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A New Possible Way to Explain DAMA Results

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ABSTRACT

The DAMA experiment clearly observes a small oscillatory signal. The observed signal is a very small energy deposit in the NaI(Tl) crystals, at a level of 2-6 keV, believed to be due to interactions of detector nuclei with the Dark Matter. The observed yearly modulation is in phase with the Earth's motion around the Sun. The DAMA detector is a 250 kg stack of NaI(Tl) detectors located in the Grand Sasso laboratory. So far, it is not well explained by proponents nor confirmed by other major Dark Matter searching experiments. We propose a new simple way to explain the DAMA signal and why nobody else observes it: rather than collisions of a 6-7 GeV/c^2 WIMP with a heavy nucleus, such as Na, I or Tl, we propose that the observed signal is due to a collision of a very light ~1 GeV/c^2 WIMP with hydrogen nucleus, where the hydrogen target comes from a small OH-contamination of NaI(Tl) crystals. The light WIMP strikes a hydrogen nucleus, producing a proton. Such a proton would then cause the emission of a few photons detected by PMTs.

Key words. DAMA experiment, Dark Matter search

1. Introduction

The DAMA experiment claims to observe the Dark Matter mass of 6-7 GeV/c^2. It is the first experiment to observe a clear oscillatory signal [Bernabei, 2013], as shown on Fig. 2. However, there is no confirmation of the DAMA's result from any LXe Dark Matter searching experiments, such as Xenon-10, Xenon-100 or LUX. This gave the author an idea that perhaps the DAMA signal is due to scattering of a light ~1 GeV/c^2 Dark Matter particle with a light nucleus; specifically hydrogen present as a tiny OH-contamination in NaI(Tl) crystals.

OH-molecules represent likely contamination of the primary NaI salt; it requires a prolonged pumping at elevated temperature to be removed [Kudin, 2011]. The exact level of this contamination in NaI(Tl) crystals is a proprietary information, as indicated by Saint-Gobain Co. However, we learned from Hilger Co. that the OH-contamination at a level of a few ppm is likely. Generally, these companies keep air humidity to less than ~2% when machining the crystal and assembling the NaI(Tl) detector, although again this is proprietary knowledge. But, knowing how hard it is to keep humidity low in gases without appropriate filtration, it would seem to us that water contamination at a level of a few ppm is easily possible. Once in the detector, DAMA NaI(Tl) crystals are of course protected against the moisture, by sealing them while flowing a boil-off nitrogen; however, the sealed chamber is opened from time to time. The exact history of each crystal is probably not known, i.e., there may be variation among crystals; and apparently there is some variation of the signal as well. In our calculations we will assume the hydrogen contamination at a level of ~1 ppm. This number can be tweaked as we get more information. We believe that a push towards ultra-pure NaI(Tl) or other pure crystals may remove the signal completely, if this paper is correct.

The WIMP-proton scattering cross-section is not known at all at present. In this paper we will treat it as an independent variable.

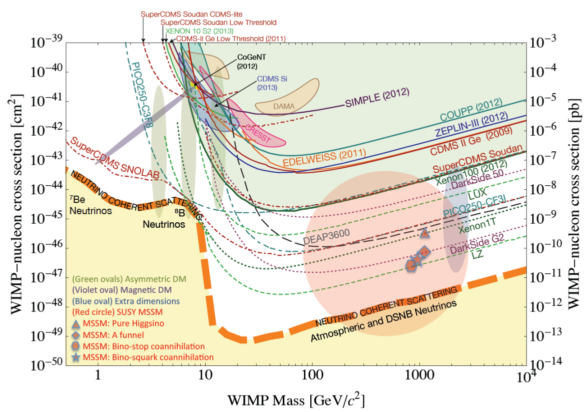

Fig. 1. The cross-section limits to detect the WIMP mass by various experiments (Snowmass, 2013). The graph also shows the low limit, below which, experiments will have to deal with the neutrino background. One also can see clearly, that a WIMP mass below ~5 GeV/c^2 would not be detected by most of present experiments, because their nucleus mass is too high. One needs a hydrogen target to have a chance to detect the light WIMP.

