STRUCTURAL PARAMETERS OF STELLAR DISKS FROM TWO MICRON ALL SKY SURVEY IMAGES OF EDGE-ON GALAXIES

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ABSTRACT

We present results of an analysis of the $J$, $H$, and $K_s$ Two Micron All Sky Survey (2MASS) images of 139 spiral edge-on galaxies selected from the Revised Flat Galaxies Catalog. The basic structural parameters scale length ($h$), scale height ($z_0$), and central surface brightness of the stellar disks ($\mu_0$) are determined for all selected galaxies in the near-infrared (NIR) bands. The mean relative ratios of the scale heights of the thin stellar disks in the $J$:$H$:\textit{K}$\_s$ bands are $1.16:1.08:1.00$, respectively. Comparing the scale heights obtained from the NIR bands for the same objects, we estimate the scale heights of the thin stellar disks corrected for the internal extinction. We find that the extinction-corrected scale height is, on average, $11\%$ smaller than that in the $K$ band. Using the extinction-corrected structural parameters, we find that the dark-to-luminous mass ratio is, on average, $1.3$ for the galaxies in our sample within the framework of a simplified galactic model. The relative thicknesses of the stellar disks $z_0/h$ correlates with their face-on central surface brightnesses obtained from the 2MASS images. We also find that the scale height of the stellar disks shows no systematic growth with radius in most of our galaxies.

Key words: galaxies: halos – galaxies: photometry – galaxies: spiral – galaxies: structure – infrared: galaxies

Online-only material: machine-readable table

1. INTRODUCTION

Study of the parameters of galactic components via decomposition of the rotation curves is often ambiguous in the case of spiral galaxies. The same rotation curve often may be explained by models with very different parameters of the components. The dark-to-light mass ratio may vary several times between the models explaining well the same rotation curve, especially if the latter is smooth and featureless (see, for example, de Blok et al.\textsuperscript{2001}; Bizyaev \& Zasov\textsuperscript{2002}; Dutton et al.\textsuperscript{2005}). Incorporating information about the stellar velocity dispersion from observations helps to significantly constrain the masses of galactic components (Bottema\textsuperscript{1993}; Khoperskov et al.\textsuperscript{2001}) and relieve some ambiguities that appear in the modeling of rotation curves, but observing the distributions of the velocity dispersion is a rather difficult task. The stellar disk thickness can be used as an alternative to the stellar velocity dispersion (Zasov et al.\textsuperscript{2002}). Studies of the vertical structure of stellar disks alone allow the constraint of some dark halo parameters (Bahcall\textsuperscript{1984}; Zasov et al.\textsuperscript{1991, 2002}; Bizyaev et al.\textsuperscript{2003}; Bizyaev \& Kajsin\textsuperscript{2004}). Note that not all galaxies are suitable for such studies: inferring the structural parameters for a spiral galaxy with a significant bulge from photometric data alone is dangerous and should be supplemented with concerns of a different mass-to-light ratio for different galactic subsystems (see discussion by Abadi et al.\textsuperscript{2003} regarding difference between photometrically and dynamically identified subsystems).

Infrared observations are crucial for studies of the structure of edge-on galaxies. The dust attenuation makes the extraction of the structural parameters difficult from the optical data. In the near-infrared (NIR) bands, the galaxies are much more transparent, which facilitates studies of the structure of galaxies. The all-sky 2MASS survey (Skrutskie et al.\textsuperscript{2006}) offers a good opportunity to increase the number of edge-on galaxies available for studies in the near-infrared bands. Although faint parts of the galaxies are not seen in the 2MASS images, the thin disks of the galaxies are obtained with a sufficient signal-to-noise ratio (S/N).

In this paper, we focus on the determination of stellar disk structural parameters corrected for the internal extinction. One approach to the problem is to perform the modeling of the radiation transfer in three-dimensional stellar-gaseous disks (like in Xilouris et al.\textsuperscript{1999}; Kylafis et al.\textsuperscript{2001}; Bianchi\textsuperscript{2007}). Such studies require rather deep images, although there are attempts to apply this kind of analysis to a larger sample of moderate quality (Bizyaev\textsuperscript{2007}). In the present paper, we develop another approach to study the extinction-corrected structure of the stellar galactic disks comparing the parameters of the disks obtained from different NIR bands.

