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Recent developments in dark matter searches

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Abstract. A brief review is first given of the forms of dark matter that are hypothesized, and a summary of the basic observational evidence for dark matter is provided. Then a summary of recent results from indirect and direct detection dark matter search experiments is given. Some discussion is also done of MOND theories along with recent analysis of galaxy surface density data that provides some support for such theories.

Keywords. Dark matter; detection; observation; modified neutron dynamics.

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1. Introduction

Astronomical observation, especially driven by cosmic microwave background (CMB) and large scale structure (LSS) data, indicates that the matter content of the Universe cannot be completely comprised of visible baryonic matter. In fact, what is suggested by the data is that the visible baryonic matter can only be a small fraction of the total matter content, $\sim$4% only, with the remainder comprised of dark energy at $\sim$74% and dark matter at $\sim$22%, as summarized in figure 1. Dark energy is a hypothetical substance that permeates all space and increases the rate of expansion with the most common example of dark energy being a cosmological constant. Dark matter is a substance that does not emit or scatter electromagnetic radiation, and until now its existence has only been inferred through its gravitational effects. The idea of dark matter was first asserted by Zwicky in 1934 to explain the orbital velocities of galaxy clusters. For several decades the only evidence to suggest dark matter was the rotation curve data of galaxies [1,2] and galaxy clusters. More recently, evidence for dark matter has been reinforced from CMB [3] and LSS data as well as from gravitational lensing [4].

There is no clear idea as to what the dark matter substance is, with several theories having been developed. Much effort has been put into detecting dark matter, rather than inferring it simply from observational data. The past few years have seen a vast amount of activity in ground and space-based detectors in search for evidence of dark matter. In this review, I shall first discuss some background details about the hypothesized forms of dark matter and about the various experimental means by which dark matter detection is attempted.

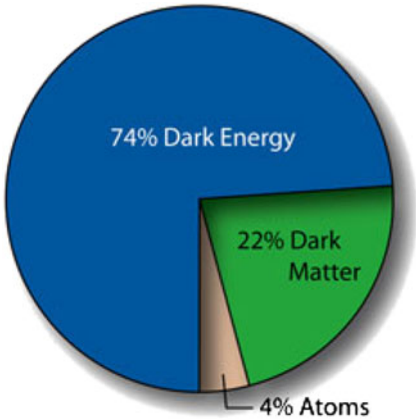

Figure 1. Cosmic budget.

The main observational evidence for dark matter will also be reviewed. After that, I shall review the various detector experiments that have been going on in the past couple of years and report the current status of results from these experiments.

Measurement of dark matter can be divided into direct and indirect detection, astronomical observation and collider data. Direct detection experiments are those in which the dark matter particle is supposed to collide with some other detectable particle, usually a semi-heavy element. These experiments are typically done deep underground to eliminate background. Moreover, these experiments are sensitive to heavy dark matter particles, which can create a noticeable impact on the atoms. Indirect detection experiments look for secondary particles, such as positrons, antiprotons, antideuterons, γ-rays and neutrinos, which could originate from annihilation of dark matter particles in the Universe. Astronomical observation typically looks for some sort of deviation in the motion of an astronomical object, which cannot be explained by the standard expectations based on a Universe containing only visible matter. For example, deviations in the rotation of galaxies or galaxy clusters is one of the oldest observational means for looking for dark matter. Finally, collider data are focussed on producing and detecting an actual dark matter particle in a particle collider.

Dark matter is classified in various ways. In terms of its thermodynamic properties, it can be either hot dark matter, where the dark matter particles are relativistic at the time of structure formation, cold dark matter (CDM), where the particles are nonrelativistic at the time of structure formation, or the intermediate case of warm dark matter. Also dark matter can be classified in terms of its interaction properties, with baryonic dark matter, which is composed of protons and neutrons but is nonemitting, or nonbaryonic dark matter, which is composed of matter that interacts very weakly with ordinary matter and is detectable only (at least so far) through its gravitational interactions. Of this list, cold dark matter has been the most successful in agreeing with the known observational data. Hot dark matter could not explain galaxy formation. In general, to explain small-scale structure in the Universe, cold or warm dark matter is needed.

