Asociación Argentina de Astronomía
Boletín de artículos científicos

Expected neutrino background for the future ANDES laboratory

M.M. Saez[1], K.J. Fushimi[1], M.E. Mosquera[1,2] & O. Civitarese[2,3]

[1] *Facultad de Ciencias Astronómicas y Geofísicas, UNLP, Argentina*
[2] *Departamento de Física, UNLP, Argentina*
[3] *Instituto de Física de La Plata, CONICET–UNLP, Argentina*

Contact / msaez@fcaglp.unlp.edu.ar

Resumen / Existen diversos detectores operativos que buscan señales de partículas de materia oscura mediante técnicas de detección directa, todos ellos ubicados en el hemisferio norte. Actualmente, hay dos proyectos en desarrollo con el objetivo de tomar datos desde el Sur. Uno es el experimento SABRE en Australia, que ya se encuentra en fase de prueba. El otro, es el laboratorio ANDES, un laboratorio subterráneo que se prevé instalar en la provincia de San Juan, Argentina, en el complejo Agua Negra. El detector directo de materia oscura que albergará el laboratorio ANDES medirá diferentes señales de fondo de neutrinos. En particular, dos contribuciones dependientes de la ubicación serán los geoneutrinos y los neutrinos originados en reactores. Hemos calculado el fondo de neutrinos para el sitio específico del laboratorio ANDES, incluidos los flujos de neutrinos de reactores y geoneutrinos, y los comparamos con los esperados en otros detectores de xenon existentes. Estos estudios esperan modelar algunas de las señales esperadas en el detector y contribuir a las estrategias de detección de materia oscura que maximicen las capacidades de detección del futuro laboratorio ANDES.

Abstract / There exist several operational detectors looking for signals from dark matter particles through direct detection techniques, all located in the Northern Hemisphere. There are currently two projects under development with the goals of taking data from the South. One is the SABRE experiment in Australia, already in the testing phase. The other is the ANDES laboratory, an underground laboratory planned to be settled in the province of San Juan, Argentina, in the Agua Negra complex. Different neutrino backgrounds will be measured by the direct dark matter detector that will host the ANDES laboratory. In particular, two location-dependent contributions will be the geoneutrinos and the reactor neutrinos background. We have calculated the neutrino floor at the site of the lab, including the neutrino fluxes from reactors and geoneutrinos, and compared them with those expected from other existing xenon detectors. These studies hope to model some expected detector signals and contribute to dark matter detection strategies that maximize the future ANDES laboratory detection capabilities.

Keywords / astroparticle physics — neutrinos — dark matter

1. Introduction

The nature of dark matter remains one of the most pressing issues in modern physics. Dark matter has not yet been directly detected, but there is evidence presented in observations at galactic scales, galaxy clusters, and cosmological observables that much of the Universe is dark (Rubin & Ford, 1970; Zwicky, 1933; Clowe et al., 2006; Aghanim et al., 2020; Schumann, 2019).

One of the most promising dark matter candidates, along with the axions, are the weakly interacting massive particles (WIMPs). If the Galaxy has a dark halo composed of WIMPs, many of them should pass through the Earth and interact with matter. Direct dark matter detection experiments seek to measure the energy deposited when a dark matter particle interacts with a nucleus in a detector. The recoiling nucleus can deposit energy in the form of ionization, heat or light, signals that could be later detected (Goodman & Witten, 1985; Wasserman, 1986). While weakly interacting massive particles remain a theoretically well-motivated dark matter candidate (Majumdar, 2014), despite significant efforts, no convincing detection signatures have been observed and a sizable portion of the allowed parameter space has been constrained. Planned next-generation large-scale direct detection experiments will further explore the uncharted corners of WIMP interaction type, candidate mass, and cross-section. These experiments eventually reach a background (called neutrino-floor) from the coherent scattering of neutrinos produced from different sources (Sun, atmosphere, Earth, reactors, among others). This neutrino signal constitutes in itself an interesting subject of study, and reliably investigations can be conducted even though we do not yet know which is the appropriate dark matter candidate.

