INFORMATION ON THE MILKY WAY FROM THE TWO MICRON ALL SKY SURVEY WHOLE SKY STAR COUNT: THE STRUCTURE PARAMETERS

CHAN-KAO CHANG\(^1\), CHUNG-MING KO\(^2,3\), AND TING-HUNG PENG\(^4\)

\(^1\) Institute of Astronomy, National Central University, Jhongli, Taiwan; rex@astro.ncu.edu.tw
\(^2\) Institute of Astronomy, Department of Physics and Center of Complex Systems, National Central University, Jhongli, Taiwan; cmkko@astro.ncu.edu.tw
\(^3\) Department of Physics, University of Hong Kong, Pokfulam Road, Hong Kong, China

ABSTRACT

The \(K_s\)-band differential star count of the Two Micron All Sky Survey (2MASS) is used to derive the global structure parameters of the smooth components of the Milky Way. To avoid complication introduced by other fine structures and significant extinction near and at the Galactic plane, we only consider Galactic latitude \(|b| > 30^\circ\) data. The star count data are fitted with a three-component model: double exponential thin disk and thick disk, and a power-law decay oblate halo. Using maximum likelihood, the best-fit local density of the thin disk is \(n_0 = 0.030 \pm 0.002\) stars pc\(^{-3}\). The best-fit scale height and length of the thin disk are \(H_1 = 360 \pm 10\) pc and \(H_1 = 3.7 \pm 1.0\) kpc, and those of the thick disk are \(H_2 = 1020 \pm 30\) pc and \(H_2 = 5.0 \pm 1.0\) kpc, the local thick-to-thin disk density ratio is \(f_2 = 7\% \pm 1\%\). The best-fit axis ratio, power-law index, and local density ratio of the oblate halo are \(\kappa = 0.55 \pm 0.15\), \(p = 2.6 \pm 0.6\), and \(f_h = 0.20\% \pm 0.10\%\), respectively. Moreover, we find some degeneracy among the key parameters (e.g., \(n_0\), \(H_1\), \(f_2\), and \(H_2\)). Any pair of these parameters are anti-correlated to each other. The 2MASS data can be well fitted by several possible combinations of these parameters. This is probably the reason why there is a wide range of values for the structure parameters in literature similar to this study. Since only medium and high Galactic latitude data are analyzed, the fitting is insensitive to the scale lengths of the disks.

Key words: Galaxy: fundamental parameters – Galaxy: general – Galaxy: stellar content – Galaxy: structure – infrared: stars

Online-only material: color figure

1. INTRODUCTION

In the 18th century, the famous astronomer William Herschel showed us how the powerful star count method can help us understand our own Milky Way (Herschel 1785). The technique has been used since then by generations of astronomers. With great improvement on data collection over the years, more and more details of our Milky Way were revealed. However, the characteristic scales of smooth Galactic structures (i.e., disks and halo) obtained by previous studies do not converge to a common value as an outcome of improving data collection (see Table 1). The spread of values is attributed to the degeneracy of Galactic model parameters (i.e., the same star count data could be fitted equally well by different Galactic models; Chen et al. 2001; Siegel et al. 2002; Jurić et al. 2008; Bilir et al. 2008). This is due to the different sky regions and limiting magnitudes (i.e., limiting volumes) used in these studies (Siegel et al. 2002; Karaali et al. 2004; Bilir et al. 2006a, 2006b; Jurić et al. 2008). On the contrary, Bilir et al. (2008) and Yaz & Karaali (2010) did not show such degeneracy in determining the Galactic model parameters. This controversy is still actively debated. Therefore, systematic all sky surveys with deeper limiting magnitude and wider sky region, such as the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006), the Sloan Digital Sky Survey (SDSS; York et al. 2000), the Panoramic Survey Telescope & Rapid Response System (Pan-Starrs; Kaiser et al. 2002), and the GAIA mission (Perryman et al. 2001) could provide a good opportunity for us to study our Galaxy from a global perspective. Free from limited sky fields, astronomers can acquire much more information from the stellar distribution of these surveys.

