is thus equivalent to a fraction of the observed dark matter density. This connection can be seen in the plots in Fig. 2, where the left (right) vertical axis shows the annihilation cross-section normalized to σ_{th} (the relic density Ω_χ normalized to Ω_{DM}). If the discovery potential for an experiment with respect to one of the interaction types maps on to one times the observed dark matter density (the horizontal dashed lines in Fig. 2), that experiment will be able to discover dark matter which interacts only with that SM particle. If an experiment were to observe an interaction consistent with a DM fraction *larger than one* (yellow-shaded regions in Fig. 2), it would have discovered dark matter but we would infer that there were still important annihilation channels still waiting to be observed. Finally, if an experiment were to observe an interaction consistent with a fraction *less than one* (green-shaded regions in Fig. 2), it would have discovered one species of dark matter, which, however, could not account for all of the dark matter, and there are still important other DM species still waiting to be discovered.

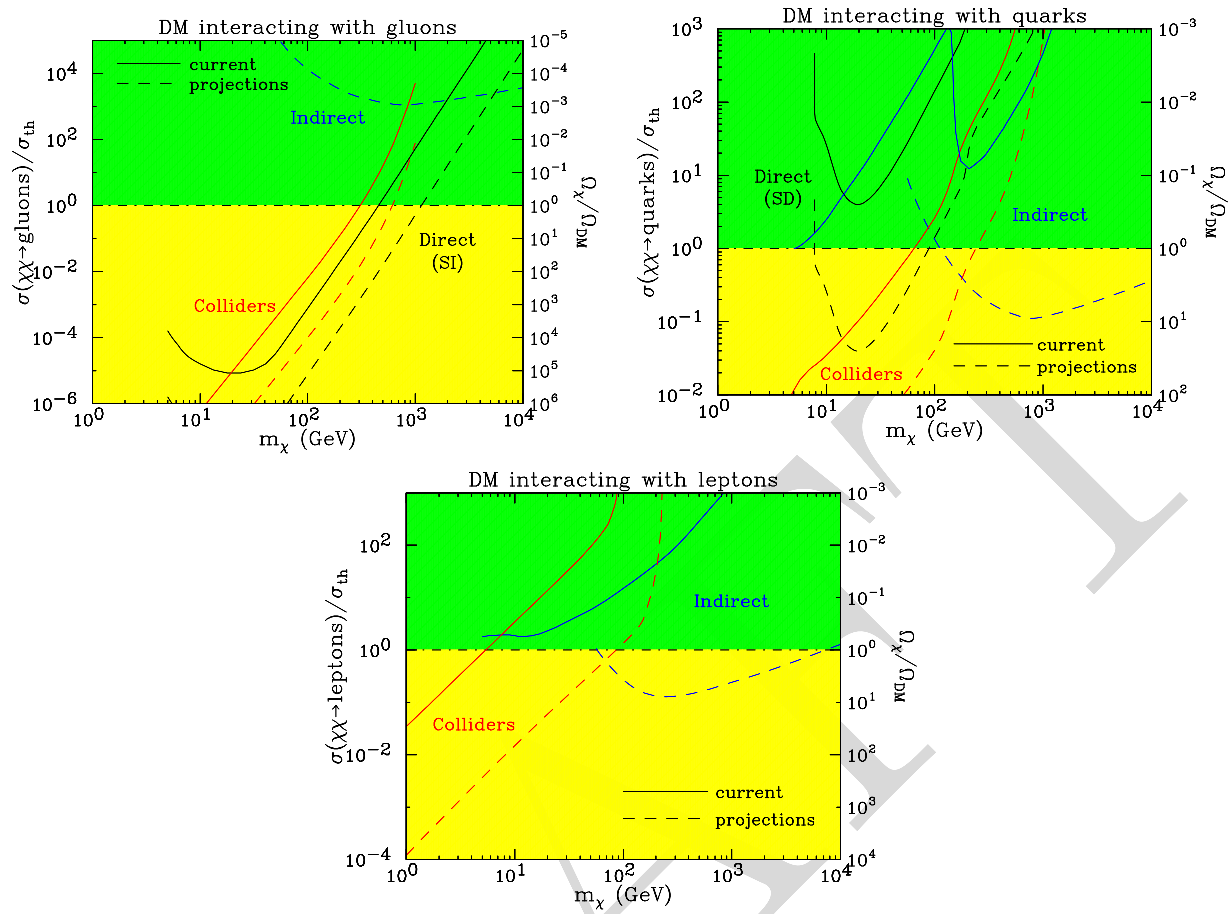

FIG. 2: Dark matter discovery prospects in the $(m_\chi, \sigma/\sigma_{\rm th})$ plane for current and future direct detection, indirect detection, and particle colliders for dark matter coupling to gluons, quarks, and leptons, as indicated.