Among the neutrino-floor components, the geoneutrinos and the reactor neutrino background contributions are those that are strongly dependent on the location. Geoneutrinos are electron antineutrinos originated within the Earth's interior by radioactive decays of ^{238}U, ^{232}Th, and ^{40}K. The geoneutrino fluxes are sensitive to the width of the Earth's crust below the laboratory site. Its study can provide important information about the heat production mechanisms and the chemical composition of the Earth's interior. Kam-

Poster contribution

LAND and Borexino experiments have already reported signals of electron antineutrinos produced in the decay chains of thorium and uranium in the Earth's crust and mantle, the reported observations correspond to inverse beta-decay reactions (Araki et al., 2005; Bellini et al., 2010), but due to its low intensity, the geoneutrino signal has not been extensively studied in direct detection dark matter searches, with the exception of some works (Monroe & Fisher, 2007; Gelmini et al., 2019). On the other hand, the electron antineutrinos are also produced in nuclear reactors by fission beta decays of ^{238}U, ^{235}U, ^{239}Pu, and ^{241}Pu. The reactor neutrinos are the primary source of background noise, and they will depend on the distances between the laboratory and the main contributing reactors.

The currently running dark matter direct detectors are located in the Northern Hemisphere, except for two projects to install detectors in the South. On the one hand, there is the SABRE experiment in Australia (Antonello et al., 2019), in PoP (Proof of Principal) phase, whose goal is to build a twin detector to the one used by the DAMA collaboration in order to compare the results obtained and avoid seasonal effects. On the other hand, the ANDES Laboratory (Civitarese, 2015; Bertou, 2012; Machado et al., 2012), which consists on the design and construction of an underground laboratory on a site adjacent to the future *Agua Negra Tunnel complex* in the Province of San Juan, Argentina (http://andeslab.org).

In this work, we have calculated the expected neutrino background produced by reactors and geoneutrinos at the ANDES laboratory site. In addition, we have analyzed the expected variations in the signals due to different geographical locations, by comparing them with the signals expected in the xenon detectors of SURF and Gran Sasso laboratories.

2. Results

In order to make predictions for the ANDES laboratory, we consider a reference detector of ^{131}Xe and the corresponding location of the ANDES site ($30°30'S$, $69°53'W$). The interaction of a neutrino with a xenon nucleus in a detector through a coherent scattering causes the nucleus to recoil with a differential rate (Lang et al., 2016)

$$\frac{dR}{dE_{\rm nr}} = N_{Xe}\int_{E^{min}} dE F_{\nu_\beta}\frac{d\sigma}{dE_{\rm nr}}(E, E_{\rm nr})\,, \quad (1)$$

here N_{Xe} is the amount of target nuclei per tonne of xenon and $E^{min} = \sqrt{m_A E_{\rm nr}/2}$, with m_A being the mass of the target nucleus. F_{ν_β} is the neutrino flux of β flavor, and $\frac{d\sigma}{dE_{\rm nr}}$ is the corresponding neutrino-nucleus scattering cross-section (Drukier & Stodolsky, 1984)

$$\frac{d\sigma}{dE_{\rm nr}}(E, E_{\rm nr}) = \mathcal{C}\left(1 - \frac{m_A E_{\rm nr}}{2E^2}\right)F^2(E_{\rm nr})\,, \quad (2)$$

where $\mathcal{C} = \frac{G_F^2 m_A}{4\pi}Q_W^2$, G_F is the Fermi constant, $Q_W = N - (1 - 4\sin^2(\theta_W))Z$, is the weak hypercharge (N and Z are the neutron and proton number respectively). Lastly, $F(E_{\rm nr})$ is the Helm nuclear form factor (Helm, 1956).