There are many experiments searching for the Dark Matter, mostly concentrating on a detection of heavy mass. Figure 1 shows an overall status of upper limits of these experiments (Snowmass, 2013). Nominally, none of these experiments was designed to search for ~1 GeV/c^2 mass. As Fig. 1 indicates there is a great opportunity to explore a cross-section of 10^{-24} – 10^{-44} cm^2 if the mass is indeed low.

A low mass WIMP of ~1 GeV/c^2, however, represents a real experimental challenge, as it requires a low mass hydrogen target. The Dark Matter cloud is believed to be stationary relatively to the Galagxy. The Earth moves with a velocity of 230 +-

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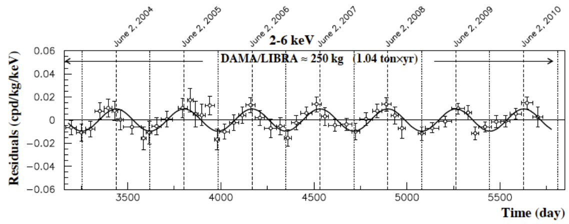

Fig. 2. Experimental residual rate of the single-hit scintillation events, measured by DAMA/LIBRA over six annual cycles in the (2-6) keV energy intervals as a function of the time [Bernabei, 2013].

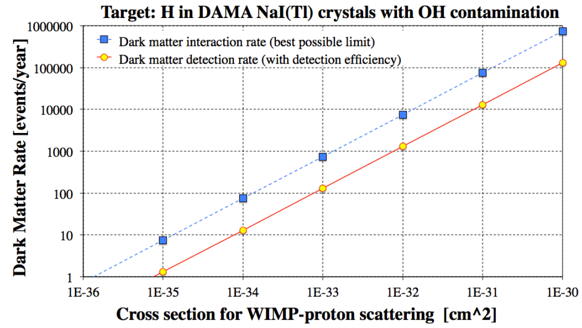

Fig. 3. This paper's prediction for the DAMA rate as a function of cross-section, assuming (a) ~1 ppm of hydrogen level in NaI(Tl) crystal, (b) PMT quantum efficiency of ~35 %, and (c) light collection efficiency of ~50 %. The calculated rate is relative corresponding to the 30 km/sec modulation.

30 km/sec in the Galactic plane, and as a result, a ~1 GeV/c^2 mass WIMP's kinetic energy oscillates between ~0.353 keV and ~0.208 keV relative to the DAMA experiment, on its yearly journey around the Sun. This provides the source of the DAMA signal modulation. When such WIMP strikes a hydrogen atom, a resulting projectile striking the NaI(Tl) crystal can be one of these combinations: (a) a proton is ejected, (b) both an electron and a proton are ejected, (c) an excited hydrogen atom is ejected, or (d) an ejected proton strikes an electron, which gets excited into the conduction band of the NaI(Tl) crystal structure until it finds an activator (Tl), with a very low ionization potential of 6.108 eV, where the de-excitation occurs via small photonic emissions, mostly in visible spectrum [Knoll, 2010]. The alkali halide inorganic crystals, such as NaI(Tl) or CsI(Tl), may have a unique advantage over other methods to detect the low mass WIMP through this effect, if they have sufficiently high OH-contamination. To calibrate this effect, one would have to measure photonic excitations with a few keV neutron beam striking NaI(Tl) crystals with varying content of the known OH-contamination.

2. DAMA experiment and new explanation of results

Figure 3 shows our prediction for the DAMA experiment rate (calculated for the 30km/sec modulation) as a function of the WIMP-proton cross-section, assuming (a) ~1 ppm of hydrogen level in NaI(Tl) crystal, (b) PMT quantum efficiency of ~35 %, and (c) light collection efficiency of ~50 %, and neglecting other possible inefficiencies. We assume that the dark matter density is ~0.3 GeV/cm^3 in our nearby Universe [Catena, 2011], which translates into the Dark Matter density of ~300 particles/liter, if we assume a mass of ~1 GeV/c^2. There are many unkown details in this problem. For example, we do not know the local Dark Matter density near Earth's location within the Galaxy, the Dark Matter mass, the hydrogen level in NaI(Tl), a probability that the WIMP-proton interaction ends up with a detectable signal, and of course, the WIMP-proton cross-section at a fraction of a keV.

