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DENSITY PROFILE OF THE MILKY WAY: COMPARISON OF DYNAMICAL MODEL AND MONTE CARLO METHOD FOR DETERMINING STELLAR SPACE DENSITIES

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Abstract. We derived stellar space density of K giants in Milky Way in direction of galactic center and south galactic pole using Monte Carlo (MC) approach for solving equations of stellar statistics. For luminosity function of K giants we assumed gaussian distribution with mean magnitude of M = 1 and standard deviation $\sigma = 0.7$. Monte Carlo method for solving equation of stellar statistics is based on randomly assigning absolute magnitudes from assumed luminosity function corrected for Malmquist bias to star with measured apparent magnitude, which leads to randomly assigned distance module. The mean value of this quantity is used to calculate distance. This way we estimated mean stellar space density in given direction. We compared derived densities in direction of galactic pole, where influence of extinction is negligible to densities derived in direction of galactic center, where influence of extinction can not be neglected. Also we compared our results with density profiles derived from N-body simulation of Milky Way like galaxy in isolation.

1. INTRODUCTION

We can observe a large number of stars and make star count for Milky Way because it is possible to separate stars in the field of view. By determaining distances to stars we can make assumpions about their space distribution. In a unit solid angle there is a very large number of stars, so we can use statistical approach for determining distances in order to derive stellar space dencities (Angelov 2013). To determine the number of stars in solid angle ω, up to some limited magnitude, we need to solve fundamental equation of stellar statistics (Spaenhauer, 1978):

$$N(m) = \omega \int_0^\infty D(r)\phi(M)r^2 dr \ , \tag{1}$$

where $N(m)$ is number of stars with apparent magnitudes between m and $m + dm$, $\phi(M)$ is known or assumed luminosity function if there is no absorption and $D(r)$ is space density at distance r.

If luminosity function is given as gaussian distribution with assumed mean luminosity and standard deviation, we have:

$$\phi(M) = \frac{1}{\sigma\sqrt{2\pi}} \exp \frac{(M- < M >)^2}{-2\sigma^2}. \tag{2}$$

Malmquist (1920) showed that this can not be assumed for arbitrary sample of stars **S**, but rather the distribution function $\phi_m(M)$ is given by:

$$\phi_m(M) = \frac{1}{\sigma\sqrt{2\pi}} \exp \frac{(M - (< M > -k_m))^2}{-2\sigma^2} \ , \tag{3}$$

where k_m is

$$k_m = \sigma^2 \ln 10 \cdot \frac{d \log(N)}{dm}. \tag{4}$$

This means that sample **S** of stars is limited by apparent-magnitude intervals which are brighter than distance-limited intervals. This deviation k_m is dependent on function $N(m)$ and standard deviation of luminosity function. We used Monte Carlo method for solving eqaution (1) and tested it in two direction.

2. MONTE CARLO METHOD

Monte Carlo (MC) method is statistical method for solving problem which is based on repeated random sampling of some quantity to obtain numerical result. A method to solve fundamental equation of stellar statistics numerically is to apply MC method on equidistant intervals of apparent magnitudes while sampling absolute magnitudes from Malmaquist corrected luminosity function and finding empirical mean of calculated distance via Pogson's law.

Let us define equidistant intervals of apparent magnitudes with $\alpha = m_\nu - m_{\nu-1}$ and let N_ν be the number of stars with apparent magnitudes in this intervals. Figures 3 and 4 show apparent magnitudes samples for two directions. Absolute magnitudes for those stars are sampled from luminosity function corrected for Malmaquist bias. Dividing our sample into multiple apparent magnitudes intervals starting from $m = 6$ with steps of $\alpha = 0.5$ and defining limiting magnitude of the sample as defined in (Gschwind 1974)

$$m_{\lim} =< M > -3 * \sigma + 5log(r) - 5 \ , \tag{5}$$

where $m_{\lim}$ is expected as we want to cover our luminosity distribution up to 3σ of population, we get samples as shown in figure 3.

We can numerically calculate k_m as

$$k_\nu = \frac{\sigma^2 \ln(10)}{2\alpha} (\log N_{\nu+1} - \log N_{\nu-1}) \ , \tag{6}$$

which is second order numerical derivative of k_m. Combining sampled absolute magnitude with observed apparent magnitudes and calculating distance to every star via Pogson's law, we derive possible distance to each star. We can derive possible stellar space density in that line of sight. Executing multiple runs on set of stars **S** we find multiple space density functions. We get the most probable density function and its deviation by finding mean and standard deviation of those functions.

