A GALACTIC WEIGH-IN: MASS MODELS OF SINGS GALAXIES USING CHEMO-SPECTROPHOTOMETRIC GALACTIC EVOLUTION MODELS

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ABSTRACT

The baryonic mass-to-light ratio ($\Upsilon_\star$) used to perform the photometry-to-mass conversion has a tremendous influence on the measurement of the baryonic content and distribution as well as on the determination of the dark halo parameters. Since numerous clues hint at an inside-out formation process for galaxies, a radius-dependent $\Upsilon_\star$ is needed to physically represent the radially varying stellar population. In this article, we use chemospectrophotometric galactic evolution (CSPE) models to determine $\Upsilon_\star$ for a wide range of masses and sizes in the scenario of an inside-out formation process by gas accretion. We apply our method to a SINGS subsample of 10 spiral and dwarf galaxies with photometric coverage ranging from the UV to the mid-IR. The CSPE models prove to be a good tool for weighting the different photometric bands in order to obtain consistent stellar disk masses regardless of the spectral band used. On the other hand, we show that the color index versus $\Upsilon_\star$ relation is an imperfect tool for assigning masses to young stellar populations because of the degeneracy affecting $\Upsilon_\star$ in all bands at low color index. The disks resulting from our analysis are compatible with the maximum disk hypothesis provided that an adequate bulge/disk decomposition is performed and that the correction for the presence of a bar is not neglected since bars disturb the internal disk kinematics. Disk-mass models including $\Upsilon_\star$ as a free parameter as well as models using our physically motivated, radially varying $\Upsilon_\star$ are presented and discussed for each galaxy.

Key words: galaxies: individual (SINGS) -- galaxies: kinematics and dynamics -- galaxies: stellar content

Online-only material: color figures

1. INTRODUCTION

The question of the exact contribution of the stellar disk to overall galaxy kinematics is a long-acknowledged problem that has received a lot of attention for as long as the mass models themselves, starting with the first determination of the mass of the Andromeda galaxy. Oepik (1922) used the rotational velocity of Andromeda and assumed that its stellar mass was proportional to its total luminous emission. The introduction of inhomogeneous ellipsoids to account for different galactic populations by Perek (1948), Kuzmin (1952), and Schmidt (1956) allowed modeling of the radial mass distribution. A step forward was taken when de Vaucouleurs (1954) established from photometric observations that the stellar surface density decreases exponentially with radius. Despite the consequently expected Keplerian decrease of the circular velocity with radius, pioneer papers found a decrease much lower than Keplerian (Rogstad 1970; Roberts 1975; Freeman 1970; Rubin et al. 1978).

The extended flat H I rotation curves available only from the very late 1970s led to the introduction of an additional component to model the rotation curve: the dark halo. This introduction completely changed our vision of the mass distribution in spiral galaxies. The total radial mass distribution in spiral galaxies is broken up into several components: a disk consisting mostly of stars depending on a free parameter, the disk mass-to-light ratio ($\Upsilon_\star$), plus, eventually, a bulge depending on another free parameter (the bulge mass-to-light ratio $\Upsilon_\bullet$), an H I+He disk that does not contain any free parameters (the helium fraction not being a free parameter) and a halo, generally spheroidal, which contains dark matter and should be described by (at least) two free parameters. In order to convert the surface brightness photometry of a galactic disk into a radial density profile, an estimation of $\Upsilon_\star$ has to be assumed in order to account for the disk being composed of billions of stars of masses, ages, and metallicities different from our Sun’s. This directly raises the question of a disk–halo degeneracy that consists of balancing the respective contributions of the disk and halo. Using ad hoc parameters, the disk mass-to-light ratio might range anywhere from $\Upsilon_\star \approx 0$ (the minimum disk hypothesis valuable for low surface brightness spirals or dwarfs) to $\Upsilon_\star = \Upsilon_\star^{\max}$ (the maximum disk hypothesis applicable to bright, early-type spirals, e.g., van Albada et al. 1985). The solutions that maximized the disk were favored by earlier authors (Carignan & Freeman 1985; Bahcall & Casertano 1985; Kent 1986).

In the 1990s, the first N-body simulations taking only dark matter into account became available and they suggested that the dark halo density profiles were peaked in the inner region of the galaxies (cuspy distribution, e.g., Navarro et al. 1996), while the observations showed the opposite (core distribution, e.g., Blais-Ouellette et al. 1999; de Blok et al. 2001). More recent simulations have revealed that the slope keeps getting shallower toward small radii (Navarro et al. 2004; Hayashi et al. 2004). In the mean time, different authors (e.g., Blais-Ouellette et al. 2004; Dutton et al. 2006; Bershady et al. 2010) have shown that the indetermination arising from the photometry-to-mass conversion of the stellar disk can lead to differences of up to a factor of 20 in the mass of the dark halo inferred. This uncertainty prevents the precise determination of the exact shape of the density profile of the dark matter halo (i.e., the cusp versus core controversy).

Our poor understanding of the baryonic processes involved in galaxy formation likely lead to the inconsistencies between
the predictions from the Λ cold dark matter (ΛCDM) theory and observations. Physical processes like adiabatic compression have been invoked as contributing even further to the cuspy dark matter distribution. The dissipation of the disk, via the infall of baryons, is thought to compress the dark halo distribution through adiabatic contraction (Blumenthal et al. 1986). Baryonic infall increases the rotational velocity in the inner regions; the effect of adiabatic contraction of the halo by the disk steepens the cuspy distribution even more. On the other hand, without major changes to the ΛCDM scenario, numerous authors introduced physical processes that might turn a cusp into a core: feedback, dynamical friction, merging, spin segregation, halo triaxiality, and bar-driven evolution, all effects that could reconcile the simulations with the observations. The effects of bars are to radially redistribute baryonic matter (Weinberg & Katz 2002). Merging of cored dark matter halos might change the dark matter distribution (Boylan-Kolchin & Ma 2004; Dehnen 2005). The dynamical friction of initially very steep cusps heated by subhalos can convert them into shallower distributions (Romano-Díaz et al. 2009). Feedback might be responsible for baryonic blowouts and baryonic mass redistribution (Navarro et al. 1996; Burkert 1995; Gelato & Sommer-Larsen 1999). N-body + hydrodynamical simulations assuming the presence of ΛCDM and a cosmological constant are now able to produce shallower dark matter density profiles within the central 1 kpc of dwarf galaxies by introducing strong outflows from supernovae that inhibit bulge formation (Governato et al. 2010, 2012; Macciò et al. 2012).

