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On the instabilities of small-scale oscillation modes on the background of a collapsing model of a Protogalaxy

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Abstract. This paper examines the instabilities of horizontal small-scale perturbation modes in the context of a collapsing self-gravitating disk model. Instability calculations were performed for three modes of small-scale perturbations: (m=9, N=17); (m=16, N=18); and (m=15, N=21). Critical diagrams were constructed, and instability increments were calculated. Initial conditions for the formation of corresponding small-scale structural formations in the context of a collapsing self-gravitating disk model were found, depending on the value of the initial virial parameter, which characterizes the collapse rate.

Keywords: Galaxy: disk, evolution, kinematics and dynamics, structure; open clusters: general

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1 Introduction

It is known that the collapse of a protogalaxy along its rotation axis occurs more strongly than in the perpendicular direction. Due to the gravitational instability of radial motions, gas clouds of protoglobular clusters easily form in a spherical protogalaxy. To study the evolutionary processes of various stellar systems, many authors have used their analog with a gas model for spherical systems with an adiabatic index of 5/3, and for disk-shaped systems with an index of 2. In the works of Antonov (1962); Binney & Tremaine (1987); Fridman & Khoperskov (2013), applications of the results from the gas medium to purely stellar systems were used. In works Nuritdinov et al. (2000); Nuritdinov & Tadjibaev (2014); Tadjibaev et al. (2015), this method was used in a reverse order, i.e., having theoretical results in the field of collisionless spherical stellar systems, they can be applied to gas systems to qualitatively study the corresponding dynamic processes. Thus, during the collapse of a spherical protogalaxy, specific small-scale perturbations can primarily form such structural formations as protoglobular star clusters. It is interesting to find out what might correspond to the instability of small-scale perturbations in a self-gravitating disk. In our opinion, the instability of small-scale perturbations in the disk subsystem can lead to the formation of gas and molecular clouds, and subsequently to the formation of a system of open star clusters (OSC).

2 System of open star clusters (OSC) in our galaxy

It is known that the flat subsystem of our Galaxy primarily contains the OSC system. In work Battinelli & Capuzzo-Dolcetta (1991), the authors investigated the structural characteristics of the OSC system in the vicinity of the Sun using the age distribution of clusters. Carraro & Chiosi (1994) studied the dependence of age on metallicity and also determined the relationship between the metallicity of the cluster and the position of the OSC. The observational properties of the Milky Way's OSC system were also discussed by Moitinho A. (2010) in terms of their influence on the structure of the spiral arms, dynamics, and chemical evolution of star-forming regions. Despite many available data on OSC, the questions regarding the origin of their system remain unresolved. Since the evolution of a collapsing protogalactic cloud occurs under the influence of gravitational instability, it is necessary to construct a radially non-stationary model for its analysis. Against this background, it is now necessary to calculate and analyze small-scale perturbations in collapsing disk-like systems, which has not yet been done by anyone. In this regard, we investigated the gravitational instability of three small-scale perturbations, the results of which can be used to study the problem of the formation of the OSC system in our Galaxy.

3 Calculation results

Previously, Nuritdinov (1993) constructed a non-stationary model of a collapsing disk and found its non-stationary dispersion equation (NDE) with wave numbers N and m. Using the NDE, large-scale modes were initially studied in detail, and a case was noted where the principal perturbation index N approaches infinity, corresponding to wave propagation in the collapsing system (Nuritdinov 1993; Nuritdinov et al. 2008; Mirtadjieva & Nuritdinov 2012). Subsequently, we investigated specific small-scale perturbations (Ganiev & Nuritdinov 2021, 2022).

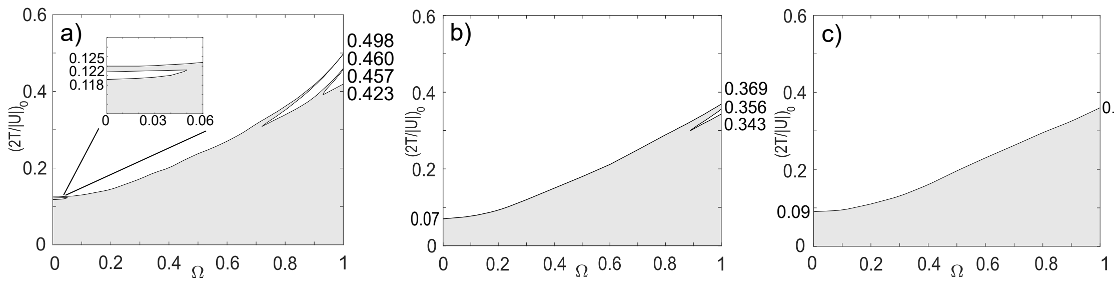

Fig. 1. Critical dependencies of the virial ratio on the rotation parameter for a) (m=9; N=17), b) (m=16; N=18), and c) (m=15; N=21) oscillation modes.

Below, we examine the instabilities of small-scale perturbations for modes (m=9; N=17); (m=16; N=18); and (m=15; N=21). Based on the results, critical dependencies of the initial virial ratio on the rotation parameter were constructed, and instability increments for the considered perturbations were computed. For these modes, corresponding dependencies of instability increments on the virial ratio at the initial collapse moment $(2T/|U|)_0$ were determined. It was found that the relevant instability region begins when $(2T/|U|)_0 \ll 1$. As can be seen, with the increase in the degree of small-scale perturbations, the instability region gradually narrows (Fig. 1). Here, it can be noted that at Ω=0 the critical initial values are $(2T/|U|)_0 \leq 0.118$, $(2T/|U|)_0 \leq 0.070$, $(2T/|U|)_0 \leq 0.090$, for the modes (m=9; N=17), (m=16; N=18) and (m=15; N=21) respectively. The results of calculations conducted in works Ganiev & Nuritdinov (2022, 2021) show that with the increase in the degree of small-scale perturbations, the stability regions in the critical diagrams also grow, while the initial condition values, on the contrary, decrease. However, in our case, regardless of the value of (N), the initial conditions for the mode $(16; 18)$ are smaller than for the mode $(15; 21)$. This may be related to the azimuthal wave number (m), which significantly affects the results. Comparison of instability increments shows that the strongest mode is $(9;17)$, and the weakest is $(16;18)$. We expected that the increment of the mode with the highest main perturbation index (N) $(15;21)$ would be the smallest for all values of the rotation parameter. However, we found that it is between the other two.

4 Summary

In this work, we considered three small-scale perturbation modes ((m=9; N=17), (m=16; N=18), and (m=15; N=21)) in the context of a collapsing self-gravitating disk model and conducted calculations of their gravitational instabilities. We found the initial conditions for these perturbation modes. Additionally, critical diagrams of the initial virial ratio versus the rotation parameter were constructed, and the increments of the instabilities were calculated. We observe that with the increase in the degree of small-scale perturbations, the stability regions in the critical diagrams also grow. It is noted that the initial conditions for the mode $(16;18)$ have smaller values than for $(15;21)$. Possible initial conditions for the formation of OSC systems in our Galaxy were found, depending on the initial virial parameter, which characterizes the collapse rate.

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