The Distribution of Dark Matter in Galaxies: 
Constant–Density Dark Halos Envelop the 
Stellar Disks

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Abstract. In this paper we review the main and the most recent evidence for the 
presence of a core radius in the distribution of the dark matter around spiral galax-
ies. Their rotation curves, coadded according to the galaxy luminosity, conform to 
an Universal profile which can be represented as the sum of an exponential thin 
disk term plus a spherical halo term with a flat density core. From dwarfs to giants, 
these halos feature a constant density region of size \(r_0\) and core density \(\rho_0\) related by 
\[
\rho_0 = 4.5 \times 10^{-2} \left(\frac{r_0}{\text{kpc}}\right)^{-2/3} \frac{M_\odot}{\text{pc}^{-3}}
\]
At the highest masses \(\rho_0\) decreases exponentially, 
with \(r_0\) revealing a lack of objects with disk masses > \(10^{11} M_\odot\) and central densities 
> \(1.5 \times 10^{-2} (r_0/\text{kpc})^{-3} M_\odot \text{pc}^{-3}\), which implies a \textit{maximum} mass of \(2 \times 10^{12} M_\odot\) for 
halos hosting spirals. The fine structure of dark matter halos is obtained from the kine-
matics of a number of suitable low–luminosity disk galaxies. The inferred halo circular 
velocity increases linearly with radius out to the edge of the stellar disk, implying a 
constant dark halo density over the entire disk region. The structural properties of ha-
os around normal spirals are similar to those around dwarf and low surface brightness 
galaxies; nevertheless they provide far more substantial evidence of the discrepancy 
between the mass distributions predicted in the Cold Dark Matter scenario and those 
actually detected around galaxies.

1 Introduction

Rotation curves (RC’s) of disk galaxies are the best probe for dark matter (DM) 
on galactic scale. Notwithstanding the impressive amount of knowledge gathered 
in the past 20 years, only very recently we start to shed light to crucial aspects 
of the mass \textit{distribution} including the actual density profile of dark halos and its 
claimed universality.

On the cosmological side, high-resolution cosmological N-body simulations 
have shown that cold dark matter (CDM) halos achieve a specific equilibrium 
density profile [16 hereafter NFW, 6, 10, 14, 11]. This can be characterized by 
one free parameter, e.g. \(M_{200}\), the halo mass contained within the radius inside 
which the average over-density is 200 times the critical density of the Universe 
at the formation epoch. In their innermost region the dark matter profiles show 
some scatter around an average profile which is characterized by a power-law 
cusp \(\rho \sim r^{-\gamma}\), with \(\gamma = 1 - 1.5\) [16, 14, 2]. In detail, the DM density profile is:

\[
\rho_{\text{NFW}}(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2}
\]
where \( r_s \) is a characteristic inner radius and \( \rho_s \) the corresponding density. Let us define the halo virial radius \( R_{\text{vir}} \) as the radius within which the mean density is \( \Delta_{\text{vir}} \) times the mean universal density \( \rho_m \) at that redshift, and the associated virial mass \( M_{\text{vir}} \) and velocity \( V_{\text{vir}} \equiv GM_{\text{vir}}/R_{\text{vir}} \). By defining the concentration parameter as \( c_{\text{vir}} \equiv R_{\text{vir}}/r_s \) the halo circular velocity \( V_{\text{CDM}}(r) \) takes the form [2]:

\[
V_{\text{CDM}}^2(r) = V_{\text{vir}}^2 \frac{c_{\text{vir}}}{A(c_{\text{vir}})} \frac{A(x)}{x}
\]

