J. Astron. Space Sci. 19(1), 19–24 (2002)

VERTICAL DENSITY DISTRIBUTION OF THE GALAXY FROM STAR COUNT ANALYSIS

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(Received January 16, 2002; Accepted February 05, 2002)

ABSTRACT

The five space density distribution $D(z)$ with distance perpendicular to the Galactic plane were combined. The scale heights and the local densities at $z = 0$ of the thin disk, thick disk, and the halo components were estimated from the nonlinear least square fits of exponential law. The scale heights of the thin disk, thick disk, and the halo components were estimated to be 260 ± 90 pc, 660 ± 220 pc, and 3.6 ± 1.4 kpc, respectively. The density ratio of each components to the thin disk component at the galactic plane, i.e., $z = 0.0$, were also derived as 1:0.07:0.002. Our model fit suggests that the thick disk component has a local density of 6.9% relative to the thin disk.

Keywords: star count, stellar content, galaxy structure

1. INTRODUCTION

The local density distribution of stellar components in the Galaxy provides clues to understand the structure and formation of the Galaxy. Counts of the number of stars in a given apparent magnitude and spectral class or color intervals per unit area on the sky have been treated the traditional data from which the density distribution along any given line of sight can be estimated. Fenkart (1966) had derived the vertical density distribution of stars from the polar region data of the Basel survey based on the $U - G$, $G - R$ colors (See, Buser, Rong, & Karaali 1998, and references therein). Two color star count survey of 18.24 square degrees at the south Galactic pole for stars brighter than $V = 19$ was made by Gilmore & Reid (1983). Three colors in UBV star count survey of 21.46 square degrees of the north Galactic pole region has been also made by Yoshii et al. (1987).

Reanalysing the Basel data of the Selected Area 57, Sandage (1987) combined the above three determinations of the density distribution with height from the Galactic plane at the solar circle for drawfs with absolute magnitude of $< M_V >= +4$ to $+5$. He found that the density gradient, $d \log D(z)/dz$, changes continuously over the observed range of distance from the galactic plane (z) extended to $z =$ 10kpc, and the vertical density distribution, $D(z)$, of galactic stellar component is related directly to the velocity dispersion $\sigma(W)$ of each component. As a result, Sandage (1987) identified the $\sigma(W)$ =17km s^{-1} component with the old thin disk (scale height ~270 pc), $\sigma(W)$ =42km s^{-1} component with the thick disk (scale height ~940 pc), and the $\sigma(W)$ =90kms^{-1} component with the extreme halo (scale height ~3.2 kpc). Recently, Buser et al. (1998, 1999) estimated the exponential scale height for the Galactic thick disk equals 0.91 ± 0.3 kpc from the new Basel RGU star count and color survey data. From the global analysis of the 2MASS data, Ojha (2001) derived the exponential scale height of 860 ± 200 pc for the Galactic thick disk.