In Section 2, we discuss the sample selection and evaluation of the stellar disk’s structural parameters, consider reliability of the parameters, and study the radial variation of the disk scale height. In Sections 3 and 4, we show how the comparison of the parameters obtained in the three NIR bands can be used to estimate the extinction-corrected scale height in the galactic disks. Section 5 considers the connection between the galactic disk thickness with parameters of the dark halos around the spiral galaxies in the frames of a simplified model. Section 6 summarizes the results of the paper.

2. SAMPLE OF GALAXIES AND ANALYSIS OF THE IMAGES

As a predefined sample of edge-on galaxies, the Revised Flat Galaxies Catalog (RFGC hereafter; Karachentsev et al.\textsuperscript{1999}) is chosen. The catalog contains visually classified extragalactic objects with a major-to-minor axes ratio $a/b > 7$. To secure enough pixels for studying the vertical structure, we select objects with the major axis greater than $1$ arcmin. This size is estimated directly from the 2MASS images at the level of...
S/N ≈ 3. Note that this size is significantly less than commonly used diameter $D_{25}$. As a result, we select 139 spiral edge-on galaxies that have images in all three 2MASS bands: $H$, $J$, and $K_S$.

We apply the technique described by Bizyaev & Mitronova (2002) to obtain the structural parameters of stellar disks of the galaxies disks. This method is based on the analysis of photometric profiles drawn parallel to the major and minor axes of the galaxy at a one-pixel interval. The volume brightness in the stellar disks is assumed to change in the radial $r$ or vertical $z$ directions as follows:

$$\rho_L(r, z) = \rho_{L0} \exp(-r/h) \text{sech}^2(z/z_0),$$

(1)

where $h$ and $z_0$ are the scale length and scale height of the disk, respectively, and $\rho_{L0} = \int \rho(0, z) dz$ is the central surface luminosity of the face-on disk, which corresponds to the central surface brightness $\mu_0$. The model photometric profiles are obtained by the integration of Equation (1) along the line of sight and then by convolution with the instrumental profile. The best-fit parameters $h$, $z_0$, and $\rho_{L0}$ are estimated for each radial or vertical profile, and then their median values are taken as the resulting scales and central surface brightness of the stellar disks, whereas the standard deviations of $h$, $z_0$, and $\rho_{L0}$ estimated from different profiles are taken as uncertainty of the parameters. The central regions of the galaxies in which bulges may exist are excluded from our analysis. The parameters $h$, $z_0$, and $\mu_0$ are obtained in the $J$, $H$, and $K_S$ bands for selected 139 galaxies. The $K_S$-based parameters are shown in Table 1.

Figure 1 shows histograms of distribution of the scale heights (top panel) and scale lengths (bottom panel) estimated for our program galaxies. In both panels, the $J$- and $H$-band scales are normalized by those in the $K_S$ band. It can be noticed that the scale heights look systematically larger, on average, in the $J$ band than those in the $K_S$ for the same galaxy. We will discuss this effect below: in Section 3 using our observational data, and in Section 2.2 with the help of artificial data.

### 2.1. Radial Variation of the Disk Scale Height

As in Bizyaev & Mitronova (2002), we investigate how the scale height $z_0$ of the stellar disks in our galaxies change with the distance to the center $r$. Our approach to the estimation of the $z_0$ is independent of the a priori assumptions about behavior of the scale height with a radius, in a contrast with the three-dimensional modeling of the radiation transfer in the stellar and dust disks. Since we analyze the vertical profiles separately from each other, this approach is insensitive to possible bending of the galactic disks. Note that if the resulting scale height $z_0(r)$ demonstrates a systematic growth with a distance to the center, it suggests that the real radial gradient of the disk scale height may be a few times greater due to the projection effects.

We fit $z_0(r)$ with a linear function of radius $r$ and find the radial gradients of $z_0$ (expressed in units of $z_0$) per scale length, see Figure 2. Different lines in Figure 2 show the histograms of the distribution of the gradient in the $J$, $H$, and $K_S$ bands in our whole sample. The median gradient $(dz_0/dr) \cdot (h/z_0)$ in the $K_S$ band is essentially zero (~0.01), as well as in the $H$ (0.) and $J$ (0.01) bands.