Amongst baryonic dark matter, there are massive compact halo objects (MACHOs), which are composed of ordinary baryonic matter that is condensed, such as black holes, neutron stars, white dwarfs, and planets. Microlensing observations suggest that as much as 20% of the dark matter in the Milky Way could be MACHOs. All evidences suggest that baryonic dark matter cannot fully account for all the dark matter needed, and so some sort of non-baryonic dark matter is needed. Amongst cold dark matter, there are various types. The most promising is the weakly interacting massive particle (WIMP), which is a heavy, as yet unknown, particle, that has weak interaction strength with ordinary matter. There is also the extremely weakly interacting particle (EWIP), which interacts below the level of weak interactions. Such particles can be very light but still be CDM since their interaction was so extremely weak that they could not thermalize in the early Universe.

The ultimate goal is to identify particular particles which constitute the dark matter. One of the earliest such candidate, and the only particle on this list that is known to exist, has been the neutrino. The total relic density of a light neutrino is [5]

$$\Omega_{\nu_i} h^2 \approx \frac{m_{\nu_i}}{93\,\mathrm{eV}}. \tag{1}$$

Thus for $h \approx 1$, to have $\sum_i \Omega_{\nu_i} \sim 0.25$ requires $\sum_i m_{\nu_i} \approx 23$ eV. An upper bound on the light neutrino mass comes from β-decay experiments, which limit $m_\nu \lesssim 1$ eV [6], and neutrino oscillation experiments, which indicate that the mass difference between the three known neutrinos is of order 1 eV [7]. Combining this information would limit $\Omega_\nu < 0.1$. Neutrinos would also be hot dark matter, since they would be relativistic at the onset of galaxy formation. The CMB and large scale structure constraints give then an even more stringent constraint of $\Omega_\nu h^2 \lesssim 0.0067$. Thus although a small fraction of the dark matter can be, and is, neutrinos, there would also have to be something else.

Historically, one of the earliest candidates for dark matter has been the axion. This is a pseudo-Nambu–Goldstone boson arising from the spontaneous breaking of the $U(1)$ symmetry of Pecci-Quinn, introduced to solve the strong CP problem. The axion is typically very light ($\lesssim$0.01 eV). However, since it couples so weakly to other matter, it never thermalizes in the early Universe, and so it behaves as cold dark matter. Theoretically, a vast mass range can exist for the axion spanning from the μeV to the keV. Data from observation, both cosmological and astrophysical, combined with laboratory data have been able to limit this range by now to a window around the meV range [8], and so the possibility of the axion particle is becoming limited.

Perhaps the most intriguing candidate at present, and the best known example of a WIMP, is the neutralino, which is a spin-$\frac{1}{2}$ weak interaction supersymmetric particle. In appealing SUSY-breaking schemes, the neutralino appears as the lightest supersymmetric particle (LSP), which implies that it is stable, and so a good dark matter candidate. The lowest mass of the neutralino would be around the SUSY breaking scale, which from the known collider data limits it to being bigger than $\sim$100 GeV. This mass range places the neutralino as an ideal WIMP candidate, and direct detection experiments could find such a particle should it be present in sufficient abundance. Moreover, supersymmetry searches are also going on at colliders with expectations being that the Large Hadron Collider (LHC) should be able to either detect or rule out supersymmetry if it breaks around the electroweak scale. A discovery of SUSY at the LHC would certainly be exciting and fuel greater speculation about the role of the SUSY LSP as a dark matter particle.

Another possibility from SUSY is the gravitino, which is the spin-$\frac{3}{2}$ superpartner to the spin-1 graviton. The mass for this particle could range from the eV to the TeV scale, depending on the SUSY breaking scenario. This particle would have extremely weak coupling, which means it is inaccessible to direct and indirect searches, and direct production at colliders would be highly suppressed for masses $\gtrsim$0.1 keV, due to its extremely weak coupling. As such, dark matter in the form of gravitinos would be very difficult to confirm.

