The Present and Future Mass of the Milky Way Halo

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ABSTRACT
A simple model for the Milky Way halo is presented. It has a flat rotation curve in the inner regions, but the density falls off sharply beyond an outer edge. This truncated, flat rotation curve (TF) model possesses a rich family of simple distribution functions which vary in velocity anisotropy. The model is used to estimate the total mass of the Milky Way halo using the latest data on the motions of satellite galaxies and globular clusters at Galactocentric radii greater than 20 kpc. This comprises a dataset of 27 objects with known distances and radial velocities, of which 6 also possess measured proper motions. Unlike earlier investigations, we find entirely consistent maximum likelihood solutions unaffected by the presence or absence of Leo I, provided both radial and proper motion data are used. The availability of the proper motion data for the satellites is crucial as, without them, the mass estimates with and without Leo I are inconsistent at the 99% confidence level. All these results are derived from models in which the velocity normalisation of the halo potential is taken as $220 \text{ km s}^{-1}$.

A detailed analysis of the uncertainties in our estimate is presented, including the effects of the small dataset, possible incompleteness or correlations in the satellite galaxy sample and the measurement errors. The most serious uncertainties come from the size of the dataset, which may cause a systematic underestimate by a factor of two, and the measurement errors, which cause a scatter in the mass of the order of a factor of two. We conclude that the total mass of the halo is $1.9^{+1.6}_{-1.7} \times 10^{12} M_\odot$, while the mass within 50 kpc is $5.4^{+3.4}_{-1.7} \times 10^{11} M_\odot$. In the near future, ground-based radial velocity surveys of samples of blue horizontal branch (BHB) stars will reduce the uncertainty in the mass estimate to $\sim 20\%$. In the coming decade, microarcsecond astrometry will be possible with the Space Interferometry Mission (SIM) and the Global Astrometry Interferometer for Astrophysics (GAIA) satellites. For example, GAIA can provide the proper motions of the the distant dwarfs like Leo I to within $\pm 15 \text{ km s}^{-1}$ and the nearer dwarfs like Ursa Minor to within $\pm 1 \text{ km s}^{-1}$. This will also allow the total mass of the Milky Way to be found to $\sim 20\%$. SIM and GAIA will also provide an accurate estimate of the velocity normalisation of the halo potential at large radii.

Key words: Galaxy: fundamental parameters – Galaxy: kinematics and dynamics – Galaxy: halo

1 INTRODUCTION
The aim of this paper is to obtain a consistent estimate of the total mass of the Milky Way halo. The structure and extent of the dark matter halos of galaxies is a matter of great strategic importance for modern astrophysics. Of course, it is especially important to extract as much information as possible about the halo of our Galaxy, the proximity of which allows it to be studied in exceptional detail. Unfortunately, the mass and size of the Milky Way halo are amongst the most poorly known of all Galactic parameters. They are much more uncertain than the distance to the Galactic Centre or the Oort’s constants, for example.

The Milky Way’s gas rotation curve cannot be traced beyond $\sim 20 \text{ kpc}$, and so it is natural to look to the kinematics of stellar tracers of the distant halo for estimates of the mass. The motions of the bound satellites of the Milky Way, together with the globular clusters, contain valuable information about the halo potential in which they are moving. Given a model of the gravity field, it is possible to constrain the values of parameters such as the halo’s extent, total mass and velocity anisotropy using the radial velocities and proper motions of the distant satellites and globular clusters. A number of authors have studied this problem (e.g., Little & Tremaine 1987; Zaritsky et al. 1989; Kuijken & Lynden-Bell 1992; Kochanek 1996), obtaining a variety of different mass estimates. One peculiarity of all previous studies, however, is the sensitivity of the mass estimates to whether or not Leo I is bound to the Milky Way. Leo I is unusual in that it has one of the largest radial velocities despite being...