FOREWORD

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Some Aspects of New CDM Models and CDM Detection Methods

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Abstract

We briefly review some recent Cold Dark Matter (CDM) models. Our main focus are charge symmetric models of WIMPs which are not the standard SUSY LSP’s (Lightest Supersymmetric Partners). We indicate which experiments are most sensitive to certain aspects of the models. In particular we discuss the manifestations of the new models in neutrino telescopes and other set-ups. We also discuss some direct detection experiments and comment on measuring the direction of recoil ions—which is correlated with the direction of the incoming WIMP. This could yield daily variations providing along with the annual modulation signatures for CDM.

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I. INTRODUCTION

The subject of the missing dark matter is clearly part of astro-particle physics. The astrophysics addresses the evidence for dark matter from rotation curves [1], gravitational lensings [2], galactic and cluster motions (notably the colliding galaxies in the “Bullet” cluster with data in X-ray, visible light and gravitational lensing [3]), structure formation and WMAP measurements [4]. These strongly suggest CDM (Cold Dark Matter) with average local density of \( \sim 0.3 \text{GeV} / (\text{cm}^3) \) and total contribution to the cosmological energy density of \( \Omega_{\text{CDM}} h^2 \sim 0.1131 \pm 0.0034 \).

Here we consider the complementary particle aspect addressing the nature of the CDM particles \( X \), its mass \( m_X \) and interactions, the models in which it arises and the its possible direct and indirect signatures in underground or space detectors.

From both theoretical and experimental points of view the models fall into two broad categories: “charge” asymmetric and symmetric.

In the first category the CDM reflects an asymmetry between the number densities \( n(X) \) and \( n(\bar{X}) \), analogous to the baryon asymmetry. After efficient \( X - \bar{X} \) annihilations only the excess, say, \( n(X) - n(\bar{X}) > 0 \) remains. Hence there can be no signal from present day annihilations in these scenarios.

For both categories putative decays of CDM particularly those with monochromatic photons can provide a signature as would the underground CDM induced nuclear recoils providing that the X-Nuclear cross section is not too small [5]. Certain aspects of the asymmetric scenarios are rather appealing. One can invoke analogs of the well-known baryon asymmetry despite the fact that there is no consensus re the origin of this asymmetry. To explain the observed \( \Omega_{\text{CDM}} / \Omega_B \sim 5 - 6 \) one needs a CDM charge asymmetry roughly similar to that of baryons and a matching moderate mass ratio so that: \( \Delta Y(X) / \Delta Y(B) \cdot m_X / m(B) \sim 5 - 6 \). This seems feasible in a scenario where the WIMPs are neutral technibaryons with a mass ratio \( m(TB) / m(B) \sim 1000 \) [6] and in recent SUSY CDM variants [7]. Conceivably the number of \( \tilde{B}' \)'s of mass \( m_{\tilde{B}'} \sim 5 - 6 \text{ GeV} \) in a “Hidden Sector” can be forced to equal that of ordinary baryons by an overall \( B + B' \) conservation. Another possibility with some obvious astrophysical pitfalls is to have six “mirror images of our S.M. and standard baryons” [8]. In certain asymmetric models the CDM consists of large nuggets with \( N(\text{baryon}) \sim 10^{20} \). These nuggets formed at the time of QCD phase transition when the temperature was
(\(T \sim 100\) MeV) contain \(\sim 83\%\) of all baryons, thereby evading constraints from BBN (Big Bang-Nucleosynthesis). These nuggets consist of strange quark matter \([9]\) or other stable forms of nuclear matter. \([10]\)

In a speculative variant the initial numbers of baryons and of anti-baryons are equal. A large \(\mathcal{O}(1)\) CP violating \(\theta_{\text{QCD}}\) at nucleosynthesis causes anti-baryonic nuggets to form 3:2 times more than baryonic nuggets leaving an excess \(\sim 1/6\) of the total number of baryon+anti-baryons as the observed unclustered baryons. \([11]\)

This then dispenses with the need for a new particle physics sector and “explains” baryogenesis as well!

In this review we focus on symmetric models, mainly those in which the CDM are WIMPs, Weakly Interacting Massive \(m_X\) \(\mathcal{O}(10 - 1000\) GeV\) Particles, rather than axions and/or other relatively light \((m_X <\) MeV\) long-lived bosons. \([12]\) “Warm” dark matter such as sterile \(\mathcal{O}(\) keV\) neutrinos were discussed at some length. These could provide Pulsar Kicks via (spatially) asymmetric emission from supernovae and their radiative decays (still not observed via monochromatic photons from decays of clustered DM in haloes) may induce an early re-ionization. \([13]\)

Elaborating on all of this and on recent experimental advances and improved bounds on standard axions and “axion-like” particles as well as on conjectured MeV bosons \([14]\) will carry us too far from the limited mission of this review.

