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Prospects of Dark Matter Direct Search under Deep Sea Water in India

V. Singh[*], V. S. Subrahmanyam, L. Singh, M. K. Singh, V. Sharma, N. S. Chouhan, M. K. Jaiswal and A. K. Soma

Physics Department, Banaras Hindu University, Varanasi 221005, India

Email: venkaz@yahoo.com

Abstract There is compelling evidence from cosmological and astrophysical observations that about one quarter of the energy density of the universe can be attributed to cold dark matter (CDM), whose nature and properties are still unknown. Around the world large numbers of experiments are using different techniques of dark matter direct and indirect detections. According to their experimental requirements location of the experiment prefer to use either underground, under ice, or under sea water. In a country like India, digging underground cavern and long tunnel is not very convenient. Therefore, authors look from the other solutions of this problem preferring to use deep sea water. In this article, we discuss the pros and corns of use of deep sea water in the dark matter search.

Keywords: Dark matter, elastic scattering, detection, sea water shielding

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1. INTRODUCTION

So far scientists have observed dark matter only through its gravitational interaction on very large scales. To understand the nature of dark matter better, searching for a more direct signal from dark matter particles through their interaction with ordinary matter will be appropriate and almost model independent. Experiments gear up towards direct detection of dark matter candidates like Weakly Interacting Massive Particles (WIMPs). Weakly interacting massive particles (WIMP, denoted by χ) are the leading candidates for CDM. There are intense experimental efforts [1] to look for WIMPs through direct detection of nuclear recoils in $\chi N \rightarrow \chi N$ elastic scattering or in the studies of the possible products through anti-χ,χ annihilations. Supersymmetric (SUSY) particles [2] are the leading WIMP candidates. The popular SUSY models prefer WIMP mass ($m\chi$) in the range of around 100 GeV, though light neutralinos remain a possibility [3]. Experimentalists may have a chance to observe such interactions since dark matter is part of our galaxy where it is more or less smoothly distributed. Therefore we expect the dark matter particles to cross the path of the earth and interact with the detectors set up for dark matter detection. The interaction rate of the dark matter particles with detector depends on the mechanism by which they interact. However, the effect that an interaction would have depends only on the velocity distribution of the particles and on their mass. The velocity distribution that can be estimated from the fact that the particles are gravitationally

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bound to our galaxy is centered about a few hundred km/s. The mass of WIMPs is expected to be in the range of a few tens to a thousand of GeV/c². Detector materials consist of a heavy nucleus surrounded by light electrons. The typical energy transferred to an electron during elastic collision would be of the order of a few tens of eV while the typical energy transferred to atomic nuclei would be in the range of a few tens of keV. The measurement of tens of keV is extremley difficult, but definitely possible, while it would be very challenging to search for interactions in the range of a few tens of eV, especially when using large detectors. Therefore experiments searching for direct signals from dark matter WIMPs typically look for nuclear recoil events. Most experimental programs optimize their design in the high-mass region and exhibit diminishing sensitivities for $m_\chi < 10$ GeV, where an allowed region due to the annual modulation data of the DAMA experiment [4] further reinforced by the first DAMA/LIBRA results [5] remains unproved. These experiments require low energy threshold of the order of sub-keV and radio pure detecting materials with ability to discriminate events due to γ –rays, electrons and neutrons. Thus, we can explore weak interaction cross-section of WIMP by observing sub-keV energy events induced by WIMP scattering off target nuclei. To reduce the cosmogenic radioactivity, experimental efforts are focused on using mountains, Antarctic Ice and seawater as naturally occurring radiation shields.