The WIMPs are the dark matter particles that perhaps are the most interesting. This arises in great part because many beyond the Standard Model theories predict new physics at the electroweak scale. This includes theories of supersymmetry and universal extra dimensions. In such theories often weakly-interacting particles of mass $\sim$100 GeV are found. This includes the neutralino mentioned above. Another example of WIMPs can be found in theories with universal extra dimensions, which then contain Kaluza–Klein (KK) states. In theories with extra-dimensional extensions of the Standard Model, the lightest KK particle (LKP) has proven to be an interesting dark matter WIMP candidate [8]. One typical feature of this model is that this model has a tower of states with masses $m^{(n)} = \sqrt{(n/R)^2 + m_{\rm EW}^2}$, where $m_{\rm EW}$ is the zero mode mass. The LKP turns out to be a good WIMP candidate. An interesting feature of KK dark matter is that it is spin-1. This implies new and different annihilation modes compared to neutralinos, such as $\nu\bar{\nu}$ and e^+e^-, which are usually very suppressed for neutralino annihilation. Recent results from indirect decay experiments have prompted more interest in KK dark matter as an important source for positrons.

The relic abundance of WIMPs can be estimated [9] and provides useful insight into their expected presence as dark matter and thus how likely they can be measured. The annihilation rate for WIMPs is

$$\Gamma(\chi\chi \to l\bar{l}, q\bar{q}, \ldots) = n_\chi \langle \sigma v \rangle, \tag{2}$$

where σ is the cross-section for annihilation of two WIMPs into all lighter Standard Model particles, v is the relative velocity, and the angular brackets imply thermal average. At early times when the Universe was very hot, $T \gg m_\chi$, so $n_\chi \sim T^3$ and $\Gamma \gg H$, where H is the Hubble parameter of the Universe. During this period, there is considerable scattering and this maintains thermal equilibrium of the WIMP particles with all other particles. Then at later times when $T \ll m_\chi$, so $n_\chi \sim T^{3/2} \exp(-m_\chi/T)$ so that $\Gamma \ll H$, there can be no annihilations and so the WIMP abundance freezes out. In particular, freeze-out occurs when $\Gamma(T_f) \sim H(T_f)$. For nonrelativistic particles $n_\chi \sim (m_\chi T/2\pi)^{3/2} \exp(-m_\chi/T_f)$ and equating the decay width to the Hubble scale leads to $\langle \sigma v \rangle (m_\chi T_f^{3/2} \exp(-m_\chi/T) \sim T_f^2/m_{\rm PL}$. Using characteristic electroweak scale parameters, $\sigma \sim 10^{-8}$ GeV and $m_\chi \sim 100$ GeV, in the region around $T_f \sim m_\chi$ one finds $T_f/m_\chi \sim 1/25$. This leads to a freeze-out abundance $n_\chi/n_\gamma \sim 25/(m_{\rm pl} m_\chi \langle \sigma v \rangle)$, which then gives the estimate

$$\Omega_\chi h^2 \sim 0.1, \tag{3}$$

which is approximately the observed dark matter density. Since many fundamental theories extending the Standard Model predict WIMP candidates, and from this estimate it also appears WIMPs produce the required density of dark matter, this coincidence has sometimes been referred to as the 'WIMP miracle'.

