PROCEEDINGS OF SCIENCE

Dark matter searches with the Super-Kamiokande detector

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This work presents indirect searches for dark matter as WIMPs (Weakly Interacting Massive Particles) using neutrino data recorded by the Super-Kamiokande detector from 1996 to 2014. No excess of neutrinos from possible dark matter sources such as Galactic Center, Sun and Earth, compared to the expected atmospheric neutrino background was found. Event samples including both electron and muon neutrinos covering a wide range of neutrino energies were used, with sensitivity to WIMPs masses down to tens of GeV.

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1. Introduction

Dark matter composes about 27% of the total mass-energy of the Universe [1]. It neither emits nor absorbs electromagnetic radiation and therefore cannot be observed directly with telescopes. However, there is a great diversity of ongoing global efforts to detect or produce dark matter particles. Indirect searches aim at the detection of dark matter annihilation products such as charged particles, photons or neutrinos in the fluxes of cosmic rays. The latter, can be produced directly or in subsequent decays of mesons and leptons. They provide very good information on their source position and energy spectra generated in dark matter annihilation processes.
Super-Kamiokande (SK) is the 50 kton water Cherenkov detector located in the Kamioka Observatory of the Institute for Cosmic Ray Research, University of Tokyo [2]. The experiment was designed to search for proton decay, study solar, atmospheric and man-made ν's, and keep watch for supernovae. Detection of neutrino interactions is based on observations of charged particles, which produce Cherenkov radiation while moving faster than c in water. The detected light gives information to reconstruct energy, direction and flavour of produced lepton.

2. Analysis

Among all neutrino sources it is worth discussing atmospheric neutrinos as they have the same energy range as is expected for WIMP induced neutrinos. In the analysis is assumed that atmospheric neutrino data collected with the SK detector could be described by two components: WIMP-induced ν's (signal) and atmospheric ν's (background). Separate Monte Carlo sets are used to simulate signal and background to avoid correlations. In order to simulate the signal, DarkSUSY [3] and WimpSim [4] are used. The models are prepared for three possible soucers (Galactic Center, Sun and Earth), different annihilation channels, and various masses of dark matter particles. The best combination of signal and background that would fully explain the data will be tried to find using a fit method. There are 18 data samples including both ν_e-like and ν_μ-like event categories used in the analyses. Each sample is binned in momentum and the cosine of the angle between event direction and direction of the Sun, Earth or the Galactic Center (depends on the considered source). The signal is largely peaked in the direction of the source, while the background is not, which enables for an effective discrimination. Additional constraints can be obtained based on neutrino energy information and proportions of signal to background in various event subsamples. Based on the simulation we perform a fit to the collected data and estimate how many WIMP-induced ν's can be contained in SK data so far.

3. Results

3.1 Galactic WIMP search

No significant contribution of WIMP-induced ν's from the Galactic Center is allowed by the data in addition to the atmospheric neutrino background. For each annihilation channel based on the limit on WIMP-induced diffuse neutrino flux, we can derive 90% CL limits on dark matter self-annihilation cross section $\langle \sigma_A V \rangle$ as a function of M_χ, as shown in Fig. 1.

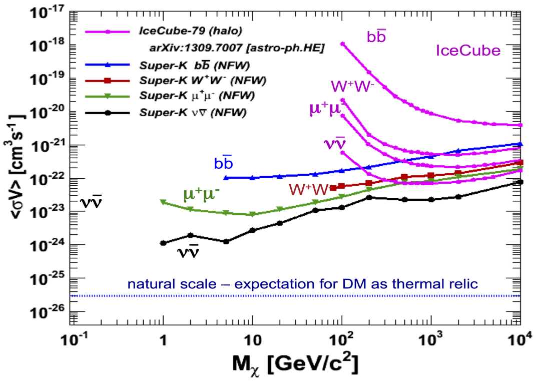

Figure 1: 90% CL upper limits on velocity-averaged dark matter self-annihilation cross section $\langle\sigma_A V\rangle$. SK limit for $\nu\bar{\nu}$ (black), $b\bar{b}$ (blue), W^+W^- (red) and $\mu^+\mu^-$ (green) annihlation modes are based on expected signal intensity from NFW halo profile [5]. The limits from the IceCube detector are indicated with purple solid lines [6]. The line at the $\langle\sigma_A V\rangle = 3\cdot10^{-26}$ cm^{3}s^{-1} is the expectation for dark matter produced thermally in the Universe's evolution [7].

3.2 Solar WIMP search

For all tested WIMP hypotheses, no contribution of dark matter induced ν's from the Sun has been found. The derived limits on the muon-neutrino flux from dark matter annihilation were converted to upper limits on WIMP-nucleon cross-section using DarkSUSY [3]. Different types of dark matter interaction with a nucleus, either an axial vector in which WIMPs couple to the nuclear spin (spin dependent, SD) or a scalar interaction in which WIMPs couple to the nucleus mass (spin independent, SI), were considered separately. We assumed a standard dark matter halo with local density 0.3 GeV/cm^3 [5], a Maxwellian velocity distribution with an RMS velocity of 270 km/s and a solar rotation speed of 220 km/s. The results are plotted together with other experimental results in Fig. 2 for SD coupling and Fig. 3 for SI coupling for the isospin-invariant case. The uncertainties related to the WIMP capture process are indicated by the shadowed regions (detailed description can be found in [8]).

