4D Modeling of the Kinematics of a Selected Subsystem of the Milky Way

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Abstract. When solving inverse problems of kinematic modeling of the Milky Way, even for a homogeneous subsystem of objects, the traditional difficulty is to take into account all the variances of the problem: the natural (dynamic) dispersion of the subsystem (ellipsoid of velocities), as well as the measurement uncertainties of the velocity components and heliocentric distances. The standard approach is 3D modeling, in which only velocity measurement errors are taken into account, often without assuming natural dispersion, and the solution is within the framework of the least squares method. However, ignoring the uncertainty of distances, as well as natural dispersion, can lead to significant systematic errors. This problem became especially relevant after the appearance of mass joint determinations of proper motions and trigonometric parallaxes (Galactic masers, Gaia catalog), since objects with large linear and relative errors in distances are inevitably present in such catalogs. The correct solution of the problem with the determination of all spatial-kinematic characteristics, as well as the velocity ellipsoid, taking into account variances of all types, is possible only within the framework of the maximum likelihood method. The corresponding algorithm—4D modeling—is developed and implemented in this paper. It involves minimizing the squares of relative deviations of the model from the observed radial velocity, proper motions, and distant characteristics with natural dispersions as unknown parameters. A distant characteristic is understood as a trigonometric parallax (in the case of absolute distances) or a distance modulus (in the case of relative, i.e. photometric, distances). The constructed iterative algorithm includes optimization of the smoothness of the rotation law and a flexible procedure for eliminating outliers in the data, generalized to a four-dimensional field of residuals. The new method allows us to obtain individual corrections for distances to sample objects. The method was tested on Galactic masers of the HMSFR type. It is shown that the inclusion of distance uncertainties in the probabilistic model greatly reduces estimates of natural velocity dispersions, and also significantly reduces the value of the distance from the Sun to the center of the Galaxy, R_0, obtained from masers. New estimate is $R_0 = 7.88 \pm 0.12$ kpc. Estimates of a number of other fundamental Galactic characteristics have been obtained.

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