2. BACKGROUND

There are lots of challenges related to the dark matter or rare event experiments. But there are two main experimental challenges and both are related to the fact that the particles we are looking for interact only very weakly with ordinary matter. The first challenge is the extremely low expected interaction rate. A very rough estimate of dark matter event rate can get from the total abundance of dark matter in the universe. This estimate gives rates as low as a few interactions per year in several hundred kg of detector material. If various sophisticated theories are applied then we can find variations in this rate by a few orders of magnitude, but even in the most optimistic scenarios the rates are rather low. This challenge forces us to consider as large a target mass as possible to see significant number of event with almost negligible radioactive contamination. But as we all know that getting very low radioactive contamination material is not possible. The second challenge is that other particles also interact with the detector material, especially neutron, typically at rates much higher than that expected from WIMP interactions; these interactions that are not from WIMPs are called background. The sources of such particles are the cosmic radiation and radioactive materials in the surrounding of the experiment, the experimental set up or even the detector material itself. To get an idea of the magnitude of this problem we just have to keep in mind that a cubic meter of regular room air has typically a few tens of radioactive decays per second. If unshielded, in an experimental search, WIMP interactions would be completely swallowed by the natural radioactivity and would have no chance to be observed.

In case of underground laboratory, mountain as an overburden is full of challenges as, in getting proper mountain location and height and in reducing various radioactive background coming from the mountain's rock as well as induced by cosmic ray. Even cosmic ray muon background calculation itself is a very big challenge due to variation in height and flatness of the mountain. Neutron interaction with ordinary matter is well known and signal of neutron event is similar to the signal of dark matter. There are various uncertainties in neutron background evaluation due to uncertainties in rock composition, purity of shielding material and mountain topology. Whereas with seawater, its composition is well understood, provides almost flat surface, low neutron production rate with excellent neutron absorption capability, no neutron back scattering, time saving and very cost effective.

The muon flux and induced activity is reduced by about one order of magnitude for every increase in depth of 1.5 kilometer water equivalent (km. w. e.). Therefore, muon induced fast neutrons play an important role in demonstrating the experimental sensitivity. Fast neutrons deposit energy via elastic and/or inelastic scattering processes. The elastic scattering is main concern for dark matter searches, since its energy deposits are in the low energy region of interest. The neutron flux incident on shielding around a detector can vary by factor of about 2-3, depending on the cavern size due to backscattering of neutrons from cavern walls. The neutrons from rock interact with shielding materials such as lead and mesmerizes us as WIMP signal in region of interest. The usage of boron loaded polyethylene shield close to target detector reduces 0.5 km. w. e. background. The raw event rate in region of interest can be further reduced by a factor more than seven by exploiting detector granularity, pulse-shape discrimination and detector segmentation, and use of active neutron veto of 99% efficiency can further reduce background level down to more than 3km. w. e. under ground. Proper under water ventilation system [6] and pressure vessel that can sustain up to a depth of ~10 km underwater have been deployed. Longer than 40 km, single high voltage & signal cables are in experimental use [7].

In transforming countries (like India) where setting up any underground laboratory is very time consuming and not straight forward exploring this alternative approach of setting up deep seawater experiment is a feasible option.

3. DETECTORS

In addition to the above mentioned benefits and available mechanical cooling system for Germanium detectors of different mass possessing high energy resolution force us to use HPGe detectors of ORTEC X-Cooler II [8, 9] at deep underwater laboratory. ORTEC has demonstrated a mechanically cooled high purity germanium detector successfully. In the absence of such detector liquid nitrogen (LN_2) cooled PHGe detectors are common in use for such purpose and in this situation evaporation and evaporation rate of LN_2 will put major challenge before experimentalists. The typical

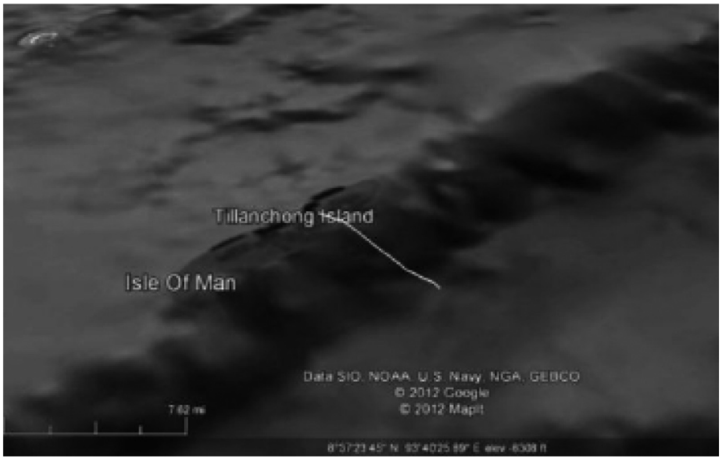

Figure 1: Google map of the Tillanchong Island.

rate of LN_2 evaporation at room temperature is 0.36 Lt/day [10] and temperature at the depth of 3000 m is in between 2-4^{o}C [11]. Therefore, with a 100 Liter Dewar an experiment can survive up 275 days without any interruption and this period is long enough to settle down the cosmogenic background in the detectors. In case of overburden each 3500m depth of seawater will give more than100 m extra overburden of freshwater.

