Star Count Method to Study Galactic Structure

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◆outlines

- Introduction
- The Galactic model
- Related articles
- Summary

➢ Based on the equation of sterllar statistics

$$N_s(m_1, m_2, l, b)d\Omega = \int_{m_1}^{m_2} dm \int_0^{\infty} r^2 dr \rho_s(r, M)\phi_s(M)d\Omega$$

➢ History of star count model

- **Bahcall & Soneira (1980)**
  two components disk + halo

- **Gilmore & Reid (1983)**
  three components thin disk + thick disk + halo

- Wainscoat et al. (1992)
 five components disk + halo + bulge + spiral arms + molecular ring

- many more structures :
 inner bars in the Galactic center (Alves 2000; Hammersley et al. 2000)

 flares and warps (Lopez-Corredoira et al. 2002; Robinet al. 2003)

 overdensities in the halo (Majewski et al. 2003)

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➢ Global smooth structure model

- three components :
  thin disk + thick disk + halo

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

- Sample stars are usually from intermediate or high galactic latitude.

- Parameters from different works still spread a wide range.

➢ Model with fine structures

- A complex model with more components arms , inner bars, flares, warps.

- Parameters used vary from work to work based on shapes and positions (Vall´ee 2008; Hou et al. 2009, Polido et al. 2013)

- Studies on substructures confined in the Galactic plane region are seriously affected by extinction.

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Estimation of absolute magnitude-dependent Galactic model parameters in intermediate latitude with SDSS and SCUSS

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➢ Model : thin disk + think disk + halo

- Disk by two exponentials functions in cylindrical coordinates

$$D_i(x, z) = n_i \exp(-(x - R_\odot)/l_i) \exp(-(|z| - z_\odot)/h_i),$$

- The de Vaucouleurs spheriod density law for halo

$$\begin{aligned} D_3(R, b, l) = {} & n_3 (R/R_\odot)^{-7/8} \{\exp[-10.093(R/R_\odot)^{1/4} + 10.093]\} \\ & \times [1 - 0.08669/(R/R_\odot)^{1/4}], \; R \geq 0.03\,R_\odot \\ & \times 1.25 (R/R_\odot)^{-6/8} \{\exp[-10.093(R/R_\odot)^{1/4} \\ & + 10.093]\}, \; R < 0.03\,R_\odot, \end{aligned} \qquad (2)$$

Data reductions

- **SCUSS and SDSS(DR8)**

$7.07\ \mathrm{deg}^2$ field located at $50° \leq l \leq 55°$, $-46° \leq b \leq -44°$.

- **Choose sample stars**

$$(u-g)_0 = \exp[-(g-r)_0^2 + 2.8(g-r)_0 - 1]. \quad (4)$$

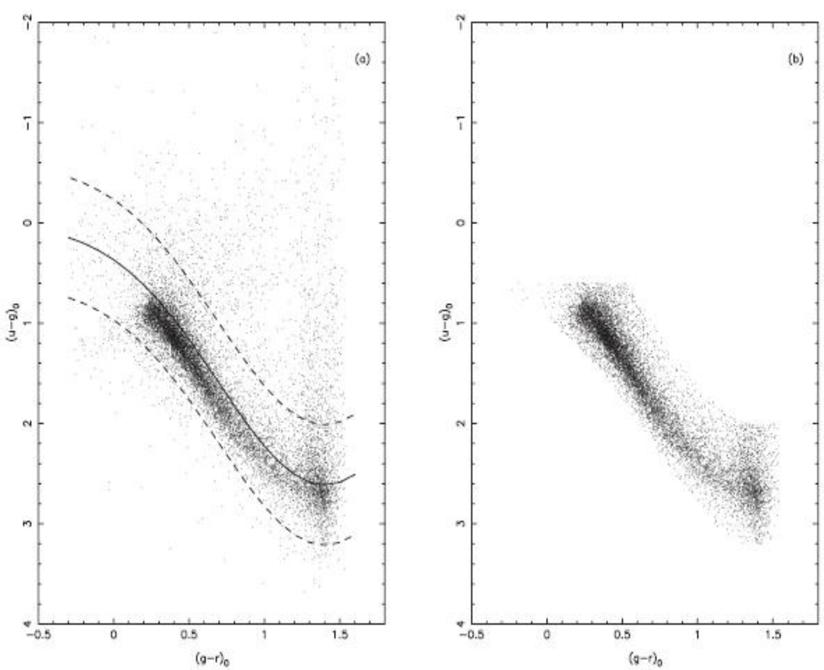

Figure 2. The distribution of stars in $(u-g)_0$ versus $(g-r)_0$ after removing some non-MS stars in $(g-r)_0$ versus $(r-i)_0$. In panel (a), the solid line describs equation (4) and the dashed lines describe the points whose distance in the vertical direction to the solid line is 0.6 mag. Panel (b) describes the final distribution of stars in $(u-g)_0$ versus $(g-r)_0$.

