Milky Way Parameters by the Results of N-body Simulation

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Abstract

The results of N-body experiments modelling the disc of our Galaxy are presented. We used the suggestion, that the disc at all radii is on the threshold of gravitational stability. This suggestion sets some limits on dynamic and kinematic parameters of the main subsystems of the Galaxy (disc, bulge and halo). In the solar neighborhood the upper bound of surface density is calculated as $58\,M_{\odot}/\mathrm{pc}^2$. We came to the conclusion, that the local minimum of the rotation curve in the region $6\,\mathrm{kpc} < r < 10\,\mathrm{kpc}$ is not the result of mass distribution, but may arise from local dynamic processes or another factors, that can cause non-circular motion. Using the observed stellar velocity dispersion and suggesting that the bar in the Milky Way is long-living, we conclude that the central maximum on the rotation curve cannot be explained by the strongly concentrated core of the bulge. The best agreement between model parameters and observed data is reached for an exponential scale length of the disc of 3 kpc. The total disc mass does not exceed $M_d = 4.5 \cdot 10^{10}\,M_{\odot}$. The relative halo mass in the sphere $r < R_{\odot} = 8$ kpc should exceed 80 % of disc mass.
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1. Some problems of Milky Way

Rotation curve is one of the most important characteristics of any galaxy. Stars rotate more slowly than gas ($V_* < V_{gas}$, where $V_{gas}(r)$ is the rotation velocity of gas and young stars and $V_*(r)$ relates to the old stars' component). Circular rotation curve $V_c(r)$ is a parameter that enables us to obtain the distributions of gravitation potential and mass. There are many papers presenting rotation curves of stellar and gaseous components of the Milky Way, obtained from observations (Fig.1). Different rotation curves were obtained for various populations of the galactic disc: CO, HI regions, H_{α}-emission regions, classical cepheids, OB-associations, planetary nebulae and AGB-stars (different symbols and lines in the Fig. 1).

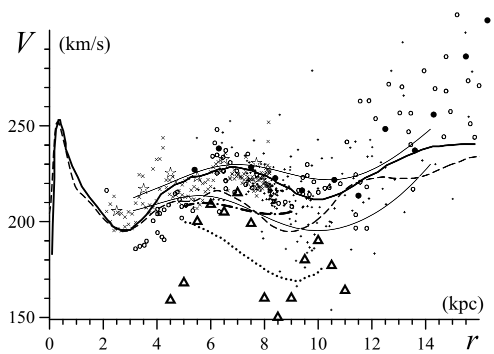

Figure 1: Rotation curves of the Milky Way, taken from different works (for details see Khoperskov & Tiurina, 2002).

Two major features are common for most of them: 1) local depression of the rotation velocity in the region $6\,\mathrm{kpc} < r < 10\,\mathrm{kpc}$ (local minimum of $V(r)$); 2) inner maximum of the rotation velocity near to the centre ($r \simeq 0.3$ kpc). These features may be caused either by mass distribution, or by some dynamic factors.

Spiral galaxies usually consists of two main components: a spherical subsystem (halo, bulge, core) and a disc subsystem (stellar and gaseous discs). Photometric data allow us to model each S-galaxy as disc+bulge system only, but the flatness of the rotation curve at far periphery enforce us to include a halo. If we use rotation curve only for modelling mass distribution of a galaxy, there will be a variety of models, because there is a well known ambiguity in interpretation: we can take low-mass disc and massive halo and bulge or low-mass spherical subsystem and massive disc, the observed rotation curve will be equally well explained in all these cases.

Photometric data give us radial and vertical scales for the distribution of brightness in disc and bulge, but there are some other parameters (like unknown M/L ratio), that give us a freedom for choosing the optimal model for mass distribution. The ambiguity disappears if we assume that the stellar disc of the galaxy is near the threshold of gravitational stability and has a minimum (for this stable state) stellar velocity dispersion c_r. So if we have constructed dynamic model, which would explain observed rotation curves of gas and stellar discs, dispersion of stellar velocities and other observed structural parameters (for example, height scale, scale length), it is possible to calculate the masses of disc and halo separately.