If the mass of the disk was to be realistically calculated with the help of models based on physical motivations, one of the three (or more) free parameters could be fixed and the task at hand could be reduced to the determination of the shape of the dark halo. The mass-to-light ratio Ψ can be constrained using arguments based on dynamics (spiral structure and swing amplification, the flaring of the H I disk, bar formation, gas flow in disk along bars or spirals, velocity dispersion in face-on and edge-on galaxies), stellar populations (color–Ψ relation), deviations from the Tully–Fischer relation, and lensing. Unfortunately, the problem is far from being unambiguously constrained by these different methods and they lead to different results.

In this paper, we focus on constraints from stellar populations by considering the evolution of the galactic stellar components and determining the collective properties of sets of stars (Bell & de Jong 2000, 2001; Bruzual & Charlot 2003). This approach is very promising since it should be able to distinguish between all particular cases of stellar populations. Stellar populations differ amongst galaxies but also within them. Numerous smoking guns such as radial differences in colors and metallicities point in the same direction: an inside-out formation process (Grebel 2011). Using a constant Ψ, would be equivalent to assuming a uniform stellar population throughout the galaxy. Any approach that would give a realistic weight to a stellar disk should take into account this radial variation as opposed to adopting a global value for Ψ. Some work has already been performed along these lines. Interesting work on this matter was carried out by Portinari & Salucci (2010); these authors analyzed the effects of a radially varying Ψ on mass modeling of toy galaxies. Walter et al. (2008) and Kassin et al. (2006) also achieved interesting results with their use of color–Ψ to fix the contribution of their galactic disks to the overall mass distribution. We use in this paper galactic chemo-spectrophotometric evolution (CSPE) models to derive the Ψ for each galaxy in a SINGS subsample comprising up to 12 photometric bands. With the help of this stellar mass-to-light ratio, we then propose a realistic mass model including a disk compounded from photometric observations in wavelengths ranging from the UV to the mid-IR. Details of the CSPE models and methodology of the transformation of disk photometry into a corresponding mass is described in Section 2.1.

The relation between the global characteristics of the CSPE models and the Ψ values they produce are presented in the first part of Section 3 while the second part of that section reports the detailed mass modeling of NGC 2403 along with the main conclusions gathered from performing the same operation on nine other galaxies in the SINGS sample. We then analyze further our results in Section 4 and discuss the limitations of our method. Results of the exact mass modeling of individual galaxies are presented in the Appendix.

2. METHODS

2.1. Stellar Disk Evolution Models

Stellar surface density profiles are computed on the basis of full CSPE models described in detail in Boissier & Prantzos (1999, 2000, hereafter BP99 and BP00), with the most recent update and application to the SINGS galaxies appearing in Muñoz-Mateos et al. (2011). These models will thus not be described in detail here; only a broad outline will be given in the following paragraph.

In the CSPE models, chemical evolution is computed for each galaxy in concentric rings evolving independently. An infall of primordial gas is assumed, and a radial as well as a temporal normalization is performed to account for different accretion histories of individual galaxies and an inside-out formation scheme.

The implementation of the star formation rate, Ψ(SFR), in the models was inspired by Kennicutt (1998) and Wyse & Silk (1989). Ψ(SFR) depends on the local gas density (the usual Schmidt Law) and angular velocity that may be due to the frequency of the spiral arms or to dynamical aspects (see, e.g., Boissier 2013). The angular velocity input in the models is computed from a baryonic disk profile embedded in a pseudo-isothermal sphere. The newly formed stars are distributed along a multi-slope Kroupa-type power-law initial mass function (IMF). Two variants of this IMF are considered: (Equation (2) of Kroupa 2001; Kroupa et al. 1993, hereafter K01 and KTG93). It has been verified that the exact shape of the input rotation curve, i.e., using a Navarro–Frenk–White dark halo profile or even an experimental rotation curve, does not affect strongly the overall chemical evolution. It is the absolute value of vtsr that most strongly affect the results; the slight radial variations in the input velocities are meaningless compared to the uncertainties related to other ingredients of the models such as the star formation efficiency, the yields of various chemical elements, etc.

Once the chemical evolution of the galaxy is obtained, the spectrophotometric properties are computed using the Geneva group stellar evolution tracks (Charbonnel et al. 1996) and the Lejeune stellar spectra library (Lejeune et al. 1997). These tracks are libraries are all metallicity dependent.

Assuming our own Galaxy is typical, the model was calibrated using properties of the Milky Way (MW) such as the local Ψ(SFR), the stellar and gas surface density, the disk scale length, the abundance gradient, the stellar and gas profiles, and the metallicity distribution of G dwarfs (Boissier & Prantzos 1999).

The model was generalized to all disk galaxies in BP00, following a cosmological framework of galaxy formation (Fall & Efstathiou 1980; Mo et al. 1998). This context offers scaling
relations with respect to those of the MW, allowing one to relate
the disk properties to the dark matter halo in which the baryonic
disk resides. A grid of models was thus built by varying the two
parameters \( v_c \) and \( \lambda \) of a pseudo-isothermal sphere halo, where
\( v_c \) is the maximal circular velocity of the disk and \( \lambda \) is its spin
parameter.

While the description above concerns the construction of a
grid of theoretical models for the evolution of galaxies, the
assignment of a specific model to an observed galaxy can be
made on the basis of, e.g., multi-wavelength profiles (corrected
for extinction). A \( \chi^2 \) best-fit procedure was performed by Muñoz-Mateos et al. (2011, hereafter JCM11) to find the
model best representing the photometry of the SINGS galaxies
amongst a grid of simulations with \( \lambda = [0.020; 0.090] \) and
\( v_c = [80; 360] \). Using the preliminary results of the \( \chi^2 \) fitting
procedure of JCM11, as well as our own fitting procedure for
some of the galaxies in our sample, we linearly interpolated the
original grid to calculate all the physical quantities required for
the calculation of the stellar mass-to-light ratio \( \Upsilon \). The final
halos grid was refined to \( \Delta \lambda = 0.001 \) and \( \Delta v_c = 1 \). We used our
own fitting procedure when the adopted distances were different
from JCM11 and for galaxies that required decomposing the
bulge and disk components.

Once a best model was chosen, it provided a mass-to-light
ratio \( \Upsilon \) that varied smoothly with radius. This \( \Upsilon \) was then interpolated to the radii of the observed galaxy and was
used along with its luminosity to obtain its detailed surface
density. The solar magnitudes used in this work to convert
the surface brightnesses of the galaxies into solar luminosities
were drawn from Oh et al. (2008) for the IRAC bands,
http://mips.as.arizona.edu/~cnaw/sun.html for the FUV and
NUV bands, and Blanton & Roweis (2007) for all the other
bands in the visible and NIR.