- **The absolute magnitude**

$$M_r = 3.2 + 13.30(r-i)_0 - 11.50(r-i)_0^2 + 5.4(r-i)_0^3 - 0.70(r-i)_0^4.$$

$$r_0 - M_r = 5\log r - 5.$$

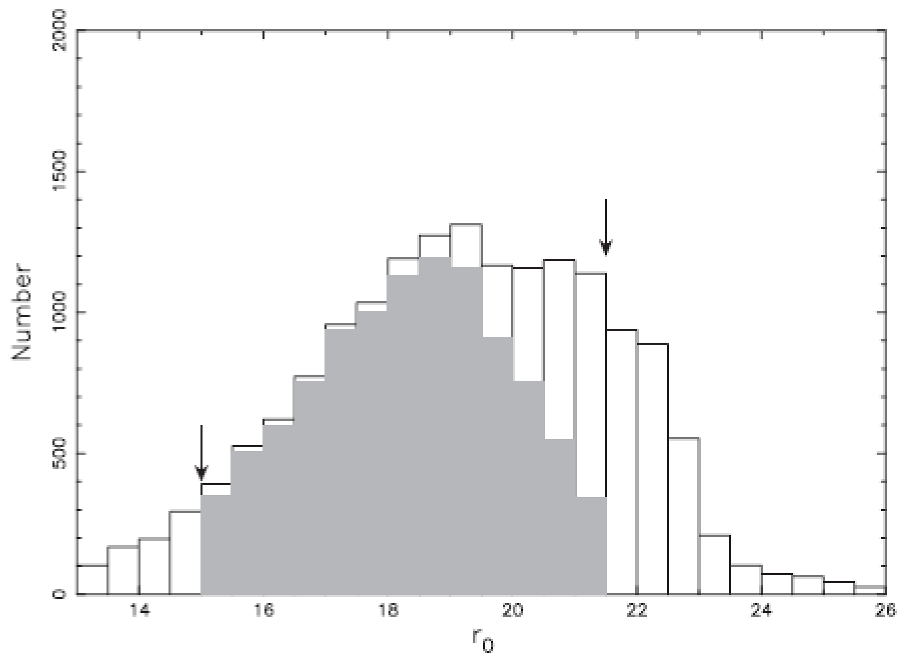

Figure 3. The apparent magnitude histogram of sample stars in the *r* magnitude. The two arrows show the bright and faint limiting *r* magnitudes in our work. The grey area represents our final sample of stars which are distributed in absolute magnitude from 4 to 13 mag.

➢ Procedures

I. Divide the absolute magnitude into five intervals

Absolute magnitude	Number	$r_{\min}$	$r_{\max}$	Component
$4 \leq M_r < 5$	2680	1000 pc	31.6 kpc	Thick+halo
$5 \leq M_r < 6$	3213	631 pc	19.9 kpc	Thin+thick+halo
$6 \leq M_r < 8$	2568	151 pc	12.6 kpc	Thin+thick+halo
$8 \leq M_r < 10$	1258	100 pc	5.0 kpc	Thin
$10 \leq M_r \leq 13$	461	25 pc	2.0 kpc	Thin

II. Divide distances into suitable number of bins

$$D(r) = \frac{N(r)}{\Delta V_{12}} \qquad \Delta V_{12} = \left(\frac{\pi}{180}\right)^2 \frac{\omega}{3}(r_2^3 - r_1^3) \qquad \sigma_D(r) = \frac{\sqrt{N(r)}}{\Delta V_{12}},$$

III. Fit the model to the observation with χ^2 method.

➢ Results

Table 4. The Galactic model parameters obtained in this study. n_i and h_i are local density and scaleheight for the thin and thick discs, respectively. κ is axial ratio of the halo. Suffixes 1, 2 and 3 denote thin disc, thick disc and halo, respectively. n_2/n_1 and n_3/n_1 are the normalization density for thick disc and halo, respectively.