where \( x \equiv r/r_s \) and \( A(x) \equiv \ln(1 + x) - x/(1 + x) \). As the relation between \( V_{\text{vir}} \) and \( R_{\text{vir}} \) is fully specified by the background cosmology, we assume the currently popular \( \Lambda \)CDM cosmological model, with \( \Omega_m = 0.3, \Omega_A = 0.7 \) and \( h = 0.75 \), in order to reduce from three to two (\( c_{\text{vir}} \) and \( r_s \)) the independent parameters characterizing the model. According to this model, \( \Delta_{\text{vir}} \approx 340 \) at \( z \approx 0 \). Let us stress that a high density \( \Omega_m = 1 \) model, with a concentration parameter \( c_{\text{vir}} > 12 \), is definitely unable to account for the observed galaxy kinematics [13]. Until recently, due to both the limited number of suitable RC’s and to uncertainties on the exact amount of luminous matter in the innermost regions of spirals, it has been difficult to investigate the internal structure of their dark halos. However, as a result of substantial observational and theoretical progresses, we have recently derived the main features of their mass distribution for a) the Universal Rotation Curve [20] built by coadding 1000 RC’s and b) a number of suitably selected RC’s [1].

2 The URC and CDM Halos

The assumed (and well supported) framework is: a) the mass in spirals is distributed according to the Inner Baryon Dominance (IBD) regime: there is a characteristic transition radius \( R_{\text{IBD}} \approx 2R_{d}(V_{\text{opt}}/220 \text{ km/s})^{1.2} \) (\( R_d \) is the disk scale-length and \( V_{\text{opt}} \equiv V(R_{\text{opt}}) \)) according which, for \( r \leq R_{\text{IBD}} \), the luminous matter totally accounts for the mass distribution, whereas, for \( r > R_{\text{IBD}} \), DM rapidly becomes the dominant dynamical component [26, 24, 1]. Then, although the dark halo might extend down to the galaxy center, it is only for \( r > R_{\text{IBD}} \) that it gives a non-negligible contribution to the circular velocity. b) DM is distributed in a different way with respect to any of the various baryonic components [20, 7], and c) HI contribution to the circular velocity at \( r < R_{\text{opt}} \), is negligible [e.g. 21].

2.1 Halo Density Profiles

Reference [20] have derived from 15000 velocity measurements of 1000 RC’s, the synthetic rotation velocities of spirals \( V_{\text{syn}}(\frac{r_{\text{opt}}}{L_I}, \frac{L_I}{L_*}) \), sorted by luminosity (Fig. 1, with \( L_I \) the I–band luminosity and \( L_I/L_* = 10^{-(M_I+21.9)/5} \)). Remarkably, individual RC’s have a very small variance with respect to the corresponding synthetic curves [20, 21, 22]: spirals sweep a very narrow locus in the
Fig. 1. Synthetic rotation curves (filled circles with error bars) and URC (solid line) with its separate dark/luminous contributions (dotted line: disk; dashed line: halo). See [20] for details.

RC-profile/amplitude/luminosity space. On the other hand, the galaxy kinematical properties significantly change with luminosity [e.g. 20], so it is natural to relate the mass distribution with this quantity. The whole set of synthetic RC’s has been reproduced by means of the Universal Rotation Curve (URC) $V_{URC}(r/R_{opt}, L_I/L_*)$ which includes: a) an exponential thin disk term [9]:

$$ V_{d,URC}^2(x) = 1.28 \beta V_{opt}^2 \ x^2 \ (I_0 K_0 - I_1 K_1)^{1.6x} $$ \hspace{1cm} (3) 

and b) a spherical halo term:

$$ V_{h,URC}^2(x) = V_{opt}^2 \ (1 - \beta) \ (1 + a^2) \ \frac{x^2}{(x^2 + a^2)} $$ \hspace{1cm} (4)
with $x \equiv r/R_{\text{opt}}$, $\beta \equiv (V_{d,URC}(R_{\text{opt}})/V_{\text{opt}})^2$, $V_{\text{opt}} \equiv V(R_{\text{opt}})$ and $a$ the halo core radius in units of $R_{\text{opt}}$. At high luminosities, the contribution from a bulge component has also been considered.

