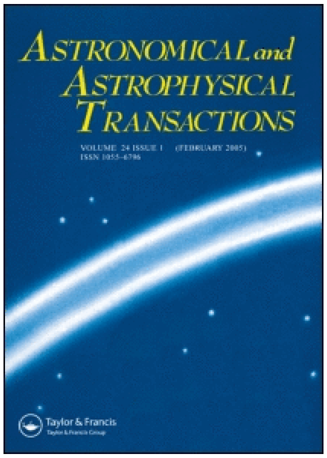

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ESTIMATION OF THE COMPONENTS OF GALAXIES USING N-BODY SIMULATIONS

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Direct numerical N-body simulation was applied to four spiral galaxies (NGC 6503, NGC 3198, NGC 891 and NGC 1566), for which the rotation curves, radial scalelengths L and radial distribution of stellar velocity dispersion of the discs are known. Models contained three-dimensional collisionless disc and 'rigid' spherical components (bulge and halo), the total relative mass μ of which was considered as a free parameter which varied from one model to another. The initial velocity dispersion was chosen at a sub-critical level for gravitational instability. It was assumed that the observed velocity dispersion of disc stars at a given radius must be equal or (in the general case) not less than the calculated one (projected onto the line-of-sight) for a given galaxy after the initially unstable model disc heats up to a steady condition. A comparison of simulated stellar velocity dispersion and rotation curves of galaxies with the observed ones favors the 'light disc' solution: $\mu \geq 2$ within the radius $r = 4L$.

KEY WORDS Numerical models of galaxies, structure of galaxies

1 INTRODUCTION AND DESCRIPTION OF N-BODY EXPERIMENTS

An analysis of mass distribution in disc galaxies is based on studying the rotation curves (RCs). However there is a well known ambiguity of the determination of the relative masses of the components: the RC usually can equally well be explained by different mass ratios μ of spherical components to the disc mass. The measured values of stellar velocity dispersion of old disc may be effectively used to choose the best model among the family of possible ones (see for example Bottema, 1993).

The general idea of this work is that the stellar discs of real galaxies should have a velocity dispersion which is equal or exceeds the minimal value necessary for the disc to be gravitationally stable at a given R. Unfortunately there are no reliable analytic criteria of stability of three-dimensional collisionless discs, otherwise one could easily find a local surface density of a disc from its RC and stellar velocity dispersion curve (DC). To avoid this problem, we use numerical simulation of an

Table. Accepted parameters of the galaxies and the values of μ for the best fit models.

Galaxy	*Type*	$r = 4L$, *kpc*	*Dist, Mpc*	M_{disc}	μ
NGC 891	SAS3	18.4	9.4	7.7×10^{10}	1.8
NGC 1566	SXS4	11.0	25	3.6×10^{10}	1.7
NGC 3198	SBT5	10.4	8.8	5.8×10^{10}	2.1
NGC 6503	SAS6	4.6	5.9	5.3×10^{10}	2.0

initially unstable collisionless disc of a given galaxy. The best fit model parameters we determine by comparing both model RC and DC with observations when the model disc becomes stable, that is when its parameters practically ceased changing.

There are only a few galaxies for which the DC has been measured up to radial distances exceeding one photometrically determined scale length L of the exponential disc. In our work we consider four galaxies (NGC 891, 1566, 3198 and 6503), for which RC, DC and L are available from the literature. The radial stellar velocity dispersions of the old discs were taken from Bottema (1993). Rotation curves were taken from the published measurements of gaseous components of galaxies.

We use the direct *p–p* method to model the dynamical evolution of a 3D disc with given values of L and μ, embedded into the rigid spherical components (bulge + halo). Gas and young stars weren't taken into account. The duration of all experiments was $\geq 10T$, where T is the period of rotation at the outer border of the disc which was chosen to be $r = 4L$. The parameters of the galaxies are given in the Table.

The initial velocity dispersion was chosen at subcritical level for the gravitational stability, which was tested for every galaxy by trial and error. In all cases the initial growth of the velocity dispersion practically ceased after 3–4T (see Figure 1*a*, where C_r is given in dimensionless units, accepting $G = 1$, $M_{\rm disc} = 1$ and $L = 0.25$). During the experiment there was no significant radial mass redistribution, so the density distribution of the disc always remained nearly exponential.