The WIMP searches requires above 5 kilometer water equivalent (km. w. e.) depth. It can be achieved with the help of proper layering of minimum required shielding of active (by the usage of cosmic-ray, neutron and anti-Compton veto detectors) and passive materials. Thus, a further control on background in the sub-keV region can be achieved. Therefore experimental searches on dark matter and $0\nu\beta\beta$-decay can be performed successfully.

4. POSSIBLE SITES AROUND THE WORLD

The Mariana Trench located at 11"21'N & 142" 12'E near Japan in the Pacific Ocean is the deepest part (location) of earth's oceans (earth itself) with a depth of 10994 meters. The director of film "*Titanic*", Mr. James Cameron visited this place in March 2012. The Indian scientists have possibility to explore Tillanchong Island site in Andaman and Nicobar Islands. It has 4161m of depth at only 15 km away from sea shore, where control room of experiment can be setup, is shown in Figure 1. Additional possible sites are tabulated in Table 1. The depth measurement through the Google earth was calibrated with the depth of ANTARIS site for the Table 1.

Table 1: Possible locations for underwater experiments that have distance less than 50 km from the sea shore.

Location	Depth (in meter)	Distance from the shore (Approx.)
16°10'05.37" S / 54°47'48.60" E Tromelin Island (South Africa)	4900	45 km
20°53'05.86" S / 57°49'44.53" E Flacq (Mauritius)	4757	50 km
20°44'16.84" S / 56°57'42.53" E Savanne (Mauritius)	4309	50 km
08°34'22.07" N / 93°44'07.67" E Tillanchong Island (India)	4161	15 km
08°14'54.58" N / 93° 51' 04.68" E Trinkat Island (India)	3993	35 km
12° 43' N / 81° 06' E Chennai (India)	3350	70 km

5. PRELIMINARY LAY-OUT OF EXPERIMENTAL SETUP

The design of an underwater dark matter search experiment presents a challenging task as it has to match various requirements concerning the detector performance, technical feasibility and project budget. During mid twentieth century several deep underwater experiments have been performed using plastic scintillation detector for studies on cosmic-ray flux [12] and scientists have used HPGe detector system to determine radio- nuclide levels in 105-KE Basin floor and walls. The ANTEC Technology provided submersible vessel [13]. The vessel was constructed by stainless steel and was designed to include HPGe detector, lead (Pb) shielding, tungsten collimator and LN_2 cryostat. The power supply and DAQ cables were fed through watertight connections in vessel. The vessel also included a vent tube of sufficient length to vent nitrogen gas [13]. Although, mechanical cooled HPGe is available; however, it demonstrates successful operation of HPGe detector in underwater laboratory using LN_2.

A detector assembly incorporating all the above mentioned requirements of dark matter search with support systems and electronic modules is shown in Fig. 2. The setup consist of p^+ point contact HPGe detector of initial mass 1 kg, 4π coverage by layered NaI(Tl) anti-Compton and liquid scintillation neutron detectors along with electronic modules of DAQ with remote control capabilities and a 100 liters LN2 dewar.