The new disk’s surface density obtained by this method was
converted to an effective rotational velocity with the help of the
task rotrmod from the Gipsy package (van der Hulst et al. 1992; Vogelaar & Terlouw 2001). Such disks will be referred
to as “weighted disks” in the remainder of this paper. The disk
adopted for mass modeling was the median surface density of
disks in all bands ranging from the UV to the IR and then
converted with rotrmod. The highest and lowest surface densities
at each radius were adopted as the upper and lower boundaries
of the error on the disk, respectively.

With this physically justified disk, it was possible to perform
a mass modeling of the rotation curve with the usual methods.
The parameters of the models thus produced are fitted with fewer
degrees of freedom.

2.2. The Sample

In order to test the method presented in Section 2.1, we
applied it to the galaxies listed in Table 1. This list is a subset
of the SINGS sample, a sample that no longer needs a long
introduction (Kennicutt et al. 2003). Its galaxies were chosen
to cover the range of properties observed in nearby galaxies.
The high-quality data gathered for the sample have been the
subject of an abundance of publications and are still the base
for numerous projects (Walter et al. 2008; Muñoz-Mateos et al.
2009b). We skimmed through the sample by applying three
criteria: (1) as late-type as possible to avoid very prominent
bulges, (2) good quality of the models to the photometry, and
(3) an inclination allowing for an accurate determination of the
rotational velocity.

![Figure 1](http://example.com/figure1.png)

**Figure 1.** Comparison of the \( \Upsilon \) profile in NUV, \( B \), \( K \), and IRAC1 bands for a model matching the parameters of the Milky Way: \( \lambda = 0.03 \) and
\( v_c = 220 \text{ km s}^{-1} \). The model generated with a KTG93 IMF is represented
by the dashed curve and the solid line corresponds to the \( K01 \) model.

(A color version of this figure is available in the online journal.)

The photometric data for those galaxies come from archives
of the GALEX survey, the Two Micron All Sky Survey, and
the Sloan Digital Sky Survey as reduced and corrected for extinction
and published in Muñoz-Mateos et al. (2009a, 2009b, hereafter
JCM09a, JCM09b). The kinematics data come from the SINGS
H\alpha and THINGS H\({\text{1}}\) studies, respectively, except as otherwise
mentioned in Table 1. Reduction processes are presented in
Walter et al. (2008), Daigle et al. (2006), and Dicaire et al.
(2008a).

3. RESULTS

3.1. \( \Upsilon \) of Model Galaxies

Figure 1 compares the \( \Upsilon \) of models including either KTG93
or \( K01 \) IMFs for fixed scaling parameters (\( \lambda = 0.03 \) and
\( v_c = 220 \text{ km s}^{-1} \)) and shows some slight differences in the
radial behavior and absolute value of \( \Upsilon \), in one IMF compared
to the other, especially in the UV bands.

These differences are due to the shallower top-heavy end
of the \( K01 \) IMF in which a larger number of massive stars are
produced. Despite this difference, the results of the two IMFs are
very close to one another. This is due to the \( K01 \) models having
a smaller fraction of mass trapped in low-mass remnants. That
increases the amount of gas available for star formation, which
in turn leads to a higher \( \Psi \) SFR through the evolution of the
galaxy, compensating partially for the lower amount of stellar
mass locked by generation. As has already been pointed out by
Muñoz-Mateos et al. (2009b), the \( K01 \) IMF tends to slightly
overestimate the UV fluxes of early-type spirals. Nevertheless,
we will show in the following section that the \( K01 \) models provide
better fits to the photometric data and more consistent
results for weighting the stellar disk in all bands than the KTG93
models.

The appearance of the \( \Upsilon \) profiles (Figure 1) is a direct
consequence of the inside-out galaxy formation process: \( \Upsilon \) is at
its maximum at the center of the galaxy and then decreases near
the exterior due to progressively younger stellar populations
and lower metallicities, which was shown for late-type spirals even
when the color gradients were relatively small (Carignan 1985).
general rule, a few simulations with particular values of \( \lambda \) (1991). Larger variations are found at shorter wavelengths since the overall luminosity of a stellar population (Charlot & Bruzual 2003; Boissier & Prantzos 1999) that are found in larger proportion in the outskirts of galaxies. Even though \( \Upsilon \) increases with the stellar population age as a general rule, a few simulations with particular values of \( \lambda \) and \( v_c \) depart from this trend in the IR bands. This is due to evolved stellar stages that, although transient, contribute enormously to the overall luminosity of a stellar population (Charlot & Bruzual 1991). Larger variations are found at shorter wavelengths since photons with higher energies are increasingly produced by short-lived stars (Bruzual & Charlot 2003; Boissier & Prantzos 1999) that are found in larger proportion in the outskirts of galaxies. This is remarkable in the UV bands where more than a tenfold variation can be seen in Figure 2 from the center to the radius. The use of \( R_{2.2d} \) as determined in the IRAC1 bands links the variation of \( \Upsilon \) to the underlying mass distribution rather than only to the luminosity. Let us stress, however, that the models assume continuous star formation. The models thus do not represent an accurate picture of the star formation history (SFH) that can be somewhat more eventful in particular galaxies. Since the models ignore the contributions of bulges and bars, they pass over mechanisms that can greatly influence the exact composition of the stellar populations (Kormendy & Kennicutt 2004).

The scaling of the properties by different sizes and concentration factors of the halos influences the star-forming histories of the resulting model galaxies by changing the accretion rate and velocities of the model galaxy; the SFR at a given radius depends directly on those two factors.

In JCM11, the authors show in their Figure 7 the relation between morphological type and the parameters of the scaling halo. As can be expected, the circular velocity differs with type, peaking for Sc galaxies. The \( \lambda \) parameter, on the other hand, shows no tendency whatsoever in the distribution except for a possible larger dispersion for extremely late-type galaxies. They stress that this result tends to confirm predictions of the \( \Lambda \) CDM paradigm that the angular momentum per unit mass is independent of epoch, total mass, and history.