In Galactic structure study, in addition to the simple and smooth two-component model (Bahcall & Soneira 1980) or the
typically subtle and obscured by a substantial foreground veil of 2MASS star count data. Here we quote Majewski et al. (2004, to identify in general. Their contribution is negligible in the observable contribution to the 2MASS star count data, are all

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| $H_1$ (pc) | $H_1$ (kpc) | $f_2$ | $H_2$ (kpc) | $H_2$ (kpc) | $f_6$ | Re(S) (kpc) | $\kappa$ | Reference |
|------------|-------------|-------|-------------|-------------|-------|-------------|---------|-----------|
| 310–325    | 0.0125–0.025 | 1.92–2.39 | ... | ... | ... | ... | ... | Yoshii (1982) |
| 300        | 0.02        | 1.45    | ... | ... | ... | ... | ... | Gilmore & Reid (1983) |
| 325        | 0.02        | 1.3     | ... | ... | 0.002 | 3 | 0.85 | Gilmore (1984) |
| 280        | 0.0028      | 1.9     | ... | 0.0013 | ... | 3.1* | 0.8 | Tritton & Morton (1984) |
| 125–475    | 0.016       | 1.18–2.21 | ... | 0.0013 | ... | 3.1* | 0.8 | Robin & Creze (1986) |
| 300        | 0.02        | 1       | ... | ... | 0.001 | 2.36 | Flat | Fenkart & Karaali (1987) |
| 285        | 0.015       | 1.3–1.5 | ... | 0.002 | ... | 2.9 | 0.9 | Yoshii et al. (1987) |
| 325        | 0.0224      | 0.95    | ... | 0.001 | 2.9 | 0.9 | ... | von Hopp & Bothun (1993) |
| 249        | 0.041       | 1       | ... | 0.002 | 3 | 0.85 | ... | Kuijken & Gilmore (1989) |
| 350        | 3.8         | 0.019   | 0.9 | 3.8 | 0.0011 | 2.7 | 0.84 | Yamagata & Yoshii (1992) |
| 290        | ...         | ...     | 0.86 | ... | ... | ... | 4 | ... |
| 325        | 0.020–0.025 | 1.6–1.4 | ... | 0.0015 | ... | 2.67 | 0.8 | ... |
| 325        | 3.2         | 0.019   | 0.98 | 4.3 | 0.0024 | 3.3 | 0.48 | ... |
| 250–270    | 2.5         | 0.056   | 0.76 | 2.8 | 0.0015 | 2.44–2.75* | 0.60–0.85 | ... |
| 260        | 2.3         | 0.074   | 0.76 | 3 | ... | ... | ... | ... |
| 290        | 4           | 0.059   | 0.91 | 3 | 0.0005 | 2.69 | 0.84 | ... |
| 249        | ...         | ...     | 0.79 | ... | ... | ... | ... | ... |
| 285        | 0.02        | 1.26/1.29 | 2.99* | 0.63 | ... | ... | ... | ... |
| 330        | 2.25        | 0.065–0.13 | 0.58–0.75 | 3.5 | 0.0013 | ... | 0.55 | ... |
| 280        | 2.8         | 0.035   | 0.86 | 3.7 | ... | ... | ... | ... |
| 300        | 0.02–0.10   | 0.7–1.0 (0.9–1.2) | 3–4 | 0.0015 | ... | 0.50–0.70 | ... | ... |
| 285        | 1.97        | ...     | ... | ... | ... | ... | ... | ... |
| 300        | 3.5         | 0.02–0.03 | 0.9 | 4.7 | 0.002–0.003 | 4.3 | 0.5–0.6 | ... |
| 265–495    | 0.07        | 0.64   | ... | 0.00125 | ... | 0.6 | ... | ... |
| 324        | 2.1         | 0.11    | 1.06 | 3.04 | ... | ... | ... | ... |
| 300        | 0.04–0.10   | 0.9     | ... | ... | ... | ... | ... | ... |
| 220        | 1.9         | ...     | ... | ... | ... | ... | ... | ... |
| 160–360    | 0.033–0.076 | 0.84–0.87 | ... | 0.0004–0.0006 | ... | 0.06–0.08 | ... | ... |
| 301/259    | 0.087/0.055 | 0.58/0.93 | ... | 0.001 | ... | 0.74 | ... | ... |
| 220–320    | 0.01–0.07   | 0.6–1.1 | ... | 0.00125 | ... | >0.4 | ... | ... |
| 206/198    | 0.16/0.10   | 0.49/0.58 | ... | ... | ... | ... | ... | ... |
| 140–269    | 0.062–0.145 | 0.80–1.16 | ... | ... | ... | ... | ... | ... |
| 220–360    | 1.65–2.52   | 0.027–0.099 | 0.62–1.03 | 2.3–4.0 | 0.0001–0.0022 | ... | 0.25–0.85 | ... |
| 167–200    | 0.055–0.151 | 0.55–0.72 | ... | 0.0007–0.0019 | ... | 0.53–0.76 | ... | ... |
| 245(300)   | 2.1(2.6)    | 0.13(0.12) | 0.743(0.900) | 3.26(3.600) | 0.0051 | 2.77* | 0.64 | ... |
| 325–369    | 1.00–1.68   | 0.0640–0.0659 | 0.860–0.952 | 2.65–5.49 | 0.0033–0.0039 | ... | 0.0489–0.0654 | ... |
| 360        | 3.7         | 0.07    | 1.02  | 5   | 0.002 | 2.6* | 0.55 | ... |