Note that some galaxies in the histogram in Figure 2 indeed show noticeable radial gradients of the scale height. In

### Table 1

| Name          | $h(K)$ (kpc) | $dh$ (kpc) | $z0(K)$ (kpc) | $dz0$ (kpc) | $\mu_0(K)$ (mag/arcsec) | $d\mu_0$ (mag/arcsec) | $z_0$ (cor.) (kpc) | $\mu_0$ (cor.) (mag/arcsec) | $M_{dark}/M_{lum.}$ |
|---------------|--------------|------------|---------------|-------------|-------------------------|-----------------------|--------------------|-----------------------------|---------------------|
| RFGC01025     | 5.33         | 0.06       | 0.88          | 0.14        | 17.73                   | 0.20                  | 0.13               | 17.66                        | 1.67                |

Notes. The table shows the RFGC names, scale length $h$ in kpc and its uncertainty in the $K_S$ band, scale height $z_0$ in kpc and its uncertainty in the $K_S$, central surface brightness $\mu_0$ in the $K_S$, extinction-corrected scale height $z_0$ (cor.) in kpc, extinction-corrected relative thickness of the stellar disk $z_0$ (cor.)/$h$, extinction-corrected central surface brightness $\mu_0$ (cor.) in the $K_S$, and dark-to-luminous mass ratio $M_{dark}/M_{lum.}$.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

Figure 1. Scale heights (top panel) and scale lengths (bottom panel) in the $J$ (dashed line) and $H$ (dotted line) bands normalized by those from the $K_S$ for our 139 galaxies. The $K_S$-based scales in both panels equal to unit for all objects.
Combination with the projection effects, it suggests significant gradients \((d z_0/dr) \cdot (h/z_0)\) in a small fraction of our galaxies.

### 2.2. Reliability of the Structural Parameters

The dust disks embedded into the stellar components of the galaxies may significantly distort the structural parameters of the stellar disks estimated even from the NIR images. We check reliability of the estimated parameters via the following simulations. A set of artificial images is created using Equation (1) and typical parameters \(h\) and \(z_0\). The surface brightness \(\mu_0\) is replaced by the luminosity surface density \(I_0\) in our simulations. Each stellar disk contains an embedded dust disk inside with scale length of 1.5 \(h\) and scale height of 1/3 \(z_0\) (according to Bianchi 2007). The face-on opacity of the dust disk corresponds to \(A_V = 1 \text{ mag}\). This value should be close to the upper limit for the face-on extinction in spiral galaxies (Kuchinski et al. 1998; Xilouris et al. 1999; Bianchi 2007). Finally, the model disks are randomly inclined by 85°–90°, and their images (i.e., two-dimensional projections to the plane of sky) are obtained via integration along the line of sight. The images are then convolved with the instrumental profile typical for the observations. Then the Poisson and Gaussian noise patterns are added to create sets of typically 30 artificial images with the same parameters but with a different random noise pattern. The images are analyzed by the same way as the real galaxies; the mean values of \(h\), \(z_0\), and \(I_0\) and their rms are estimated and then compared with the input parameters. Figures 3 and 4 give examples of how well the structural parameters can be extracted from the artificial edge-on disks made with stars and dust should they be observed in the \(J\) and \(K_s\) NIR bands. Although the scale length and the central surface brightness can be recovered with a fairly good accuracy from both \(J\) and \(K_s\) bands, the scale height in the \(J\) band looks systematically thicker due to the dust absorption effects only. The \(K_s\) scale height in this case is found to be about 15% greater than the model input scale height.

We check how the chosen values of the model parameters affect our conclusions. The amount of the dust opacity is responsible for increasing the estimated scale height and makes it thicker by 10%–15% in the \(K_s\) if \(A_V\) is of the order of 1 mag. Much higher values of the central dust opacity, more than 3 mag, make stellar disks look about twice as thick even in the \(J\) band. At the same time, the disk scale length shows relatively small variations in this case. Variations of the dust scale length between \(h\) and 2 \(h\) do not change the estimated structural parameters significantly. The dust-disk thickness affect the estimated stellar disk thickness in the most power when it is about a half of \(z_0\). Once the dust disk becomes comparable in thickness with the stellar one, it affects mostly the stellar disk surface brightness, and not \(z_0\).

