ON THE FORMATION MECHANISMS FOR ELLIPTICALS AND BULGES

A.M. FRIDMAN and V.L. POLYACHENKO
Institute of Astronomy, Moscow, Russia

Abstract. We study the formation of elliptical galaxies and the bulges of disk galaxies as a result of the collisionless collapse of a rotating star cloud. At small amounts of rotation, this process is accompanied by the bar mode of the radial orbit instability slightly modified by rotation. We refer this case to (giant) ellipticals. For moderate rotation, when the radial orbit instability is suppressed, another mode takes over, which is the direct continuation of a strongly damping mode at the limit of almost radial orbits; it turns into a practically non-damping and long-lived mode (for many revolutions), and even a slowly rotating bar may eventually be formed. It is natural to refer this case to bulges and dwarf elipticals. Then spirals could be formed from the clouds with large amounts of rotation.

1. Introduction

There exists a very natural question: to what extent may the principal differences between galaxies (or their components) be attributed only to rotation. We drew attention to this problem a long time ago, see Polyachenko, Synakh, Fridman (1972) where we suggested to classify all galaxies according to their specific angular momentum. The general scheme might be like this:

giant ellipticals	dwarf ellipticals	spirals
slow bars	bulges	fast bars

$\longrightarrow$ specific momentum (L/M)

In this scheme, slow and fast bars are Lynden-Bell's bars and those in "standard" N-body simulations, respectively.
As the first step to solving the problem, it is useful to consider the possible eigenmodes in rotating gravitational systems. Here we study the eigenmodes of the simplest model of a rotating collisionless sphere with elongated orbits. In particular by studying the properties of modes in such a model, one may hope to understand what modes and instabilities can lead to formation of giant elliptical galaxies (practically, non-rotating) and bulges of spiral galaxies (with moderate rotation).

2. Modes of rotating spheres

Within the frame of our model (Polyachenko, 1989, 1992a), which represents strongly elongated orbits as rotating "needles", the simplest equilibrium distribution function for a rotating sphere is

$$f_0(\Omega, a) = F_0(\Omega, a)(1 + \mu \frac{J_z}{J}) \quad (1)$$

where the function F_0 is the distribution function of a nonrotating sphere, Ω the precession velocity of an orbit-needle, a its size, J and J_z the orbital angular momentum and its z-component, respectively, μ a dimensionless parameter $(0 < \mu < 1)$

H. Dejonghe and H. J. Habing (eds.), Galactic Bulges, 377–379.
© 1993 *Kluwer Academic Publishers. Printed in the Netherlands.*

https://doi.org/10.1017/S007418090012368X Published online by Cambridge University Press

responsible for the rotation. Note that a distribution function of the same form (1) was first used by Synakh, Fridman, Shukhman (1971) in their study of a rotating sphere with circular orbits (but the sense of the distribution function in the case under consideration is different). It we also assume that the radial energy of each star is fixed (a =const), then one can easily derive the following dispersion relation for a small barlike perturbation of (1) (Polyachenko, 1992a,b)

$$\frac{3}{2}\left[Q^2 - 1 + x^2 g_-(x)\right] + \mu\left[-\sqrt{\pi}(x + \frac{1}{4x}) + (x^2 - \frac{1}{4})g_+(x)\right] = 0 \qquad (2)$$

where we assumed for $F_0(\Omega, a)$ a Maxwellian distribution

$$F_0(\Omega) = exp(-\Omega^2/\Omega_T^2)/\pi\Omega_T^2, \qquad (3)$$

and denoted by $x = \omega/2\Omega_T$ the dimensionless frequency (the time dependence of perturbation $\sim exp(-i\omega t)$, ω is the usual frequency). Further we have $g_\pm = f_- \pm f_+$, with

$$f_\mp = \int_0^\infty dt\ exp(-t^2)/(x \mp t), \qquad (4)$$

with $Q = 2\Omega_T/\omega_G$ the dimensionless precession velocity dispersion, ω_G the growth rate in the limit of a cold ($\Omega_T = 0$) non-rotating ($\mu = 0$) sphere. The quantity Q is so defined that $Q = 1$ corresponds to a marginally stable model at $\Omega_T = 0$, $\mu = 0$; it is similar to Toomre's (1964) stability parameter Q in the stability theory of rotating disks. Table 1 shows the growth of critical values of Q (at the onset of the radial orbit instability) when the rotation of the sphere increases. Fig.1 shows real and imaginary parts of the frequency x against Q, for $\mu = 0$, 0.1, 0.5.