Notes. The parentheses are the corrected values for binarim. The asterisk denotes the power-law index replacing Re. References indicating the original result table mean either Galactic longitude or limiting magnitude-dependent Galactic model parameters.

We prefer the second method in this paper and only use Galactic latitude $|b| > 30^\circ$ 2MASS $K_s$-band star count data to obtain the structure parameters of a three-component model. In addition, the influence of the near-infrared extinction in these regions is small. This also allows us to use a simpler extinction model for correction. We describe our model in Section 2 and the analysis method in Section 3. Section 4 provides the results and a discussion.

2. THE MILKY WAY MODEL

We adopt a three-component model for the smooth stellar distribution of the Milky Way. It comprises a thin disk, a thick disk, and an oblate halo (Bahcall & Soneira 1980; Gilmore & Reid 1983). The total stellar density $n(R,Z)$ at a location $(R,Z)$ is the sum of the thin disk $D_1$, the thick disk $D_2$, and the halo $H$,

$$n(R, Z) = n_0[D_1(R, Z) + D_2(R, Z) + H(R, Z)].$$

where $R$ is the galactocentric distance on the Galactic plane, $Z$ is the distance from the Galactic mid-plane, and $n_0$ is the local stellar density of the thin disk at the solar neighborhood. The stellar distribution of the thin disk $D_1$ and the thick disk $D_2$ decreases exponentially along $R$ and $Z$ (the so-called double exponential disk),

$$D_i(R, Z) = f_i \exp \left[ -\frac{(R - R_\odot)}{H_{1i}} - \frac{(|Z| - |Z_\odot|)}{H_{2i}} \right],$$

simpler but needs justifications. We observe that (1) the fine structures (e.g., inner bars, flares, and warps), which have observable contribution to the 2MASS star count data, are all confined in the Galactic plane region, and (2) the overdensities or substructures in the outer disk region and the halo are difficult to identify in general. Their contribution is negligible in the 2MASS star count data. Here we quote Majewski et al. (2004, p. 738) on halo substructure: “Because this substructure is typically subtle and obscured by a substantial foreground veil of disk stars, eliciting its presence requires strategies that optimize the substructure signal compared to the foreground noise.”

We adopt the second method in this paper and only use Galactic latitude $|b| > 30^\circ$ 2MASS $K_s$-band star count data to obtain the structure parameters of a three-component model. In addition, the influence of the near-infrared extinction in these regions is small. This also allows us to use a simpler extinction model for correction. We describe our model in Section 2 and the analysis method in Section 3. Section 4 provides the results and a discussion.
where \((R_\odot, Z_\odot)\) is the location of the Sun, \(H_n\) is the scale length, \(H_z\) is the scale height, and \(f_i\) is the density ratio to the thin disk at the solar neighborhood. The subscript \(i = 1\) stands for the thin disk (thus \(f_1 = 1\)) and \(i = 2\) for thick disk. We adopted \(R_\odot = 8\) kpc in our model (Reid 1993).