There is, however, one interesting exception. Solar axion to gamma conversion in single crystals in underground detectors is enhanced when the momentum of the axions or photons they covert to with known (solar) direction and magnitude—the (roughly measured) energy of the photon satisfy a Bragg condition. This modulates the expected intensity at given latitude and longitude as a function of time in a unique pattern; a feature that was used to increases the sensitivity of solar axion detection by up to two orders of magnitude. \([15]\).

A weak variant of this motif are daily modulations due to channeling of the recoil ions in underground crystals. If ever detected, these and possibly other measurements of the ion’s direction will complement the search for annual modulations suggested by Drukier, Freese, and Spergel \([17]\) and claimed to be seen by the DAMA/LIBRA collaboration.
II. SOME TWISTS ON CDM MODELS

In symmetric WIMP models the $X$ and $\bar{X}$ particles annihilate in the early universe leaving relics with $Y(X) = n(X)/s = n(\bar{X})/s \sim n(X)/n(\gamma)$. The cosmological relic density then is: $2n(X)|_{\text{freeze-out}} \times m_X$. “Freeze-out” occurs when the Hubble expansion rate $\sim T^2/m_{\text{Planck}}$ equals the rate of annihilations, namely $n(X)v(X)\sigma(X - \bar{X})$. The $v\sigma$ factor in the last expression is usually (for S wave annihilations) constant as a function of energy or temperature around $T \sim 0$. Also before freeze-out the number density $n(X)$ is proportional to the Boltzman factor $\exp(-m(X)/T)$. One generally finds [18] that $T|_{f.o.} \sim m_X/30 - m_X/20$ and a residual cosmological CDM density $\Omega(CDM)$ proportional to $1/\sigma_{\text{ann}}$.

In SUSY models with unbroken R-parity symmetry the LSP’s of masses $m_X \sim \mathcal{O}(100 \text{ GeV})$ are stable. The fact that the annihilation $X - \bar{X}$ cross section expected for the LSP’s, which are roughly of weak interaction strength, can reproduce the desired $\Omega_{\text{CDM}} = \Omega(X) \sim 0.2$ appears to be a success of these SUSY models. Also WIMPs of $\sim 100$ GeV mass are kinematically ideal for direct detection via nuclear recoils in the underground detectors using nuclei of similar masses. As collider experiments keep tightening the lower bounds on the masses of Squarks, Sleptons and Gluinos and underground searches lower the upper bounds on the nuclear cross sections, the parameter space for minimal SUSY models with acceptable $\Omega(X)$ keeps shrinking. Also, Ref. [19] suggested that generic cancelation between the mass of the CDM and its couplings can generate the correct $\Omega_{\text{CDM}}$ without the MSSM LSP.

In common SUSY scenarios the LSP’s are “Neutralinos”: superpositions of Binos, Winos and Higgsinos and in some classes of models the LSP’s are Sneutrinos or Gravitinos. The LSP’s may be detected at the end of the decay chains of the pair of SUSY partners hopefully to be produced at the LHC manifesting as missing transverse energy/momentum. R parity violations or production of NLSP’s, slightly more massive than and decaying to the LSP’s yield a more dramatic signature of “Displaced” vertices correlated with the main event with missing momentum at both the original and the displaced vertex. Longer-lived Gluino LSP’s also arise in Split SUSY scenarios [20], where the sfermions are much heavier than the gauginos. Also a gravitino LSP can be long lived [21].

The WIMPs can have locally enhanced densities (e.g., at the galactic center and much more at the solar and earth’s cores). The enhanced $X - \bar{X}$ annihilations into positrons and...
photons (or into energetic neutrinos which can escape the sun/earth) afford indirect WIMP detection methods. These issues have been elaborated in theses and reviews and “Dark SUSY” codes where aspects of SUSY models can be numerically studied [22].