2. Observation

All evidence so far found for dark matter has come from astronomical observation. Historically, the first evidence of dark matter made by Zwicky came from studying the orbital velocity data from galaxy clusters, and recognizing that to explain this motion required some missing mass is required. Even today, rotation curves of galaxies and galaxy clusters remain one of the key pieces of evidence suggesting dark matter. For a galaxy, the rotation velocity of matter moving around it at a distance r from the centre should obey the Keplerian relation

$$v_c^2(r) = \frac{GM(r)}{r}, \tag{4}$$

where $M(r)$ is the galaxy mass contained within the radius r. A galaxy is typically described in terms of a central region, where much of the visible matter is and a surrounding spherical halo, with a diameter usually a few times bigger than the central region. The halo comprises globular clusters, which are tightly bound collection of stars, and lies close to the edges of the galactic central region. In addition, it is hypothesized that a much bigger dark matter halo exists, which extends 3–4 times the diameter of the galactic central region and dominates the total mass of the galaxy. For a typical spiral galaxy, such as our Milky Way, visible matter extends out to about $\sim$10 kpc. If no other mass were present, $M(r)$ would be a constant beyond some distance, then one would expect

$$v_c^2 \sim 1/r \tag{5}$$

beyond that point. Instead, what is typically found from observational data from many galaxies that have been studied is that v_c flattens at large distances [1,2]. This flattening could be very conveniently explained if there were a dark matter halo with $M(r)$ rather than being constant at large r, instead it grew linearly. This is therefore an indirect suggestion, and one of the most compelling, of missing matter.

In the past few decades, other observational data have also pointed at dark matter. Gravitational lensing of galaxy clusters has shown distortions, whose explanations require more matter than what is visible [4]. A very striking evidence came a few years ago in the observation of the collision of two galaxy clusters [10]. A gravitational lensing map created of this Bullet cluster showed that the gravitational potential did not trace the plasma distribution, which is the dominant baryonic mass component, but rather approximately traced the distribution of galaxies. The suggestion is that the galaxies contain more mass than just that is visible. Evidence for dark matter from another direction comes from recent high precision measurements of the cosmic microwave background (CMB) radiation. The most recent results from the seven year WMAP data indicate that the best fit to the data gives a dark matter content around 22% [3].

There are problems with the dark matter paradigm, not the least being that so far no direct detection of a dark matter particle has been made, despite extensive efforts. Moreover, the rotation curves of giant elliptical galaxies do not show the flattening of v_c at large distances, thus they require no dark halo [11]. Also the halo model used to fit data into a galaxy profile has three free parameters, velocity dispersion of dark matter particles, inner cut-off radius and mass-to-luminosity ratio, but the model needs to be tuned and even then can have difficulty in producing an observed dip in the data [12].

An alternative to the picture of dark matter being particles has been that the anomalies in observation arise due to a modified Newtonian dynamics (MOND) [13]. In this theory, modifications of Newtonian dynamics is governed by the acceleration scale of the object. In particular, once the acceleration of a particle is less than the characteristic scale a_0, the standard Newtonian gravitational field gets modified. The fitting of MOND dynamics to galaxy rotation curves finds the value of the characteristic low acceleration scale to be $a_0 = 1.2 \times 10^8$ cm s^{-2} [13], which is below measurable scales in the laboratory. This picture can explain the rotation curves of spiral galaxies. In addition, for elliptical galaxies the MOND explanation is that they have much greater accelerations outside the core, and so there is only minimal modification to the standard Newtonian gravitational force. The original MOND theory, for nonrelativistic dynamics, has been extended to a relativistic version RAQUAL [14] and more recently a General Relativistic version called tensor-vector-scalar (TeVeS) [15]. TeVeS has been shown to explain galaxy curves, galaxy distributions and CMB data [16].

Recent analysis of the surface density of a wide range of galaxies has made the picture of a particle explanation to dark matter less clear. What was found in [17] was the surface density Σ, which is defined as