The halo is a power-law decay oblate spheroid flattening in the Z-direction,

\[
H(R, Z) = f_h \left[ \frac{R^2 + (Z/Z_\odot)^2}{R_\odot^2 + (Z/Z_\odot)^2} \right]^{-\pi/2},
\]

where \(\kappa\) is the axis ratio, \(\rho\) is the power index, and \(f_h\) is the local halo-to-thin disk density ratio.

Chang et al. (2010) showed that the whole sky \(K_s\)-band luminosity function can be well approximated by a single power law with a power-law index \(\gamma = 1.85 \pm 0.035\), a bright cutoff at \(M_b = -7.86 \pm 0.60\) and a faint cutoff at \(M_f = 6.88 \pm 0.66\). We adopt this luminosity function in the following analysis. In normalized form, it is

\[
\psi(M_{K_s}) = \frac{2 \log_{10}(\gamma - 1)}{5[10^{2\gamma-1}M_b^5 - 10^{2\gamma-1}M_f^5]} 10^{0.4(M_f-5)}.\]

Table 2 lists our searching parameter space and the finest grid size we used. The key parameters in our study are \(R_\odot, Z_\odot, n_1, n_2, H_1, H_2, f_2, f_h, \kappa, \rho\), which have considerable contribution to the star count data, and the relatively complex extinction correction at the low Galactic latitude region, we avoid low galactic latitudes, and only consider data in Galactic latitude \(|b| > 30^\circ\). Although several overdensities in the halo (such as Sagittarius, Triangulum-Andromeda, Virgo, etc.) were identified, they cannot be picked up from the overwhelming foreground field stars on star count data without additional information (e.g., color, distance, metallicity, etc.; Majewski et al. 2004). Therefore, their contribution to the 2MASS \(K_s\)-band differential star count is negligible and will not affect our result. We also exclude the areas around the Large and Small Magellanic Clouds for their significant stellar population.

3. THE DATA AND ANALYSIS METHOD

3.1. The 2MASS Data

The 2MASS point-source catalog (2MASS PSC; Cutri et al. 2003) is employed to carry out the \(K_s\)-band differential star count for the entire Milky Way. We divide the whole sky into 8192 nodes according to level 5 hierarchical triangular mesh (HTM; Kunszt et al. 2001). The level 5 HTM samples the whole sky in roughly equal areas with an average angular distance of about \(2^\circ\) between any two neighboring nodes. The amount of stars within a \(1^\circ\) radius of each node (i.e., each node covers \(\pi\) deg\(^2\)) is then retrieved with a bin size \(K_s = 0.5\) mag via the 2MASS online data service (Cutri et al. 2003 catalog). Our selection criterion is: the object must be detected in all \(J, H, K_s\), and \(K_s\) bands and have signal-to-noise ratio \(\geq 5\). Since the limiting magnitude of the 2MASS \(K_s\) band is 14.3 mag, has 10 signal-to-noise ratio and 99% completeness (see Table 1 in Skrutskie et al. 2006), and \(K_s \leq 5\) mag objects have relatively large photometric error, we only compare 2MASS data with our simulation data from \(K_s = 5-14\) mag.

In order to minimize the effects coming from the close-to-Galactic-plane fine structures (e.g., flares, warps, arms, budge and bars, etc., which have considerable contribution to the star count data), and the relatively complex extinction correction at the low Galactic latitude region, we avoid low galactic latitudes, and only consider data in Galactic latitude \(|b| > 30^\circ\). Although several overdensities in the halo (such as Sagittarius, Triangulum-Andromeda, Virgo, etc.) were identified, they cannot be picked up from the overwhelming foreground field stars.

3.2. The Analysis Method

The maximum likelihood method (Bienayme et al. 1987) is applied to compare the \(K_s\)-band 2MASS differential star counts and the simulation data to search for the best-fit structure parameters of the three-component Milky Way model. Our fitting strategy is as follows.

1. Take \(R_\odot = 8\) kpc.
2. Choose one \(Z_\odot\) and work out the maximum likelihood value by fitting the nine parameters \((n_0, H_{z1}, H_{z1}, f_2, H_{z2}, f_h, \kappa, \rho)\).
3. Repeat step 2 for other \(Z_\odot\).
4. Pick the \(Z_\odot\) that corresponds to the maximum of the maximum likelihood values in step 3.
5. Repeat steps 2–4 for finer grid size of the nine-parameter fit and a narrower range of \(Z_\odot\) around the one found in step 4.
6. The uncertainty is estimated by adding Poisson noise on the simulation data to see how the likelihood varies. The difference of the likelihoods of 500 realizations of the same model, differing by the Poisson statistics only, gives a range of likelihood around the maximum likelihood that defines the confidence level.