Let us stress that the halo velocity functional form (4) does not bias the mass model: it can equally account for maximum–disk, solid–body, no–halo, all–halo, CDM and core–less halo mass models. In practice, the synthetic curves $V_{\text{syn}}$ select the actual model out of the family of models $V_{URC}^2(x) = V_{h,URC}^2(x, \beta, a) + V_{d,URC}^2(x, \beta)$, where $a$ and $\beta$ are free parameters. Adopting $a \simeq 1.5(L_I/L_\ast)^{1/5}$ and $\beta \simeq 0.72 + 0.44 \log(L_I/L_\ast)$ [20] or, equivalently, the corresponding $a = a(\beta)$ and $\beta = \beta(\log V_{\text{opt}})$ plotted in Fig. 2, the URC reproduces the synthetic curves $V_{\text{syn}}(r)$ within their r.m.s. (see Fig. 1). More in detail, at any luminosity and radius, $|V_{URC} - V_{\text{syn}}| < 2\%$ and the 1σ fitting uncertainties on $a$ and $\beta$ are about 20% [20].

To cope with this observational evidence and conveniently frame the halo density properties, we adopted the empirical profile proposed by Burkert [3]:

$$\rho_b(r) = \frac{\rho_0 r_0^3}{(r + r_0)(r^2 + r_0^2)}$$

where $\rho_0$ and $r_0$ are free parameters which represent the central DM density and the scale radius. Within spherical symmetry, the mass distribution is given by:

$$M_b(r) = 4M_0 \{ \ln(1 + r/r_0) - \arctan(r/r_0) + 0.5 \ln[1 + (r/r_0)^2] \}$$

with $M_0$, the dark mass within the core, given by $M_0 = 1.6\rho_0 r_0^3$. The halo contribution to the circular velocity is then:

$$V_h^2(r) = GM_b(r)r$$

Although the dark matter core parameters $r_0$, $\rho_0$ and $M_0$ are in principle independent, the observations reveal a clear correlation [3]:
\[ M_0 = 4.3 \times 10^7 \left( \frac{r_0}{\text{kpc}} \right)^{7/3} M_\odot \]  

which, together with the above relationship, indicates that dark halos represent a 1–parameter family which is completely specified, e.g. by the core mass.

**Fig. 3.** URC-halo rotation curves (filled circles with error bars) and the Burkert model (solid line). The bin magnitudes are also indicated.

We then compare the dark halo velocities obtained with (3) and (4), with the Burkert velocities \( V_b(r) \) of (5)-(7), leaving \( \rho_0 \) and \( r_0 \) as free parameters, i.e. we do not impose the relationship (8). The results are shown in Fig. 3: at any luminosity, out to the outermost radii (~ 6\( R_d \)), \( V_b(r) \) is indistinguishable from \( V_{h,URC}(r) \). More specifically, by setting \( V_{h,URC}(r) \equiv V_b(r) \), we are able to reproduce the synthetic rotation curves \( V_{syn}(r) \) at the level of their r.m.s. For \( r >> 6R_d \), i.e. beyond the region described by the URC, the two velocity profiles progressively differ.

The values of \( r_0 \) and \( \rho_0 \) from the URC agree with the extrapolation at high masses of the scaling law \( \rho \propto r_0^{-2/3} \) [3] established for objects with core radii \( r_0 \) ten times smaller (see Fig. 4). Let us notice that the core radii are very large: \( r_0 \gg R_d \) so that an ever-rising halo RC cannot be excluded by the data. Moreover, the disk-mass vs. central halo density relationship \( \rho_0 \propto M_d^{-1/3} \), found
for dwarf galaxies [3], according to which the densest halos harbor the least massive disks, holds also for disk systems of stellar mass up to $10^{11} M_\odot$ (see Fig. 4).

![Figure 4](image_url)

**Fig. 4.** (up) Disk mass (in solar units) vs central halo density $\rho_0$ (in g/cm$^3$) for normal spirals (filled circles). The straight line is from [3] (bottom) central density vs core radii (in kpc) for normal spirals (filled circles). The straight line and the point are from the dwarfs sample of [3]. The curved line is: $\rho_0 = 5 \times 10^{-24} r_0^{-2/3} \exp - (r_0/27)^2$ g/cm$^3$.