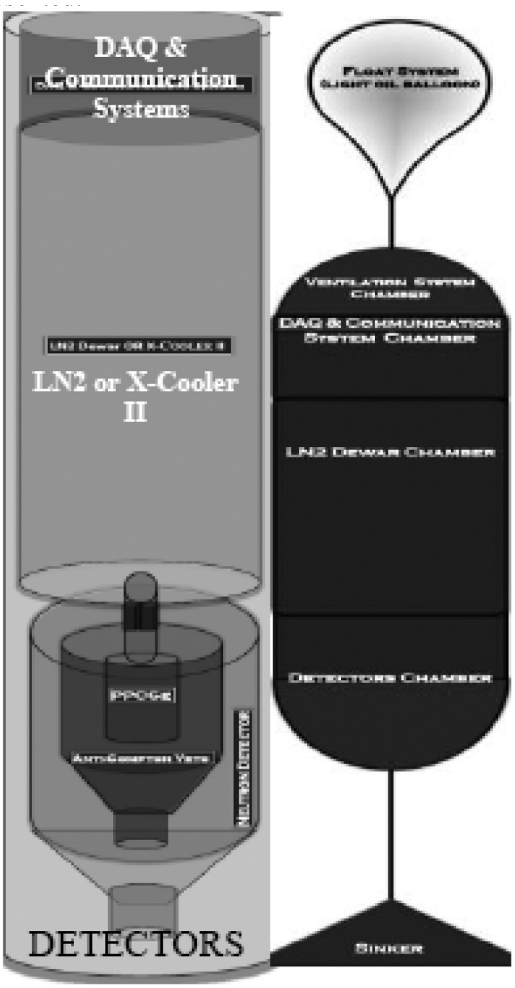

Figure 2: Preliminary lay-out of detector assembly.

The entire configuration will be inside a high pressure & water resistant vessel that will float ~1km up from the sea bed or as required, with the help of light-oil filled balloon. Vessel will get stability with a heavy Pb sinker. The vessel will be connected to the shore based control room through power cables. This type of experiment provides a high probability to explore the properties of WIMP. In the final phase setting the assembly in Mariana Trench will enrich the scientific goal and stamp India's name in understanding the 23% of universe energy density. The detail study and feasibility of this experiment will be presented.

REFERENCES

[1] R. J. Gaitskell, Annu. Rev. Nucl. Part. Sci. **54**, 315 (2004). http://dx.doi.org/10.1146/annurev.nucl.54.070103.181244

[2] H. H. Haber and M. Schmitt, J. Phys. G **33**, 1105 (2006).

[3] A. Bottino et al., Phys. Rev. D **72**, 083521 (2005). http://dx.doi.org/10.1103/PhysRevD.72.083521

[4] C. Savage, P. Gondolo, K. Freese, Phys. Rev. D **70**, 123513 (2004); http://dx.doi.org/10.1103/PhysRevD.70.123513 P. Gondolo and G. Gelmini, Phys. Rev. D **71**, 123520 (2005); http://dx.doi.org/10.1103/PhysRevD.71.123520 R. Bernabei et al., Riv. Nuovo Cimento Soc. Ital. Fis. **26**N1, 1 (2003).

[5] R. Bernabei et al., Eur. Phys. J. C **56**, 333 (2008), www.ntis.gov/search/product.aspx?ABBR=DE200515 010373.

[7] J. Aguilar et al., NIM A **656**, 11 (2011). http://dx.doi.org/10.1016/j.nima.2011.06.103

[8] D. L. Upp et al., J. Radioanalytical and Nucl. Chem, **264**, 121 (2005). http://dx.doi.org/10.1007/s10967-005-0684-y

[9] R. L. Coleman, J. S. Bogard and M. E. Murray, (2002), www.ornl.gov/~webworks/cppr/y2001/rpt/ 115263.pdf. www.kgw-isotherm.com/downloads/ww.windows2universe.org/earth/Water/temp.html.

[12] S. Higashi et al., IL Nuov Cime XLIII, 334 (1966). http://dx.doi.org/10.1007/BF02752862

[13] R. J. Arthur et al., (2003) www.osti.gov/bridge/product.biblio.jsp?osti_id=15 010373.

Venktesh Singh did his maters from Avadh University, Faizabad in 1991 and earned doctorate degree in 1998 from Banaras Hindu University. Did several years of postdoctoral ship in USA and Taiwan and joined as Asstt. Professor in Banaras Hindu University in 2005. He is experimentalist, effectively contributing in PHENIX, CBM, TEXONO, INO, NOvA and LBNE collaborations. Currently focused on the study of neutrino properties and search for dark matter particles. At Banaras Hindu University our group consists of two (03) faculties and 12 research students,a complete blend of theory and experiment.