The ratio of spheroidal to disc masses μ was considered as a free parameter, which varies from one experiment to another.

During the experiments we checked the evolution of the disc parameters to be convinced that its mass remains practically constant and the value of L is close to its photometric value. For some models we also checked how the results of simulations are sensitive to the number of particles N in the model in order to be sure that the 'heating' of the disk is not a consequence of the limited number of particles. It was found that the results practically do not depend on the value of N, if $N > 15000$–25000. This conclusions is illustrated in Figure 1*b*, where the dimensionless radial velocity dispersion is plotted as a function of N for different radial distances r.

In all cases in the first stage of the evolution, temporary spiral arms appear which evidently heat up the disc. These spirals fade away after about 3T time (Figure 2).

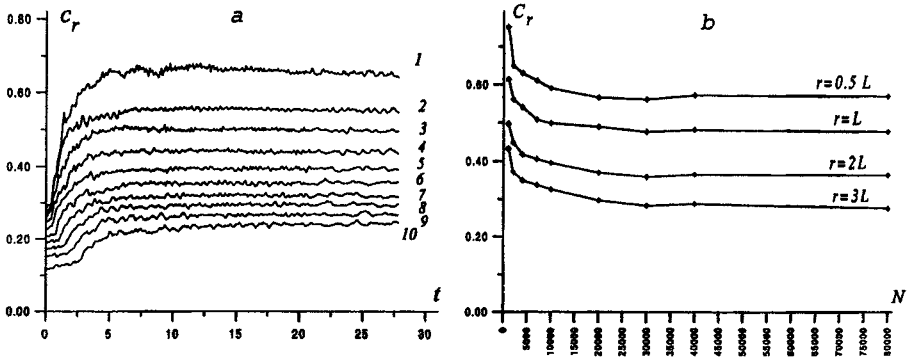

Figure 1 *a*, Example of evolution of C_r for different radii of disc (1 is for $r = 0$, 10 is for $r = 4L$); *b*, Dependence of C_r at different r on the number of particles used in models after $10T$.

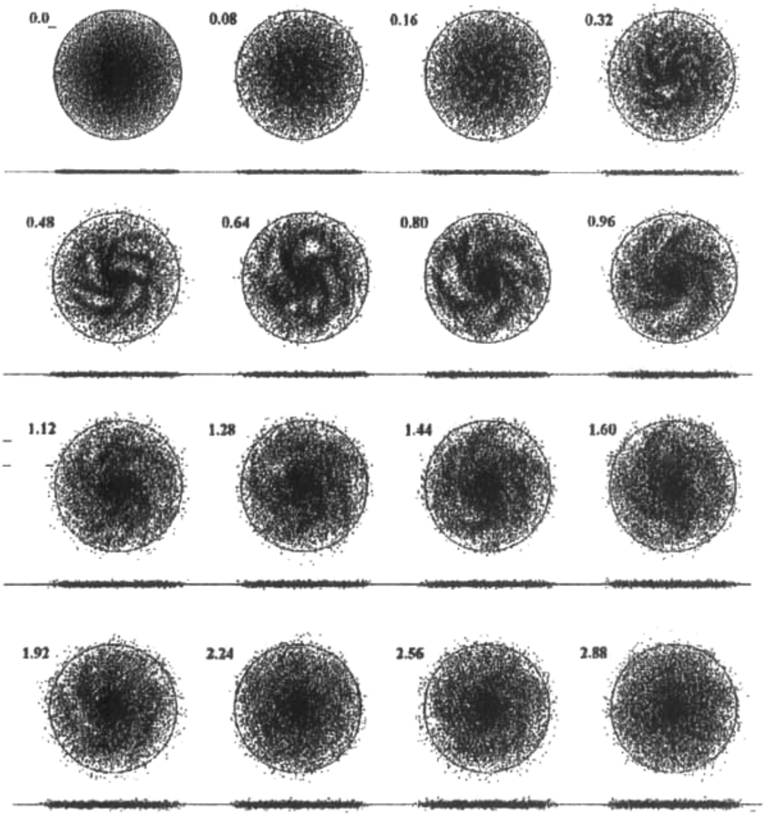

Figure 2 Maps of point distribution during the period $t \leq 3T$.