The above relationship shows a curvature at the highest masses/lowest densities that can be related to the existence of an upper limit in the dark halo mass $M_{200}$ which is evident by the sudden decline of the baryonic mass function of disk galaxies at $M_{200}^{\text{max}} = 2 \times 10^{11} M_\odot$ [26], that implies a maximum halo mass of $M_{200}^{\text{max}} \sim \Omega_0/\Omega_b M_d^{\text{max}}$, where $\Omega_0$ and $\Omega_b \simeq 0.03$ [e.g. 5] are the matter and baryonic densities of the Universe in units of critical density. From the definition of $M_{200}$, by means of eq. (6) and (8), we can write $M_{200}$ in terms of the “observable” quantity $M_0$: $M_{200} = \eta M_0$. For $(\Omega_0, z) = (0.3, 3)$, $\eta \simeq 12$; notice that there is a mild dependence of $\eta$ on $z$ and $\Omega_0$ which is irrelevant for the present study. From simple manipulation of previous equation- we obtain an upper limit for the central density, $\rho_0 < 1 \times 10^{-20} (r_0/\text{kpc})^{-3}$ g/cm$^3$, which implies a lack

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1 The virial halo mass is given by $M_{200} \equiv 200 \times 4\pi/3 \rho_c R_{200}^3 \Omega_0 (1 + z^2) g(z)$ with $z$ the formation redshift, $R_{200}$ the virial radius, for $g(z)$ see e.g. [2]; the critical density is defined as: $\rho_c \equiv 3/(8\pi) G^{-1} H_0^2$. 

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of objects with $\rho_0 > 4 \times 10^{-25}$ g/cm$^3$ and $r_0 > 30$ kpc, as is evident in Fig. 4. Turning the argument around, the deficit of objects with $M_d \sim M_d^{\text{max}}$ and $\rho_0 > 4 \times 10^{-25}$ g/cm$^3$, suggests that, at this mass scale, the total-to-baryonic density ratio nears the cosmological value $\Omega/\Omega_b \approx 10$.

2.2 Testing CDM

Out to two optical radii, the Burkert density profile reproduces, for the whole spiral luminosity sequence, the DM halos mass distribution. This density profile, though at very large radii coincides with the NFW profile, approaches a constant, finite density value at the center, in a way consistent with an isothermal distribution. This is in contradiction to CDM halo properties which predict [e.g. 10] that the velocity dispersion $\sigma$ of the dark matter particles decreases towards the center to reach $\sigma \rightarrow 0$ for $r \rightarrow 0$. The dark halo inner regions, therefore, cannot be considered as kinematically cold structures but rather as “warm” regions with size $r_0 \propto \rho_0^{-1/5}$. The halo core sizes are very large: $r_0 \sim 4 - 7 R_d$. Then, the boundary of the core region is well beyond the region where the stars are located and, as in [7], even at the outermost observed radius there is not the slightest evidence that dark halos converge to a $\rho \sim r^{-2}$ (or a steeper) regime.

