MICROLENSING RESULTS AND THE GALACTIC MODELS

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Microlensing results towards the LMC strongly depend on the properties of both the luminous and the dark matter distribution in the Galaxy. The two main sources of uncertainty come from the poor knowledge of the rotation curve at large galactocentric distance and from the possibility that MACHOs follow radial orbits in the outer Galaxy. Given these uncertainties MACHO mass values $\sim 0.1 \, M_\odot$ are still consistent with observations and thus brown dwarfs are to date viable candidates for MACHOs.

1 Introduction

Microlensing events towards the Large Magellanic Cloud (LMC) entail that a sizable fraction of the halo dark matter of the Galaxy is in the form of MACHOs (Massive Astrophysical Compact Halo Objects). However, although the evidence for MACHOs is firm, robust results are only the value of the optical depth $\tau = 2.9^{+1.4}_{-0.9} \times 10^{-7}$ reported by the MACHO\(^a\) team and the lower limit $\sim 10^{-2} \, M_\odot$ to the average MACHO mass $m_M$ found by the MACHO and EROS\(^b\) collaborations. Further results, in particular $m_M$ and the halo mass $f_M$ in form of MACHOs, strongly depend on the assumed distributions of dark and visible matter. In this respect, usually the standard halo model - which assumes spherical symmetry, flat rotation curve and Maxwell-Boltzmann statistics - and a “median” disk model are taken as a baseline for comparison. Within these assumptions the MACHO team reported the values $m_M = 0.5^{+0.3}_{-0.2} \, M_\odot$ and $f_M = 50^{+30}_{-20}\%$.

Actually, the previous hypotheses for the distribution of dark and visible matter can be relaxed and one can consider a set of models for the halo - flattened or spherical and/or in which the MACHOs do not obey the Maxwell-Boltzmann statistics - and for the disk - “maximal” or “minimum” -, without entering in contradiction with the observed galactic rotation curve.

Here we investigate the expected microlensing results for a class of halo models based on the King-Michie distribution function. For these models we determine in a self-consistent way the distribution of dark matter and study the effect of considering different parameters for the visible part of the Galaxy (for more details see\(^c\)).

2 Model and microlensing results

We assume that the Galaxy contains two main component, namely, the visible (stars) and the dark component (MACHOs). We consider stars to be distributed

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according to a central bulge and an exponential disk. Relevant parameters are the bulge mass $M_b = 2 \pm 1 \times 10^{10} M_\odot$, the local projected star mass density $\Sigma_0 = 50 \pm 25 M_\odot \text{pc}^{-2}$ and the disk scale length $h = 3.5 \pm 1 \text{kpc}$.

MACHOs are assumed to be described by the King-Michie distribution function. As it is well known, this function introduces an energy and angular momentum cutoff in the velocity space, which take into account the existence of an upper limit to the MACHO velocity at any point in the halo (the local escape velocity) and the possibility that MACHOs located in the outer part of the halo follow more radial orbits. Visible and dark components are considered to be in hydrostatic equilibrium in the gravitational potential $V$ solution of the Poisson equation, which we solve assuming spherical symmetry for the dark mass distribution. Correspondingly, we obtain the MACHO mass density

$$\rho_H(r) = A (2\pi \sigma^2)^{-3/2} e^{[W(r) - W(0)]} \left( \frac{r_a}{r} \right) \int_0^{W(r)} [e^{-\xi} - e^{-W(r)}] F(\xi) \, d\xi,$$

where $W(r) = -V(r)/\sigma^2$ is the energy cutoff parameter, $r_a$ the anisotropy radius, $\lambda = (r/r_a)\sqrt{\xi}$ and $F(\lambda)$ is the Dawson integral. $A$ is a normalization constant and $\sigma$ is the one-dimensional MACHO velocity dispersion.