2.1. Expected neutrino signal at ANDES detector

The expected geoneutrino fluxes shown in Table 1 have been obtained following the References Machado et al. (2012); Wan et al. (2017); Huang et al. (2013) and assuming a fully radiogenic Earth. The reactor signal for ANDES laboratory was calculated following the References Mueller et al. (2011); Gelmini et al. (2019) and taking into account the Argentinian and Brazilian reactors listed in Table 2. The fission fraction and the average released energy for each nuclear reactor isotope were taken from Reference Gelmini et al. (2019) and for the neutrino spectra, we used the one modelled in Reference Mueller et al. (2011), based on a phenomenological fit to data. Once the reactor and geoneutrino fluxes were obtained, we calculated the interaction rate for each signal following equation 1. The differential recoil rates for the geoneutrino and reactor signals expected at ANDES laboratory, are presented in Figure 1. In addition, we show the total neutrino floor expected for the site, which also includes contributions of solar and atmospheric neutrinos. We have assumed the solar fluxes predicted in reference Haxton et al. (2013), and the atmospheric flux predictions given in reference Battistoni et al. (2005).

Component	Flux [10^6 cm^{-2}s^{-}1]
U	5.40
Th	5.05
K	24.04

Table 1: Geoneutrino fluxes of uranium, thorium and potassium expected at the ANDES laboratory.

Reactors	Power [MWt]	Location	Distance [km]
Atucha I	1179	$33°58'S$ $59°12'W$	1084
Atucha II	2160	$33°58'S$ $59°12'W$	1084
Embalse	2064	$32°13'S$ $64°26'W$	553
Angra I	1882	$23°0'S$ $44°27'W$	2640
Angra II	3764	$23°0'S$ $44°27'W$	2640

Table 2: Argentina and Brazil nuclear reactors near to the ANDES laboratory. The distance shown in the last column represents the distance between the nuclear power plant and the ANDES laboratory.

2.2. Comparison with other xenon detectors

Given that the studied signals depend on the laboratory location, we have performed comparisons with two other xenon detectors: the LUX detector in the Sanford Underground Research Facility (SURF), and the Xenon1T detector, situated below Gran Sasso mountain in Italy.

In Figure 2 we show the ratio between the expected rates in ANDES and Gran Sasso, and between ANDES and SURF, for the geoneutrino (upper panel) and reac-

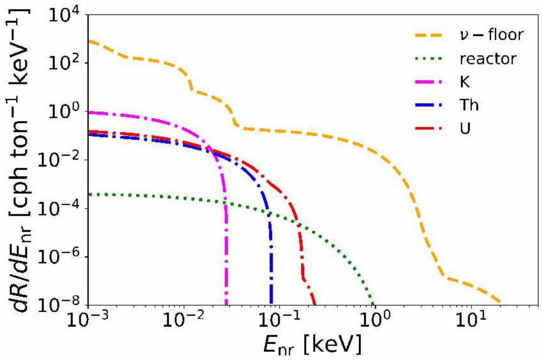

Figure 1: Differential recoil rates of neutrino background contributions for the test detector of ^{131}Xe at ANDES lab. Dashed-line: total neutrino floor; dotted-line: reactor contributions; dotted-dashed-lines: geoneutrino contributions.

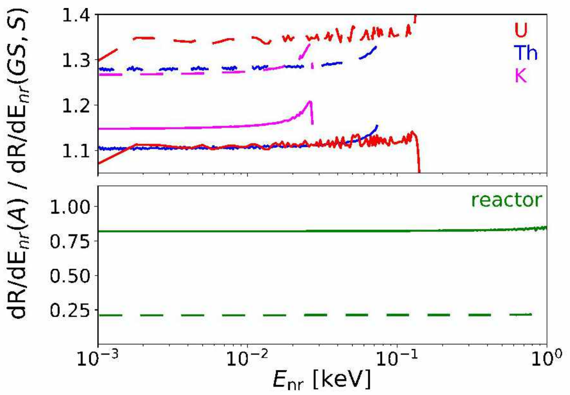

Figure 2: Ratio of differential recoil rates expected for the ANDES laboratory ($dR/dE_{nr}(A)$) with respect to the expected at the Gran Sasso (GS) and SURF (S) laboratories ($dR/dE_{nr}(GS, S)$). Solid lines: comparison with SURF detector. Dashed lines: comparison with Gran Sasso detector. Upper panel: ratio of geoneutrino signals. Bottom panel: ratio of the reactor signals.