The inclination of the stellar disk to the line of sight is an important parameter, and it increases the stellar disk thickness estimated in our modeling by more than 15%, if the inclination becomes greater than 5°. On the other hand, the relatively small inclination has almost no effect on the recovered stellar disk scale length and central surface brightness. More than 5° inclination in galactic disks would create a problem with the estimation of \(z_0\) (see also de Grijs et al. 1997), but such galaxies should fail the RFGC catalog criteria and we do not expect to have many of the highly inclined disks in our sample. If the size of the modeling disk is so small that its true scale height is much less than the seeing, the resulting \(z_0\) becomes independent.
are within our accuracy of the estimation of the scale length. The vertical gradients of metallicity and age, and hence contribution of the stellar population effects to the vertical color variations within the thin stellar disk, are usually small (Tadross 2003; Seth et al. 2005; Allende Prieto et al. 2006). Even if we assume the large values for the vertical gradient of [Fe/H] as in de Grijs & Peletier (2000), −0.2 dex kpc−1, this would create less than 1% longer scale heights in the J than that in the Ks due to the stellar population gradients. The amplitude of the changes of scale lengths and scale heights between the H and Ks bands is roughly a half of that between the J and Ks.

We conclude that the scale heights of the pure thin stellar disk (i.e., without dust) estimated from the J, H, and Ks images should appear the same. All significant scale height variations have to be addressed to the reddening effects. This is in agreement with the conclusions by Dalcanton & Bernstein (2002). Note that in some cases of extraordinary objects like a superthin galaxy UGC 7321 (Matthews & Wood 2001), the reddening alone cannot explain the observed optical color (B−R), (R−H) variations in the vertical direction, and vertical gradients of metallicity and age are required for the stellar population. At the same time, Matthews & Wood (2001) note that the superthin’s H−K color gradients might be explained by the wavelength-dependent dust absorption alone.

4. STRUCTURAL PARAMETERS OF THE THIN STELLAR DISKS CORRECTED FOR EXTINCTION

Following Kylafis & Bahcall (1987), we consider a vertical luminosity profile of an edge-on image of a stellar disk with the volume brightness \( \rho_L(z) = \rho_{L,0} \exp(-z/z_0) \). An embedded co-planar dust disk with its scale height \( z_d < z_0 \) absorbs and scatters the light in dependence of the dust extinction coefficient \( k_\lambda = k_\lambda,0 \exp(-\tau_\lambda/(z/z_d)) \). For simplicity, we neglect the dust scatter appealing to the Bianchi (2007) conclusion that the structural parameters of stellar disks in the three-dimensional modeling of the light distribution with or without scattering are not significantly different. As in Kylafis & Bahcall (1987), the brightness distribution along the minor photometric axis \( z \) in such a disk is \( I(z) = I_0(z) \exp(-\tau(z)/(z_\star)) \), where \( I_0(z) \) is the brightness profile in the case of zero extinction, and \( \tau \) is the optical depth across the whole edge-on disk, which also depends on the vertical distance over the galactic plane \( z \). For small \( \tau \), \( I(z) \approx I_0(1 - 0.5 \tau(z)) \). The observed scale height \( z_\lambda \) of the stellar disk with added extinction is connected with its projected brightness along the selected profile as \( I(z) = I_{\star,0} \exp(-z/z_\star) \). Given \( I_0(z) = I_\star \exp(-z/z_\star) \), we find that \( 1/z_\star \approx 1/z_\lambda(1 - \tau(0)) \). Therefore, estimating the thickness of the stellar disk with dust from its edge-on profiles, we expect to find

\[
z_{\star,0} = z_\lambda(1 + C_\lambda \tau_\star),
\]

where \( z_{\star,0} \) is the \( z_\star \) estimated from the disk’s brightness profile at a certain photometric band, and the optical depth in the plane of the disk in a certain photometric band is \( \tau_\star = C_\lambda \tau_\star \). We assume that \( C_\lambda \) equals 0.276, 0.176, and 0.112 in the J, H, and Ks bands, respectively (Schlegel et al. 1998). Since the V-band optical depth \( \tau_\star \) and \( z_\star \) are fixed for the same disk, we use linear regression and fit a line to three data points (for J, H, and Ks values) at \( C_\lambda = z_{\star,0} \) diagram to find \( z_\star \).