The rate at which a single star is microlensed is given by

$$\Gamma = 2Dr_E \rho_0 \frac{1}{\sqrt{\bar{\mu}}} \int_0^{+v_c} dv_T \int_0^1 d\bar{x} \left( \frac{v_T}{v_0} \right)^2 \gamma(1/2) H(\bar{x}),$$

where all MACHOs have been assumed of the same mass $\bar{\mu}$ (in solar units), $D$ is the LMC distance, $r_E = \sqrt{4G\rho_0 D/c}$, $H(\bar{x}) = \rho_H(\bar{x})/\rho_0$ ($\rho_0$ is the local mass density) and $f(\bar{x}, v_T)$ is the projection of the MACHO velocity distribution function in the plane perpendicular to the line of sight. For an experiment monitoring $N_\star$ stars during an observation time $t_{obs}$ the total number of expected events will be $N_{ev} = N_\star t_{obs} \Gamma$. The expected event duration $T$ is defined as

$$T = \frac{r_E}{v_0} \sqrt{\bar{\mu}} \frac{\gamma(1)}{\gamma(1/2)},$$

where the $\gamma(m)$ functions are given by

$$\gamma(m) \equiv \int_0^{+v_c} dv_T \int_0^1 d\bar{x} \left( \frac{v_T}{v_0} \right)^{2-2m} v_T f(\bar{x}, v_T) [\bar{x}(1 - \bar{x})]^{m} H(\bar{x}).$$

Finally, the average MACHO mass $\bar{M}$ is given by

$$\bar{M} = \frac{<\tau^1>}{<\tau^{-1}>} \gamma(0)/\gamma(1),$$

where $<\tau^1>$ and $<\tau^{-1}>$ are determined through the observed microlensing events.

Our model results are given in Table 1, where the dark matter parameters are the core radius $a$, the local mass density $\rho_0$ and the anisotropy radius $r_a$. We
consider three models of luminous matter corresponding to the “minimum” (rows 1 and 4), the “median” (rows 2 and 5) and the “maximum” (rows 3 and 6) disk model. Here we take only models which lead to a flat rotation curve in the region 5 kpc < r < 50 kpc.

Results for the standard halo model are given in the lines 1-3. The radial anisotropy (lines 4-6) has the effect to decrease $N_{ev}$ and $[\gamma(0)/\gamma(1)]$ (which is related to the expected average MACHO mass), while the event duration $T$ gets increased. The decrease of $N_{ev}$ is mainly due to the reduction of the halo mass $M_H^{LMC}$ up to the LMC distance, while the reduction of $v_r$ leads to an increase of $T$.

Till now, we assumed a flat rotation curve in the range 5 – 50 kpc. Actually, the galactic rotation curve is well measured only in the range 5 – 20 kpc. Thus, to select acceptable physical models one should require that: i) the total variation in $v_{r_{rot}}(r)$ in the range 5 kpc < r < 20 kpc is less than 14%; ii) the rotational velocity $v_{r_{rot}}(LMC)$ at the LMC is in the range 150 – 307 km s$^{-1}$. With these assumptions we find that microlensing results strongly depend on $v_{r_{rot}}(LMC)$ and can vary up to a factor ~ 6 (see Figs. 1 and 3 in [115x312]).

In conclusion the variation in the expected microlensing results is at least within 30% from the value one gets for the standard halo model, due to anisotropy effect. This factor strongly increases if one allows for less restrictive conditions on the galactic rotation curve.

References

1. F. De Paolis, G. Ingrosso, Ph. Jetzer & M. Roncadelli, *PRL* 74, 14 and *AA* 295, 567 (1995)
2. C. Alcock et al., astro-ph 9611059
3. C. Renault et al., *AA* 324, L69 (1997)
4. F. De Paolis, G. Ingrosso & Ph. Jetzer, *ApJ* 470, 493 (1996)
5. A. De Rújula, Ph. Jetzer & E. Massó, *MNRAS* 250, 348 (1991)
6. K. Griest, *ApJ* 366, 412 (1991)
7. E.I. Gates, G. Gyuk & M.S. Turner, *PRL* 74, 3724 (1995)