For our choice of parameters, and taking into account the DAMA modulation peak rate of ~0.01 cpd/kg/keV (see Fig. 3), it seems that the WIMP-proton scattering cross-section is rather high: 10^{-32}–10^{-31} cm^2. The correct number has to be determined by the DAMA experiment at the end, as one has to have an access to details of the data analysis, which should include a proper treatment of all possible backgrounds.

It is interesting to compare our prediction for the DAMA WIMP-nucleon cross-section range with upper limits obtained by Tevatron and LHC experiments, where WIMP is measured in "$\overline{WIMP} + WIMP$ + jets" events [Beltran, 2010]. This is shown in Figure 4. Although there is a large range of possible values for ~1 GeV/c^2 WIMP, it is clear that the accelerator-based cross-section upper limits are lower than values obtained from the model based on the OH-impurity in DAMA crystals. Some small discrepancy could be tweaked to lower the DAMA cross-sections, for example, by increasing the OH-contamination level in NaI(Tl) crystals, or by increasing the local Dark Matter density near the Earth. The WIMP-nucleon scattering cross-section may also be energy dependent; the DAMA data require a calculation at a fraction of a keV. Another way to resolve this discrepancy is to assume that the Na nucleus is actually involved in the WIMP scattering, i.e., assume the standard explanation provided until now (this is because the OH-contamination represents much smaller density).

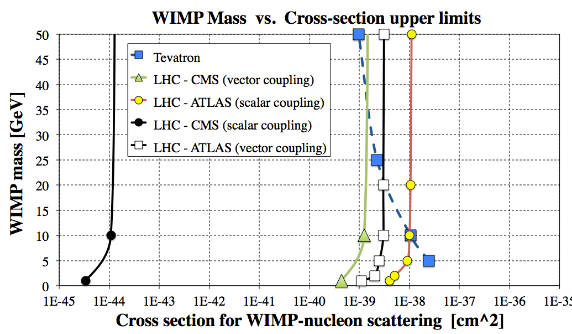

Fig. 4. Upper limits of WIMP-nucleon cross-sections as a function of the WIMP mass, plotted for Tevatron [Beltran, 2010] and LHC [ATLAS, 2013],[CMS, 2013]. There is a large range of possible values of cross-section limits for ~1 GeV/c^2 WIMP.

3. Conclusion

This paper suggests that the measured oscillation in the DAMA experiment may be caused by a scattering of a light ~1 GeV/c^2 WIMP on hydrogen, which happens to be a contamination in the NaI(Tl) crystals. This contamination may vary from crystal-to-crystal, causing different rates. This idea would start work quantitatively if the hydrogen contamination of DAMA NaI(Tl) crystals is at a level of ~1 ppm or above and the WIMP-proton cross-section is above 10^{-33} cm^2. The more pure NaI(Tl), the less likely it will work.

The cross-section prediction for the DAMA experiment was compared to limits obtained by Tevatron and LHC experiments ATLAS and CMS. Although there are still several unknowns in our assumptions, there seems to be a large discrepancy. This weakens the argument of this paper somewhat, but since the WIMP was not yet discovered, it may be interesting to pursue these thoughts further.

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References

R.Bernabei *et al.*, Dark Matter investigation by DAMA at Gran Sasso, arXiv:1308.5109, 2013.

K.A.Kudin *et al.*, Effect of CO3 and OH impurities on thermal growing conditions of large size NaI(Tl) crystals and their quality, Functional Materials 18, No.2 (2011).

G. Knoll, Radiation detection and measurement, Wiley, ISBN: 978-0-470-13148-0, 4th edition, 2010, page 240.

R.Catena and P.Ullio, The local Dark Matter phase-space density and impact on WIMP direct detection, arXiv:1111.3556v1, 15 Nov., 2011.

M.Beltran *et al.*, Maverick dark matter at colliders, arXiv:1002.4137v2, 2010.

ATLAS collaboration, Search for dark matter candidates and large extra dimensions in events with a jet and missing transverse momentum with the ATLAS detector, arXiv:1002.4137v2, 2013.

CMS collaboration, Search for new physics in monojet events in pp collisions at 8 TeV, CMS PAS EXO-12-048, 2013.