Direct Dark Matter Search by Annual Modulation

[Recent results from XMASS]

September-7, 2015

SUMMARY
The XMASS experiment conducted a search for dark matter by means of the annual modulation caused by the earth’s rotation around the sun. The data used for this analysis was accumulated between November-2013 and March-2015.

A model independent analysis showed a weak modulation effect, however, this result could be explained by a fluctuation of the background at the level of 7 to 17%. If we assume the standard WIMP dark matter, we can exclude almost all the allowed region claimed by the modulation result of the DAMA/LIBRA experiment in Italy. This is the first extensive search over their allowed region exploiting the annual modulation with high statistic data.

EXPLANATION
There are many strong evidences that dark matter exists in our universe with the amount of 5 to 6 times larger than the ordinary matter. However, we do not know what dark matter is. Among many candidates of dark matter particles, it is thought that WIMPs (Weakly Interacting Massive Particles) is one of the well-motivated ones. However, there is no experimental indication of WIMPs yet in direct dark matter search experiments. This negative situation is also true so far for the collider experiment where we expect such particles to be produced. In this situation, it is natural that the other dark matter candidates are getting highlighted.

Contrast to the standard ‘heavy mass’ WIMPs, the ‘light mass’ WIMPs is also one of those candidates. In fact, there exists a confusing situation for the ‘light mass’ WIMP region. Namely some experiments indicate the signal but others do not, and this situation has been persistent for more than 10 years. The DAMA/LIBRA experiment claimed a positive evidence of the annual modulation with more than 9 $\sigma$ effect in their 1.33 ton $\cdot$ years of data taken over the 13 annual cycles with the 100
kg to 250 kg of NaI scintillator crystals.

The XMASS experiment at Kamioka in Japan holds 832 kg of liquid xenon as a target material for the interaction of the dark matter particles, and is able to reach the DAMA/LIBRA exposure in less than two years. In addition to that, comparing to their energy threshold of 2keV, the lower energy threshold of about 1keV achieved by XMASS will allow higher sensitivity for the dark matter searches.

In November 2013, after refurbishing the detector to reduce the background that was found in the commissioning run of XMASS, we have successfully resumed the data taking. We have carried out the annual modulation search by using data until March in 2015.

XMASS detector is sensitive not only the nuclear recoil signal from WIMPs, but also the electron and gamma signals emitted from, for example, interactions with electrons in the Xe atoms of other candidates of dark matter.

Due to this fact we have performed a dark matter model independent analysis as well as the model dependent analysis assuming the standard WIMPs. In the case of model independent analysis, we found a weak modulation effect, however, this result could be explained by a fluctuation of the background at the level of 7 to 17% and therefore not significant (Fig.1). In the case of the standard WIMP dark matter model, we have constrained the deposited energy spectrum to the expected recoil energy of the scattering of WIMPs. The result excluded almost all the allowed region of the DAMA/LIBRA experiment (Fig.2). This is the first extensive search over their allowed region exploiting the annual modulation with high statistic data.

The WIMP events observed in the detector are expected to be highest rate in June and lowest in December due to the rotation of the earth around the sun. However, if the detector energy threshold is low enough, we might see some energy regions where we expect to observe lower count rate in the summer, so-called the ‘cross over’ phenomena. With the current XMASS threshold, we start to see the cross over above ~60GeV WIMP mass. The current result favors this cross over although the
statistical significance is small. In this analysis, the best fit parameters are about 100 GeV WIMP mass at 2-3σ.

However, in this case, the expected event from the best fit parameters exceed our total observed event, therefore this results contradict internally and therefore not physical.

To improve our result and deepen the understanding, XMASS will continue to take more data and make effort to reduce systematic uncertainty.

These results will be reported at TAUP2015 conference at Torino in Italy that will start from September 7.

XMASS collaboration consists of
Kamioka Observatory, Institute for Cosmic Ray Research, the University of Tokyo;
Kavli Institute for the Physics and Mathematics of the Universe (WPI), the University of Tokyo;
Information and Multimedia Center, Gifu University;
Department of Physics, Kobe University;
Miyagi University of Education;
Solar Terrestrial Environment Laboratory, Nagoya University;
Kobayashi-Masukawa Institute for the Origin of Particles and the Universe, Nagoya University;
Department of Physics, Tokai University;
Department of Physics, Tokushima University;
Department of Physics, Faculty of Engineering, Yokohama National University;
Center for Underground Physics, Institute for Basic science, Korea;
Korea Research Institute of Standards and Science, Department of Physic, Korea;

The program is the inter-university cooperative research program at Kamioka underground observatory.

Spokesperson of the XMASS Collaboration:
Yoichiro Suzuki
Kavli Institute for the Physics and Mathematics of the
Universe (WPI), the University of Tokyo

Director of Kamioka Observatory:
Masayuki Nakahata
Kamioka Observatory, Institute for Cosmic Ray Research,
the University of Tokyo
Fig. 1. Data points show observed amplitude of the seasonal variation (vertical axis) as a function of energy (horizontal axis). We do not explain the energy scale here, but note that the energy scale for electron events is shown in keVee. Green(1σ) and yellow(2σ) bands the probability of the background fluctuation.

Fig. 2. Comparison of the WIMP-nucleon cross sections of the past and the current experiments. The black solid curve labeled XMASS shows the 90% C.L. upper limit obtained by the seasonal variation analysis. Green (1σ) and yellow (2σ) bands show the sensitivity of this analysis.