Table 2 lists our searching parameter space and the finest grid size we used. The key parameters in our study are \(n_0, H_{z1}, f_2, H_{z2}\) (see Equations (1) and (2)). The first two play a primary role on the variation of the likelihood value while the latter two play a secondary role. The other five parameters \(H_{z1}, H_{z2}, f_h, \kappa, \rho\) (see Equations (1)–(3)) are non-key parameters, which means they play a minor role and do not affect the likelihood value as much as the key parameters.

4. THE RESULTS AND DISCUSSION

Table 3 lists our best-fit results with the corresponding uncertainties. Figure 1 shows contour plots of likelihood against different pairs of parameters. The contour changes dramatically...
along the key parameters $n_0$, $H_{z1}$, $f_2$, and $H_{z2}$, but changes relatively mildly along the other parameters $H_{z1}$, $H_{z2}$, $f_2$, $p$, and $\kappa$. This indicates the importance of the key parameters in determining the best-fit result.

Degeneracies exist between some pairs of key parameters, such as $(n_0, H_{z1})$, $(n_0, f_2)$, $(H_{z1}, f_2)$, etc. Here, degeneracy means that the likelihood value stays almost the same when the pairs of parameters change together in a particular way. A similar degeneracy between the local thick-to-thin disk ratio $f_2$ and the scale height of the thick disk $H_{z2}$ has been reported in Chen et al. (2001), Siegel et al. (2002), Jurić et al. (2008), and Bilir et al. (2008). Consequently, it is possible that different combinations of parameters can be regarded as “acceptable” fitting. For example, if we choose a higher local stellar density $n_0$, then we can pick a smaller $H_{z1}$ such that the likelihood value is very close to the maximum likelihood value and assign it as the “best-match” scale height of the thin disk. Therefore, a thin light color diagonal strip shows up on the $n_0$ against $H_{z1}$ contour plot in Figure 1. Furthermore, similar trends happen in other pairs of key parameters. When one parameter of the pair is higher, we can get a similar likelihood value by lowering the other parameter (see the corresponding two-parameter contour plots of key parameters in Figure 1). This anti-correlation is not unexpected. The number of stars along the line of sight in the model increases when any one of the key parameters increases. Thus, for a given observed number of stars, an increase in one key parameter can be compensated by a decrease in the other. Perhaps this is the reason that our best-fit scale height of the thin disk, $H_{z1} = 360$ pc, is somewhat larger than the reported values, $H_{z1} = 285$ pc, in the Lopez-Corredoira et al. (2002) study (they also use the star count of 2MASS to obtain Galactic model parameters). Our best-fit local stellar density