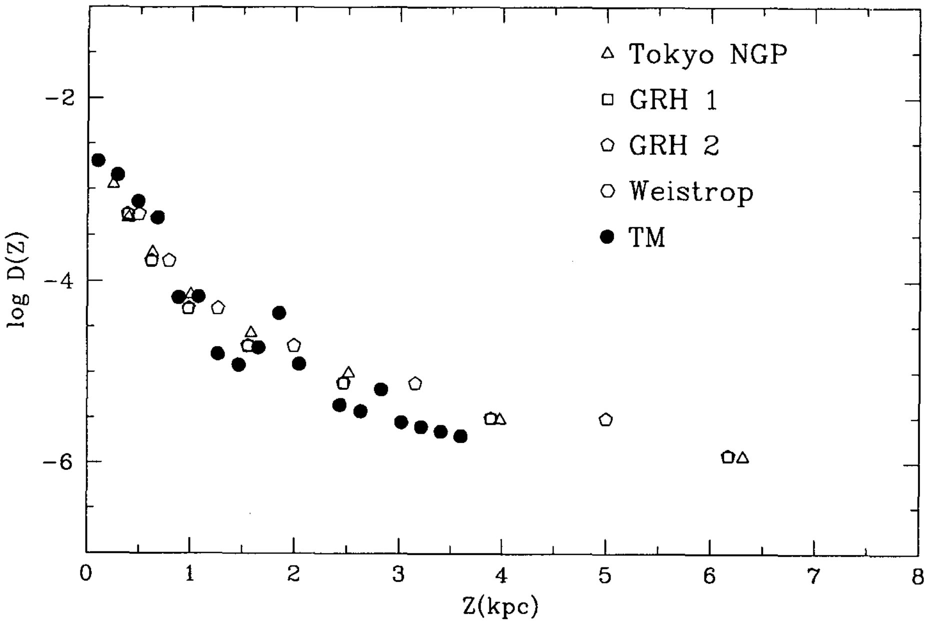

Figure 1. Derived vertical stellar space density distribution.

In this paper, we seek the vertical density distribution of stellar components in the Galaxy by using the classical star count data which were not used in Sandage(1987)'s analysis. General star count analysis technique has been applied to determine the local density distribution, from which we derived scale heights of the thin disk, thick disk, and the extreme halo components.

2. METHOD OF GENERAL STAR COUNT ANALYSIS

To obtain the density distributions, we have to solve the star count, $A(m, S)$, equation

$$A(m, S) = \omega \int D_s(r)\Phi(m + 5 - 5\log(r) - a(r), S)r^2 dr \quad (1)$$

for $D_s(r)$, where ω is the solid angle in square radians, Φ is the stellar luminosity function, and $D_s(r)$ is the true density function with respect to the distance. By S, we shall mean here the full MK spectral type in both spectral class and the luminosity class. Many studies of star count, however, have been based on general star counts giving $A(m)$, the total number of stars at apparent magnitude m, i.e., irrespective of spectral class S. For general star counts, $\Phi(M)$ denotes the general luminosity function

$$\Phi(M) = \Sigma\Phi(M, S) \quad (2)$$

and the density function $D(r)$ is to be interpreted as the total number of all types of stars per unit volume at distance r.

Table 1. Estimated star count data.

Name	M_V	$A(m)/\text{deg}^2$	References
Tokyo NGP	11.0	2.71	Stobie & Ishida (1987)
	12.0	4.75	
	13.0	7.78	
	14.0	10.72	
	15.0	16.31	
	16.0	23.81	
	17.0	29.22	
	18.0	43.94	
GRH SGP	12.5	6.9	Gilmore et al. (1985)
	13.5	7.9	
	14.5	8.5	
	15.5	9.9	
	16.5	23.9	
	17.5	38.4	
	18.5	45.7	
GRH	12.5	10.3	Gilmore et al. (1985)
$l = 37°, b = -51°$	13.5	13.3	
	14.5	19.2	
	15.5	23.5	
	16.5	36.8	
	17.5	59.0	
	18.5	92.6	
Weistrop	12.5	6.5	Weistrop (1972)
$l = 65°.5, b = 85°.5$	13.5	12.0	
	14.5	21.5	
	15.5	24.3	
	16.5	28.5	
	17.5	39.5	

Solving the star count equation for $D(r)$, there are two common methods, that is, $(m, \log\pi)$ and Malmquest's methods (Mihalas & Binney 1981). Among these two methods, we applied the former $(m, \log\pi)$ method which is the more general and flexible because it make few restrictive assumptions and can be used with an arbitrary luminosity function. At first, the limited numbers of a given area must be devided by the volume contained within each volume interval. This volume element is,

$$\Delta Vol = \frac{1}{3}\omega(r_1^3 - r_2^3), \tag{3}$$

where r_1 and r_2 are the inner and outer boundaries of the particular volume shell. Now, an analysis can be made via the principal equation for the star counts,

$$A(m) = \omega \int D(r)\Phi(M)r^2 dr \tag{4}$$

where $A(m)$ is the number of stars per unit area of solid angle ω at m in the interval dm.