$$\Sigma \equiv \int_0^\infty \rho(r)\mathrm{d}r, \tag{6}$$

where $\rho(r)$, the matter density of the galaxy, is nearly constant at $\log[\Sigma/(M_\odot \mathrm{pc}^{-2})] = 2.15 \pm 0.2$, independent of galaxy type. A further study [18] showed that the surface density of just the luminous matter up to the core radius, defined as the distance where the local dark matter density reaches a quarter of its central value, is also constant at $\Sigma/(M_\odot \mathrm{pc}^{-2}) = 72^{+42}_{-52}$. The implication of this would be that central baryonic surface density is correlated with core radius, or alternatively stated, there is a close correlation between the enclosed surface densities of luminous and dark matter in galaxies. Since these results suggest that a single scale governs the dynamics of all galaxies, it is hard to reconcile these results with the picture of dark matter as particles. However, from the perspective of MOND-type theories, there already is a scale, the low acceleration scale a_0. In [19] it was shown that this value of a_0 leads to $\log[\Sigma_{\mathrm{MOND}}/(M_\odot \mathrm{pc}^{-2})] = 2.14$, which is close to the results in [17].

Thus, while the search for dark matter particles continues in earnest, it is by no means a forgone conclusion that is the unequivocal answer to the unexplained observational data. The next sections will discuss recent results from indirect and direct detection searches of dark matter.

3. Indirect detection

Indirect detection of dark matter measures the flux of secondary particles, comprising electrons, positrons, protons, antiprotons, photons and neutrinos, which emerge from the annihilation of dark matter from some distant location in the galaxy. This detection is often done in space or high up in the atmosphere, which thus removes or minimizes atmospheric sources of these secondary particles.

Recently, several indirect detection experiments have been underway and reporting. The payload for antimatter exploration and light-nulcei astrophysics (PAMELA) [20,21] is a space-based satellite-borne experiment that detects electrons, positrons, protons and antiprotons in an energy range less than around $\sim$100 GeV. The advanced thin ionization calorimeter (ATIC) [22] is a balloon-based experiment that measures the $e^+ + e^-$ differential energy spectrum. The high-energy steroscopic system (HESS) [23] is a Cherenkov ground-based telescope which measures the $e^+ + e^-$ differential energy spectrum. Finally the Fermi large area telescope (LAT) [24] is a satellite-borne experiment that measures γ-rays in the energy range 20 MeV–300 GeV.

Some excitement was created by the PAMELA experiment results (figure 2), which for the positrons showed an excess above that expected from the background model, for energies greater than 10 GeV. However at the same time, the antiproton-to-proton flux ratio in figure 3 was consistent with what the background model expects. The ATIC experiment also found an excess of electrons above that expected from the background model, in the energy range 300–800 GeV, as shown in figure 4. One interpretation of this excess would be WIMP annihilation [25]. However, other interpretations have also been put forward. Two alternative explanations are that the excess is being caused by γ-ray astrophysical sources, such as the powerful Geminga pulsar [26], or a supernova explosion of a massive star [27]. The Fermi LAT measurements will provide important information about the distribution of γ-ray sources in the galaxy, which should improve the knowledge of the background astrophysical model, and establish whether γ-ray sources such as Geminga could explain the positron and electron excesses.

The explanation of these excesses due to WIMP dark matter is not straightforward. Using the expected local average dark matter number density, the standard annihilation rate for thermally produced halo WIMPs, $\langle \sigma v \rangle = 3 \times 10^{-26}$ cm^3 s^{-1}, is too small to explain the