3 Individual RC’s and CDM

To derive the halo density from an individual rotation curve is certainly complicated, however, the belief according to which RC’s lead to ambiguous halo mass modeling [e.g. 28] is incorrect. In fact this is true only for rotation curves of low spatial resolution, i.e. with $< 3$ measures per exponential disk length-scale $R_d$, as for most of HI RCs. Since the parameters of the galaxy structure are very sensitive to the shape of the rotation curve in the region $0 < r < R_d$, that corresponds to the region of the RC steepest rise, then the mass model cannot be inferred if such a region is poorly sampled and/or radio beam–biased. Instead, high–quality optical RCs with tens of independent measurements in the critical region probe the halo mass distribution and resolve their structure. Since the dark component can be better traced when the disk contributes to the dynamics in a modest way, it is convenient to investigate DM–dominated objects, like dwarf and low surface brightness (LSB) galaxies. It is well known that for the latter there are claims of dark matter distributions with regions of constant density well different from the cusped density distributions of the Cold Dark Matter scenario [e.g. 8, 13, 3, 4, 11, 12, 27]. However, these results are far from certain being 1) under the (unlikely) caveat that the low spatial resolution of the RCs does not bias the derived mass model and 2) uncertain, due to the limited amount of available kinematical data [see 29]. Since most of the properties of cosmological halos are claimed universal, we concentrate on a small and particular sample of RCs, that, nevertheless, reveal the properties of the DM halos around spirals. A more useful strategy has been to investigate a number of high–quality optical rotation curves of low luminosity late–type spirals, with
$I$–band absolute magnitudes $-21.4 < M_I < -20.0$ and that $100 < V_{opt} < 170$ km $s^{-1}$. Objects in this luminosity/velocity range are DM dominated [e.g. 20] but their RC’s, measured at an angular resolution of $2''$, have a spatial resolution of $w \sim 100(D/10 \, \text{Mpc}) \, \text{pc}$ and $n_{\text{data}} \sim R_{opt}/w$ independent measurements. For nearby galaxies: $w << R_d$ and $n_{\text{data}} > 25$. Moreover, we select RC’s of bulge–less systems, so that the stellar disk is the only baryonic component for $r \lesssim R_d$.

In detail, we take from [19] the rotation curves of the ‘excellent’ subsample of 80 galaxies, which are suitable for an accurate mass modeling. In fact, these RC’s properly trace the gravitational potential in that: 1) data extend at least to the optical radius, 2) they are smooth and symmetric, 3) they have high spatial resolution and a homogeneous radial data coverage, i.e. about $30 - 100$ data points homogeneously distributed with radius and between the two arms. From this subsample we extract 9 rotation curves of low luminosity galaxies ($5 \times 10^9 L_\odot < L_I < 2 \times 10^{10} L_\odot$; $100 < V_{opt} < 170$ km $s^{-1}$), with their $I$–band surface luminosity being an (almost) perfect radial exponential. These two last criteria, not indispensable to perform the mass decomposition, are however required to infer the dark halo density distribution. Each RC has $7 - 15$ velocity points inside $R_{opt}$, each one being the average of $2 - 6$ independent data. The RC spatial resolution is better than $1/20 R_{opt}$, the velocity r.m.s. is about 3% and the RC’s logarithmic derivative is generally known within about 0.05.

### 3.1 Halo Density Profiles

We model the mass distribution as the sum of two components: a stellar disk and a spherical dark halo. By assuming centrifugal equilibrium under the action of the gravitational potential, the observed circular velocity can be split into these two components:

$$V^2(r) = V_D^2(r) + V_H^2(r)$$ (9)

By selection, the objects are bulge–less and the stellar component is distributed like an exponential thin disk. Light traces the mass via an assumed radially constant mass–to–light ratio. In the r.h.s of (9) we neglect the gas contribution $V_{gas}(r)$ since in normal spirals it is usually modest within the optical region [21, Fig. 4.13]: $\beta_{gas} = (V_{gas}^2/V^2)_{R_{opt}} \sim 0.1$. Furthermore, high resolution HI observations show that in low luminosity spirals: $V_{gas}(r) \simeq 0$ for $r \leq R_d$ and $V_{gas}(r) \simeq (20 \pm 5)(r-R_d)/2R_d$ for $R_d \leq r \leq 3R_d$. Thus, in the optical region: $i)$ $V_{gas}^2(r) \ll V^2(r)$ and $ii)$ $d[V^2(r) - V_{gas}^2(r)]/dr \gtrsim 0$. This last condition implies that by including $V_{gas}$ in the r.h.s. of (9) the halo velocity profiles would result steeper and then the core radius in the halo density larger. Incidentally, this is not the case for dwarfs and LSBs: most of their kinematics is affected by the HI disk gravitational pull in such a way that neglecting it could bias the determination of the DM density. The circular velocity profile of the disk is given by (3) and the DM halo will have the form given by (4). Since we normalize (at $R_{opt}$) the velocity model $(V_h^2 + V_d^2)^{1/2}$ to the observed rotation speed $V_{opt}$, $\beta$ enters
explicitly in the halo velocity model and this reduces the free parameters of the mass model to two.