In models with low \( \lambda \), the evolution and enrichment of the central parts are more rapid, hence the higher center-to-edge difference in \( \Upsilon \), in all bands. A higher \( v_c \) (and thus a higher galactic mass) results in a higher \( \Upsilon \) at the center due to older

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**Table 1**

| Name      | Type | Distancea (Mpc) | P.A.  | Inclination | Model Parameters | Distinctive Feature |
|-----------|------|-----------------|-------|-------------|------------------|--------------------|
| NGC 0925  | SAB(s)d | 9.3             | 282   | 58          | 9.5              | 152               | Presence of a bar |
| NGC 2403  | SAB(s)cd | 3.2             | 307   | 58          | 5.1              | 116               | Presence of a very small bar |
| NGC 3198  | SB(rs)c | 13.8            | 35    | 70          | 4.7              | 172               | Presence of a bar |
| NGC 3621  | SA(s)cd | 6.6             | 339   | 57          | 2.5              | 146               |                  |
| NGC 4254  | SA(s)c  | 17              | 35    | 30          | 2.8              | 240               | c,d Prominent bulge and presence of a bar |
| NGC 4321  | SAB(s)bc | 18              | 30    | 32          | 4.0              | 293               | Prominent bulge and presence of a bar; gas depleted Virgo cluster galaxy; starburst in the central kiloparsec, LINERc,d,f |
| NGC 4569  | SAB(rs)ab | 17             | 23    | 65          | 4.0              | 270               | Prominent bulge and presence of a bar; gas depleted Virgo cluster galaxy; starburst in the central kiloparsec, LINERc,d,f |
| NGC 5055  | SA(rs)bc | 10.1            | 285   | 57          | 3.0              | 250               |                  |
| NGC 7793  | Sa(s)d  | 3.9             | 278   | 49          | 3.9              | 101               |                  |
| DDO 154   | IB(s)m  | 4.3             | 35    | 44          | 7.7              | 32                | Dwarf galaxy     |

**Notes.**

a Classifications are from the NED (RC3 Catalog; de Vaucouleurs 1963).

b Distances are those adopted for the SINGS sample as in the works by Walter et al. (2008), Gil de Paz et al. (2007), and Kennicutt et al. (2003).

c,d H i velocities from Gahathakurta et al. (1988).

d H i surface densities from Chung et al. (2009).

e H i velocities from Knapen et al. (1993).

f Special model for the evolutionary history of this particular galaxy.

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**Table 2**

| Name      | Type | Distancea (Mpc) | P.A.  | Inclination | Model Parameters | Distinctive Feature |
|-----------|------|-----------------|-------|-------------|------------------|--------------------|
| NGC 0925  | SAB(s)d | 9.3             | 282   | 58          | 9.5              | 152               | Presence of a bar |
| NGC 2403  | SAB(s)cd | 3.2             | 307   | 58          | 5.1              | 116               | Presence of a very small bar |
| NGC 3198  | SB(rs)c | 13.8            | 35    | 70          | 4.7              | 172               | Presence of a bar |
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| NGC 7793  | Sa(s)d  | 3.9             | 278   | 49          | 3.9              | 101               |                  |
| DDO 154   | IB(s)m  | 4.3             | 35    | 44          | 7.7              | 32                | Dwarf galaxy     |

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**Figure 2.** Relation between the variation of \( \Upsilon \), from the center to 2.2 \( Rd \), and the parameters \( \lambda \) and \( v_c \). The series of points joined by a line have a common \( v_c \) (\( v_c = 360 \text{ km s}^{-1} \)) are represented with the darkest shades. (A color version of this figure is available in the online journal.)
stellar populations caused by a more rapid infall rate of gas in higher density regions (Boissier & Prantzos 2000; Heavens et al. 2004).

Our own relation between color and $\Upsilon_*$ for each band is presented in Figure 3 and the coefficients of the first-degree polynomial in Table 2, for the sake of comparison with data from Bell & de Jong (2001).

Our relation between $\Upsilon_*$ and $(B - R)$, while showing the same trend, has a significant offset from the most similar case: the infall model of Bell & de Jong (2001). Our relation also shows a slightly shallower slope in both the $B$ and $K$ bands. This finding is due to the details of the ingredients of the two different models (the exact shape of the IMF, the SFR versus gas density, etc.). Nevertheless, for the color range covering galaxies $(B - R \sim 0.6 - 1.8)$, our relation in the optical agrees with that of Bell et al. (2003), showing that independent CSPE models yield similar results.

A degeneracy of the relation causes dispersion in $\Upsilon_*$ in all bands at very low color index. This low index is found in the exterior regions of galaxies characterized by populations with a more recent SFH, a lower dispersion of ages, and a higher fraction of young stars. In these populations, the color varies because of the contribution of young massive stars, but very old stars no longer dominate the luminosity and thus a variety of luminosities can correspond to the same color index depending on the age dispersion of the population. These populations are characterized by a lower metallicity, which contributes to the scatter as well since the color–$\Upsilon_*$ relation is weaker at low metallicities. It unfortunately means that in this particular color regime, it is impossible to determine $\Upsilon_*$ unequivocally only by the observable color gradient.

### 3.2. Mass Models of Individual Galaxies

We present here the results of disk weighting by $\Upsilon_*$ for all the individual galaxies of our sample as well as the mass modeling resulting for each. Two different types of mass models were performed for each galaxy.

1. A conventional mass model where the disk’s mass was inferred directly from the IRAC1 band photometry. Its $\Upsilon_*$ and the dark halo parameters were left free to vary in a best-fit approach.

2. The median of the $\Upsilon_*$-weighted disks in all available photometric bands was used as the stellar disk and the dark halo parameters were determined by a best-fit approach.

In the remainder of this paper, type (1) models are referred to as “constant-$\Upsilon_*$, as free parameter” models and type (2) models are referred to as “weighted-disk” models.

A pseudo-isothermal halo was used for modeling in both cases, and was also used for the scaling of the CSPE models. The two mass models were made with the interactive task manager rolimas of the Gipsy package.

The prominence of the bulge in the case of earlier type galaxies (NGC 4321 and NGC 4569) called for the decomposition of the photometry profile into bulge and disk components. A conventional de Vaucouleurs bulge and a strictly exponential disk were used (de Vaucouleurs 1948; Freeman 1970) with crude starting values set by fitting a straight line through the radius showing a visible agreement with an exponential disk and a subsequent $\chi^2$ minimization approach.

A $\chi^2$ fitting procedure was repeated on the exponential disk thus obtained to find the most appropriate model in the grid and the $\Upsilon_*$ was calculated anew for those results. Contrary to the fit procedure adopted in JCM11, our procedure takes into account the fact that in those two particular galaxies, the UV photometry was either unavailable or unreliable so an inferior weight was given to the UV and $u$ and $g$ bands compared to the visible and IR bands. The adopted $\Upsilon_*$ conversion for the bulge was supplied by the global relations connecting the color index to $\Upsilon_*$ in each band presented in the previous section (relations shown in Figure 3).