By restricting the analysis to a narrow range of colors, we restrict the data to a narrow range of absolute magnitude. Furthermore, by choosing distance intervals separated by $\Delta \log r = 0.2$ and apparent magnitude intervals of ± 0.5 mag (i.e., 1 magnitude for the total interval), the star count

Table 2. Space density distributions from star count.

Name	$< Z$(kpc)$>$	Vol (pc^3)	log(D(z))
Tokyo NGP	0.25	2.42×10^3	-2.95
	0.40	9.62×10^3	-3.31
	0.63	3.83×10^4	-3.69
	1.00	1.52×10^5	-4.15
	1.58	6.07×10^5	-4.57
	2.51	2.42×10^6	-5.01
	3.98	9.62×10^6	-5.52
	6.31	3.82×10^7	-5.94
GRH SGP	0.50	1.92×10^4	-3.44
	0.79	7.64×10^4	-3.99
	1.26	3.80×10^5	-4.65
	2.00	1.21×10^6	-5.09
	3.16	4.82×10^6	-5.30
	5.01	1.92×10^7	-5.70
	7.94	7.64×10^7	-6.22
GRH	0.39	1.92×10^4	-3.27
$l = 37°, b = -51°$	0.62	7.64×10^4	-3.78
	0.98	3.80×10^5	-4.30
	1.55	1.21×10^6	-4.71
	2.46	4.82×10^6	-5.12
	3.89	1.92×10^7	-5.51
	6.17	7.64×10^7	-5.92
Weistrop	0.50	1.92×10^4	-3.27
	0.79	7.64×10^4	-3.78
	1.26	3.80×10^5	-4.30
	1.99	1.21×10^6	-4.71
	3.15	4.82×10^6	-5.12
	5.00	1.92×10^7	-5.51
TM	0.10		-2.69
	0.29	-	-2.84
	0.49	-	-3.13
	0.68	-	-3.31
	0.88	-	-4.18
	1.07	-	-4.17
	1.26	-	-4.80
	1.46	-	-4.92
	1.65	-	-4.73
	1.85	-	-4.35
	2.04	-	-4.91
	2.43	-	-5.36
	2.63	-	-5.43
	2.82	-	-5.19
	3.02	-	-5.55
	3.21	-	-5.60
	3.40	-	-5.65
	3.60	-	-5.70

equation can be replaced by a single calculation, giving the space density as,

$$D(< r >) = A(m)/\Delta Vol, \qquad (5)$$

where $< r >$ is $(r_1 + r_2)/2$.

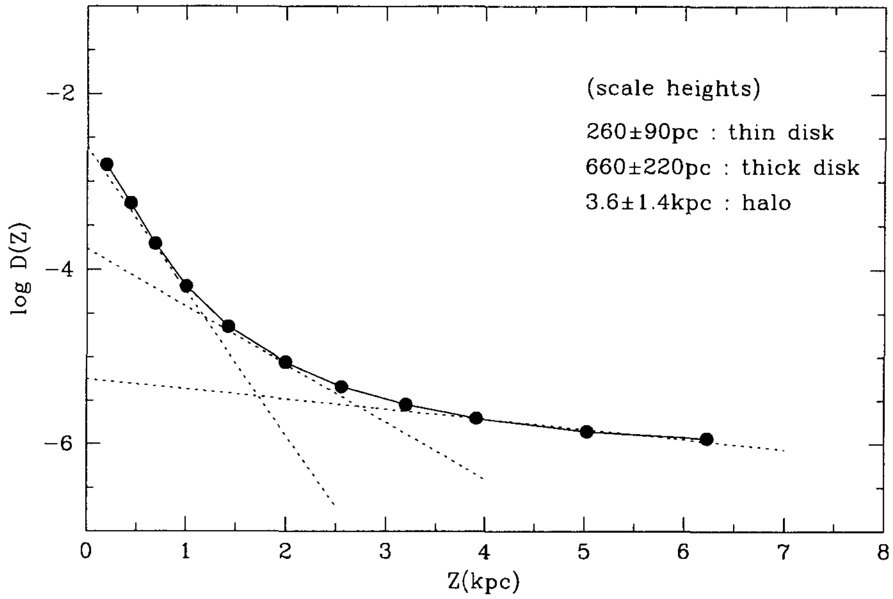

Figure 2. Decomposed space density distributions of thin disk, thick disk, and the extreme halo components (dotted lines). Solid line is the mean space density distribution derived from the data in Table 2.