M_r (mag)	$n_1(R_\odot, z_\odot)$ (stars kpc^{-3})	h_1 (pc)	$n_2(R_\odot, z_\odot)$ (stars kpc^{-3})	h_2 (pc)	n_2/n_1 (%)	$n_3(R_\odot, z_\odot)$ (stars kpc^{-3})	κ	n_3/n_1 (%)
[4–5)			$(4.35^{+0.48}_{-0.47})$E(5)	575^{+20}_{-20}		$(1.54^{+0.14}_{-0.15})$E(3)	$0.84^{+0.020}_{-0.040}$	
[5–6)	$(1.25^{+0.05}_{-0.05})$E(6)	350^{+10}_{-10}	$(2.06^{+0.32}_{-0.31})$E(5)	675^{+30}_{-35}	$16.5^{+2.50}_{-2.50}$	$(7.95^{+0.70}_{-0.75})$E(3)	$0.45^{+0.025}_{-0.025}$	$0.64^{+0.06}_{-0.06}$
[6–8)	$(4.63^{+0.25}_{-0.28})$E(6)	194^{+12}_{-12}	$(7.17^{+0.70}_{-0.69})$E(5)	525^{+15}_{-15}	$15.5^{+1.50}_{-1.50}$	$(3.01^{+0.65}_{-0.60})$E(4)	$0.20^{+0.025}_{-0.025}$	$0.65^{+0.14}_{-0.13}$
[8–10)	$(1.31^{+0.10}_{-0.09})$E(7)	180^{+5}_{-4}						
[10–13]	$(2.32^{+0.27}_{-0.27})$E(7)	103^{+5}_{-5}						
[4–13]	$(1.66^{+0.08}_{-0.07})$E(7)	205^{+7}_{-7}	$(1.37^{+0.13}_{-0.12})$E(6)	595^{+15}_{-15}	$8.25^{+0.75}_{-0.75}$	$(8.23^{+1.65}_{-1.64})$E(3)	$0.575^{+0.025}_{-0.025}$	$0.05^{+0.01}_{-0.01}$