The case of barred galaxies cannot be ignored: these objects represent at least half of galaxies by conservative estimates (de Vaucouleurs 1963) and could reach as much as two-thirds of the population if the IR classification is considered (Knapen et al. 2000; Hernandez et al. 2005). As was shown previously by numerous authors (Bournaud & Combes 2002; Athanassoula & Misiriotis 2002; Hernandez et al. 2005), the effect of bars on the dynamical potential is substantial, driving several processes to the point where a big part of the evolution of galaxies could be their doing (Kormendy & Kennicutt 2004). Not only does the bar modify the overall history of the galaxy, but it also alters the rotational velocity by transporting gas and stars toward the center of the galaxy. The alteration of the observed velocity thus depends on the orientation of the bar with respect to the position angle of the galaxy (Dicaire et al. 2008b). If the bar is parallel to the major axis, the observed velocities are lower than would be expected from an axisymmetric potential; on the contrary, if the bar is perpendicular to the major axis, the observed velocities are higher. For the median case where both position angles display a $45^\circ$ angle, the bar does not have any effect whatsoever on the observed velocities (Athanassoula & Misiriotis 2002). The exact correction of a two-dimensional (2D) velocity field would be beyond the scope of this paper, but it should nevertheless be possible to apply a coarse first-order correction to the rotation curve to palliate this known effect.

#### 3.2.1. NGC 2403: the Typical Case

Situated at a distance of 3.2 Mpc, NGC 2403 is the most typical late-type spiral in our sample. This galaxy does not show any signs of interaction even though it is part of the M82 group. Hernandez et al. (2005) studied this object in their BHBar sample and concluded that although this galaxy is classified as an SAB, the bar is weak, not very well defined and has no
Figure 4 shows the fits to the photometry of the models; the two different IMFs are equally good for both. The higher UV fluxes yielded by the K01 models are clearly visible in the figure and in this particular case fit the observations better. As was already mentioned by JCM11, several galaxies show truncation or anti-truncation of the disk, which the models fail to reproduce (as seen in Figure 4). However, since these discrepancies occur at a low signal-to-noise ratio and are within the uncertainties of the V band data, it is difficult to distinguish them from simple problems in the background subtraction. This departure from the classical exponential disk profile at large radii has a very minimal effect on the overall mass model of the galaxy since these outer parts have a lesser impact on the global kinematics, and particularly on the determination of the halo parameters, because very little mass is involved.

The weighting operation was performed with the two different sets of models (KTG93 and K01) on all galaxies, but since the fit gave slightly more consistent results for all galaxies with the latter, only the K01-weighted disks are presented here. In this particular case, both the K01 and KTG93 models give good fits, even in the UV, with differences in stellar surface densities of the order of $\approx 300 \, M_\odot \, pc^{-2}$ at the center when considering all bands. Figure 5 shows the difference between the effective circular velocities of disks whose stellar density is derived directly from the photometry profiles (with $\gamma_\star = 1$) and disks whose stellar density is derived from the photometry profile weighted by the CSPE models.

Due to the higher $\gamma_\star$ in the central regions of galaxies, the velocity of the disks peak at lower radii than their unweighted counterparts. This effect is all the more pronounced for galaxies represented by models with low $\lambda$ because of the much faster evolution of the inner parts of these galaxies. As a direct consequence, the mass models constructed with the weighted disks differ significantly from the ones derived from constant-$\gamma_\star$ simple models. As discussed in the previous section, IR bands constitute an exception to this rule: their $\gamma_\star$ values show less radial variation than the other bands to the point where they can almost be considered constant. In the example presented in Figure 6, the best-fit model yields a halo with parameters $(\rho_0 = 31.1 \, M_\odot \, pc^{-3}; R_c = 3.6 \, kpc; \gamma = 0.67)$ for the...
Figure 6. Best-fit halo mass models for NGC 2403 using (a) the $\Upsilon_{\text{IRAC1}}$-as free parameter mass model (b) the CSPE-weighted median disk-mass model. (A color version of this figure is available in the online journal.)

IRAC1-unweighted disk compared to the $(\rho_0 = 142 M_\odot \text{pc}^{-3}; R_c = 1.6 \text{ kpc})$ values generated by the K01-weighted disk model. If we compare our results from the median disk with those available in the literature, we find that we have very similar parameters of the dark halo to those of de Blok et al. (2008): $\rho_0 = 153 M_\odot \text{pc}^{-3}; R_c = 1.5 \text{ kpc}$. Their $\Upsilon_{\text{IRAC1}}$, originating from Bell & de Jong (2001), is very different from the one we use for this band for the calculation of the median disk. It is slightly more than twice ours but with more substantial radial variation.

A second iteration of this procedure was performed to take into account the kinematics as a supplemental constraint on the fit. The parameters $R_c, \rho_0$ of the dark halo determined in the weighted-disks mass models were converted into $\lambda$ and $v_c$ values using Equation (1). The corresponding CSPE model was then used to start anew the weighting procedure. In the case of this galaxy, the photometry of the new model is offset in magnitude, but it does reproduce the general trend in all bands (Figure 7). The fit to the rotation curve in this new model is similarly good to the parameters of the weighted-disk model (Figure 8).

This coherence does not guarantee the veracity of this new solution and it should be treated with care: the photometry of the different bands weighted by the $\Upsilon_{\text{IRAC1}}$ of this new simulation produces disks with greater variation from one photometric band to another than does the case of the simulation selected only by the match to the photometry of the disk. The quadratic addition of all the velocity components in the mass model makes the more massive component (i.e., the halo) determine the overall appearance of the velocity curve and it therefore conceals the effect of the different weightings of the disk. As we stated in Section 2.1, the exact form of the velocity curve has a smaller influence than its maximal velocity and thus the kinematics are a less constraining condition than the photometry on this type of models.

In all other cases except for NGC 7793, the evolution model determined by the dark halo parameters found for our $\Upsilon_{\text{IRAC1}}$-weighted disk model did not satisfactorily fit the photometric data and was not used to generate the iterated-mass models.

3.2.2. Application of the Method to Other Galaxies

Galaxies being as different as they are from one another, each one is described in detail in the Appendix to assess their particularities. This paragraph provides a summary of the general tendencies of the whole sample.

The uniqueness of each galaxy renders a summary difficult, but it is also a conclusion in itself. The galaxies of our sample presenting either a bar or enhanced stellar activity all showed less consistency between the mass density profiles derived from each band with one another compared to the ideal low-activity axisymmetric profiles. All galaxies showed a convincing fit of the kinematics data when using the CSPE models for the determination of the disk mass. In general, the best-fit parameters we evaluated from the $\Upsilon_{\text{IRAC1}}$-weighted disk models were in good agreement with the results found in the
most recent literature, notably those published by the THINGS group (except for a few galaxies for reasons detailed in the Appendix).