For the convenience of the comparison of the vertical scales, we normalize the J- and H-scale heights in each galaxy by their Ks-band scale height. The upper panel in Figure 5 compares
the normalized scale heights. Each line in the panel connects three thicknesses for one galaxy. The tendency to observe the stellar disks thicker in the $J$ than in the $K_s$ is well seen. The histogram in the lower panel in Figure 5 shows the distributions of all normalized $z_0$ in three NIR colors. The vertical thick line designates formally the scale heights in the $K_s$ that are all equal to unity due to the normalization.

We calculate the scale height $z_s$ corrected for the extinction (or extinction-free hereafter) using Equation (2), which gives $z_s \leq z_0(K_s)$. The distribution of $z_s$ normalized by the $z_0(K_s)$ is also shown in the lower panel in Figure 5. The median $z_s/z_0(K_s)$ is about 0.89, i.e., the thin stellar disks in our galaxies are 11% thinner than it can be estimated from the analysis of the vertical profiles from the $K_s$-band images. The extinction-free scale heights are given in Table 1.

We observe no systematic variations in the scale length between the NIR bands, as can be seen in Figure 6, which is the same as Figure 5 but drawn for the scale lengths. This is not a surprise because our simulations shown in Figures 3 and 4 suggest rather small systematic variations of the radial scale length among the NIR bands, and proximity of the $h$ estimated from the $J$, $H$, and $K_s$ bands to its extinction-corrected value. Using the scale length $h$ from the $K_s$ band and extinction-corrected scale heights, we find that the mean radial-to-vertical scale ratio in the thin extinction-free stellar disks of galaxies in our sample is 5.6.

5. THICKNESS OF THE STELLAR DISKS AND MASS OF THE DARK HALOS

The thickness of the stellar disk is sensitive to the gravitational potential of the disk + bulge + halo system in the vertical direction (e.g., Bahcall 1984). Therefore, the relative thickness of the stellar disk $z_0/h$ may provide some information about the spherical-to-disk mass ratio. As a first step, we consider a very simplified model of a galaxy that consists of a stellar exponential disk embedded into a spherical dark halo.

The total mass of the exponential stellar disk with the central surface density $\Sigma_0$ is

$$M_d = 2\pi \Sigma_0 h^2.$$  \hfill (3)

The total mass of all components of the galaxy is

$$M_r \sim V^2 h,$$  \hfill (4)

where $V$ is the disk’s rotational velocity. Following Zasov et al. (1991) and Kregel et al. (2005), we assume that the disk thickness depends on the local surface density $\Sigma$ and vertical velocity dispersion $\sigma_z$:

$$z_0 \sim \sigma_z^2 / G \Sigma,$$  \hfill (5)

and the ratio of the vertical-to-radial velocity dispersions is $\sigma_z/\sigma_r = \text{const}$. This is a rather coarse but fair approximation; see Polyachenko & Shukhman (1977), Bottema (1993), Gerssen et al. (2000), and Kregel et al. (2005).

We incorporate an assumption of the marginal stability of the stellar disk, i.e.,

$$\sigma_r = Q \cdot 3.36 \Sigma / \varpi,$$  \hfill (6)
The relation “live” halos that respond to the gravitational potential of disks.

Figure 7. Relative disk thickness $z_0/h$ is shown against the spherical-to-disk mass ratio $M_s/M_d$. Here $M_s$ is the mass of the spherical component (halo and bulge, in a general case), and $M_d$ is the mass of the disk component. The $M_s$ and $M_d$ are estimated within the limits of the stellar disk (4h). This figure comes from simplified N-body simulations (Mikhailova et al. 2001), and each symbol corresponds to a certain numerical model. The models were run with a variety of parameters for the disk, dark halo, and bulge. The upper curve corresponds to the bulgeless models, whereas the lower one is for the models with some bulge contribution.

