MACHO versus HST: how bright can dark matter be?

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Recent results from gravitational microlensing experiments, such as MACHO, indicate that a substantial fraction of the Galactic dark matter (DM) is in compact form, with a typical mass in the range $\sim 0.05 - 1 \, M_\odot$. This mass range favours the DM being either low-mass hydrogen-burning stars or white-dwarf remnants of an early stellar population. There appears however to be a conflict between microlensing and other results, such as from Hubble Space Telescope (HST), which argue against a high DM fraction in hydrogen-burning stars or their remnants. Here I discuss the possibility that the DM detected by MACHO comprises low-mass stars residing in globular cluster associations. I show that such a scenario can reconcile HST and MACHO results and can also satisfy cluster dynamical constraints.

1 Results from MACHO and HST

Gravitational microlensing results towards the Large Magellanic Cloud obtained in the first 2 years of the MACHO experiment indicate that $20 - 80\%$ of the DM comprises objects with masses between $0.05 - 1 \, M_\odot$. These statistical estimates are highly model dependent, though the quoted spread in values is typical of a number of near-isotropic halo models considered by the MACHO collaboration.

In principle, the lenses responsible for the MACHO results need not be baryonic but may instead be in some other form of compact matter, such as primordial black holes. However, primordial black holes must form at a relatively late epoch in the early universe in order to explain the microlensing mass scales, in which case they may modify nucleosynthetic predictions for the production of the light elements. Such a modification would almost certainly destroy the very precise correspondence between the predicted and observed light-element abundances, a correspondence which forms one of the cornerstones of Big-Bang cosmology.

Assuming the lenses are baryonic in origin, the MACHO mass estimates imply low-mass stars or white-dwarf remnants. Sub-hydrogen-burning “stars”, or brown dwarfs, are not quite excluded, though their allowed mass is confined to a rather narrow range. However, analyses of HST fields obtained in the $V$ and $I$ bands place strong limits on the halo contribution of both low-mass stars and white dwarfs. White dwarfs are limited to a halo fraction below $10\%$ if their age does not exceed $14 \, Gyr$, and low-mass stars must contribute no more than $4\%$ to the DM if they have solar metallicity, or less than $1\%$ if their metallicity is the same as or less than that of Population II stars. Thus, it appears difficult to reconcile the microlensing and HST results.

2 Constraints on clusters

In this talk I choose to re-examine the HST constraints on low-mass stars. In obtaining the above constraints one makes the very strong assumption that the local dark halo stellar distribution is perfectly smooth on scales comparable to the...
Figure 1: MACHO, HST and dynamical constraints on VLM star clusters of mass $M$ and radius $R$ as a function of allowed halo fraction $f_h$. The upper plateau to the right shows the MACHO 95% lower limit on $f_h$ from optical depth estimates. The lower plateau to the left shows the HST 95% upper limit on VLM stars in the limiting case of a smooth stellar distribution. The curved surface adjoining the two plateau is the HST 95% upper limit on clusters. This limit continues to rise asymptotically above the MACHO plateau but is truncated here for clarity. The dashed lines projected onto the MACHO lower-limit plane bound cluster parameters which satisfy all dynamical constraints. Its intersection with the MACHO plateau indicates cluster parameters which satisfy MACHO, HST and dynamical constraints. A star mass of $m = 0.092 \, M_\odot$ is assumed.

observation volume. How do such limits change if the stellar distribution is not smooth but instead clumpy? Specifically, consider a scenario in which the halo DM comprises dark globular clusters of very low-mass (VLM) stars with mass $m$ just above the hydrogen-burning limit. If these stars have a more or less primordial composition then they are effectively metal free, in which case the condition for hydrogen burning is $m > m_{\text{burn}} = 0.092 \, M_\odot$.

The assumption of clustering is motivated both by the observation of visible globular cluster systems in the inner Galaxy and by theoretical DM formation scenarios which explain the existence and distribution of visible globular clusters and predict the existence of a population of dark globular clusters. Such dark clusters are predicted to have a more or less isothermal distribution (as required to explain the halo DM problem) and comprise either brown dwarfs or VLM stars.

The additional assumption of clustering introduces an additional form of constraint, namely dynamical constraints on populations of very massive halo objects. Such constraints place lower and upper bounds on both the cluster mass $M$ and radius $R$ for a given halo fraction $f_h$. The constraints come from a variety of considerations: tidal forces acting across the clusters; cluster–cluster collisions; evaporation timescales; and their disruptive effects on visible cluster populations.
Figure 1 brings together the MACHO, HST and dynamical constraints for dark clusters comprising zero-metallicity VLM stars with mass $m = m_{\text{burn}}$. The HST limits are derived from an analysis of 51 fields obtained by Gould et al.\(^{13}\) The assumed halo model is a simple cored isothermal sphere, denoted model S by MACHO in its halo model analysis\(^{2}\), and has a local density $\rho_0 = 0.008 \ M_\odot \ pc^{-3}$. Evidently, clusters with mass in the range $M \sim 10^3 - 10^6 \ M_\odot$ and radius $R \sim 3 - 100 \ pc$ can satisfy all dynamical constraints whilst reconciling the MACHO and HST results.

The one caveat for the model is that one requires a very large fraction of the stars, more than 95%, to remain inside the clusters until the present. This is because the HST observations limit the fraction of stars which can have escaped from the clusters to form a smooth background. However, if the escaped stars have not yet phase mixed sufficiently to form a smooth background then the cluster membership constraint can be weakened.

3 Summary

Whilst HST appears to rule out compact baryonic objects in the mass interval $0.1 - 1 \ M_\odot$ from comprising more than $\sim 10\%$ of the halo DM, microlensing results indicate that such objects provide between $20 - 80\%$ of the DM.

A scenario in which a substantial fraction of the halo DM comprises dark globular clusters of VLM stars can explain the apparently contradictory results from MACHO and HST, whilst satisfying all known constraints arising from their dynamical effects.

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