### Table 3

| Parameters | Value  | Uncertainty |
|------------|--------|-------------|
| Thin disk  |        |             |
| $H_{z1}$   | 3.7 kpc| 1.0 kpc     |
| $H_{z1}$   | 360 pc | 10 pc       |
| $n_0$      | 0.030 stars pc$^{-3}$ | 0.002 stars pc$^{-3}$ |
| $Z_\odot$  | 25 pc  | 5 pc        |
| Thick disk |        |             |
| $H_{z2}$   | 5.0 kpc| 1.0 kpc     |
| $H_{z2}$   | 1020 pc| 30 pc       |
| $f_2$      | 7%     | 1%          |
| Spheroid   |        |             |
| $\kappa$   | 0.55   | 0.15        |
| $p$        | 2.6    | 0.6         |
| $f_0$      | 0.20%  | 0.10%       |
As a result, our fitting tends to choose a larger scale height corresponding value cited in Lopez-Corredoira et al. (2002). We do not see any obvious deviation in the Galactic latitude $|b| > 30^\circ$ areas, only in the Large Magellanic Cloud and the Small Magellanic Cloud areas. For confirmation, we plot the integrated star count from $K_s = 5$ to 14mag along the Galactic longitude and latitude for the $|b| > 30^\circ$ areas in Figures 3 and 4. We see that the 2MASS data and our best-fit model agree well and that there are only some small deviations in the nodes at the anti-Galactic center $b \sim 30^\circ$. The significant spikes in Figures 3 and 4 are due to the populations of the Large Magellanic Cloud and the Small Magellanic Cloud. To test how these small deviations affect the key parameters’ selection, we exclude these small deviations and re-analyze the data with fixed non-key parameters. It shows only the scale height of the thick disk shifting slightly but still within our error estimation. We do not see any significant differences of reported overdensities in sky regions with $|b| > 30^\circ$. Thus, we conclude that the three-component model can describe the Milky Way structure sufficiently well for high Galactic latitude regions and the single power-law luminosity function of Chang et al. (2010) is a good approximation as well. Since our main purpose is to search for the global Galactic model parameters, we do not try to explore the best-fit result for each node individually as what Cabrera-Lavers et al. (2007), Bilir et al. (2008), and Yaz & Karaali (2010) have done in their studies to seek the variations of disk model parameters with Galactic longitude. Instead, we treat the differences of the 2MASS data to our best-fit model as deviations from a global smooth distribution. We believe that similar variations in disk model parameters will be obtained if we use a similar analysis procedure (i.e., searching best-fit parameters for each node), but this is beyond the scope of this work. Because we do not consider flares, warps, and other overdensities in our model, there are some discrepancies between the 2MASS data and the model in the low Galactic

![Figure 2. Ratios of observed to model integrated star count from $K_s = 5$ to 14 mag.](image)

The color indicates the values of the ratios.

from $K_s = -8$ to 6.5 mag is $n_0 \sim 0.030$ star pc$^{-3}$, which is about half of $\sim 0.056$ star pc$^{-3}$, the corresponding value cited in Eaton et al. (1984), and a bit lower than the $\sim 0.032$ star pc$^{-3}$ corresponding value cited in Lopez-Corredoira et al. (2002). As a result, our fitting tends to choose a larger scale height of the thin disk. If we force our local stellar density to be about half of $\sim 0.056$ star pc$^{-3}$, then the “best-fit” scale height of the thin disk would be $\sim 320$ pc, which is closer to their result. If we choose an even higher local stellar density, then the “best-fit” scale height of the thin disk would be made between 200 and 300 pc, which is similar to most recent studies (see Table 1). Moreover, we do not apply binarism correction in our analysis, and it has been shown that scale length and scale height might be underestimated without binarism correction (Siegel et al. 2002; Jurić et al. 2008; Ivezić et al. 2008; Yaz & Karaali 2010).

For our purpose, we deem that in order to lift the degeneracy it is crucial to have a reliable near-infrared luminosity function by observation or a near-infrared local stellar density. Unfortunately, systematic study in this direction is yet to come. Some related studies, such as synthetic luminosity function (see, e.g., Girardi et al. 2005) or luminosity function transformed from optical observation (see, e.g., Wainscoat et al. 1992) do exist, but some uncertainties still need to be settled (e.g., the initial mass function, mass–luminosity relation for NIR, and color transformation between different wavelengths, etc.). Once the “true” local stellar density is known, the “true” structure of the Milky Way would be revealed.

In order to see how good the agreement is between 2MASS data and our best-fit model, we show an all sky map of the ratios of observed to predicted integrated star count from $K_s = 5$ to 14 mag for each node as a function of position on the sky in Figure 2; the color indicates the values of the ratios.