Numerical N-body simulations (Zasov et al. 1991; Mikhailova et al. 2001) in which the spherical subsystem was introduced as a fixed potential confirm Equation (7). Figure 7 is adopted from Mikhailova et al. (2001) with additions from later simulations by A. Khoperskov (2009, private communication). Figure 7 shows that the stellar disk thickness $z_0/h$ is sensitive to the relative mass of the spherical component $M_s$ normalized by the $M_d$. Both $M_s$ and $M_d$ are determined within the limits of the stellar disk (four scale lengths in the simulations). The circles in Figure 7 correspond to different numerical models with various parameters of the disk and dark halo subsystems, as well as with different bulges. The upper curve corresponds to the bulgeless models, whereas the lower one is for the models with some bulge contribution.

Contemporary and more realistic N-body simulations include “live” halos that respond to the gravitational potential of disks. The relation $z_0/h$ versus $M_s/M_d$ should look very similar in those simulations as in Figure 7 for the galaxies in which the spherical subsystems dominate by mass (i.e., for large $M_s/M_d$). For the spherical subsystems with masses $M_s \lesssim M_d$, Figure 7 illustrates an extreme case, and its top left part (large $z_0/h$ and small $M_s/M_d$) demonstrates the lower limit for the mass of the spherical subsystem given the disk thickness $z_0/h$. Preliminary results from N-body simulations (A. Khoperskov 2009, private communication) with a live halo suggest not essential corrections to $M_s/M_d$ inferred from $z_0/h$ according to Figure 7 (of the order of 15%). We encourage the reader to assume our further estimations of the halo-to-disk mass ratio made from the disk thickness as lower limits for the real $M_s/M_d$.

Following Figure 7, we calculate the distribution of the dark halo mass $M_{\text{halo}}$ expressed in the units of the stellar disk mass for our galaxies. The RFGC members are “flat” galaxies that are not expected to harbor large bulges, so we assume here that $M_{\text{halo}} = M_s$. We find the following relation for bulgeless galaxies from Figure 7: $M_{\text{halo}}/M_d = -0.9419 + 0.3737(h/z_0)$. According to this formula, the median value of $M_{\text{halo}}/M_d$ is about 1.3 within our sample. The histogram of the distribution of $M_{\text{halo}}/M_d$ is shown in Figure 8. No correlations between $M_{\text{halo}}/M_d$ and absolute magnitude, maximum of rotational velocity, or radial gradient of the scale height are found for our galaxies. A tendency to observe higher $M_{\text{halo}}/M_d$ in the objects with a larger scale length $h$ is found, although this relation shows large uncertainty.

Following the same basic assumptions, we can include the central surface density $\Sigma_0$ into consideration. As follows from our definition of the disk and total galaxy mass, $M_s/M_1 \sim \Sigma_0 h^2/V^2 h = \Sigma_0 h/V^2$. We perform a linear fit between log $V$ and log $h$ for our galaxies with known $V$ and found that $h \sim V^{1.42}$. It seems more correct to utilize non-edge-on galaxies to study such a correlation, and Kormendy (1990) and Walker (1999) suggest $h \sim V^{1.5}$, respectively, for arbitrary inclined disks. If the latter relation is accepted, it gives $M_s/M_1 \sim \Sigma_0/V^{0.5}$, and in combination with Equation (7) we come to the following relation between the disk thickness and its central surface density:

$$ z_0/h \sim \Sigma_0/h^{1/3} . $$

The upper panel in Figure 9 shows the relation between $h/z_s$ (i.e., extinction-corrected inverse thickness of the disks) and the central surface brightness in the $K_s$ band $\mu_0(K)$. Here $\mu_0(K)$ was corrected for the extinction according to formula (2). The correction is rather small, and its median value for our sample of galaxies is about 0.1 mag arcsec$^{-2}$. This is in a very good agreement with the face-on extinction derived by Graham & Worley (2008).

