Astrometric Mock Observations for Determining the Local Dark Matter Density

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To determine the local dark matter density (LDMD) around the solar system is a classical problem in astronomy since [1]. In recent years, dedicated searches for candidates of dark matter (DM) particles have intensified. Experiments aiming at direct detection of the DM particles look for signals from recoil of DM particles with nuclei inside the detector. Thus, the event rates of the direct detection are clearly proportional to the LDMD around the solar system. This is why the problem of determining the LDMD at the solar position has recently been attracting a great deal of attention.

Recently, Garbari et al. [2,3] have devised a novel method to determine the LDMD from stellar distribution and vertical velocity dispersion profiles perpendicular to the Galactic plane, which they named a minimal assumption (MA) method. Their method has the advantages of abolishing conventional approximations and using only a few assumptions. Their determinations preferred higher dark matter densities than conventional values although the previous results are within their quoted errors.

This study is aimed at carefully scrutinizing the MA method and examining influence on the LDMD determination with the MA method by observational uncertainties. We discuss how the determinations of the LDMD vary with observational precisions on parallax, proper motion and line-of-sight velocity measurements. For these aims, we create mock observation data for stars being dynamical tracers based on an analytical galaxy model and apply parametrized observational errors to the mock data. We evaluate the accuracy of determining the LDMD by applying the MA method to the mock data. In addition, we estimate a sample size and observational precision required to determine the dark matter density with accuracy.

We find that the MA method is capable of determining the LDMD with accuracy if the sample size and observational precisions are satisfactory. The sample size required is approximately 6,000 stars. The random errors of parallaxes and proper motions can cause systematic overestimation of the dark matter density. We estimate the required precisions of the parallax measurements to be approximately 0.1–0.3 milliarcseconds at 1 kpc away from the sun; the proper motion precisions do not seem to be as important as the parallaxes. Also, we find that the line-of-sight velocity errors can cause either underestimation or overestimation of the dark matter density, which is contingent on distance-dependence of the errors.

From these results, we expect that use of the *Hipparcos* catalog would overestimate the LDMD because of the imprecise parallax measurements if the MA method is applied; however, we emphasize the capability of their method. [2] was making use of the *Hipparcos* catalog which might lead to their high LDMD. We expect that *Gaia* will provide data precise enough to determine the LDMD.

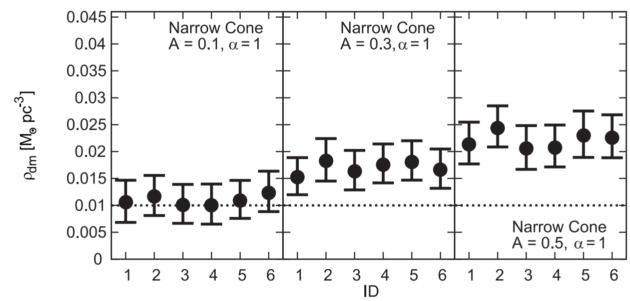

Figure 1: Influence of the astrometric distance errors on determining the LDMD. The panels from the left to right indicate the results of adopting A = 0.1 0.3 and 0.5, respectively, where A is parallax measurement precision at 1 kpc away from the sun. In each case, we conduct the same computation with different tracer samples generated in the same conditions (ID = 1–6) with 24,000 sample stars. The horizontal dotted line indicates the true LDMD assumed in our model.

References

[1] Oort, J. H.: 1932, *Bull. Astron. Inst. Neth.*, **6**, 249.
[2] Garbari, S., Read, J. I., Lake, G.: 2011, *MNRAS*, **416**, 2318.
[3] Garbari, S., Liu, C., Read, J. I., Lake, G.: 2012, *MNRAS*, **425**, 1445.