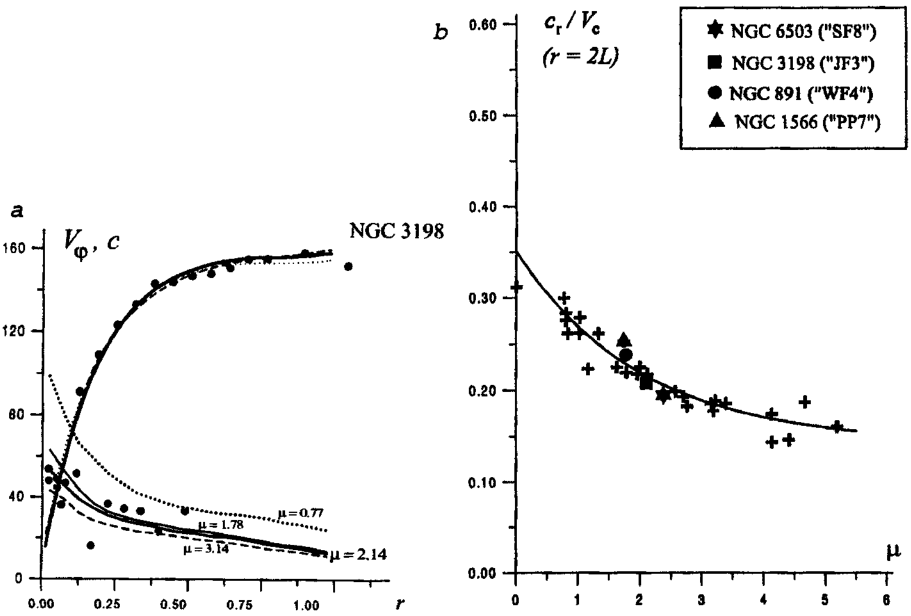

Figure 3 *a*, RC (diamonds) and DC (circles) for different experiments for NGC3198. *b*, The relationship between C_r/V_c and μ. C_r and V_c were taken from different models at $r = 2L$.

The results of the experiments for NGC 3198 are shown in Figure 3*a*. Different curves relate to the resulting RC and DC for models with μ between 0.8 and 3.

All models fit the observed rotation curve quite well, but those with low μ give DC which in general is higher than the observed one. Similar results were found for other galaxies. Thick curves on Figure 3*a* are given for the best fit model ($\mu = 2.1$)

We have compared the models with the so-called maximal disc solution, which is often used for the determination of masses of disc and halo from the known RCs (see for example van Albada, 1985; Kent, 1986). In all cases, if we take the maximal disc, a strong bar develops in the central part of a galaxy, which heats the central disc. But even beyond the bar the model for the maximal disc in all cases exceeds the observed values. It forces one to choose a more massive dark halo.

The best fit models for our galaxies give discs, the total mass of which is significantly lower than the mass of spherical components: the values of μ, determined for $r = 4L$ are about 2 (see Table).

In 1983 Morozov, following the stability criterion, predicted the relationship between the ratio of radial velocity dispersion over the velocity of rotation and the relative mass of spherical components μ. This relationship, obtained for the set of our models, is illustrated in Figure 3*b*. This confirms the tight connection between the relative mass of spherical components and the relative value of C_r.

2 RESULTS

We constructed numeric 3D-models of galactic discs of four spiral galaxies which are in good agreement with the photometric scale of the discs, the rotation curves of the galaxies and the dispersion velocity curves simultaneously. Our numeric experiments show that the models which correspond to the maximum disc solution overestimate the mass of a disc significantly. For the considered galaxies the values of the spherical over the disc mass ratio is found to be ~ 2 within $r = 4L$. The results confirm the existence of a tight relationship between the relative mass of spherical and disc components μ and the radial velocity dispersion over the circular velocity ratio C_r/V_c.

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