In Fig. 2, we assemble the discovery potential and current bounds for several near term dark matter searches which are sensitive to interactions with quarks and gluons, or leptons. It is clear that the searches are complementary to each other in terms of being sensitive to interactions with different SM particles. These results also illustrate that within a given interaction type, different search strategies better probe different values of the dark matter mass. For example, direct searches for dark matter are very powerful for masses around 100 GeV, but have difficulty at very low masses, where the dark matter particles carry too little momentum to noticeably affect heavy nuclei. This region of low mass is precisely where collider production of dark matter is easiest, since the strategy relies on the dark matter producing noticeable missing momentum, and colliders are able to fill in this parameter region for interactions with quarks and gluons.

C. Post-Discovery Complementarity

As important as a broad program of complementary searches is to establishing a compelling signal for dark matter, it becomes even more important after a signal has been reported for several reasons.

First, as is well known, many tentative dark matter signals have already been reported. The potential identification of a quarter of the Universe will require extraordinary proof in the form of verification by other experiments.

Second, each search strategy has its limitations. For example, as noted in Sec. IV A, the discovery of a dark matter signal at particle colliders only establishes the production of a particle with lifetime greater than about 100 ns. The assumption that this particle contributes to dark matter requires an extrapolation in lifetime of 24 orders of magnitude! It is only by corroborating a particle collider discovery through another method that one can claim that the collider discovery is relevant for cosmology.

Last, the discovery of dark matter will usher in a rich and decades-long program of dark matter studies. Consider the following scenario: The LHC sees a missing energy signal, and precision measurements find evidence that it is due to a 60 GeV neutralino. This result is confirmed by direct search experiments, which discover a signal consistent with this mass. However, further LHC and ILC studies constrain the neutralino's predicted thermal relic density to be half of Ω_{DM}, implying that it is not a thermal relic, or that it makes up only half of the dark matter. The puzzle is resolved when axion detectors discover a signal, which is consistent with axions making up the rest of the dark matter, and progress in astrophysical theory, simulations, and observations are consistent with dark matter composed entirely of CDM. The combined data establish a new standard cosmology in which dark matter is composed of equal parts neutralinos and axions, and extend our understanding of the early Universe back to neutralino freezeout, just 1 ns after the Big Bang. Direct and indirect detection rates are then used to constrain the local dark matter density, halo profiles, and substructure, establishing the new fields of neutralino and axion astronomy.

This two-component scenario is more complicated than assumed in many dark matter studies, but it is still relatively simple — as is often noted, the visible Universe has many components, and there is no reason that the dark Universe should be any simpler. As simple as this scenario is, however, it illustrates the point that, even for dark matter candidates that we have studied and understand, the information provided by several approaches will be essential to understanding the particle nature of dark matter and its role in astrophysics and cosmology. A balanced program with components in each of the four approaches is required to cover the many well-motivated dark matter possibilities, and their interplay will likely be essential to realize the full potential of upcoming discoveries.

V. CONCLUSIONS

To be written.

APPENDIX: DARK MATTER PROJECTS

TABLE I: Current and planned direct detection experiments.

Status	Experiment	Target	Technique	Location	Major Support	Comments
Current	LUX	350 kg liquid Xe	Ion., Scint.	SURF	DOE, NSF, European	
Planned	LZ	7 ton liquid Xe	Ion., Scint.	SURF	DOE, NSF, European	
Current	Xenon100	62 kg liquid Xe	Ion., Scint.	LNGS	DOE, NSF, European	
Planned	Xenon1T	3 ton liquid Xe	Ion., Scint.	LNGS	DOE, NSF, European	
Planned	PandaX-1	1.2 ton liquid Xe	Ion., Scint.	Jinping	Chinese	
Planned	PandaX-2	3 ton liquid Xe	Ion., Scint.	Jinping	Chinese	
Current	XMASS-I	800 kg liquid Xe	Scint.	Kamioka	Japanese	
Planned	XMASS-1.5	5 ton liquid Xe	Scint.	Kamioka	Japanese	
Current	DarkSide-50	50 kg liquid Ar	Ion., Scint.	LNGS	DOE, NSF, European	
Planned	DarkSide-G2	5 ton liquid Ar	Ion., Scint.	LNGS	DOE, NSF, European	
Current	ArDM	1 ton liquid Ar	Ion., Scint.	Canfranc	European	
Current	MiniCLEAN	500 kg liquid Ar/Ne	Scint.	SNOLab	DOE	
Current	DEAP-3600	3.6 ton liquid Ar	Scint.	SNOLab	Canadian	
Planned	CLEAN	40 ton liquid Ar/Ne	Scint.	SNOLab	DOE	
Current	COUPP-60	CF_3I	Bubbles	SNOLab	DOE, NSF	
Planned	COUPP-1T	CF_3I	Bubbles	SNOLab	DOE, NSF	
Current	PICASSO		Bubbles	SNOLab	Canadian	
Current	SIMPLE		Bubbles	Canfranc	European	
Current	SuperCDMS	10 kg Ge	Ion., Phonons	Soudan	DOE, NSF	
Planned	SuperCDMS	100 kg Ge	Ion., Phonons	Soudan	DOE, NSF	
Current	Edelweiss	4 kg Ge	Ion., Phonons	Modane	European	
Current	CRESST	10 kg $CaWO_4$	Scint., Phonons	LNGS	European	
Planned	EURECA	Ge, $CaWO_4$				
Current	CoGeNT	Ge	Ion.	Soudan	DOE	
Current	TEXONO	Ge	Ion.		Chinese	
Current	DAMA/LIBRA	NaI			European	
Current	ELEGANT	NaI			Japanese	
Planned	DM-Ice	NaI				
Planned	CINDMS	NaI			Chinese	
Current	KIMS	CsI				
Current	DRIFT		Ion.			
Current	DMTPC	CF_4 gas	Ion.	WIPP		
Planned	NEXT	Xe gas	Ion., Scint.	Canfranc		
Planned	MIMAC		Ion.	Modane		
Planned	Superfluid He-4					
Planned	DNA	DNA				
TO BE CONTINUED						

