学位報告４

別紙４

報告番号	※　　甲　　第　　　　　号

主　論　文　の　要　旨

論文題目　Study of capture and annihilation of a few GeV WIMPs inside the Sun by using an underground neutrino detector
（地下ニュートリノ検出器を用いた太陽による数 GeV 質量 WIMP の捕獲と対消滅の研究）

氏　　名　CHOI Koun

論　文　内　容　の　要　旨

Dark matter is an enigmatic invisible existence to most of gravity of the universe. Weakly interacting massive particles (WIMPs) are favored as particle candidates for non-baryonic cold dark matter, as their interaction strength can explain the thermal relic abundance of dark matter. Recent event excesses or annual modulation signals reported by direct detection experiments such as DAMA/LIBRA, CoGeNT, CRESST and CDMS II Si would suggest possible evidence for WIMPs with light mass in a few or a few tens of GeV/c^2. However, they conflict with null results from other experiments such as XENON100, LUX and SuperCDMS. A promising way to identify a WIMP particle is to search for excess of a high-energy neutrino flux coming from the Sun, called “solar WIMP search”. WIMPs in the dark matter halo could scatter off nuclei inside the Sun and be captured, then pair-annihilate producing neutrinos from decays of the annihilation products which propagate through the Sun and may be detected in neutrino detectors. Thanks to the hydrogen-rich composition and huge gravity of the Sun, tight limits on the scattering cross section of WIMPs to protons by spin-dependent interaction have been placed by neutrino telescopes such as Super- Kamiokande, IceCube, Baksan and ANTARES.

For critical interpretation of indirect search by neutrino detectors and comparison to direct detection experiments, astrophysical uncertainties are a key issue. Especially for light WIMP region, the velocity distribution of WIMPs in the dark matter halo are known to be a large uncertainty source for direct detection searches. The effect of the uncertainties from velocity distribution of WIMPs in the solar WIMP search are precisely evaluated. We examine various sources of uncertainties including local circular speed of the Sun, high-velocity cut of halo, halo shapes from cosmological simulations and the existence of the dark disc. We conclude that the impact from the uncertainties on the velocity distribution on solar WIMP search are not significant. The estimated size of the total uncertainty is found to be less than 24% for 20 GeV/c^2 WIMPs for scenarios without the dark disc. For heavier WIMPs, the uncertainty is larger but still below about 50%.

Super-Kamiokande (SK), a Water Cherenkov neutrino observatory located in Kamioka mine in Japan, is used to search for light WIMPs. The signal acceptances for a few GeV/c^2 WIMPs are improved by one to two orders of magnitude by using vertex- contained type of neutrino events, which is much better sensitivity for spin-dependently coupling WIMPs than any other direct detection experiments. To discriminate signal from overwhelming atmospheric neutrino background events, we perform a least- squares fit on event bins finely defined by using angle, energy and flavor information. By fitting 3,903-days of SK I-IV data, we examine the best-fit contribution of WIMP- induced neutrino events added to back-ground events. For the tested 4–200 GeV/c^2 WIMP masses and several annihilation channels, the data is in agreement with no- WIMP contribution and new constraints on WIMP-nucleon cross-sections are obtained. We set the current best limit on the spin-dependent (SD) WIMP-proton cross section for WIMP masses below 200 GeV/c^2 (at 10 GeV/c^2, 1.49×10^{-39} cm^2 for $\chi\chi \rightarrow b\bar{b}$ and 1.31×10^{-40} cm^2 for $\chi\chi \rightarrow \tau^+\tau^-$ annihilation channel), also eliminating $\tau^+\tau^-$ dominantly annihilating WIMPs with spin-independent (SI) coupling as a candidate for DAMA and CoGENT claimed signals. We also rule out some new parameter space for SI coupling WIMPs below 6 GeV/c^2 by $\tau^+\tau^-$ annihilation channel.

The upper limit on SD or SI WIMP-nucleon scattering cross sections obtained in this work carries an uncertainty of about 30% for 4 GeV/c^2 WIMP, which increases for higher WIMP masses and resulting up to 60% (100%) for SD (SI) coupling WIMPs of 200 GeV/c^2 mass. The possibility of the co-rotating dark disc can largely boost the signal and hence makes the interpretation of solar WIMP search conservative compared to direct detection. In this thesis, astrophysical uncertainties, including uncertainties from the velocity distribution, are quantified and reflected on the new limits from the SK for the first time. We also find that the contradistinctive responses to high- velocity and low-velocity tails of direct and indirect detections tell us that a solar WIMP search can be a good complementary method to entangle uncertainties afflicting direct detection. In terms of not only good sensitivity for signal but also unique sensitivities and insensitivities to astrophysical properties, the usefulness of this result and the searches from future neutrino detectors are highlighted.