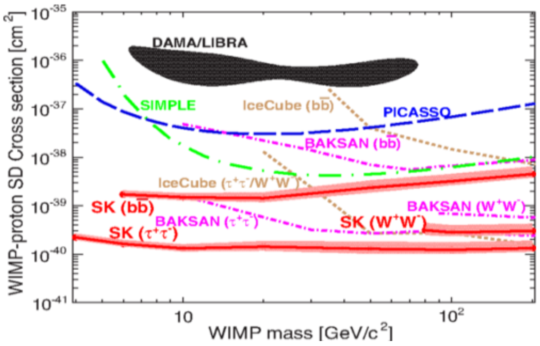

Figure 2: 90% CL upper limits on SD WIMP-proton cross section are shown in red solid with uncertainty bands to take account uncertainties in the capture rate for the $b\bar{b}$, W^+W^- and $\tau^+\tau^-$ channels from top to the bottom. Also limits from other experiments: IceCube (dashed brown), BAKSAN (dot-dashed pink), PICASSO (long-dashed blue) and SIMPLE (long dot-dashed green) are shown. The black shaded contour is the 3σ CL allowed region claimed by DAMA/LIBRA (see [8] for references).

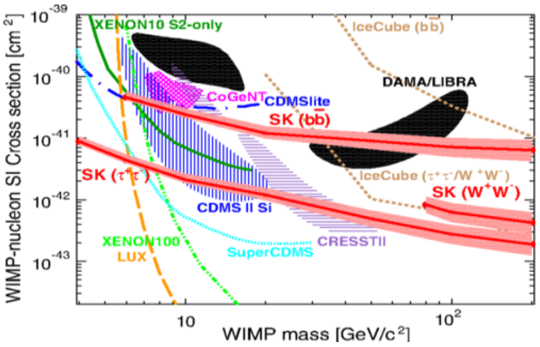

Figure 3: 90% CL upper limits on the SI WIMP-nucleon cross section. Also event excesses or annual modulation signals reported by other experiments: DAMA/LIBRA (black, 3σ CL), CoGeNT (magenta, 90% CL), CRESSTII (violet, 2σ CL), CDMS II Si (blue, 90% CL), and limits: IceCube (dashed brown), SuperCDMS (dotted cyan), CDMSlite (long dot-dashed blue), XENON10 S2-only (dash triple dot dark green), XENON100 (dash double dot green) and LUX (long-dashed orange) are shown (see [8] for references).

3.3 Earth WIMP search

For the Earth, the SI interaction dominates in the capturing process. The rate at which dark matter particles are captured in the Earth depends on their mass. If it almost matches one of the heavy elements in the Earth, the capture rate will increase considerably (see Fig. 4). The preliminary results of sensitivity studies are plotted together with other experimental results in Fig. 5.

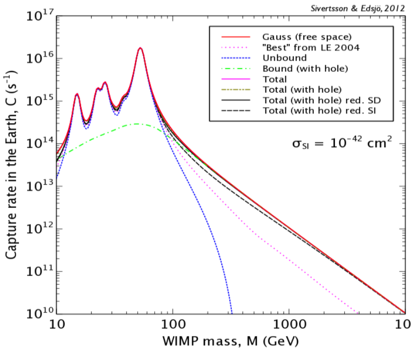

Figure 4: Capture rate for WIMP particles in the Earth [9]. The peaks correspond to resonant capture on the most abundant elements ^{16}O, ^{24}Mg, ^{28}Si and ^{56}Fe and their isotopes.

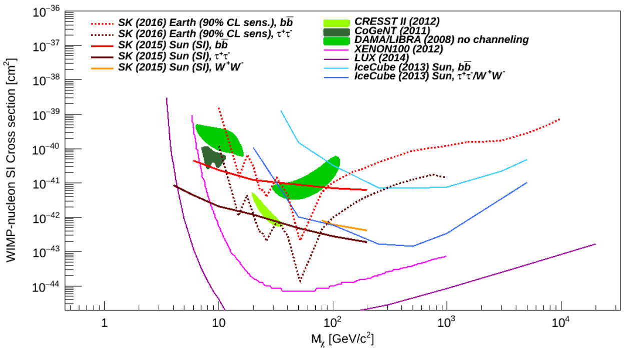

Figure 5: Dashed lines show 90% CL upper limits on SI WIMP-nucleon cross section estimated from sensitivity studies. Background only scenario was assumed. Also limits from other experiments and SK Solar WIMP search are shown (see [8] for references).

Acknowledgments

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