We will not study these models and focus on the more recent crop of CDM models. Various key ingredients of the new models appeared some time ago. This includes the “inelastic” [23], and “exciting” [24] DM models, Sommerfeld enhancement by \( (1/v) \) of \( v \cdot \sigma(X-\bar{X})_{\text{ann}} \) due to exchange of “light” particles [25, 26, 27] and the positrons from the decays of the latter [28]. Recently putative positron anomalies and the possibility “Hidden valley” [29] physics be detected at the LHC instead of or in addition to standard SUSY, launched a “Unified” CDM model incorporating all of these [27]. Further models where the U(1) gauge boson U is enlarged to a non-abelian Higgs sector were studied in Refs. [30, 31, 32]).

Finding how specific predictions of any given model manifest in specific WIMP indications in each experiments is lengthy and redundant. Rather we address features abstracted from (classes of) models and their manifestation in the various (classes of) experiments.

To illustrate these issues, consider the “minimal” extended model with DM charged under only a new abelian gauge-group. It has the basic scales of the WIMPs’ mass \( m_X \sim 100 \text{ GeV} - \text{TeV} \), the vector-boson mass at \( m_U \sim \mathcal{O}(\text{GeV}) \) and \( \Delta m_X = m'_X - m_X \sim 100 \text{ keV} \) splittings between the lowest WIMPs. Each of these scales is phenomenologically constrained. Thus \( \Delta m_X \) was chosen to explain the large annual modulations seen by DAMA without conflicting with bounds on WIMP—nuclear cross sections implied by other experiments. Also, \( m_U > \text{MeV} \) is essential to allow its \( e^+e^- \) decays to explain PAMELA [33] and ATIC [35] excesses (or the weaker yet more solid putative anomaly) in the positron spectrum recently found at FERMI LAT [36].

These disparate masses can be all explained via a simple pattern of radiative corrections. Finally even very heavy fields carrying ordinary E.M. and the new U(1) charge induce a small kinetic mixing: \( \epsilon F^{\mu\nu}_{\text{em}} F'_{\mu\nu} \) between the new “dark photon” of field strength \( F' \) and the ordinary photon (and also \( Z \)) of strength \( \epsilon \sim e \epsilon'/8\pi^2 \sim 10^{-3} \). The U(1) meson is a multi-tasking “workhorse” achieving all the following:

(i) Sommerfeld Enhancement (S.E.):

The \( U \) exchange between \( X \) and \( \bar{X} \), enhances the annihilation cross section by: \( \pi \cdot \alpha'/v \). This can be \( \mathcal{O}(10 - 100) \) for the small relative velocities, say, \( v < 10^{-3} \) in haloes but not in the early universe with freeze-out \( v \sim 1/3 \). The S.E. manifests classically in the
 enhancement of gravitational accretion of slow particles onto a compact star. Quantum mechanically, in the absence of S.E. $v\sigma$—rather than $\sigma$—is constant in the low energy region. Hence the enhancement is by $\sim 1/v$ only.\footnote{The very low velocities of relic protons and antiprotons at and after recombination and ensuing dramatic S.E. enhancement explain the present complete absence of slow anti-protons. (Note that the massive $U$ exchange falls exponentially for distances greater than the Compton wavelength of the $U$ boson, and unlike for photons, the enhanced cross section saturates at $\sigma \sim \pi \cdot (1/m_U)^2$.)}

(ii) Preferred Annihilation Channels:

Unless we postulate appreciable couplings to ordinary weak bosons $X - \bar{X}$ annihilate predominantly into a pair of $U$’s. Via its mixing with the photon the $U$ quickly decays to all kinematically allowed $l^+l^-$ and $q - \bar{q}$ pairs. The latter manifest as $\pi^+\pi^-$ pairs, $\pi^+\pi^-\pi^0$ triplets and as kaons and nucleon anti-nucleon pairs. The absence of antiproton excess at high energies \cite{37} suggests that $m_U < 2m_N$. Bounds on high energy photons from the direction of the galactic center suggests taking $m_U \sim 0.7$ GeV so as to avoid strong $\pi^0$ production (followed by $\pi^0 \rightarrow 2\gamma$, yet allow $U$ decays to $e^+e^-$ and $\mu^+\mu^-$. \cite{34}

(iii) WIMP-Nucleus Couplings:

The $U$-photon mixing generates coherent spin independent WIMP-nucleus interactions and nuclear cross sections comparable to those due to $Z^0$ exchange as the $\epsilon$ factor is compensated by $(m_Z/m_U)^2$.