tor (lower panel) components. Given that the ANDES laboratory would be located near the subduction of the Pacific and Continental tectonic plates, an area with one of the thicker Earth's crust, the geoneutrino signal might be more significant than in other laboratory sites (Gelmini et al., 2019; Huang et al., 2013; Machado et al., 2012). In particular, we observe that the rate generated by geoneutrinos in ANDES is 20% higher than expected in Gran Sasso and 10% higher than expected in SURF. Instead, the reactor neutrino background in ANDES is expected to be 80% smaller than the measured in Gran Sasso since the latter receives neutrinos from the Tricastin, Cruas, St. Alban, and Bugey reactors. In the case of LUX, the SURF laboratory receives neutrinos from the Monticello, Prarie Island, and Cooper Nuclear Station reactors. We find that the reactor neutrino background in ANDES results 25% smaller than the measured in SURF location.

3. Conclusions

We have made specific predictions for the ANDES laboratory, considering a reference detector of xenon. We have evaluated the neutrino floor, including the neutrino fluxes from reactors and geoneutrinos specifics for the laboratory site. For the ANDES reactor component, we have considered the operative reactors Atucha I, Atucha II, Angra I , Angra II, and Embalse. For the geoneutrino signal, we have calculated the contributions corresponding to U, Th, and K. To infer the features that should be observed due to the change of location, we have compared the expected signal between the test ANDES detector and the Xenon1T and LUX detectors. We have found that the noise from reactors in ANDES is lower than in the other sites studied, while the geoneutrino signal is higher. These results place ANDES as one of the laboratories with the best conditions to carry out geoneutrinos-related studies. This work hopes to contribute to a better understanding of the expected background in the next generation of experiments that could take place in the future ANDES laboratory.

Acknowledgements: This work was supported by a grant (PIP-2081) of the National Research Council of Argentina (CONICET), and by a research-grant (PICT 140492) of the National Agency for the Promotion of Science and Technology (ANPCYT) of Argentina. O. C. and M. E. M. are members of the Scientific Research Career of the CONICET, M. M. S. is a Post Doctoral fellow of the CONICET and K. J. F. is a Doctoral fellow of the CONICET.

References

Aghanim N., et al., 2020, A&A, 641, A6
Antonello M., et al., 2019, EPJ C, 79, 363
Araki T., et al., 2005, Nature, 436, 499
Battistoni G., et al., 2005, Astropart. Phys., 23, 526
Bellini G., et al., 2010, Phys. Lett. B, 687, 299
Bertou X., 2012, Eur. Phys. J. Plus, 127, 104
Civitarese O., 2015, Nuclear and Particle Physics Proceedings, 267-269, 377. X Latin American Symposium of High Energy Physics
Clowe D., et al., 2006, Astrophys. J., 648, L109
Drukier A., Stodolsky L., 1984, Phys. Rev. D, 30, 2295
Gelmini G.B., Takhistov V., Witte S.J., 2019, Phys. Rev. D, 99, 093009
Goodman M.W., Witten E., 1985, Phys. Rev. D, 31, 3059
Haxton W., Hamish Robertson R., Serenelli A.M., 2013, ARA&A, 51, 21
Helm R.H., 1956, Phys. Rev., 104, 1466
Huang Y., et al., 2013, Geochemistry, Geophysics, Geosystems, 14, 2003
Lang R.F., et al., 2016, Phys. Rev. D, 94, 103009
Machado P., et al., 2012, Phys. Rev. D, 86, 125001
Majumdar D., 2014, *Dark Matter: An Introduction*, Taylor & Francis
Monroe J., Fisher P., 2007, Phys. Rev. D, 76, 033007
Mueller T.A., et al., 2011, Phys. Rev. C, 83, 054615
Rubin V.C., Ford W. Kent J., 1970, Astrophys. J., 159, 379
Schumann M., 2019, JPG, 46, 103003
Wan L., et al., 2017, Phys. Rev. D, 95, 053001
Wasserman I., 1986, Phys. Rev. D, 33, 2071
Zwicky F., 1933, Helv. Phys. Acta, 6, 110