It is important to remark that, out to $R_{\text{opt}}$, the proposed Constant Density Region (CDR) mass model of (4) is instead neutral with respect to all the proposed models. Indeed, by varying $\beta$ and $a$, we can efficiently reproduce the maximum–disk, the solid–body, the no–halo, the all–halo, the CDM and the core-less–halo models. For instance, CDM halos with concentration parameter $c = 5$ and $r_s = R_{\text{opt}}$ are well fit by (4) with $a \simeq 0.33$.

For each galaxy, we determine the values of the parameters $\beta$ and $a$ by means of a $\chi^2$–minimization fit to the observed rotation curves:

$$V^2_{\text{model}}(r; \beta, a) = V^2_d(r; \beta) + V^2_d(r; \beta, a)$$

A central role in discriminating among the different mass decompositions is played by the derivative of the velocity field $dV/dr$. It has been shown [e.g. 18] that by taking into account the logarithmic gradient of the circular velocity field defined as: $\nabla(r) \equiv \frac{d \log V(r)}{d \log r}$ one can retrieve the crucial information stored in the shape of the rotation curve. Then, we set the $\chi^2$-s as the sum of those evaluated on velocities and on logarithmic gradients:

$$\chi^2_V = \sum_{i=1}^{nV} \frac{(V_i - V_{\text{model}}(r_i; \beta, a))^2}{\delta V_i}$$

and

$$\chi^2_\nabla = \sum_{i=1}^{n\nabla} \frac{(\nabla(r_i) - \nabla_{\text{model}}(r_i; \beta, a))^2}{\delta \nabla_i},$$

with $\nabla_{\text{model}}(r_i, \beta, a)$ given from the above equations. The parameters of the mass models are finally obtained by minimizing the quantity $\chi^2_{\text{tot}} \equiv \chi^2_V + \chi^2_\nabla$.

![Fig. 5. Halo parameters ($a$ is in units of $R_{\text{opt}}$) with their uncertainties](image)

The parameters of the best–fit models are shown in Fig. 5. They are very well specified: the allowed values span a small and continuous region of the ($a$, $\beta$) space. We get a “lowest” and a “highest” halo velocity curve by subtracting from $V(r)$ the maximum and the minimum disk contributions $V_d(r)$ obtained by substituting in (3) the parameter $\beta$ with $\beta_{\text{best}} + \delta \beta$ and $\beta_{\text{best}} - \delta \beta$, respectively. The derived mass models are shown in Fig. 6, alongside with the separate disk and halo contributions. It is then obvious that the halo curve is steadily increasing, almost linearly, out to the last data point. The disk–contribution $\beta$ and the
halo core radius $a$ span a range from 0.1 to 0.5 and from 0.8 to 2.5, respectively. In each object the uniqueness of the resulting halo velocity model can be realized by the fact that the maximum–disk and minimum–disk models almost coincide. Remarkably, we find that the size of the halo density core is always greater than the disk characteristic scale–length $R_d$ and it can extend beyond the disk edge (and the region investigated).

Fig. 6. CDR model fits (thick solid line) to the RCs (points with errorbars). Thin solid lines represent the disk and halo contributions. The maximum disk and the minimum disk solutions are also plotted (dashed lines).

3.2 Testing CDM

In Fig. 7 we show the halo velocity profiles for the nine galaxies. The halo circular velocities are normalized to their values at $R_{opt}$ and expressed as a function of the normalized radius $r/R_{opt}$. These normalizations allow a meaningful comparison between halos of different masses. It is then evident that the halo circular velocity, in every galaxy, rises almost linearly with radius, at least out to the disk edge: $V_h(r) \propto r$ for $0.05R_{opt} \lesssim r \lesssim R_{opt}$.