If $X$ and $X’$ are Majorana components then only off-diagonal $X’XU$ couplings are allowed. Since $X’$ and $X$ are almost degenerate this does not affect the S.E. The $U$ decay $X’ \rightarrow X + \nu + \bar{\nu}$ mediated via $U - Z^0$ mixings has a lifetime longer than the age of the universe. \cite{38} However, one can naturally add to the dark sector other light bosons $b^0$, $b^0’$, etc., and the decay of $X’ : X’ \rightarrow X + b^0$ followed by $b^0 \rightarrow 2\gamma$ can be made fast enough so as to meet all observational and astrophysical constraints.

How do all these novel aspects affect the possible experimental signatures of dark matter? Particularly interesting is the signal of upward going muons in neutrino telescopes, pointing either to the center of the earth or to the core of the sun. Such muons originate from interactions in earth of the energetic neutrinos from WIMPs annihilating at the respective cores. Unlike the case of putative electromagnetic signals from WIMP annihilations in space, this peculiar upward-going muon signal cannot be “faked” by any known astronomical
mechanisms. Most stages involved in generating the flux of energetic neutrinos from the sun (or earth) are now different from the well-studied case of Neutralino LSP’s.\[18\]

The S.E. of $X - \bar{X}$ annihilations enhances the signal particularly if high WIMP densities ensuring a steady state (where every accreted WIMP eventually annihilates) are not achieved. This is the case for WIMP accumulations in earth where the important helpful role of S.E. in generating the signal has been recently emphasized.\[39\]

However, if the particle responsible for the Sommerfeld enhanced $X\bar{X}$ annihilations is the above $U$, and further $U$ is the only “light” boson appreciably coupled to the WIMPS, then the $U$-pair annihilation channel dominates and the energetic neutrino signal disappears. The $U$’s decay into muon or pion pairs which in turn decay to neutrinos. Such energetic neutrinos are indeed expected along with the electrons and positrons from annihilation of halo WIMPs. However, in annihilations in the solar/terrestrial cores, the pions and muons produced therein encounter large (150/20gr/cm$^3$) densities and lose all their energies before decaying to $\mathcal{O}(30 \text{ MeV})$ neutrinos. Only prompt neutrinos from decays of $Z, W, b, c$ quarks and $\tau$’s are relevant for neutrino telescopes. A $U$ of sub GeV mass cannot decay into a pair of $\tau$’s. Still the “minimal” initial model can be extended to have substantial annihilations to $Z$’s and $W$’s thereby supplying the energetic neutrinos analyzed in the JGK review.

Another kinematical issue can arise. One may wonder if the requirement of exciting in the first collision of $X$ in the solar core the $X'$ with $\Delta m_X = m'_X - m_X \sim 100 \text{ keV}$ decrease the fraction of such collisions which lead to gravitationally bound WIMP. Further this $\Delta m_X$ can prevent the slow $X$ WIMPs from re-scattering into $X'$ WIMPs even on heavy, say, Iron targets, and thus impede the last stages of further WIMP concentration.

This was studied in detail in Ref.\[40\] finding sufficient WIMP concentration in the stellar core. Thus for $X - \bar{X}$ annihilations with appreciable branchings into prompt neutrinos one can exclude using Super-Kamiokande data\[41\], DAMA type WIMP nuclear cross sections.

**III. DAMA/LIBRA, THE ANNUAL MODULATIONS AND PROSPECTS OF DAILY MODULATIONS RELATED TO CHANGING RECOIL DIRECTIONS**

Many experiments searched for nuclear recoil due to collisions of WIMPs in a wide variety of low background underground detectors and did not find it. The task of “proving” that CDM exists is daunting.\[42\] One looks for isolated nuclear recoils where a WIMP of mass
$m_X$ transferred to a target nucleus of mass $m(A, Z) \sim A$ GeV a momentum $q, q \sim \mu \cdot v$ where the reduced mass $\mu$ is for a large or small ratio of masses $r = m_X/m(A, Z)$, the smaller among the WIMP and nuclear masses, and $v \sim 10^{-3}$ is a “virial” velocity of the in-falling WIMP. When both masses are $\sim 100$ GeV the transfer can be as large as 100 MeV and the corresponding recoil energy $q^2/2m(A, Z) \sim 50$ keV. In general, only some portion of the recoil energy, the so-called “quenching factor” $\sim 10\%$ manifests in the measured electromagnetic signal. The latter signal is the electron hole current in some Germanium semiconductor detectors or the scintillation photons in the sodium-Iodine (Na-I) single crystals of DAMA and LIBRA. Recalling that most H.E. detectors have $\mathcal{O}(100$ MeV) thresholds helps appreciate how difficult it is to reliably measure the resulting $\sim 5$ keV signals. Also even deep underground nuclear spallation by penetrating $\mathcal{O}(\text{TeV})$ muons can yield neutrons which drift towards the detectors and leave some isolated imprint there.

