THE STRUCTURE OF DARK MATTER HALOS IN DWARF GALAXIES

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1. Introduction

Some dwarf galaxies have HI rotation curves that are completely dominated by a surrounding dark matter (DM) halo (e.g. Carignan & Freeman 1988). These objects represent ideal candidates for an investigation of the density structure of low-mass DM halos as the uncertainties resulting from the subtraction of the visible component are small, even in the innermost regions. Flores & Primack (1994) and Moore (1994) compared the observed DM rotation curves with the profiles, predicted from cosmological cold dark matter (CDM) calculations. They found an interesting discrepancy: whereas the calculations lead to a DM density distribution which diverges as $\rho \sim r^{-1}$ in the inner parts, the observed rotation curves indicate shallow DM cores which can be described by an isothermal density profile with finite central density.

2. The universal density profiles of DM halos

More recently, Burkert (1995) investigated the DM rotation curves in detail and found that they are self-similar, as expected from scale free cosmological models. Figure 1 shows the DM mass distribution as derived from the HI-rotation curves of those dwarf spiral galaxies which are known to be completely DM dominated. All four profiles indeed follow the same universal mass relation. The mass distribution as predicted from cosmological CDM simulations (Navarro et al. 1995) leads to too much mass at small radii as a result of the central density cusp. Even the frequently used modified isothermal profile does not provide a good fit to the observations in the outer regions due to the linear divergence of mass with radius. The solid

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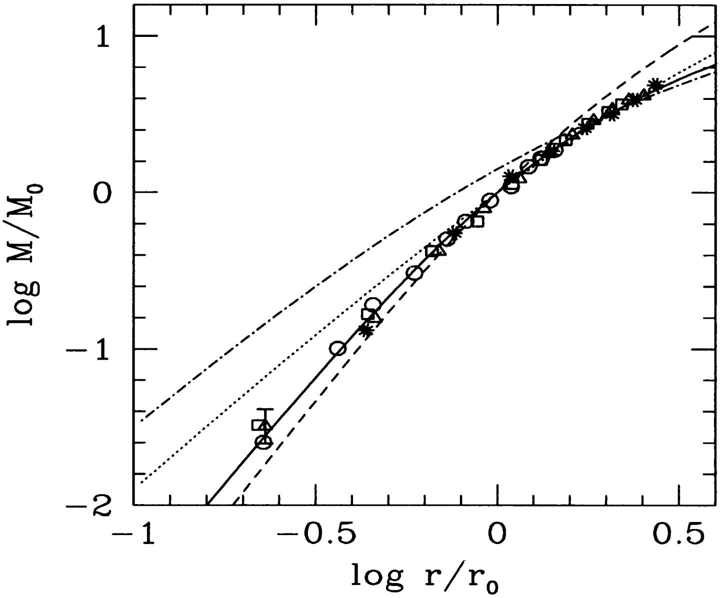

Figure 1. Dark matter mass profiles are shown for the following dwarf spiral galaxies (Burkert, 1995): DDO154 (open triangle), DDO105 (open square), NGC3109 (open circle) and DDO170 (starred). The errorbar at the innermost triangle represents the observational uncertainty in the inner region. The isothermal fit with core radius r_0 is shown as dashed curve, the solid line shows the revised profile, given in the text. The dotted and dot-dashed curve show the mass profiles as predicted from CDM calculations with formation redshifts of $z = 0.6$ and $z = 1.5$, respectively.

line shows a density distribution which fits the observations very nicely over the whole observed radius range:

$$\rho_{DM}(r) = \frac{\rho_0 r_0^3}{(r + r_0)(r^2 + r_0^2)} \tag{1}$$

where ρ_0 and r_0 are free parameters which represent the central DM density and a scale radius, respectively.