3. THE VERTICAL STELLAR DENSITY DISTRIBUTION FROM STAR COUNT

Stobie & Ishida (1987)'s data of 21.46 $\deg^2$ toward the north Galactic pole have been analysed by using only the star counts between $0.3 < B - V < 0.6$. We have assumed that stars in this color range have an absolute magnitude near the globular cluster turnoff at $M_V = +4$. Two color surveys of 11.5 $\deg^2$ at the south Galactic pole and 17.14 $\deg^2$ at the mid-galactic latitude ($l = 37°, b = -51°$) were made by Gilmore et al. (1985). We collected their star count data of $B - V = 0.3, 0.5$ and derived the observed $A(m)$ values. Weistrop (1972) has given the 13.5 $\deg^2$ star count data near the north galactic pole as $l = 65°.5$ and $b = 85°.5$. To compare with the other observations, we used their data only between $0.3 < B - V < 0.6$. We list the determined $A(m)$ values of these four data set in Table 1.

Using these various star counts, we estimated the space density distribution, $D(r)$, applying the $(m - \log \pi)$ method described in Section 2. Table 2 shows space density distributions extended to a maximum distance of $z = 7.94$ kpc above the galactic plane. On the other hand, Tritton & Morton (1984) presented the space density distribution of stars on the direction of $l = 36°.5$ and $b = -51°$ from the galactic plane, extending to a distance of $z = 3.60$ kpc. We added their data in our analysis of stellar density distribution, and list in Table 2. Figure 1 shows the density distribution, $D(z)$ perpendicular to the galactic plane for the five data set listed in Table 2.

4. RESULTS

The five space density distribution for $D(z)$ agree well each other remarkably, as shown in Figure 1. The filled circles in Figure 2 are the mean values of the density distribution at arbitrary distances perpendicular to the galactic plane, which were measured by eye in Figure 1. The scale heights and the local densities at $z = 0$ of each component were estimated from the nonlinear least square fits applying the exponential laws to the data of the filled circles in Figure 2. As results, we calculated scale heights of the thin disk, thick disk, and the halo components to be 260 $\pm$ 90 pc, 660 $\pm$ 220 pc, and 3.6 $\pm$ 1.4 kpc, respectively. The fits also provided the density ratios of each component to the thin disk component at the galactic plane, i.e., $z = 0.0$, is 1:0.07:0.002. Note that our best model suggest that the thick disk component has a local density of 6.9% relative to the thin disk.

As mentioned in Sec. 1, Sandage (1987) also identified the old thin disk (scale height $\sim$270 pc), the thick disk (scale height $\sim$940 pc), and the extreme halo (scale height $\sim$3.2 kpc), giving density normalization at $z = 0$ of 1:0.11:0.005. Compared the derived space density distribution of us with the Sandage (1987)'s, the thin disk and the halo component show very similar density profiles. On the other hand, the thick disk profile of us has slightly smaller space densities at a given position than of Sandage's. Our estimate of scale height (660 pc) for the thick disk still seems to be smaller than the recent studies of space density distribution of thick disk (e.g., 0.91 $\pm$ 0.3 kpc: Buser et al. 1998, 1999; 860 $\pm$ 200 pc: Ojha 2001). Here, we caution that the density distribution of the stellar component in the Galaxy is related to the velocity dispersions of the component. Therefore, the kinematic properties of the thick disk component should be reanalysed to estimate much accurate density profiles, and we need more studies of the thick disk component not only for the space density distribution but also for the kinematic properties.

ACKNOWLEDGEMENTS: This paper is supported by Creative Research Initiatives of the Korean Ministry of Science and Technology.

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