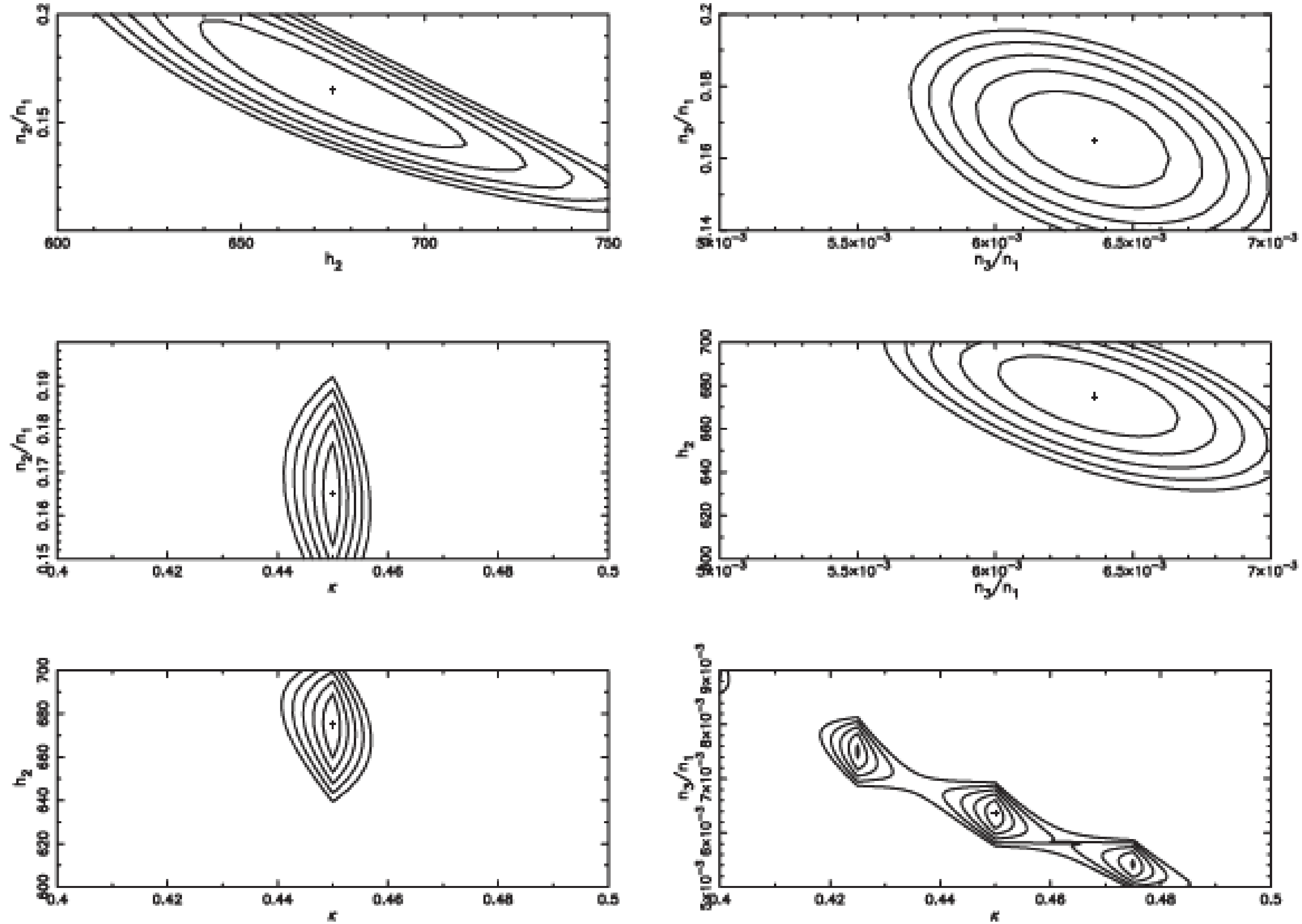

Figure 5. Contour plotted of the χ^2 value of pairs of thick disc and halo parameters in the absolute magnitude interval $5 \leq M_r < 6$. The cross mark represents the best-fitting values of the Galactic model parameters.