Table 1

μ	0.0	0.1	0.2	0.3	0.4	
Q_{cr}	1.000	1.145	1.220	1.280	1.335	
μ	0.5	0.6	0.7	0.8	0.9	1.0
Q_{cr}	1.385	1.430	1.475	1.520	1.560	1.600

3. Discussion

As is seen from Fig.1a and Table 1, the growing mode finishes at some critical value of Q: $Q = Q_{cr}(\mu)$, the latter being dependent on the amount of rotation (μ). In the region $Q < Q_{cr}$, the radial orbit instability (somewhat modified by rotation) dominates. Rather many facts are accumulated to date which support this scenario for the formation of elliptical galaxies (Polyachenko, 1981) as a dissipationless collapse accompanied by the radial orbit instability. All oscillations at $Q > Q_{cr}(\mu)$ are damping (see Fig.1b). But we would like to draw attention to

https://doi.org/10.1017/S007418090012368X Published online by Cambridge University Press

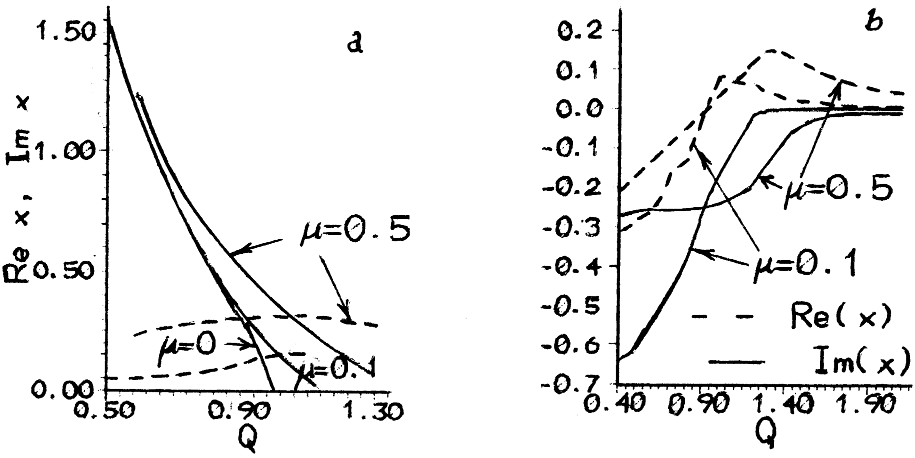


Fig. 1. Eigen frequencies (x) of the rotating sphere (1) against Q (a) growing mode, (b) damping mode

the fact that strongly damping eigenmodes at small Q's turn into practically non-damping modes at larger Q's when the radial orbit instability is suppressed. The decrement of the mode γ goes to values much less than the pattern's angular velocity Ω_p: at $Q > Q_{cr}$, $\gamma/\Omega_p = 2\sqrt{\pi}\Omega_p/\Omega_T \ll 1$. So in this limit we have a slowly rotating, long-lived bar. Once such a bar is formed due to suitable initial conditions, then it can exist for a long time. Possibly, such conditions occur when bulges are formed.

