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Search for dark matter annihilation in the earth using the ANTARES neutrino telescope

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ABSTRACT

A search for a neutrino signal from WIMP pair annihilations in the centre of the Earth has been performed with the data collected with the ANTARES neutrino telescope from 2007 to 2012. The event selection criteria have been developed and tuned to maximise the sensitivity of the experiment to such a neutrino signal. No significant excess of neutrinos over the expected background has been observed. Upper limits at 90% C.L. on the WIMP annihilation rate in the Earth and the spin independent scattering cross-section of WIMPs to nucleons σ_p^{SI} were calculated for WIMP pair annihilations into either $\tau^+\tau^-$, W^+W^-, $b\bar{b}$ or the non-SUSY $\nu_\mu\bar{\nu}_\mu$ as a function of the WIMP mass (between 25 GeV/c^2 and 1000 GeV/c^2) and as a function of the thermally averaged annihilation cross section times velocity $\langle\sigma_A v\rangle_{Earth}$ of the WIMPs in the centre of the Earth. For masses of the WIMP close to the mass of iron nuclei (50 GeV/c^2), the obtained limits on σ_p^{SI} are more stringent than those obtained by other indirect searches.

1. Introduction

The Universe consists of a large fraction of dark matter (DM) [1–3]. DM particles do not interact electromagnetically, are stable on cosmological time scales, cannot be dominantly baryonic, and must move with non-relativistic speeds already at the structure formation epoch. The DM relic abundance today as a result of thermal production requires a particle with a thermally averaged annihilation cross-section of about

$$\langle\sigma_A v\rangle = 3 \cdot 10^{-26} \quad \mathrm{cm}^3\mathrm{s}^{-1}, \tag{1}$$

which is the natural scale at which a weakly-interacting particle [4] would be expected. The hypothetical Weakly Interacting Massive Particles (WIMPs) are therefore widely regarded as excellent DM candidates. Such particles arise in different theories, such as supersymmetric (SUSY) models [4] (the fact that SUSY predicts a particle with the right properties is often referred to as the 'WIMP miracle') or models with extra dimensions [5]. WIMPs from supersymmetric models, such as the Minimal Supersymmetric Extension of the Standard Model are widely regarded as the most promising dark matter candidates. In most cases the lightest supersymmetric particle is the lightest neutralino.

WIMPs can be detected either in collider experiments by observing missing energy and momentum in particle collisions, directly via the observation of the nuclear recoils from the scattering of WIMPs off nuclei [6–9] or indirectly [10] via the observation of products from WIMP self-annihilations.

Most indirect experiments rely on the fact that DM particles present in the Galactic halo may lose energy by interacting with nuclei of massive objects, as for example the Sun and the Earth itself, and may accumulate in the centre of these bodies under their gravitational potential. As shown in Section 2, the accumulated DM particles may then self-annihilate. Among the final-state particles of the decay products, neutrinos can almost freely escape the massive objects, reaching neutrino telescopes located near the surface of the Earth. The energy spectrum of the produced neutrino flux depends on the specific nature of DM particles [11] (in the following, the WIMP scenario will be assumed), the DM annihilation channel and mass. The expected neutrino event rates are also a function of the DM local density and velocity distribution and of the chemical composition of the celestial trapping object.

Searches for neutrinos from the direction of the Sun [12–16] of the Galactic Centre [17,18] and of the Earth core [19,20] have already been carried out by neutrino telescopes and other neutrino experiments [21,22].

WIMPs become gravitationally bound to the Earth if their velocity is smaller than the escape velocity from Earth, which ranges from 11.1 km/s to 14.8 km/s (at the surface and at the centre respectively). The velocity of WIMPs follows a Maxwell–Boltzmann distribution, the canonical value for the velocity dispersion is 270 km/s (this value is subject to considerable uncertainty [4]). Under these conditions, only a small fraction of WIMPs would lose enough energy to become captured if there is a large difference between the mass of the WIMP and the mass of the nucleus the particle is scattering on. Capture of WIMPs in the Earth is expected