3. N-BODY MODEL

We construct stable N-body model of spiral galaxy using GalactICs package (Widrow, et al. 2005, Widrow et al. 2007). There are three components that are included in N-body representation: disk and bulge represent baryonic matter and the third component is dark matter halo. Galaxy were evolved for 2 Gyrs with Gadget2 code (Springel et al. 2005). Parameters for N-body realisation are combination of values given in (Widrow et al. 2005). We assumed exponential profile of the disk in radial direction, with scale length of 2.8 kpc and mass $4.58 \cdot 10^{10} M_{\odot}$. This is done in order to compare with stellar space densities derived from MC method. We wanted to see if K giants follow density profile of baryonic matter derived from numerical model, or can we make more stable galaxy with parameters calculated from observed distribution of giants.

4. RESULTS AND DISCUSSION

We applied MC method on K type giants in direction of south galactic pole and galactic center using catalogues from SIMBAD database (we mostly used objects from SDSS and 2MASS surveys). Direction of galactic pole is chosen because the influence of interstellar absorption is smaller then in direction of galactic center. We use absolute magnitude $M = 1$ and standard deviation of $\sigma = 0.7$, for luminosity function corrected for Malmquist bias. Distributions of absolute magnitudes are given in figures 5 and 6.

Because field of view is not round, thus we could not use ω as solid angle, we selected only stars which are in 10 degrees radius around center of FOV, this is shown in figures 1 and 2.

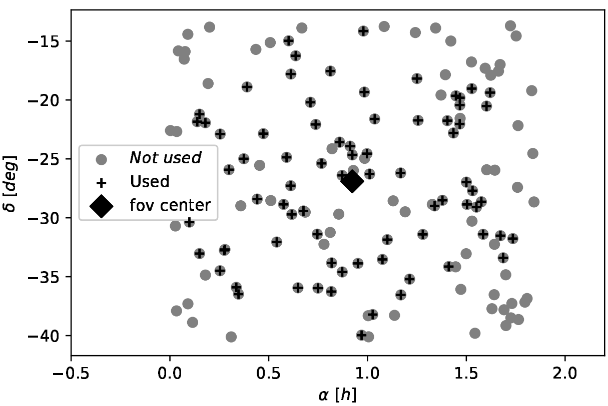

Figure 1: Field of view in direction of south galactic pole.

Using MC method described in previous section we can derive stellar space density and compare them to true density derived from catalog in which we have absolute magnitudes.

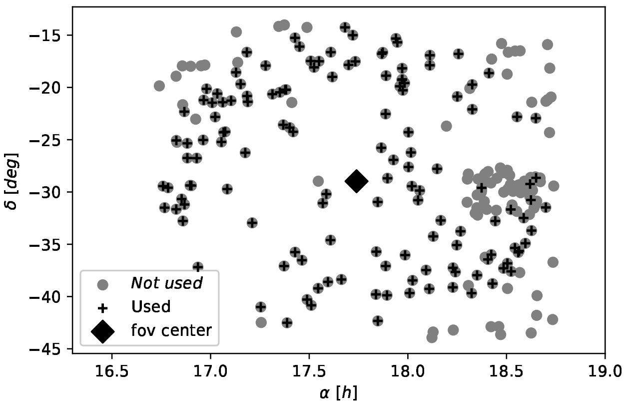

Figure 2: Field of view in direction of galactic center.

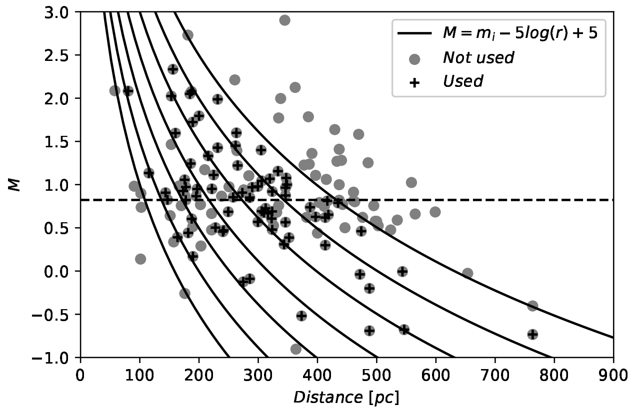

Figure 3: Apparent magnitude samples (south galactic pole).

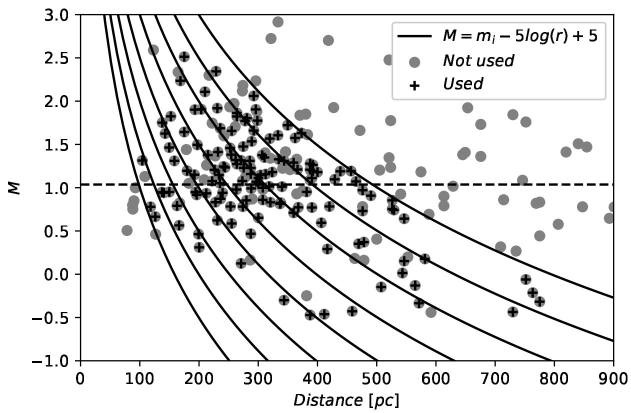

Figure 4: Apparent magnitude samples (galactic center).