We do not see any obvious deviation in the Galactic latitude $|b| > 30^\circ$ areas, only in the Large Magellanic Cloud and the Small Magellanic Cloud areas. For confirmation, we plot the integrated star count from $K_s = 5$ to 14mag along the Galactic longitude and latitude for the $|b| > 30^\circ$ areas in Figures 3 and 4. We see that the 2MASS data and our best-fit model agree well and that there are only some small deviations in the nodes at the anti-Galactic center $b \sim 30^\circ$. The significant spikes in Figures 3 and 4 are due to the populations of the Large Magellanic Cloud and the Small Magellanic Cloud. To test how these small deviations affect the key parameters’ selection, we exclude these small deviations and re-analyze the data with fixed non-key parameters. It shows only the scale height of the thick disk shifting slightly but still within our error estimation. We do not see any significant differences of reported overdensities in sky regions with $|b| > 30^\circ$. Thus, we conclude that the three-component model can describe the Milky Way structure sufficiently well for high Galactic latitude regions and the single power-law luminosity function of Chang et al. (2010) is a good approximation as well. Since our main purpose is to search for the global Galactic model parameters, we do not try to explore the best-fit result for each node individually as what Cabrera-Lavers et al. (2007), Bilir et al. (2008), and Yaz & Karaali (2010) have done in their studies to seek the variations of disk model parameters with Galactic longitude. Instead, we treat the differences of the 2MASS data to our best-fit model as deviations from a global smooth distribution. We believe that similar variations in disk model parameters will be obtained if we use a similar analysis procedure (i.e., searching best-fit parameters for each node), but this is beyond the scope of this work. Because we do not consider flares, warps, and other overdensities in our model, there are some discrepancies between the 2MASS data and the model in the low Galactic
latitude regions (see Figure 2). These fine structures make the star distribution fluffier in the vertical direction toward the edge of the Milky Way. Hence, the discrepancy between the 2MASS data and the model increases vertically toward the anti-Galactic center region. In addition, the absence of Galactic bulge in our model contributes to the large discrepancy in the central Galactic areas. The difference in the low Galactic latitude region needs more delicate analysis to rectify (see, e.g., Lopez-Corredoira et al. 2002; Momany et al. 2006).

4.1. Summary

In summary, we set forth to study the global smooth structure of the Milky Way using a three-component stellar distribution model which is comprised of two double exponential disks (one thin and one thick) and an oblate halo. The $K_s$-band 2MASS star count is used to determine the structure parameters. To avoid the complication introduced by the fine structures and complex extinction correction close to Galactic plane, we use only Galactic latitude $|b| > 30^\circ$ data. There are 10 parameters in the model, but only 4 of them play a dominant role in the fitting process. They are the local stellar density of the thin disk $n_0$, the local density ratio of thick-to-thin disk $f_2$, and the scale heights of the thin and thick disks $H_z^1$ and $H_z^2$. The best-fit result is listed in Table 3. In short, the scale height of the thin and thick disks are $360 \pm 10$ pc and $1020 \pm 30$ pc, respectively; the scale length of the thin disk is $3.7 \pm 1.0$ kpc and that of the thick disk is $5.0 \pm 1.0$ kpc (the uncertainty in scale length is large because it is not very sensitive to high latitude data.) The local stellar density ratios of the thick-to-thin disk and halo-to-thin disk are $7\% \pm 1\%$ and $0.20\% \pm 0.10\%$, respectively. The local stellar density of the thin disk is $0.030 \pm 0.002$ stars pc$^{-3}$.

An all sky comparison of the 2MASS data to our best-fit model is shown in Figure 2. A good agreement in the Galactic latitude $|b| > 30^\circ$ areas is expected from our fitting procedure. In low Galactic latitude regions, fine structures (such as flares, warps, etc.) increase the effective scale height toward the edge of the Milky Way. This is reflected in the fan-like increase in discrepancy toward the anti-Galactic center regions.

Degeneracy (i.e., different combinations of parameters give similar likelihood values) is found in pairs of key parameters (see Figure 1). Thus, different combinations of parameters may fit the data almost as good as the best-fit one, and these are all legitimate “acceptable” fittings in view of the uncertainty. Therefore, accompanying our lower local stellar density of 0.030 stars pc$^{-3}$ (from $K_s = -8$ to 6.5 mag) is a higher thin disk scale height of 360 pc. In the context of NIR star count, the NIR luminosity function or the NIR local stellar density is imperative to determine the scale height and other Milky Way structure parameters. We hope that systematic study on the luminosity

![Figure 3](image-url)

**Figure 3.** Integrated star count from $K_s = 5$ to 14 mag of 2MASS data as a function of the Galactic latitude. Solid line is the model prediction.
function and the local stellar density in near-infrared will be available in the near future.

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Figure 4. Integrated star count from Ks = 5 to 14 mag of 2MASS data as a function of the Galactic longitude. Solid line is the model prediction.
