

N-BODY SIMULATIONS: ADVANTAGES AND PROBLEMS

The N-body simulations method is widely used in astrophysics and cosmology. The article briefly lists its advantages, disadvantages and possible errors. It is concluded that the results of computer simulation not only cannot replace the data of astronomical observations, but also are not a sufficient reason to reject new hypotheses that do not have other drawbacks, other than the discrepancy between their conclusions and the results of N-body simulations.

Key words: N-body simulations method, astrophysics, cosmology.

Introduction. In this paper, I want to discuss the advantages and problems of the N-body simulations method, which in recent decades has become one of the main approaches used in the study of problems of large-scale structure formation, galactic dynamics, the evolution of accretion disks, the dynamical evolution of star clusters, etc. The method allows one to numerically investigate an evolution of a dynamical system of particles. The essence of the method is that the initial position and velocities are set for N point objects, the equations of motion of these particles are integrated numerically.

These objects move under the influence of their mutual gravitational forces. In the simplest case it is assumed that only the Newtonian force of universal gravitation acts on the particles. As is well known, it is impossible to obtain an analytical solution of this problem even in the case $N = 3$. At the same time, a numerical solution can be obtained for a much larger number of bodies. This is used, for example, in solving problems of celestial mechanics. We talk about N-body simulations when N is very large, it is usually limited only by the computational abilities of the computer or cluster used. The study of the evolution of a system yields many useful results. For more details see [1]. The abundance of valuable results obtained with the help of N-body simulations made it one of the main tools for the study of dynamical systems. N-body simulations have made an enormous contribution to the study of the formation of structure in the Universe, including galaxies, and they are one of the most valuable tools in this field. However, this method has its own problems, which should not be forgotten. Below I will list some of them

Interactions. We can limit ourselves to taking into account only the gravitational interaction in the case of particles of the so-called mirror matter, i.e. dark matter, which does not participate not only in strong and electromagnetic, but also in weak interactions, provided that it is not affected by forces unknown to us, like "dark electromagnetism". In this case, instead of general relativity, the Newtonian formula with an infinite rate of interaction is usually used. The gravitational wave radiation and its back-reaction is very rarely taken into account. In many cases this is an adequate approximation, but not in all.

If baryonic matter is present in the simulations, then it should be remembered that it undergoes friction forces and other dissipative processes, pressure, including radiation, is able to stick together and form compact objects. It can interact electromagnetically and be a source of electromagnetic radiation. If we consider the formation of a large-scale structure, a galaxy, or planets in a proto-planetary cloud, the results of the evolution of the system are different because of the different impact of non-gravitational forces. The fact that different particles in the same situation behave differently is clearly seen in the example of the Bullet Cluster (1E 0657-56), where dark matter and stars pass through the galaxy, while the hot gas slows down during collisions [2]. Therefore, a program for calculating simulations involving baryonic matter must describe the properties of the latter, i.e. include calculations based on hydrodynamics, molecular physics, propagation of mechanical, electromagnetic and thermal waves and other branches of physics.

Naturally, this significantly complicates the program and increases the volume of calculations, which reduces the maximum possible number of particles N during calculation at the same computing power. Therefore, the part of the program that describes baryonic matter is often simplified to the limit, and sometimes even more. Therefore, the results of N-body simulations obtained with the help of different programs often differ significantly from each other. An example is the simulation of the formation of galaxies in [3–5].

One can also recall significantly different estimates of the degree of ellipticity of the dark halo of galaxies obtained by different authors in the papers [6–8].

Dynamical friction. No matter how large the number of particles in a computer simulation, it is many orders of magnitude smaller than the true number of DM particles for any reasonable choice of their mass. If we use N particles when modeling a region of space with a total mass of matter m_{tot} , then the "effective mass of the particle" will be equal to m_{tot}/N , which is typically the mass of a galaxy or a cluster. In some highly successful N-body simulations these masses are from 10^6 to 10^{12} of the solar mass.

The energy loss of a particle with mass m moving with the velocity v through the media with matter density ρ is given by [9]

$$\frac{dE}{dt} = -\frac{4\pi G^2 m^2 \rho}{v} \ln\left(\frac{b_{max}}{b_{min}}\right), \quad (1)$$

where G is the gravitational constant and b is the collision parameter. Taking into account that $E = \frac{mv^2}{2}$, we get $\frac{dv}{dt} \sim m$.

The energy loss due to the process of dynamical friction could be effective for the star in a cluster, but very weak for the DM particles with masses of 10^{24} g or similar.

Mass distribution. In nature, objects that can be conditionally considered pointlike on the corresponding scale usually have different masses. This applies to galaxies, stars, planetosimals, and so on. Replacing them with objects of equal mass, which is often done, worsens the adequacy of the simulation.

Simulations vs observations. Surprisingly for some, the results of N-body simulations cannot in any way replace real astronomical observations. This applies to all data obtained from computer simulations. Observations provide information about what is happening in nature, and often it turns out to be unexpected or contrary to currently accepted theories. Mathematical modeling can only show what its authors put into the program.

The results of N -body simulations can reveal the hidden features of the evolution of a system, clearly illustrate its important details, and help reveal the empirical regularities and characteristics of systems formed as a result of evolution. But they cannot go beyond the limits of the algorithm implemented by the calculation program. They may show all the errors associated with the factors listed above, as well as with the wrong choice of initial conditions.

Conclusions. N -body simulations is a powerful modeling tool and is widely used in cosmology and astrophysics. However, its use is not a reliable alternative to astronomical observations. The results of N -body simulations may not be very adequate, both due to errors and simplifications in the algorithm and underlying model, and for the reasons described above related to the lack of computing power. The discrepancy between the conclusions of some theory and the results of N -body simulations is not a 100% reason to reject this theory.

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МОДЕЛЮВАННЯ З N -ЧАСТИНКАМИ: ПЕРЕВАГИ ТА ПРОБЛЕМИ

Коротко перераховано переваги, недоліки та можливі помилки методу моделювання з N -частинками, застосованому в астрофізиці та космології. Зроблено висновок про те, що результати комп'ютерного моделювання не тільки не можуть замінити дані астрономічних спостережень, але і не є достатньою підставою відкидати нові гіпотези, що не мають інших недоліків, відмінних від розбіжності їхніх висновків із результатами моделювання з N -частинками.

Ключові слова: метод моделювання з N -частинками, астрофізика, космологія.