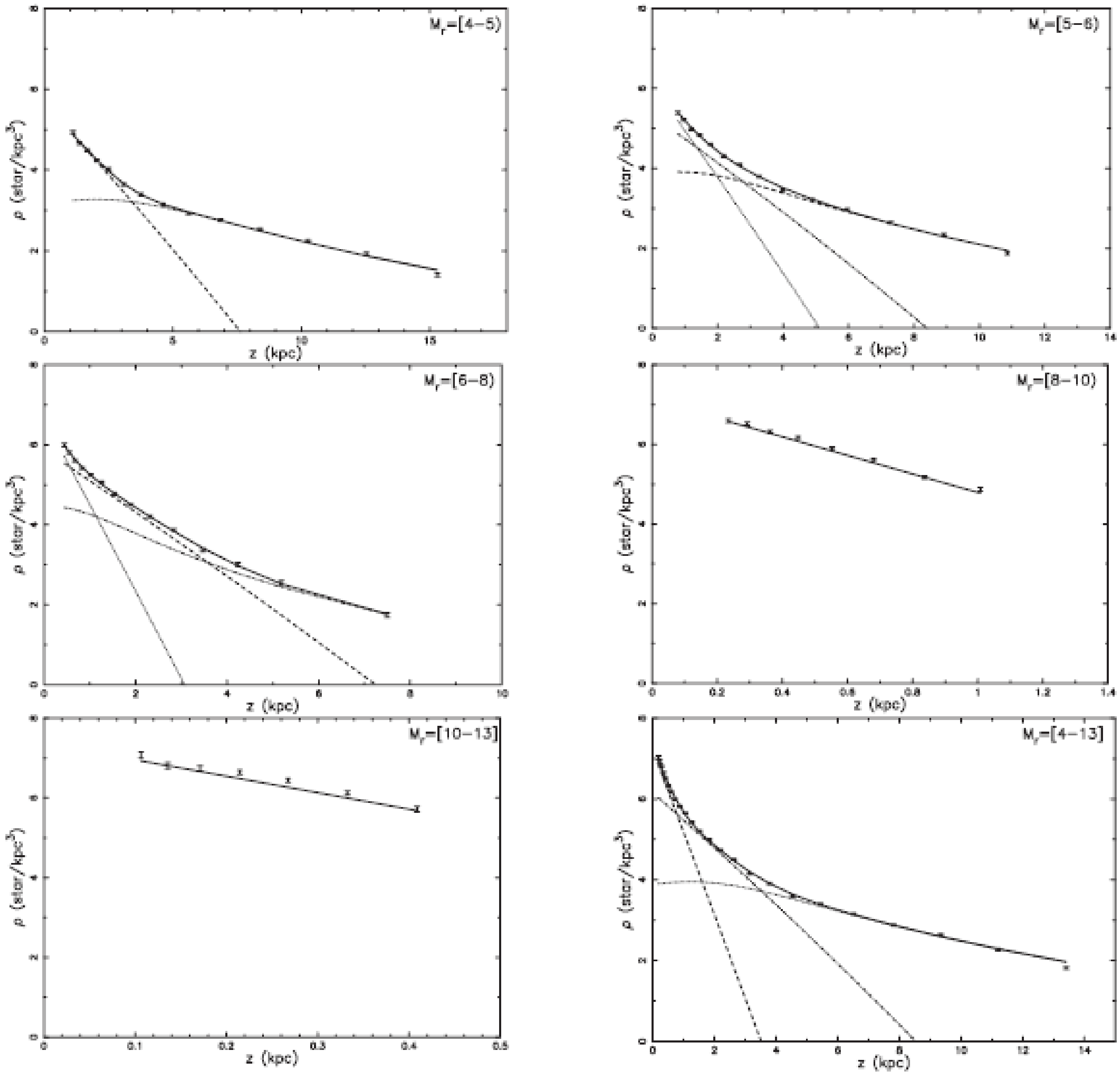

Figure 6. Observed (dots with error bars) and evaluated (solid line) space density functions combined for the considered population components which correspond to those listed in Table 4.

Conclusion

- **Parameters of the thin disc and halo monotonically change with absolute magnitude.**
- **Parameters of the thick disc change non-monotonically.**
- **a new method to estimate the Galactic structure parameters in order to break the degeneracy**

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A GALAXY MODEL FROM TWO MICRON ALL SKY SURVEY STAR COUNTS IN THE WHOLE SKY, INCLUDING THE PLANE

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ABSTRACT

We use the star count model of Ortiz & Lépine to perform an unprecedented exploration of the most important Galactic parameters comparing the predicted counts with the Two Micron All Sky Survey observed star counts in the J, H, and K_S bands for a grid of positions covering the whole sky. The comparison is made using a grid of lines

➢ Model :

young disk + old disk + a spheroid+ spiral arms + a bar

- **Disks:**

$$n_{d,i}(r,z,s) = n_{d,i}(R_0,0,s)e^{-\frac{R_0-r}{\alpha_i}+\beta_i(\frac{1}{R_0}-\frac{1}{r})-\frac{z}{h_i(r)}}.$$

$$h_i(r) = z_i e^{\frac{0.4(r-R_0)}{R_0}},$$

- **Spheroid:**

$$n_{\rm sph}(R,s) = \frac{C_1}{\zeta(\zeta+a_H)^3}, \quad \zeta = \sqrt{(z/\kappa)^2+R^2}$$

- **Spiral arms:**

$$r_{\rm arm} = q e^{(\theta-\theta_0)\tan(i)},$$

Density perpendicular to the arm's length is described by a Gaussianfunction (HWHM) is ~180 pc

- **Bar:**

$$r_{\rm bar} = \left\{ \left[\left(\frac{x'}{x_0}\right)^2 + \left(\frac{y'}{y_0}\right)^2 \right]^2 + \left(\frac{z'}{z_0}\right)^4 \right\}^{\frac{1}{4}}$$

$$n_{\rm bar} = (n_{d,Y} + n_{d,O}) C_{\rm bar}\, e^{-\frac{1}{2} r_{\rm bar}^2},$$

Table 3
Limits for Parameters Search

Parameter	Symbol	Lower	Upper
Radial scale length of thin/thick disks (pc)	α_Y, α_O	500	7000
Radii of the central hole in thin/thick disks (pc)	β_Y, β_O	0	6000
Length parameter of the spheroid (pc)	a_H	100	4000
Spheroid to disk density ratio	$N_{\rm sph}/N_D$	0.001	0.020
Oblate spheroid parameter	κ	0.5	0.9
Density contrast of the spiral arms	C_S	0.0	3.0
Density contrast of the bar	$C_{\rm bar}$	0.0	5.0
Scale height of the thin disk (pc)	z_Y	50	400
Scale height of the thick disk (pc)	z_O	200	1000
Bar half length (pc)	$l_{\rm bar}$	700	4000
Orientation angle of the bar (deg)	$\theta_{\rm bar}$	11	53

➢ Data :