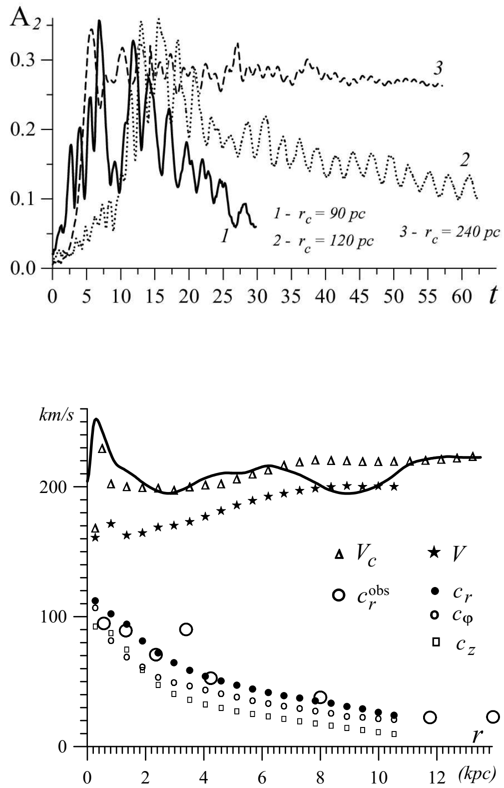

Figure 2: The results of dynamic simulation. (**a**) The evolution of Fourier-harmonics amplitude of the bar-mode in models with different core scales r_c. The decrease of amplitude at small r_c indicate the bar decay. (**b**) The radial distributions of velocity and velocity dispersion in the best model

2. Dynamic simulation of Milky Way

We used dynamic modelling of N-body, using Tree-code ($10^5 \div 5 \cdot 10^5$ particles) and Particle-Particle algorithms ($N = (1 \div 4) \cdot 10^4$). We studied the dynamic evolution of the self-gravitating 3D-disc, weakly unstable initially, which was embedded into the potential of the "rigid" spherical subsystem (halo, bulge, core). During the evolution there is a disc heating (increasing of the velocity dispersion) from the initial unstable state. The disc comes to the stationary state at the end of evolution. For this model disc, which possesses a minimum value of stellar velocity dispersion at a given radius, we compare all its parameters, like surface density, radial, vertical and azimuthal dispersions, disc scales of height and length with the observed ones. In particular, we came to the conclusion, that if we try to explain the central maximum of Milky Way rotation curve (see Fig.1) by presence of the concentrated core, it would be impossible to create a long-lived bar (Fig.2a) in this dynamic model. The physical mechanism of bar destruction in the presence of a concentrated core is similar to activity of a central massive black hole (Hasan & Norman, 1990).

The presence the of local dip in circular rotation velocity V_c in the region $r \simeq 6 \div 10$ kpc contradicts observed kinematic data of the ratio of velocity dispersions $c_r/c_\varphi = 1.58$ (Dehnen & Binney, 1998) and the results of our dynamic simulation.

The dynamic model that best satisfies the data sets of observations, gives the following parameters of the main components: **bulge** with mass $M_b \leq 1.2\cdot 10^{10} M_\odot$ and scale of core $r_c \geq 200$ pc; **disc** with full mass $M_d = 4.4\cdot 10^{10} M_\odot$ and surface density in Solar neighborhood $\sigma_\odot \leq 58 M_\odot/\mathrm{pc}^2$, radial scale 3 kpc and scale height $z_0 = 0.5$ kpc; **halo** with the relative mass $\mu = M_h/M_d \geq 0.87$ at $r < R_\odot$ and $\mu \geq 1.6$ at 4 radial scales (~ 12 kpc). The ratio between the circular velocity of the disc component V_c^{disc} and the complete circular velocity V_c at the radius $r = 2.2L = 6.6$ kpc is equal to $V_c^{disc}/V_c = 0.73$.

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References

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