The halo density profile has a well defined (core) radius within which the density is approximately constant. This is inconsistent with the singular halo
density distribution emerging in the Cold Dark Matter (CDM) halo formation scenario. More precisely, since the CDM halos are, at small radii, likely more cuspy than the NFW profile: $\rho_{CDM} \propto r^{-1.5}$ [e.g. 14], the steepest CDM halo velocity profile $V_h(r) \propto r^{1/4}$ results too shallow with respect to observations. Although the mass models of (4) converge to a distribution with an inner core rather than with a central spike, it is worth, given the importance of such result, also checking in a direct way the (in)compatibility of the CDM models with galaxy kinematics. We assume the NFW two–parameters functional form for the halo density [15, 16, 17], given by (1). Though N–body simulations and semi–analytic investigations indicate that the two parameters $c_{\text{vir}}$ and $r_s$ correlate, they are left independent to increase the chance of a good fit. For the object under study a generous halo mass $M_{\text{vir}}$ upper limit is $M_{up} = 2 \times 10^{12} M_\odot$.

The fits to the data are shown in Fig. 8 and compared with the NFW models: for seven out of nine objects the latter are unacceptably worse than the CDR solutions, moreover in all objects, the CDM virial mass is too high high: $M_{\text{vir}} \sim 2 \times 10^{12} M_\odot$ and the resulting disk mass–to–light ratio too low. The inadequacy of the CDM model for our sample galaxies is even more evident if one performs the fit after removing the constraint on virial mass. In fact, good fits are obtained only for very low values of the concentration parameter ($c_{\text{vir}} \simeq 2$) and for ridiculously large virial velocities and masses ($V_{\text{vir}} \simeq 600–800 \text{ km s}^{-1}$; $M_{\text{vir}} \simeq 10^{13} – 10^{14} M_\odot$). These results can be explained as effect of the attempt, by the minimization routine, to fit the NFW velocity profile ($V(r) \propto r^{0.5}$) to data intrinsically linear in $r$.

4 Conclusions: an Intriguing Evidence

The dark halos around spirals emerge as an one–parameter family; it is relevant that the order parameter (either the central density or the core radius) corre-
lates with the luminous mass. However, we do not know how it is related to the global structural properties of the dark halo, like the virial radius or the virial mass. The halo RC, out to $6R_d$, is completely determined by parameters, i.e. the central core density and the core radius, which are not defined in present gravitational instability/hierarchical clustering scenario. In fact the location of spiral galaxies in the parameter space of virial mass, halo central density and baryonic mass, determined by different processes on different scales, degenerates with no doubt into a single curve (see Fig. 4), we recall that: $\rho_0 = \frac{\pi}{24} \frac{M_{200}}{r_0^3}$ and $M_d = G^{-1} \beta V^2_{opt} R_{opt}$, of difficult interpretation within the standard theory of galaxy formation. Crucial insight has come from disk–halo density decompo-

Fig. 8. NFW best–fits solid lines of the rotation curves (filled circles) compared with the CDR fits (dashed lines). The $\chi^2$ values are also indicated.

sitions of a number of disk galaxies. These galaxies have a relevant amount of dark matter: the contribution of the luminous matter to the dynamics is small and it can be easily taken into account. Moreover, the high spatial resolution of the available rotation curves allows us to derive the separate dark and luminous density profiles. We find that dark matter halos have a constant central density region whose size exceeds the stellar disk length–scale $R_d$. As result, the
halo profiles disagree with the cuspy density distributions typical of CDM halos, which, therefore, fail to account for the actual DM velocity data.

Pointing out that a review on the various efforts aimed to cope with the core radii evidence will be published elsewhere, we conclude by stressing that, for any theory of galaxy formation, time is come to seriously consider that stellar disks (and perhaps also stellar spheroids) lay down in dark halos of constant density.

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