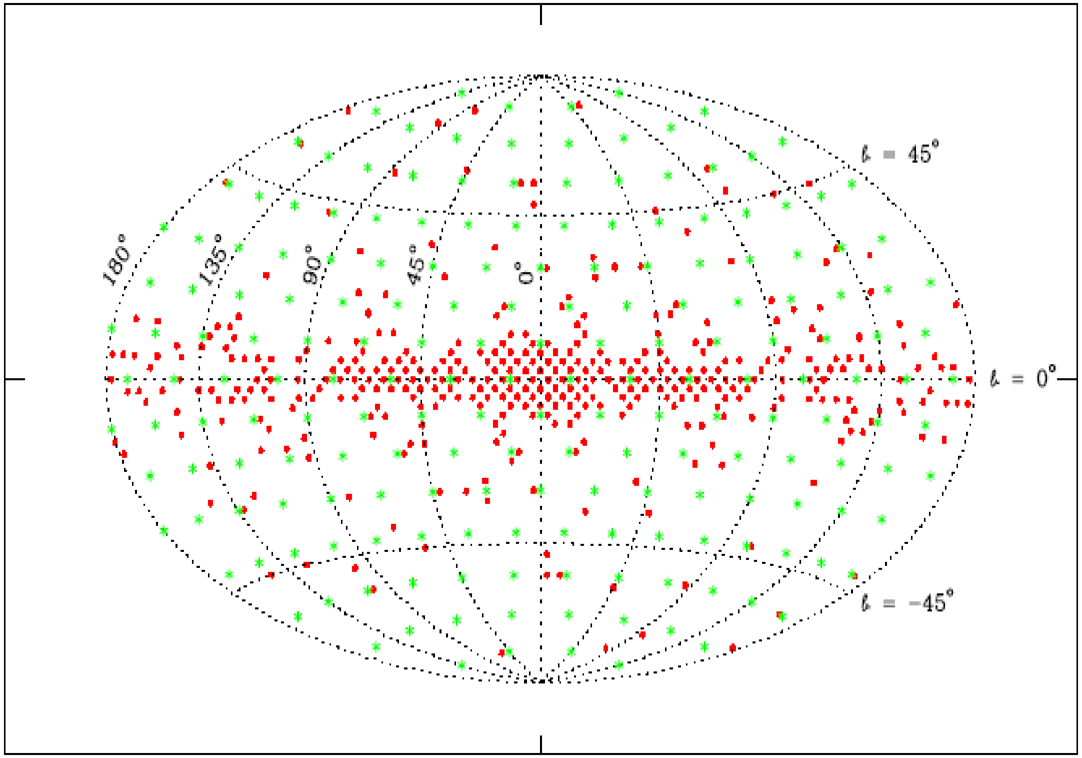

Figure 2. Illustration of the $N_{\mathrm{side}} = 4$ (192 points) basic grid in green and a finer grid with 382 points drawn from the $N_{\mathrm{side}} = 16$ HEALPix scheme (red).

➢ Parameter estimations:

- **The Markov Chain Monte Carlo (MCMC) method (**Gilks et al. 1996**)**
- **Nested Sampling method (**Skilling 2004**)**

➢ Results :

- **Parameters**

Table 4
Results from MCMC, NS, and MCMC+NS for the $N_{\mathrm{side}} = 4$ HEALPix Grid

Parameter	MCMC	NS	MCMC+NS
α_Y (pc)	(1230^{+190}_{-170})	(1200^{+190}_{-170})	(1190^{+170}_{-160})
α_O (pc)	(4750^{+920}_{-690})	(5150^{+920}_{-690})	(4420^{+850}_{-750})
β_Y (pc)	(920^{+2570}_{-570})	(2140^{+2570}_{-570})	(2770^{+1700}_{-600})
β_O (pc)	(1740^{+2570}_{-1430})	(100^{+2570}_{-100})	(4760^{+1240}_{-730})
a_H (pc)	(1940^{+570}_{-640})	(1350^{+570}_{-640})	(1000^{+550}_{-410})
N_{sph}/N_D	$(0.0073^{+0.0064}_{-0.0036})$	$(0.0058^{+0.0064}_{-0.0036})$	$(0.0058^{+0.0072}_{-0.0033})$
κ	$(0.55^{+0.10}_{-0.05})$	$(0.76^{+0.10}_{-0.05})$	$(0.74^{+0.09}_{-0.04})$
C_S	$(0.9^{+3.3}_{-0.5})$	$(1.0^{+3.3}_{-0.5})$	$(2.3^{+1.1}_{-0.7})$
C_{bar}	$(3.0^{+0.9}_{-2.5})$	$(0.4^{+0.9}_{-0.4})$	$(3.5^{+1.5}_{-0.3})$
z_Y (pc)	(170^{+40}_{-30})	(170^{+40}_{-30})	(170^{+40}_{-40})
z_O (pc)	(680^{+120}_{-90})	(710^{+120}_{-90})	(730^{+130}_{-90})
$l_{\mathrm{bar}}{}^*$ (pc)	2000	2000	2000
$\theta_{\mathrm{bar}}{}^*$ (deg)	30	30	30

