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MICROLENSING AND THE COMPOSITION OF THE GALACTIC HALO

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By means of extensive galactic modeling we study the implications of the more than 100 microlensing events that have now been observed for the composition of the dark halo of the Galaxy. Based on the currently published data, including the 2nd year MACHO results, the halo MACHO fraction is less than 60% in most models and the likelihood function for the halo MACHO fraction peaks around 20% - 40%, consistent with expectations for cold dark matter models.

Gravitational microlensing provides a valuable tool for probing the baryonic contribution to the dark matter in the halo of our Galaxy. However, even with precise knowledge of the optical depths toward the LMC and bulge, it would still be difficult to interpret the results because of the large uncertainties in the structure of the Galaxy. As it is, small number statistics for the LMC lead to a range of optical depths further complicating the analysis. Detailed modeling of the Galaxy is essential to drawing reliable conclusions.

The values of the parameters that describe the components of the Galaxy are not well determined; in order to understand these uncertainties we explore a very wide range of models that are consistent with all the data that constrain the Galaxy. We consider two basic models for the bulge, a triaxial model with the long axis oriented at an angle of about 10° with respect to the line of sight toward the galactic center, and an axisymmetric model. The bulge mass is not well determined, and we take $M_{\rm Bulge} = (1-4)\times 10^{10} M_\odot$. For the disk component we consider a double exponential distribution and take the sum of a "fixed," thin luminous disk and a dark disk with varying scale lengths $r_d = 3.5 \pm 1\,$kpc, and thicknesses $h = 0.3\,$kpc, and $1.5\,$kpc. We also consider a model where the projected mass density varies as the inverse of galactocentric distance. We constrain the local projected mass density of the dark disk to be $10 M_\odot \leq \Sigma_{\rm VAR} \leq 75 M_\odot\,{\rm pc}^{-2}$. The dark halo is assumed to be comprised of two components, baryonic and non-baryonic, whose distributions are independent. We first assume independent isothermal distributions for the MACHOs and cold dark matter, with core radii varying between 2 and 20 kpc. Since there are indications from both observations[1] and CDM simulations[2] that halos are significantly flattened, we also consider models with an axis ratio $q = 0.4$ (E6 halo) for both the baryonic and non-baryonic halos. While flattening does affect the local halo density significantly, increasing it by roughly a factor of $1/q$, it does not affect the halo MACHO fraction significantly[3]. Finally, we consider the possibility that the MACHOs are not actually in the halo, but instead, due to dissipation, are more centrally concentrated in a spheroidal component.

We then require that the following observational constraints be satisfied: circular rotation speed at the solar circle ($r_0 = 8.0\,\mathrm{kpc} \pm 1\,\mathrm{kpc}$) $v_c = 220\,\mathrm{km\,s^{-1}} \pm 20\,\mathrm{km\,s^{-1}}$; peak-to-trough variation in $v(r)$ between 4 kpc and 18 kpc of less than 14%; local escape velocity $v_{\mathrm{ESC}} > 450\,\mathrm{km\,s^{-1}}$ and circular rotation velocity at 50 kpc, $180\,\mathrm{km\,s^{-1}} \leq v_c(50\,\mathrm{kpc}) \leq 280\,\mathrm{km\,s^{-1}}$. We also impose constraints from microlensing, both toward the bulge and toward the LMC. In calculating the optical depth toward the bulge, we consider lensing of bulge stars by disk, bulge and halo objects; for the LMC we consider lensing of LMC stars by halo and disk objects. We adopt the following constraints based upon microlensing data: (a)[4,5] $\tau_{\mathrm{BULGE}} \geq 2.0 \times 10^{-6}$ and (b)[6,7] $0.4 \times 10^{-7} \leq \tau_{\mathrm{LMC}} \leq 4 \times 10^{-7}$.

We summarize here our main results; details of the analysis can be found in ref. 8.

- The implications of the second year MACHO results for the halo MACHO fraction are shown in Figure 1. Incorporating the full set of constraints we find that the halo MACHO fraction is less than 60% in most models and peaks at a value of 20% − 40%. However, there are a small number of allowed models with a halo MACHO fraction greater than 80%. In addition to having a smaller total halo mass, these models all require an optical depth toward the LMC of greater than 2.5×10^{-7}, and most have $\tau_{LMC} \geq 3.5 \times 10^{-7}$.

- Bulge microlensing provides a crucial constraint to galactic modeling and eliminates many models. It all but necessitates a bar of mass at least $2 \times 10^{10} M_\odot$ and provides additional evidence that the bulge is bar-like. Because of the interplay between the different components of the Galaxy, the bulge microlensing optical depth indirectly constrains the MACHO fraction of the halo. On the other hand, LMC microlensing only constrains the MACHO fraction of the halo.

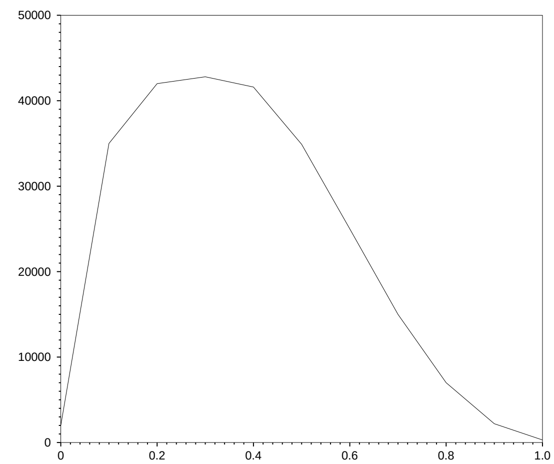

Figure 1: The number of viable models as a function of halo MACHO fraction.

- Viable models with no MACHOs in the halo (where the LMC optical depth is due to a thick disk or spheroidal component population) are difficult unless $\tau_{LMC} \lesssim 2.0 \times 10^{-7}$.

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