3. Scale relations for dark matter halos

According to equation 1 the density profiles of dark matter halos are completely described by two parameters: ρ_0 and r_0. It is important to investigate whether there exists a relation between these parameters which would provide information on the primordial fluctuation spectrum from which these

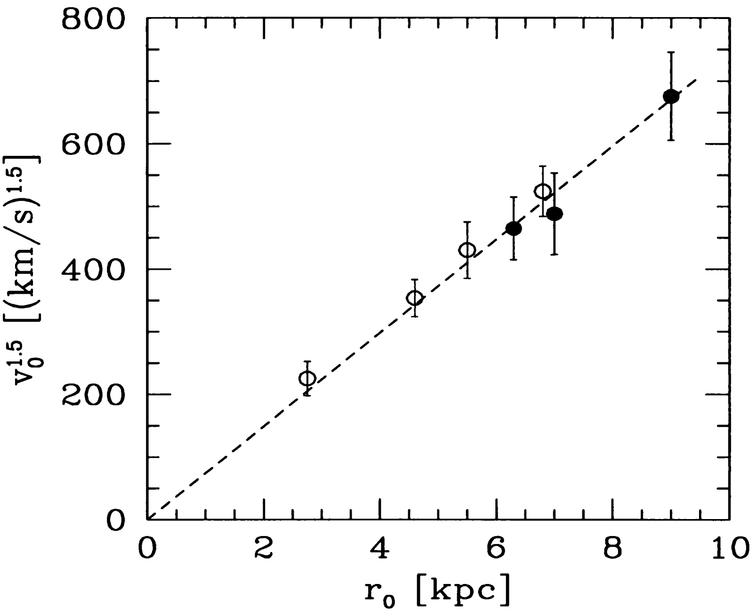

Figure 2. The scaling relation between the rotational velocity v_0 measured at r_0 is shown for the DM halos, investigated by Burkert (1995). Open circles represent the four DDO galaxies which have been used also in figure 1. The filled circles show three additional galaxies: NGC55, NGC300 and NGC1560. The dashed line is a fit through the data points.

objects formed. Instead of ρ_0 which cannot be observed directly, figure 2 shows the rotational velocity v_0 of the DM rotation curves at r_0 as a function of r_0. We find a strong linear correlation between r_0 and $v_0^{1.5}$. Using equation 1 and assuming spherical symmetry one can derive the following scaling relations for low-mass DM halos:

$$
\begin{aligned}
v_0 &= 17.7 \left(\frac{r_0}{kpc}\right)^{2/3} \frac{km}{s} \\
M_0 &= 7.2 \times 10^7 \left(\frac{r_0}{kpc}\right)^{7/3} M_\odot \\
\rho_0 &= 2.7 \times 10^{-2} \left(\frac{r_0}{kpc}\right)^{-2/3} \frac{M_\odot}{pc^3}
\end{aligned}
\tag{2}
$$

where M_0 is the total DM mass inside r_0.

These scaling relations indicate that the observed DM halos represent a one-parameter family with the density profiles being completely determined by the scale length r_0. As Burkert (1995) demonstrates, there exists a cosmological explanation for the equations 2, if one assumes that all halos formed from primordial CDM density fluctuations with the same initial amplitude. Otherwise one would expect a much larger spread of the data points shown in figure 2. It is however puzzling that only fluctuations with a certain fixed primordial amplitude should have managed to form the DM halos around dwarf spiral galaxies.

4. Discussion

Cosmological models predict DM density profiles with shapes that disagree with the observations. This might indicate that secular dynamical processes affected the central halo regions, leading to shallower DM profiles at the end. Suppose, for example, that the dwarf spirals had a much larger baryonic mass originally. In the case of gas it is likely that these low-mass systems experienced a strong galactic wind which could have removed a substantial gas fraction by this leading to strong fluctuations in the gravitational potential. At the end, the systems became DM dominated even in the inner regions and the gravitational fluctuations could have affected the inner DM density structure, leading to shallow central density profiles. It is however unlikely in such a scenario, that the energetic processes which lead to the galactic wind are so fine tuned that the resulting potential changes always lead to the same, self-similar dark matter density profiles, representing a one-parameter family as described by the equations 1 and 2. Even if the DM halos initially were a one-parameter family, one would expect that mass loss introduces a second independent parameter which reflects the efficiency with which the baryonic processes affect the inner DM halo. The discrepancy between the observed and theoretically predicted DM profiles and the existence of scaling relations are more likely directly coupled with the formation history of DM halos and therefore might indicate that some important physical features which are related to the nature and origin of dark matter are still missing in cosmological models.

References

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