• Comparison with Results in the Literature

Parameter	Our Result	Value from Literature	Source
α_Y (pc)	(2120 ± 200)	(2500^{+800}_{-600})	Fux & Martinet (1994)
		2600	Freudenreich (1998)
		(2100 ± 300)	Porcel et al. (1998)
		(3300 ± 600)	Feast (2000)
		1700	Lépine & Leroy (2000)
		(2800 ± 300)	Ojha (2001)
		(2100^{+220}_{-170})	López-Corredoira et al. (2002)
		(3500 ± 300)	Larsen & Humphreys (2003)
		2400	Picaud & Robin (2004)
		(2600 ± 520)	Jurić et al. (2008)
		2200	Reylé et al. (2009)
		(3700 ± 1000)	Chang et al. (2011)
α_O (pc)	(3050 ± 500)	3500	Reid & Majewski (1993)
		(2800 ± 800)	Robin et al. (1996)
		(3000 ± 1500)	Buser et al. (1999)
		2300	Lépine & Leroy (2000)
		(3700 ± 800)	Ojha (2001)
		(4700 ± 200)	Larsen & Humphreys (2003)
		(3600 ± 720)	Jurić et al. (2008)
		(5000 ± 1000)	Chang et al. (2011)
β_Y (pc)	(2070^{+2000}_{-800})	3000	Freudenreich (1998)
		2600	Lépine & Leroy (2000)
		2000–4000	López-Corredoira et al. (2004)
		(1310 ± 1030)	Picaud & Robin (2004)
z_Y (pc)	(205 ± 40)	325	Reid & Majewski (1993)
		250–270	Robin et al. (1996)
		100	Lépine & Leroy (2000)
		(310^{+60}_{-45})	López-Corredoira et al. (2002)
		(245 ± 49)	Jurić et al. (2008)
		(360 ± 10)	Chang et al. (2011)
z_O (pc)	(640 ± 70)	1400–1600	Reid & Majewski (1993)
		760	Robin et al. (1996)
		390	Lépine & Leroy (2000)
		900	Larsen & Humphreys (2003)
		(900 ± 180)	Jurić et al. (2008)
		(1020 ± 30)	Chang et al. (2011)

a_H (pc)	(400 ± 100)	3000	Gilmore (1984)
		2670	Reid & Majewski (1993)
		$1900^{*,a}$	Binney et al. (1997)
		420	Lépine & Leroy (2000)
		(4300 ± 700)	Larsen & Humphreys (2003)
		$(2500^{+1730}_{-160})^{*,b}$	Vanhollebeke et al. (2009)
N_{sph}/N_D	(0.0082 ± 0.0030)	0.00125	Bahcall & Soneira (1980)
		0.0083	Guglielmo (1990)
		0.00358	Ruelas-Mayorga (1991)
		(0.002–0.003)	Larsen & Humphreys (2003)
		0.0051	Jurić et al. (2008)
		(0.002 ± 0.001)	Chang et al. (2011)
κ	(0.57 ± 0.05)	(0.80 ± 0.05)	Reid & Majewski (1993)
		0.8	Lépine & Leroy (2000)
		0.6	Robin et al. (2000)
		(0.55 ± 0.06)	Chen et al. (2001)
		(0.65 ± 0.05)	Girardi et al. (2005)
		(0.64 ± 0.01)	Jurić et al. (2008)
C_S	$(2.0^{+0.6}_{-0.8})$	1.32	Drimmel & Spergel (2001)
		1.2–1.4	Grosbøl et al. (2004)
		1.30	Benjamin et al. (2005)
		1.3–1.5	Liu et al. (2012)