Table 3 summarizes the results of the two different mass models performed for our whole sample of galaxies. The two last columns present the equivalent $R_e$ and $\rho_0$ of the scaling halo used in the evolution models. The conversion relations, from Fall & Efstathiou (1980), Boissier & Prantzos (1999), and Mo et al. (1998), are the following:

$$R_e = \frac{70 \alpha \nu_c}{220},$$

$$\rho_0 = \frac{\nu_c^2}{17.284 \pi R_e^2}.$$  

4. DISCUSSION

Here we further discuss the implications of the results presented so far and the limits of the methods used.

A general remark should be made about the use of $H\alpha$ and $HI$ data: although $H\alpha$ was formerly considered as providing the best resolution for kinematic data, $HI$ data are now almost as spatially resolved. Nevertheless, a comparison between the two for a whole set of galaxies led to the conclusion that resolution is not the only factor at play explaining the differences. Daigle (2010) concluded that the optical depth is to blame for the disparity commonly seen between the two gaseous components.

While we use bands from the NUV to the mid-IR, we are well aware that the UV is not the best band in which to estimate stellar masses. However, we decided to keep these measurements because their impact on the median density is minimal.

The set of CSPE models employed here is successful in reproducing a wide range of observable properties of galaxies. By assuming that the MW is typical, Boissier & Prantzos (2000) used the most precise data then available to calibrate several parameters (e.g., gas accretion rate and star formation efficiency) and further refined their method by taking into account some properties of a sample of nearby galaxies (Boissier et al. 2003). Ten years later, with a plethora of data from large galactic surveys, Muñoz-Mateos et al. (2011) verified that the model still predicts correctly the main characteristics of galaxies. In the current study, we found that not only do those models reproduce well the photometry of galaxies, but they also supply physically motivated $\Upsilon*$ weighting factors leading to disk masses fluctuating very little from one photometric band to another.

We believe our models provide good results to first order in view of how well they reproduce the photometry profiles. In the future, some adjustments could make these models even more physically realistic. First comes the question of the IMF. A universal IMF has been used here and seems to provide good results. But while some authors consider the universal IMF to be representative (Bastian et al. 2010; Calzetti et al. 2011), some others have raised concerns about its validity (Meurer et al. 2009; Boselli et al. 2009). No unequivocal confirmation of this variability of the IMF has been supplied to date, but if it turned out to be the case, it would certainly be interesting to introduce those changes in the models. There also should be an update in the models for a better handling of the advanced stellar phases and circumstellar dust emission, especially in the NIR. Finally, radial transport should be implemented to consider cases where a significant mass exchange can take place (e.g., barred galaxies). This could have complex effects on the UV profiles (lowering metallicity with outer gas; bringing fuel to the very center) while the presence of bars might help in reducing star formation. Detailed investigations of such effects should then be performed.
We defined our “maximum-disk” as was originally meant in Carignan & Freeman (1985); i.e., as the maximum velocity that the disk can adopt without overshooting the observed velocity curve, and not as the 0.85 \( V_{\text{max}} \) fixed in Sackett (1997) because of the different conformation of the density profile of radially varying \( \Upsilon \), and radially constant \( \Upsilon \).

The approach used here, i.e., taking into account all photometric bands to construct a median stellar disk for mass modeling, is very thorough but should not be necessary in view of the consistent results obtained for all bands in most galaxies. The topic was discussed at length by several authors already (Bell & de Jong 2001; Bruzual & Charlot 2003; de Blok et al. 2008), but let us stress once again that the IR bands, and especially the mid-IR IRAC bands, are indeed appropriate for determining disk masses because of their almost flat \( \Upsilon \), profiles in present-day galaxies of the nearby universe. In all galaxies, we found those bands to reproduce convincingly the median disks found by the full method. The only difficulty is to find the appropriate CSPE model when one has only a few bands at one’s disposal. The \( \Upsilon \),–color relation comes in handy in this case, but as one can see from Figure 3, no color index allows for the unambiguous determination of \( \Upsilon \), in the IR bands at a low color index, though the best results would follow from the use of (FUV-R). Only the outskirts of galaxies should be subject to such a problem and the mass model is less sensitive to variation in these regions than it would be if the variation occurred at more central radii where more mass is involved.

It would be very interesting and most certainly worth additional work to establish the limits of the validity of these models for spheroidal components and then use them for spiral galaxies with important bulges or elliptical galaxies. Some effort should also be employed toward a method exploiting the full 2D information of the velocity maps. Zibetti et al. (2009) have already constructed 2D maps of \( \Upsilon \), of galaxies with the help of the Bell & de Jong (2001) \( \Upsilon \),–color relationships. This, along with analysis techniques of 2D velocity information, such as the ones developed, for example, by Wiegert (2010), is the next logical step leading to a realistic treatment of kinematics information in galaxies.

Our disks are compatible with maximum disks because of their higher \( \Upsilon \), values in the center. This is ultimately due to the inside-out formation scheme allowing for more mass in the center in the form of an older stellar population. This conformity with the maximum disk hypothesis also means that in order not to overshoot the velocities in the center, all relevant corrections need be made in the rotation curve.

The individual results of the previous section show that elements such as a bulge or a bar can no longer be considered insignificant with this new method of fixing the disk mass. It is important to mention the presence of galaxies in Figure 9 having disks that look over-maximal. Even if at first glance it is not physical to accept over-maximal disks, we kept them as is because the median disk was below the higher bound of the error bars of the rotation curve, and that is not even considering the lower bound of the error bars on the mass of the disk. This nevertheless gives rise to questions about whether the stellar component should be systematically split up into bulge and disk components. Figure 15 convincingly demonstrates the lessening effect of this decomposition on the disk’s contribution to the rotation curve; galaxies with even a smallish bulge like NGC 3198 are probably tainted by the effects of a neglected bulge.