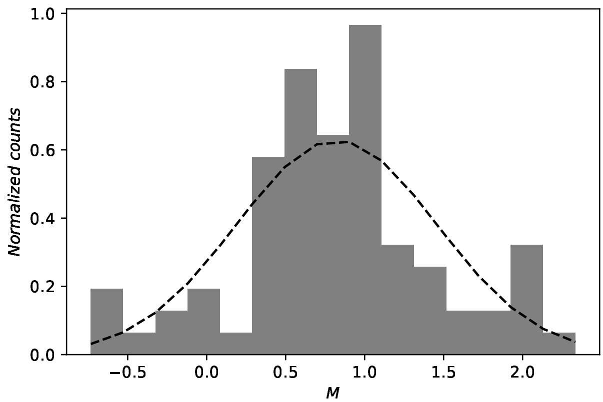

Figure 5: Distribution of absolute magnitudes, direction of south galactic pole.

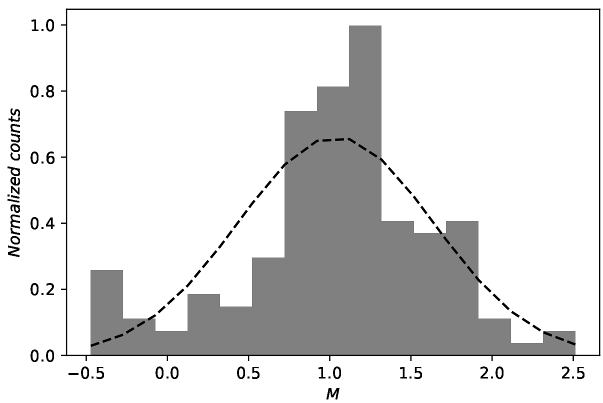

Figure 6: Distribution of absolute magnitudes, direction of galactic center.

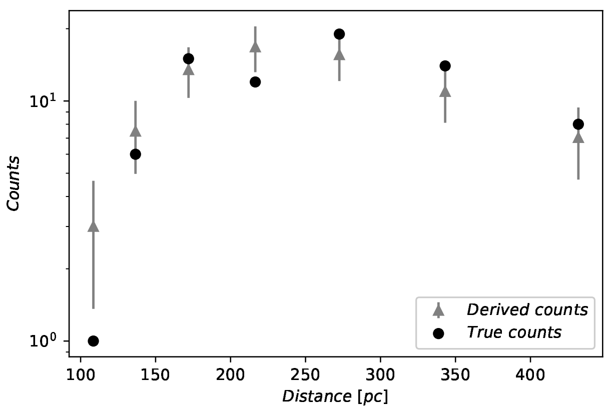

Figure 7: Derived stellar space density in direction of south galactic pole.

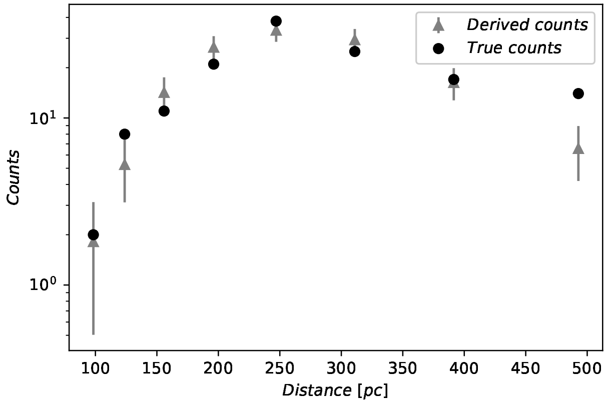

Figure 8: Derived stellar space density in direction of galactic center.

As we can see from figures 7 and 8 density function derived via MC method are in good agreement with true density function derived from observerd absolute magnitudes.

5. SUMMARY

For determining stellar space densities, we can use Monte Carlo method. It is tested on K giants, because giants are bright stars, so we can measure distances on large scales inside Galaxy (not only vicinity of the Sun). If we compare results from two directions: galactic pole and galactic center, we would expect disagreement between predicted and observed stellar counts, in the direction to center because of extinction. In this paper it is shown that there is no difference between this two directions, because the method was tested for stars with distances up to 1 kpc. Testing of the method on larger distances and bigger samples is need to be done. The nature of distinction between these two directions can be a tracer for gas and dust. Also, we constructed numerical model of spiral galaxy similar to Milky Way and Andromeda in order to test parameters against observed space distribution of stellar mass in the disk.

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