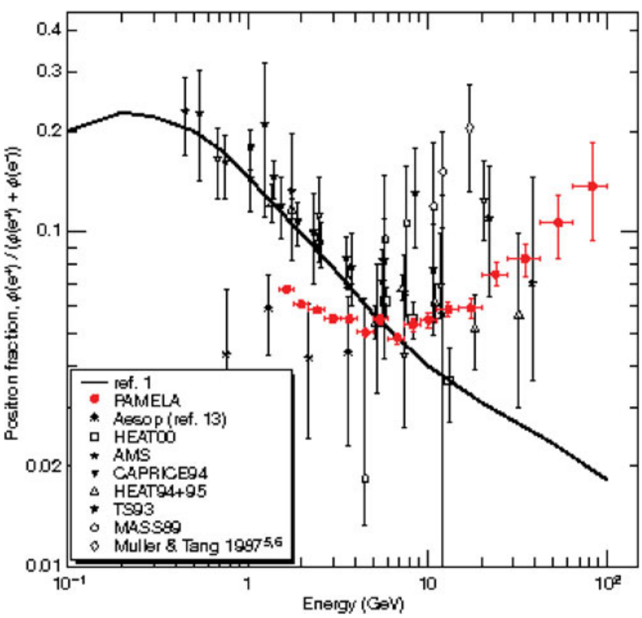

Figure 2. PAMELA positron fraction and comparison with other experiments and secondary model (figure from [20]).

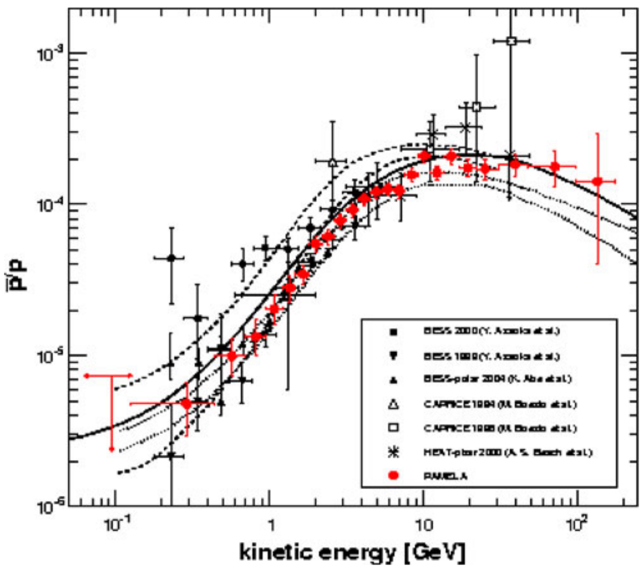

Figure 3. PAMELA antiproton-to-proton flux ratio and comparison with other experiments (figure from [21]).

measured results. This is usually quantified in terms of a boost factor $B_{\rm tot}$, which is the factor increase of the differential flux needed from the the predicted value to agree with the observed value, and is found to be $B_{\rm tot} \sim 200$. To explain this boost factor, it has been argued that the annihilating WIMP particles are interacting prior to annihilation and that

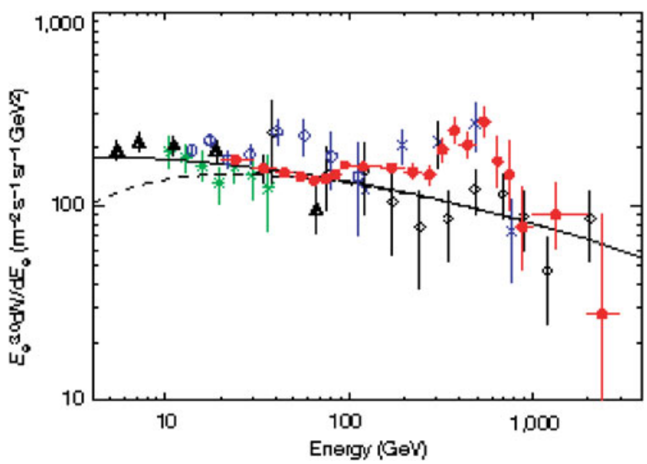

Figure 4. ATIC electron differential energy spectrum at the top of the atmosphere (red filled circles) and comparison with previous measurements including AMS (green stars), HEAT (open black triangles), BETS (open blue circles) and PPB-BETS (blue crosses) (figure from [22]).