TABLE II: Current and planned indirect detection experiments.

Status	Experiment	Target	Location	Major Support	Comments
Current	AMS	e^+/e^-, anti-nuclei	ISS	NASA	Magnet Spectrometer, Running
	Fermi	Photons, e^+/e^-	Satellite	NASA, DOE	Pair Telescope and Calorimeter, Running
	HESS	Photons, e^-	Namibia	German BMBF, Max Planck Society, French Ministry for Research, CNRS-IN2P3, UK PPARC, South Africa	Atmospheric Cherenkov Telescope (ACT), Running
	IceCube/ DeepCore	Neutrinos	Antarctica	NSF, DOE, International *Belgium, Germany, Japan, Sweden)	Ice Cherenkov, Running
	MAGIC	Photons, e^+/e^-	La Palma	German BMBF and MPG, INFN, WSwiss SNF, Spanish MICINN, CPAN, Bulgarian NSF, Academy of Finland, DFG, Polish MNiSzW	ACT, Running
	PAMELA	e^+/e^-	Satellite		
	VERITAS	Photons, e^+/e^-	Arizona, USA	DOE, NSF, SAO	ACT, Running
	ANTARES	Neutrinos	Mediterranean	France, Italy, Germany, Netherlands, Spain, Russia, and Morocco	Running
Planned	CALET	e^+/e^-	ISS	Japan JAXA, Italy ASI, NASA	Calorimeter
	CTA	Photons	ground-based (TBD)	International (MinCyT, CNEA, CONICET, CNRS-INSU, CNRS-IN2P3, Irfu-CEA, ANR, MPI, BMBF, DESY, Helmholtz Association, MIUR, NOVA, NWO, Poland, MICINN, CDTI, CPAN, Swedish Research Council, Royal Swedish Academy of Sciences, SNSF, Durham UK, NSF, DOE	ACT
	GAMMA-400	Photons	Satellite	Russian Space Agency, Russian Academy of Sciences, INFN	Pair Telescope
	GAPS	Anti-deuterons	Balloon (LDB)	NASA, JAXA	TOF, X-ray and Pion detection
	HAWC	Photons, e^+/e^-	Sierra Negra	NSF/DOE	Water Cherenkov, Air Shower Surface Array
	IceCube/ PINGU	Neutrinos	Antarctica	NSF, Germany, Sweden, Belgium	Ice Cherenkov
	KM3NeT	Neutrinos	Mediterranean	ESFRI, including France, Italy, Greece, Netherlands, Germany, Ireland, Romania, Spain, UK, Cyprus	Water Cherenkov
	ORCA	Neutrinos	Mediterranean	ESFRI, including France, Italy, Greece, Netherlands, Germany, Ireland, Romania, Spain, UK, Cyprus	Water Cherenkov
TO BE CONTINUED					

TABLE III: Current and proposed particle colliders.

Status	Collider	Type	E_{COM}, Luminosity	Major Support	Comments
Current	LHC	pp	8 TeV, 20 fb^{-1}	DOE, NSF	
Upcoming	LHC	pp	14 TeV, 300 fb^{-1}	DOE, NSF	
Proposed	HL LHC	pp	14 TeV, 3000 fb^{-1}		
Proposed	VLHC	pp	33-100 TeV		
Proposed	Higgs Factory	e^+e^-	250 GeV		
Proposed	ILC, CLIC	e^+e^-	0.5-3 TeV		
Proposed	Muon Collider	$\mu^+\mu^-$	6 TeV		
TO BE CONTINUED					

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