Sensitivity Study for Dark Matter Experiments Searching for Annual Modulation

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ABSTRACT

Dark matter (DM) is postulated to account for the "unseen" mass whose gravitational effects on galactic objects have been observed. Weakly interacting massive particles (WIMPs) are hypothetical particles serving as one of the solutions to the dark matter problem. We adopt the dark matter model in our galaxy in which the dark matter halo is nearly at rest relative to luminous matter in the Milky Way. Therefore, the flux of WIMPs depends on Earth's motion relative to dark matter. DM experiments search for the recoil events of WIMPs on target materials. The halo model predicts that as Earth orbits the sun, DM's modulating relative velocity induces seasonal fluctuation in dark matter event rates. The DArk MAtter experiment/NaI (DAMA/NaI) has sought for and claimed to observe such annual modulation signature. Nonetheless, the DAMA/NaI results are controversial because they are inconsistent with the null observations from other direct search experiments, such as CDMS and XENON100. As the modulation signal may be due to unknown background in the DAMA/NaI, different experiments are being proposed to cross-check DAMA/NaI modulation. In its early stage, an experiment is being proposed in the Southern Hemisphere because seasonal fluctuations therein are 180 degrees out of phase with the Northern Hemisphere where DAMA/NaI is located. In this paper, we first review and study the halo model in detail. We then further investigate several conditions for experiments to probe the DAMA/NaI allowed region. Assuming null observation of WIMP events and a Poisson distribution for background events, we study the effects of different exposure times, background levels, and energy thresholds on the limit curve. In order to rule out DAMA/NaI allowed region at 90% confidence level, we find corresponding background and exposure conditions necessary for the proposed experiments that search for annual modulation.