these interactions increase the annihilation cross-section through the Sommerfeld enhancement effect. In [28] the annihilation cross-section with Sommerfeld enhancement of two neutralinos, which are ideal WIMP candidates, was calculated, in which W and Z gauge bosons were considered as the exchange particles that create the Sommerfeld enhancement. They found $B_{\rm tot} \sim 30$ for dark matter masses less than 10 TeV, which would not be enough. However, the Sommerfeld enhancement mechanism also predicts a series of resonances where the boost factor is much bigger. For the vector boson masses around their Standard Model values, ~90 GeV, they found the resonance to occur at a dark matter mass around ~4.5 TeV. The Sommerfeld enhancement effect has been examined for a variety of cases including Goldstone pseudoscalar exchange, excited states and unparticle exchange. Although it can help boost the annihilation rate, in generic cases it does not appear to be sufficient. As such, should dark matter be the explanation to the positron and electron excesses found in the PAMELA and ATIC experiments, other reasons would be needed, such as a larger local dark matter density in some nearby regions around our own in the galaxy, and possibly some combination of dark matter origin and astrophysical background might need to be considered.

4. Direct detections

Direct detection methods look for interaction of dark matter particles by detectors based on Earth. These detectors are typically placed deep underground, since dark matter is expected to interact only with weak coupling to matter, thus easily penetrate through the ground, whereas other cosmic ray particles with the exception of neutrinos, will be stopped. Thus a detector deep underground can limit all background greatly. The detectors are typically filled with target nuclei of some element such as germanium, xenon, silicon, or iodine. These detectors are sensitive in observing weakly interacting particles that recoil off the nuclei. Thus the dark matter particles must be heavy enough to affect the nuclei. As such, direct detection is typically in search of WIMP dark matter. The dark matter particle, χ, is expected to interact with the quarks in the nuclei. Some simple estimates can give the expected interaction rate [9]. If one assumes that WIMPs make up our Galaxy's halo, then the local spatial density would be $n_\chi \sim 0.004(M_\chi/100\ \text{GeV})^{-1}\,\text{cm}^{-3}$, which is roughly one per litre and would be moving with velocity $v \sim 200$ km/s. A typical WIMP cross-section for elastic scattering off quarks for, say, the neutralino is $\sigma \sim 10^{-41--36}\text{cm}^2$. The interaction rate is then $R \sim n_\chi \sigma v \sim (0.004\ \text{cm}^{-3})(10^{-36}\ \text{cm}^2)(2 \times 10^7\ \text{cm/s}) \sim 10^{-24}\ \text{yr}^{-1}$. If there are $10^{23} M/(Ag)$ nuclei in the detector, then say for $A \sim 100$, one expects

$$R \sim 1/\text{kg/yr} \tag{7}$$

events, approximately one event per year per kilogram of the detector material. This number suggests a very low interaction rate, and thus typical direct detection experiments run for a period of several months.

There are two types of interactions of the WIMP particles to the nuclei, axial and scalar. These are often referred to as the spin-dependent and spin-independent interactions, respectively. Experimental results are often expressed in terms of an exclusion plot, such as the one shown in figure 5 (taken from [29]), which accounts for recent experimental results.

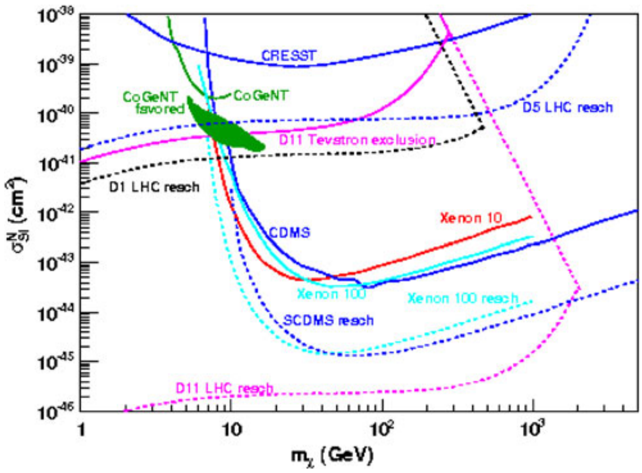

Figure 5. Recent experimental limits on spin-independent WIMP direct detection (figure from [29]).