Recent advances in cryogenics allow also calorimetric measurements.\cite{44}

Cooling a Germanium crystal of $\sim 100\text{cm}^3$ volume to very low temperatures reduces the specific heat ($c_v \sim T^3$) so that even the tiny recoil energy deposited measurably heats it up. By jointly measuring both the ionization energy and the total calorimetric deposition the CDMS experiment reduces the purely E.M. background for which the two are equal.

Several underground experiments are carried out or planned with a different primary goal of finding neutrinoless double beta decays in samples enriched with the proper isotopes. However, also the IMB and Kamiokande which discovered the neutrino pulses from supernova 1987a and atmospheric neutrino oscillations, were designed to look for nucleon decay.

It is much more difficult to estimate the nuclear cross section than the $X - \bar{X}$ annihilation rates unless we commit to specific models (such as neutralino LSP’s). If we treat the nucleus as a point particle, then $d\sigma/dt \sim G^2_F$, with $G_F$ an equivalent Fermi constant (which for the spin-independent case is $\sim A$), then $\sigma = \int_0^{t_{\text{max}}} d\sigma/dt$ yields when $m(\text{WIMP}) \sim m(A, Z)$. This then allows probing X-nucleon cross sections down to $\sigma(X - N) \sim 10^{-43}$ cm$^2$. The above is somewhat modified by nuclear form factor damping which becomes important for $q \cdot R(A, Z) \sim 1/2 R(Z, A)/\text{Fermi} \gg 1$.

Lacking a clear positive! signature for recoils due to CDM, it is extremely difficult to claim that some excess of events seen in underground experiments above expected backgrounds are indeed nuclear recoils due to WIMP interactions. Some time ago the ingenious suggestion of annual modulations of the WIMP signal had been made in Ref. \cite{17}. The basic underlying
kinematics is rather simple: Let us make the reasonable assumption that the WIMPs and their velocities are isotropically distributed in the rest frame of our galactic halo. The motion of the sun due to the galactic rotation and another small radial component generate in the rest frame of the sun a WIMP drift or “WIMP Wind” at a fixed direction ($\sim 42^\circ$ with respect to the earth’s rotation axis) and velocity $v_D \sim 230\text{km/sec}$, comparable to the estimated virial isotropic velocity in the halo: $<v^2>^{1/2} \sim 220 \sim \text{km/sec}$. It turns out that the $\sim 30\text{km/sec}$ velocity of the earth around the sun (more precisely, half this value due to the $60^\circ$ angle between the ecliptic and galactic planes) adds to or subtracts from $v_D$ at the beginning of June and September, respectively. Hence, we expect that the WIMP flux and also the WIMP’s energies will be maximal/minimal at these times with a modulation amplitude of order 6%.

Only the DAMA experiment which has been running for roughly 10 years, recently as DAMA/LIBRA with more than double the number of the ultra-pure large Na-I crystals, claims to see this modulation with the correct phase. On face value the rather large $\sigma(X-N)$ that the amplitude of modulations suggests conflicts with rather stringent bounds implied by the lack of CDM discovery in other Germanium and Xenon detectors. There have been, however, several attempts of using modified WIMP models and the different target nuclei/materials in order to reconcile DAMA’s signal with the other experiments. Specifically: Ref. [45] suggested relatively light WIMPs of mass $m_X < 10 \text{ GeV}$ so that only tiny recoil energies are expected in the experiments with the heavier targets. Yet non-negligible recoils in scattering on the relatively light sodium could be detected by the the low threshold DAMA experiments. Note that for such light WIMPs the $X$-Na cross section is enhanced only by $\sim A^2$ and with $A \sim 30$, the required $X-N$ cross sections are rather high.