The lower panel in Figure 9 demonstrates the plot of $h/z_s$ versus the central surface density estimated from observations as $2.30(M/L)_S 2.512^{24-\mu_0}$. The numerical coefficient in the formula corresponds to the $K_s$-band solar absolute magnitude 3.33 mag. We assume the constant $(M/L)_S = 1$ here. The trend in Figure 9 is in agreement with formula (8). The very big scatter of points in Figure 9 can be attributed to the relatively low accuracy in the $\mu_0$, $h$, and $z_s$, and even more uncertainty is due to the nonconstant
value of the mass-to-light ratio (M/L). The scatter of this relation can be lowered dramatically if only large \((h > 4 \text{ kpc})\) galaxies with the scale height gradient in the \(K_s\) band are considered, see Figure 10. In this case, the inverse disk thickness (\(h/z_s\)) depends on \(\mu_0(K)\) as

\[
h/z_0 = 47.557 - 23.069 x + 3.016 x^2,
\]

where \(x = \log(2.3 \cdot 2.512^{24-\mu_0(K)}) = 0.4 \times (25.11 - \mu_0(K))\). The solid curve in Figure 10 represents this equation. Apparently, the large spiral galaxies whose stellar disks are not flared can be better described by the toy-model developed above. Establishing the correlation between the \(\mu_0\) and \(h/z_s\) may be useful for estimating the disk thickness and \(M_{\text{halo}}/M_d\) in disky galaxies with arbitrary inclination.

Note that our model is oversimplified, and attempts to estimate only the \(M_{\text{halo}}/M_d\) ratio. Should we need to know the values of \(M_{\text{halo}}\) or \(M_d\) taken apart, or structural parameters of the dark halo, the rotation curve modeling has to be incorporated. Such additional parameter as the disk thickness helps to decrease the ambiguity during the rotation curves decomposition. Special attention should be given to correspondence between the photometrically and dynamically inferred parameters of galactic subsystems. An example of \(N\)-body simulations of an early-type disk galaxy (Abadi et al. 2003) demonstrates that photometry may fail to trace the dynamically distinct subsystems in the central parts of bulge-harboring galaxies. In our consideration, we avoid central parts of galaxies, and using the RFGC objects prevents us from considering bulge-dominated stellar systems.

The weakness of the simplified assumptions in the modeling described above encourages us to apply a more realistic simulations of the stellar disk vertical structure. Since it requires extensive numerical simulations and better quality infrared data, and will gain from the incorporation of rotation curves decomposition, we defer such more complex consideration to a further paper.

### 6. SUMMARY AND CONCLUSIONS

We study how the dust absorption affects the basic structural parameters (disk central surface brightness, vertical and radial scales) of stellar disks in spiral galaxies estimated from the NIR \(J\), \(H\), and \(K_s\) images. Using 2MASS data, we compare the structural parameters estimated from different NIR bands focusing on the scale height of thin stellar disks. The stellar disks look thinner in the 2MASS \(K_s\) band in comparison with the \(H\) and \(J\) bands. We employ this fact to figure out the extinction-corrected scale height \(z_0\) of the thin stellar disk.

Using 139 relatively large galaxies selected from the 2MASS catalog, we find that the mean vertical scale height (\(z_0\)) ratios are 1.16:1.08:1.00:0.89 in the \(J:H:K_s\)-extinction-free bands, respectively. This means that the radial scale length estimated from the \(K_s\) images is very close to the extinction-corrected one, whereas the scale height is overestimated by 11% on average. The mean extinction correction for the face-on central surface brightness is only about 0.1 mag arcsec\(^{-2}\).

The median radial-to-vertical scale ratio for our sample is about 6. Using a relation between the stellar disk thickness and the halo-to-disk mass ratio obtained from a simplified model, we estimate the dark-to-luminous mass ratio in our galaxies within the limits of their optical disks. Its mean value is about 1.3. A relation between the stellar disk thickness and its central surface brightness is observed for the galaxies from our sample, although it shows significant scatter and is affected by uncertainty in additional parameters. This relation is more prominent for large \((h > 4 \text{ kpc})\) galaxies from our sample and can be utilized for coarse estimating the disk thickness and relative mass of the dark halo in large spiral galaxies arbitrarily inclined to the line of sight.

We also find that the scale height does not change systematically along the radius in most of our galaxies. Only a small fraction of galaxies demonstrates a noticeable radial growth of the scale height.

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