These plots are usually less constraining both at low WIMP mass, due to the low recoil energy, and at high WIMP mass, because the number density decreases as $n_\chi \sim 1/M_\chi^{-1}$. As such, the tightest constraints in these plots are typically in the middle WIMP mass range, as is the case in figure 5.

There are many types of direct search detectors, with the active detector types ranging from scintillator, semiconductors and noble liquids. Dark matter WIMP particles entering the detector on occasion will elastic scatter with the nuclei of the detector, causing it to recoil, with the recoil energy measured. Despite the detectors being underground, there is still the possibility of background particles being present and interact with the detector. As such, most direct detection experiments do a second independent measurement of the energy deposited by the recoil nucleon, such as total energy and specific ionization. This allows rejection of background. Several experiments follow these basic procedures such as the cryogenic dark matter search (CDMS) II [30] and Zeplin-III [31] amongst many others. A different approach is not to have a procedure for background elimination, but rather infer the presence of dark matter from annual modulation. As the Earth orbits the Sun, it changes its direction in the dark matter halo thus altering the dark matter flux into the detector. This should then lead to an annual modulation in the detected recoils. Only one dedicated experiment takes this approach, DAMA, and that have reported an annual modulation [32].

One of the most recent results was reported at the end of 2009 from CDMS II, and it caused some excitement. This experiment uses an array of 30 particle detectors made of semiconductor, which operate at cryogenic temperatures and positioned in the Soudan Underground Laboratory, Minnesota (USA) at a depth of around 700 m below the ground. CDMS II had a total exposure for dark matter detection of 612 kg-days. The excitement was caused by the report of two events in the signal region, the first time direct detection experiments based on background elimination techniques have have had such success. They estimated a 23% probability of observing two or more background events in this region.

These findings set an upper limit on the WIMP-nucleon elastic scatting spin-independent cross-section of 7×10^{-44} cm^2 for a WIMP mass of 70 GeV, or when combining with the previous results of CDMS II it gives the upper limit of 3.8×10^{-44} cm^2. The exclusion plot (figure 5), contains these recent results of CDMS II. This figure also contains another recent direct detection experiment, Xenon100 [33], which is a liquid xenon detector. This experiment found that the WIMP-nucleon spin-independent scattering cross-section must be above 3.4×10^{-44} cm^2 for 55 GeV WIMPs at 90% CL. Figure 5 also shows future estimates from SuperCDMS (SCDMS) [34] and Xenon100. In addition, this figure shows the current Tevatron exclusion limits and projected estimates for LHC, both of which provide much greater constraint at the low end of the WIMP mass scale.

More recently, Zeplin-III has also started reporting results. Zeplin-III is a liquid/gas xenon detector located at the Palmer Laboratory at Boubly Mine, UK at a depth of 2850 m beneath the surface. Zeplin-III was exposed to dark matter detection for 63 kg–days. It found that for cross-sections consistent with the DAMA modulation signal, there remained a 90% CL allowed region for WIMP masses in the range 45–60 GeV, which is more stringent than limits from previous xenon and germanium experiments which include CDMS II. This has provided the most stringent constraint from a xenon target on the DAMA results.

5. Summary

At present, dark matter research is in an era in which vast amounts of data are being collected and interpreted. In particular, there is considerable new data about dark matter from direct and indirect detection experiments as well as new data from observation. The data are as yet inconclusive as to the actual detection of dark matter. At present two viewpoints can equally be taken on the prospect of existence of dark matter. An optimistic view on the existence of dark matter is that the PAMELA positron enhancement is due to dark matter annihilation to mainly leptonic channels. Moreover, CDMS II has seen the precursors of direct dark matter detection. Alternatively, a pessimistic view on the existence of dark matter can be that all indirect detection results have astrophysical explanations. Again, the CDMS II results are not convincing and may not be supported with future data. Finally, the results on surface density find universal galaxy scales as suggestive of MOND-type explanations rather than existence of dark matter. Only future data and careful analysis will give further insights, possibly in the near future.

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