We compared the maximal velocities of our disks with the maximal-disk hypothesis. Figure 9 should make it clear that maximum disks are compatible with our results. Once again, this is due to the higher \( \Upsilon \), values in the inner regions of disks, making the disk maximal at small radii. This is at odds with the results from Bershady et al. (2011), who observe sub-maximal disks in a face-on sample of spiral galaxies. This is in part due to the definition they adopt of a maximal disk as being \( V_{\text{disk, max}} = 0.85 V_{\text{max}} \) that does not take into account the amplified contribution due to the radially dependent \( \Upsilon \). For the sake of reference with the literature, we traced the comparison between the maximal velocity of our disks with the Sackett (1997) criterion for disk maximality (0.85 × \( V_{\text{obs, max}} \)). The results are shown in Figure 10. According to Sackett’s criterion, all of our disks would be sub-maximal, but if we were to heighten our disks to reach \( V_{\text{disk, max}} = 0.85 V_{\text{obs, max}} \), the inner parts of the disk velocities would dramatically overshoot the actually observed rotation curves. Only one galaxy lies well below the max-disk relation: DDO 154, as was expected from previous studies of the mass distribution in dwarf galaxies. The smallest galaxies are dominated by the dark halo component and the stellar disk is still building up in our models.
1. The CSPE models prove to be a good tool to weight the different photometric bands in order to obtain consistent stellar disk masses regardless of the spectral band used. The models provide radially dependent $Y_\star$ values. The dispersion in effective circular velocity for all bands is on average of the order of $\sim 30\%$.
2. Once the disk is determined by physically motivated models, it becomes impossible to ignore the effects of bulges and bars; those essential corrections need to be made.
3. The agreement of the multi-wavelength observations with the model is a hint that a galaxy has had a standard evolution history and $Y_\star$ can be reliably applied even though each and every galaxy is unique and small discrepancies will inevitably arise.
4. The color index versus $Y_\star$ relation is an imperfect tool for assigning masses to young stellar populations because of the degeneracy affecting $Y_\star$ in all bands at low color index.
5. Mostly radius-independent mid-IR $Y_\star$ values are advisable to use as tracers of stellar mass when only a limited number of photometric bands are available for nearby galaxies.
6. Disks resulting from the method shown above are compatible with the max-disk hypothesis, and show a trend of higher disk contribution to the overall mass of the galaxy with increasing total mass of the latter.
7. For most galaxies, the halo used to perform the scaling of the properties of the model and the dark halo derived from the actual rotation curve agree to within 40\%.
8. This method achieved good results for both regular and dwarf galaxies.

A certain number of improvements can still be implemented such as modifications to the CSPE models themselves and the full 2D treatment of kinematic data, but our methodology nevertheless constitutes a step forward from constant-$Y_\star$ methods, mainly because $Y_\star$ can no longer be considered a free parameter at any radius.

Some interesting future work for this multi-wavelength method would be a similar study for higher-redshift galaxies where the impact of younger stellar populations would significantly modify the appearance of the $Y_\star$ profiles, particularly in the mid-IR.

We would like to thank Juan Carlos Muñoz-Mateos for kindly providing the results of his ready-to-use multi-wavelength data for all galaxies in our SINGS subsample. We are also grateful to the THINGS $\mathrm{H\small\text{I}}$ team for making their data available to the whole community.

**APPENDIX**

This appendix describes the details of mass modeling of the nine remaining galaxies of our sample. Figure 12 shows the velocities of the resulting disks in every photometric band for each galaxy while Figures 13 and 14 present their actual mass models with conventional and CSPE-determined methods.

**NGC 0925.** The bar of this galaxy extends to 56.5 $\prime\prime$ (2.55 kpc) and is oriented parallel to the major axis of the galaxy (Martin 1995; Hernandez et al. 2005), hence its maximum effect on the rotation curve. As shown by Dicaire et al. (2008b), the true rotation velocity should be higher in the inner parts if proper corrections are applied to account for the presence of the bar. Accordingly, one can see in Figure 13 the rotation curve behaving almost as a solid body and the velocities of the
Figure 12. Rotation velocities of the disks for the whole sample of galaxies as seen in different wavelengths. (A color version of this figure is available in the online journal.)
This indicates that the models do not reproduce correctly the SFH as a function of radius and it is probably due to interaction. The model in this case poorly constrains $\Upsilon_\star$ and its radial variation.

The type (2) mass model provides a passable fit to the data. It is not very surprising, due to the non-circular effects above mentioned, that the model would fit well the general trend but not the details of the rotation curve. Using different estimators,
Kranz et al. (2001) find $\Upsilon_{\star, K}$ consistent in the mean with ours ($\Upsilon_{\star, K} = 0.23–0.74$ compared to our $\Upsilon_{\star, K} \sim 0.53$).

NGC 4321 (M100). Another member of the Virgo cluster, this galaxy with noteworthy arms and bulge is one of those requiring bulge/disk decomposition and subsequent refitting to find the most appropriate model. In order to split the two components, we performed a least-squares fit of the photometry profiles by a sum of a pure de Vaucouleurs spheroid and an exponential disk (de Vaucouleurs 1963; Freeman 1970). The first-guess estimate was obtained by fitting an exponential disk to the region affected neither by the bulge nor by the arms and subtracting the component from the photometry profile to determine the parameters of the spheroidal component. The size of the bulge was left free to vary in all bands, but the result gave consistent size estimates. Only the disk was used to find the best model in the grid. This new fitting procedure is delicate due to the peculiar photometry profile caused by the presence of the arms between 4.4–6.1 kpc and 8.7–12.2 kpc. We thus performed the new $\chi^2$-minimization excluding the affected radii. The quality of the fit might have suffered from taking into account only a subset of the available radii.

We did not adopt a radius-dependant $\Upsilon_{\star}$ for the bulge since the stellar population in this case is, by its evolutionary history and dynamics, thought to be much more uniform than the one in the disk. This of course might be disputed when a pseudo-bulge is considered but should be correct for a typical de Vaucouleurs spheroid. Indeed, we verified that neither of our two earlier-type galaxies showed a strong color gradient in their bulges before settling the issue. The density we adopted for the bulge comes from data of the extracted bulge component in the grid. This new fitting procedure is delicate due to the peculiar photometry profile caused by the presence of the arms between 4.4–6.1 kpc and 8.7–12.2 kpc. We thus performed the new $\chi^2$-minimization excluding the affected radii. The quality of the fit might have suffered from taking into account only a subset of the available radii.

The difference between the as-is photometry curve and the quadratic sum of its bulge and disk components is striking ($\Delta v \approx 75 \text{ km s}^{-1}$), especially in the innermost radii where the fate of the mass model is sealed. This grand design spiral, just like many members of the Virgo cluster, has been studied the fate of the mass model is sealed. This grand design spiral, which should have the effect of raising the rotation curve due to the bar from the non-circular effect of the very strong arms, just as it is hard to distinguish the effect of the bulge and the bar on the luminosity profile. But if we applied a velocity correction of such a large amplitude as the one suggested by Knapen et al. (1993), it would clearly be difficult to reconcile the observed velocity with the one due to the combined bulge and disk. Wada et al. (1998) find an $\Upsilon_{\star, H\alpha}$ ratio that is consistent with our own estimate at the very center.

NGC 4569 (M90). This galaxy is far from being a textbook case for kinematic studies. Not only does it possess a considerable bulge, but its position in the Virgo cluster and its well-documented gas depletion makes it a weird beast of the galactic zoo (Vollmer et al. 2004; Boone et al. 2007; Chemin et al. 2006). As such, a special model was devised taking into account the gas-stripping event from ram pressure leading to the peculiar SFH of the galaxy to compute the stellar disk density (Boissi et al. 2006). As was the case for NGC 4321, the splitting of the profile into bulge and disk constituents results in a considerable change in the effective velocities. This, of course, is due to the spheroidal rather than the planar distribution of the mass in a bulge.