$C_{\rm bar}$	$(3.4^{+1.0}_{-1.5})$		
$l_{\rm bar}$ (pc)	(1250^{+500}_{-250})	1610–2030	Dwek et al. (1995)
		900	Stanek et al. (1997)
		<3128	Freudenreich (1998)
		1750	Bissantz & Gerhard (2002)
		3900	López-Corredoira et al. (2007)
		~1250	Gonzalez et al. (2011)
		~1460	Robin et al. (2012)
		~1490	Wang et al. (2012)
		~680	Cao et al. (2013)
$\theta_{\rm bar}$ (deg)	$(12_{-1}{}^{+15})$	(20 ± 10)	Dwek et al. (1995)
		20–30	Stanek et al. (1997)
		~14	Freudenreich (1998)
		12	López-Corredoira et al. (2000)
		15–30	Bissantz & Gerhard (2002)
		20–35	López-Corredoira et al. (2005)
		43	López-Corredoira et al. (2007)
		(42.44 ± 2.14)	Cabrera-Lavers et al. (2008)
		$(15^{+12.7}{}_{-13.3})$	Vanhollebeke et al. (2009)
		~30	Gonzalez et al. (2011)
		25–27	Nataf et al. (2013)
		13	Robin et al. (2012)
		20	Wang et al. (2012)
		29–32	Cao et al. (2013)

● Comparison with observed counts

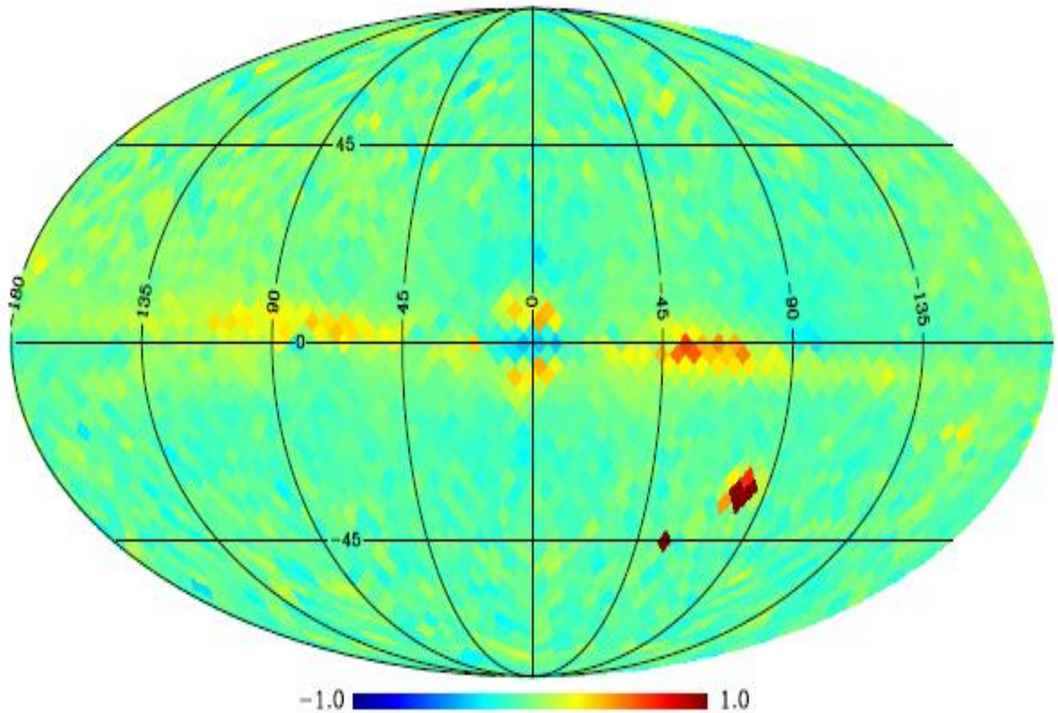

Figure 13. (a) Observed cumulative star counts for $K_S < 11$ sampled according to the $N_{\rm side} = 16$ HEALPix scheme (3072 grid points). Each grid point is the result of a cone search of one square degree area. The counts are color-coded in a logarithmic scale to facilitate visualization. (b) Predicted cumulative star counts from our model in the same band with the same count coding as in (a). (c) Relative differences $(C_{(\rm obs,11)} - C_{(M,11)})/C_{(M,11)}$ of (a) and (b) color coded in a linear scale, to emphasize the details.

Conclusion :

- The results show a good agreement with the values of α_Y , α_O, z_Y , z_O, N_{sph}/N_D,and κ found in the literature.
- The "hole in the disk",β shows a strong anti-correlation with α.
- The value of a_H found in this study describes the cusp in star counts close to the Galactic center.
- A moderate anti-correlation between the oblateness of the spheroid, κ, and the constant of normalization, Nsph/ND. There is also a definite anti-correlation between zY and zO.

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- **Summary**

- **The parameters depend on both the properties and locations of the sample stars.**
- **We still need a new method to estimate the Galactic structure parameters in order to break the degeneracy.**
- **The presence of an irregular structure makes the research about the Galactic structure more complex.**

Thank you!