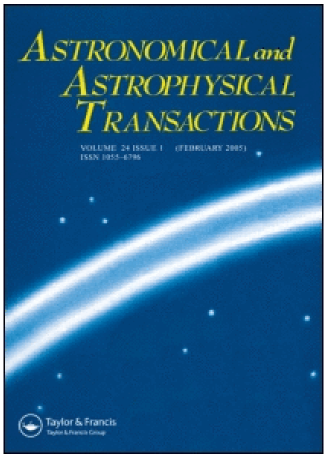

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Non-linear, non-radial evolution of disk-like models of galaxies

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NON-LINEAR, NON-RADIAL EVOLUTION OF DISK-LIKE MODELS OF GALAXIES†

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Non-radial oscillations of disk-like models are studied numerically. The dependence of the oscillations period and the amplitude on initial perturbations is found.

KEY WORDS Celestial mechanics, stellar dynamics – non-linear oscillations

According to the present cosmogonic concepts, the galaxies cannot be born at once in a stationary state and must pass through the phase of global oscillations. It is possible that some galaxies are oscillating at present. Naturally, such oscillations affect the motion of individual particles (stars and galaxies). Here we consider the process of the oscillations themselves including nonlinear effects. We examine a circular disk (Bisnovatyi-Kogan, 1971; Bisnovatyi-Kogan and Zel'dovich, 1970). It is interesting for us to study the possibility of the determination of the pulsation law and the stability. Let us consider perturbations that preserve the homogeneity of the spatial density and the elliptical form in the perturbed state. Then the connection between the non-perturbed coordinates and velocities, $\mathbf{r}_0$, $\mathbf{v}_0$, and the perturbed ones, $\mathbf{r}$, $\mathbf{v}$, can be described by the generating function

$$W(\mathbf{r}, \mathbf{v}_0, t) = \frac{1}{2}\mathbf{r}\mathbf{M}(t)\mathbf{r} + \mathbf{r}\mathbf{N}(t)\mathbf{v}_0 + \frac{1}{2}\mathbf{v}_0\mathbf{P}(t)\mathbf{v}_0. \tag{1}$$

Equations which describe a non-linear evolution of this model have been derived by Antonov and Nuritdinov (1977), Nuritdinov (1977) as a system of three differential equations in a matrix form. For numerical integration, because the matrices $\mathbf{M}$, $\mathbf{N}$ and $\mathbf{P}$ have discontinuous elements, this system has then been transformed to following from

$$\begin{cases} \dfrac{d\mathbf{U}}{dt} = \mathbf{T}; & \dfrac{d\mathbf{S}}{dt} = \mathbf{S}_1; \\[2ex] \dfrac{d\mathbf{T}}{dt} = -2\mathbf{U}\mathbf{K}_2; & \dfrac{d\mathbf{S}_1}{dt} = -2\mathbf{S}\mathbf{K}_2; \end{cases} \tag{2}$$

where $\mathbf{K}$ is a twodimensional matrix determining the potential of the disk $\Phi = -\mathbf{r}\mathbf{K}_2\mathbf{r}$,

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$$\mathbf{K}_2 = \lambda(t)\mathbf{K}_1 + \mu(t)\mathbf{E}, \tag{3}$$
$$\mathbf{K}_1 = \left[\mathbf{U}^*\mathbf{U} + \mathbf{S}^*\mathbf{S} + \Omega(\mathbf{S}^*\mathbf{J}\mathbf{U} - \mathbf{U}^*\mathbf{J}\mathbf{S})\right]^{-1}, \tag{4}$$

where $\lambda(t)$ and $\mu(t)$ are scalar functions of time, $\mathbf{E}$ is the unit matrix,

$$\mathbf{J} = \begin{Vmatrix} 0 & 1 \\ -1 & 0 \end{Vmatrix},$$

Ω is the ratio of the centroid velocity to the circular velocity at same point ($0 < \Omega < 1$).

The matrices $\mathbf{U}$, $\mathbf{T}$, $\mathbf{S}$ and $\mathbf{S}_1$ are determined by $\mathbf{M}$, $\mathbf{N}$ and $\mathbf{P}$. For the determination of the scalar function λ and μ, the invariance of the determinants and the traces of the matrices at the rotation of the coordinates system is useful. Therefore,

$$\mu = \frac{1}{2}\left[\alpha + \beta - \lambda\left(\frac{1}{a^2} + \frac{1}{b^2}\right)\right], \quad \lambda = \frac{\beta - \alpha}{1/b^2 - 1/a^2} \tag{5}$$

at cuentricity $k \to 0$, $\mu \to -\frac{3}{8a^3}$, $\lambda \to \frac{3}{8a}$. Here a and b are the semiaxes, α and β are functions of a and b.

The initial conditions are $\mathbf{U}_0 = \mathbf{H}$, $\mathbf{S}_0 = \mathbf{T}_0 = 0$, $\mathbf{S}_{01} = \mathbf{H}$, where

$$\mathbf{H} = \begin{Vmatrix} \kappa & 0 \\ 0 & \kappa^{-1} \end{Vmatrix},$$

here κ is the ratio of the perturbed semimajor axis to the non-perturbed one (then at $t = 0$, $a = \kappa$ and $b = \kappa^{-1}$). A numerical integration of the system of differential equations has been carried out by the Everhart's method. As the parameter characterizing the deformation of the model, the concept of the statistical amplitude has been introduced:

$$\varepsilon = \frac{1}{\nu}\int_0^\nu \left(\frac{S_{ell}}{S_{cir}} - 1\right)^2 dt = \frac{1}{\nu}\int_0^\nu (ab-1)^2 dt. \tag{6}$$

From numerical experiments, the dependence ε on the value of initial perturbation κ and Ω has been obtained. The results are quite consistent with theoretical predictions about the existence of a boundary between stable and unstable oscillations at $\Omega \leq \sqrt{\frac{125}{486}} = 0.507$. Spectral analysis allows to add to this result the dependence of the period of the oscillations on the initial perturbation at different Ω.

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DISCUSSION

Ossipkov: Who has found the critical value Ω_{crit} theoretically?
Kirbigekova: To my knowledge it was found by Dr. Nuritdinov.