Smith and Weiner [23] suggested that the inelastic scenario can explain DAMA if scattering with nuclei is dominated by inelastic transition into an excited state, roughly $\mathcal{O}(100 \text{ keV})$ above the DM state. The very severe limit on $\sigma(X-N)$ from the CDMS and Xenon and CREST experiments stem from assuming elastic WIMP nuclear scattering and the lack of the much larger fraction of low energy events expected in models with elastic scattering. In contrast the endothermic process in the inelastic scenarios tends to generate larger recoils and such higher energy events are indeed seen at some level in these experiments. Also in this scenario the higher end of the WIMP velocity distribution which is more sensitive to the annual modulations is used. For further discussions of all these issues see Ref. [46].
In principle, solar axions to which the other experiments are largely insensitive could also manifest in DAMA. However, since the sun is closest during the (northern) winter, the modulations of such a signal are completely out of phase with the DAMA observation. In this connection it is worthwhile to note the established $\sim 5\%$ enhancement of the TeV muon flux underground [47] at Grand SASSO in the summer. This increase is due to the “swelling up” of the hotter atmosphere so that the first hadronic interactions of a high energy cosmic ray producing energetic pions occurs higher up in the atmosphere and these pions can travel a longer distance in the more dilute atmosphere and have a better chance to decay into muons before interacting. Since the heating up effect is maximal in August rather than in June this cannot explain DAMA. Still a repeat of DAMA in the southern hemisphere seems vital in order to clearing lingering doubts.

One of the arguments used by the DAMA collaboration to explain why they see a signal which others failed to see utilizes channeling of the recoil ions. Channeling operates in crystals but not in amorphous detectors like liquid Xenon. If the recoiling ions make small angles with respect to some Bragg planes of low Miller indices, then rather than going on and colliding with many nuclei, the ions keep reflecting from these planes and stop after a much longer distance. The channeled ions tend to lose a much higher fraction of their energy via electromagnetic processes, scintillation in DAMA’s case, than unchanneled ions. Summings over the 100, 110 and 111 planes we find that on average $\sim 25\%$ of the Iodine or Sodium ions with low $O(5\text{ keV})$ energy are channeled. [48]

Most ($\sim 97\%$) of DAMA’s data are in the $3 – 6\text{ keV}$ range. If we identify these as the unchanneled sample then the true energies are $\sim 30 – 60\text{ keV}$ and channeling effects are much smaller. Still channeling should have generated a high energy “echo” of the DAMA signal. The more interesting alternative is that the signal is mainly due to the channeled events which could be the case for low WIMP masses. In this case the daily changing efficiency of channeling can conceivably be detected as discussed in Ref. [49] and also briefly below.

Modulations of the ion recoil directions could be very important CDM signatures. Since the modulated signal is due to the constant direction of the WIMP wind the variations are according to the sidereal rather than the solar days. This makes any putative effect robust to any systematic variations of temperature, noise, grid voltage, etc. While reminiscent of earlier work on variation of the rate of $\gamma \rightarrow \text{axion}$ conversion in single crystals with the angle between the direction to the sun and the various principle Bragg planes, the effect here is
diluted in several stages:

1. Unlike the unidirectional solar axions (all of which originate from the sun) the virial random velocity component of the WIMPs, comparable to the drift velocity, smooths the directional WIMP distribution making it far less peaked in the “Wind” direction.

2. The axion converted in static fields into a photon with exactly the same energy and direction as the original axion. In the present case, after colliding with a WIMP the recoil ion moves in the forward hemisphere. Yet it does not exactly follow the direction of the initial WIMP even for the case of point-like particles or isotropic (pure S wave) collisions in the center mass system. This further broadens the distribution of the directions of the recoil ions relative to the WIMP wind. Further,

3. Form factor effects decrease the momentum transfer whereas the correlations between the direction of the recoiling ion and the original WIMP are maximal for maximal transfers.

All the above tend to randomize the recoil direction so that even if ideally it could be exactly found experimentally it will serve as a weaker indicator for WIMPs.

For fully oriented crystalline detectors one can use the twice-a-day modulations of the WIMP signal due to the changing angle between the WIMP wind and the crystal planes with the rotation of the earth.\[49\].

Four years earlier a similar idea had been suggested in Ref. \[50\]. The advantage of this suggestion is that the Stilbene crystal has low monoclinic symmetry and hence the variation of the channeling efficiencies with time are likely to be large. This is not the case for the highly symmetric cubic or diamond lattices of Na-I and Germanium where at any time of day there are channeling through various 100, 110 and 111 crystalline planes moderating the daily variations. Still large scale such crystalline underground detectors exist and searching these modulations in the data is certainly worthwhile. The modulations occur almost twice a day. The reason is that most underground experiments are within \( \pm 3^\circ \) away from the 45° latitude and the direction of the WIMP wind is radially inward at 48°. Neglecting the \( \sim 3^\circ \) discrepancies the 180° degree rotation of the earth occurring every twelve hours are, in fact, 12-hour rotations of the earth and becomes a symmetry rotation around a 110 axis.
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