The agreement of the rotational velocity of the weighted stellar component (disk and bulge) to the actual measured H$\alpha$ and H$\alpha$ rotation curves is visibly inadequate in the inner regions where the bulge dominates the contribution of said stellar component. Let us stress that the BP99 and BP00 models describe the evolution of disk galaxies and not of spheroidal objects. The $\Upsilon_{\star}$ computed from these models can therefore be off because of differences in the SFHs of the bulge and disk. The almost solid body appearance of the rotation curve could be due to a past stripping event according to Vollmer et al. (2004). Another reason for this discrepancy might be the large-scale bar supposedly present in the center, where a lot of emission due to a strong star-forming nucleus can be seen (Boone et al. 2007; Laurikainen & Salo 2002). This bar sits at an angle compatible with a decrease in the observed rotational velocities.

NGC 5055 (M63). NGC 5055 is a moderately inclined SABc galaxy with a slightly declining rotation curve. Blais-Ouellette et al. (2004) found strong kinematic motions in the inner regions ($R < 300$ pc). The dark halo parameters we obtain are radically different from those of de Blok et al. (2008) because they performed a bulge/disk decomposition and we did not. One might think that in this case the dark halo we find should be less concentrated than that found by the THINGS team because, by not splitting the luminosity profile, we overestimate the rotational velocities of the disk. The situation is, however, a little different; the $\Upsilon_{\star}$ used by de Blok et al. (2008) is higher than ours.

NGC 7793. This galaxy could also have been used as a template model for our studies but its slightly higher inclination made us prefer NGC 2403. The models fit well the photometry in all bands and accordingly the error on the determination of the disk is low.

Dicaire et al. (2008a) showed the rotation curve to be truly declining with their very deep H$\alpha$ observations reaching the
confines of the THINGS rotation curve. They used B-band photometry to estimate the disk mass and an isothermal dark halo. As can be seen in Table 4, the parameters of our isothermal halo and those from Dicaire et al. (2008a) and Carignan & Puche (1990) are quite different because of dissimilar values chosen for \( Y_\star \). Because of our much lower value of \( Y_\star \), it was suspected to have more perceptible repercussions on dwarf galaxies. It is not a benign question because of rapidly decreasing with radius, we find a more concentrated halo with a higher central density.

**DDO 154.** We chose DDO 154 as a test of our method on dwarf galaxies. It is not a benign question because of the overlook of radial transport and outflows in the models. This omission has negligible effects in "regular galaxies," the overlook of radial transport and outflows in the models. It is not a benign question because of dissimilar values chosen for \( Y_\star \). Because of our much lower value of \( Y_\star \), it was suspected to have more perceptible repercussions on dwarf galaxies. Models supplementing the original grid were calculated for B Dwarf galaxies. Models supplementing the original grid were calculated for Dwarf galaxies. While this omission has negligible effects in "regular galaxies," it was suspected to have more perceptible repercussions on dwarf galaxies. Models supplementing the original grid were calculated for Dwarf galaxies. The \( \chi^2 \) fitting procedure was once again performed on this grid extension and the result reproduced DDO 154's photometry as well as it had the regular galaxies. Quality photometry data were available only for five bands, but those included the UV and IR bands. We stick to performing the mass models with the K01 models-weighting even though in this particular case the KTG93 models reconcile better the UV and IR ranges. The mass model presented in Figure 14 shows the overall domination of dark matter at all radii of the galaxy. The disk’s contribution to the velocity lies far below the total rotation curve. As can be seen in Table 4, our results differ from those of Carignan & Purton (1998). Our \( Y_\star \) is \( \sim \) 6 times lower than theirs, thus our halo is two times more centrally concentrated than theirs while the central concentration is not very different. On the other hand, if we compare our results to de Blok et al. (2008) who follow a similar procedure to our own, we find almost perfect agreement.

### Table 4
Comparison of Disk and Dark Halo Parameters from This Work and Other References

| Name         | Reference                  | \( Y_\star \) (IRAC1) |\( R_\star \) (kpc) | \( \rho_0 \) \( \left( 10^{-3} M_\odot pc^{-3} \right) \) |
|--------------|----------------------------|-----------------------|---------------------|---------------------------------------------------|
| NGC 0925     | This work,                 | 0.26–0.28             | 7.29                | 11.5                                              |
|              | Walter et al. (2008)       | 0.65 (IRAC1)          | 9.67                | 5.9                                               |
| NGC 2403     | This work,                 | 0.25–0.31             | 1.58                | 142.0                                             |
|              | de Blok et al. (2008)      | 0.30–0.60             | 1.5                 | 153                                               |
| NGC 3198     | This work,                 | 0.21–1.54             | 2.38                | 70.5                                              |
|              | van Albada et al. (1985)   | 3.8 (B)               | 12                  | 4                                                 |
|              | Blais-Ouellette et al. (2001), de Blok et al. (2008) | 4.8 (B) | 2.5 | 5.7 |
|              |                            | 0.7–0.8 (IRAC1)       | 2.72                | 47                                                |
| NGC 3621     | This work,                 | 0.27–0.47             | 4.29                | 26.6                                              |
|              | de Blok et al. (2008)      | 0.4–0.8 (IRAC1)       | 2.8                 | 48.9                                              |
| NGC 4254     | This work,                 | 0.3–0.53              | 10.6                | 14.5                                              |
|              | Kranz et al. (2001)        | 0.23–0.74             | ...                | ...                                               |
| NGC 4321     | This work,                 | 0.36–0.56             | 1.56                | 395.8                                             |
|              | Wada et al. (1998)         | 0.2–0.8 (H)           | ...                | ...                                               |
| NGC 4569     | This work,                 | 0.40–0.46             | 25.71               | 19.1                                              |
| NGC 5055     | This work,                 | 0.31–0.42             | 5.42                | 18.9                                              |
|              | de Blok et al. (2008)      | 0.5–1.1 (disk) and 1.3 (bulge) (IRAC1) | 45 | 0.9 |
| NGC 7793     | This work,                 | 0.23–0.84             | 1.23                | 166                                              |
|              | Carignan & Puche (1990), Dicaire et al. (2008a) | 2.2 (B) | 2.7 | 40 |
|              |                            | 2.6 (B)               | 2.9                 | 27                                                |
| DDO 154      | This work,                 | 0.16–0.22             | 1.23                | 30.6                                              |
|              | Carignan & Purton (1998), de Blok et al. (2008) | 1.2 (B) | 2.5 | 22.0 |
|              |                            | 0.32 (IRAC1)          | 1.32                | 28.5                                              |

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