References

Polyachenko, V.L., Synakh,V.S., Fridman,A.M., 1972, *Sov.Astron.*, **48**, 1174

Polyachenko, V.L., 1981, *Sov.Astron.Lett.*, **7**, 142

Polyachenko, V.L., 1989, *Sov.Astron.Lett.*, **15**, 385

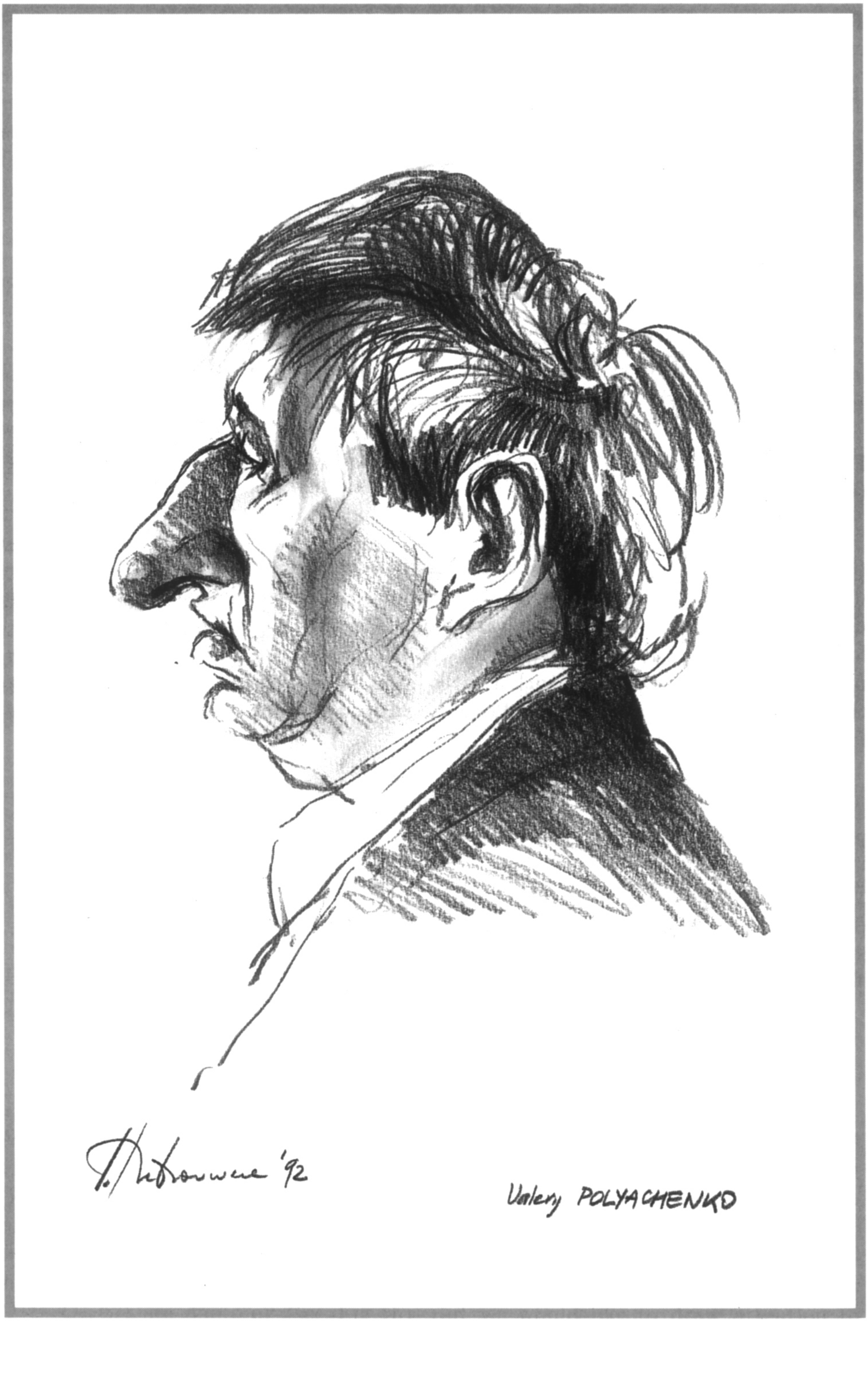
Polyachenko, V.L., 1992a, *Sov.Astron.*, **69**, to be published

Polyachenko, V.L., 1992b, *Astron.Tsirk*, to be published

Synakh, V.S., Fridman, A.M., Shukhman, I.G., 1971, *Reports of USSR Acad.Sci.*, **201**, 827

Toomre, A., 1964, *Astrophys.J.*, **139**, 1217

https://doi.org/10.1017/S007418090012368X Published online by Cambridge University Press



https://doi.org/10.1017/S007418090012368X Published online by Cambridge University Press