Barred Galaxies
ASP Conference Series, Vol. 91, 1996
R. Buta, D. A. Crocker, and B. G. Elmegreen, eds.

Galactic Slow Bar as an Unstable Mode of a Stellar Disk

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Abstract. An estimate for the slow bar instability boundary for a generalized disk polytropic model is derived. The effects of a spherical halo are studied: it turns out that a halo can be favorable to this instability (at the same time suppressing the bending instability).

1. Introduction

We think that the appearance of a typical barred galaxy resembles most an established disk normal mode (in general, non-linear). As a normal mode, the bar- spiral structure arose also in all reasonable N-body simulations. It is also valid for the N-body simulations of slow bars we recently began (Polyachenko & Polyachenko 1994) (all previous work was devoted to fast bars); the present paper explored those models further. From N-body calculations, we derived an estimate of the stability boundary. We also study the effects of a massive spherical halo: It turn out that a halo can be favorable to the radial orbit instability (at the same time suppressing the bending instability).

As is clear from the names, fast and slow bars differ first in their pattern speeds; accordingly, a fast bar ends near the corotation resonance while a slow bar is of order of the inner Lindblad resonance (ILR) radius in size (see below, Figure 2b). It is assumed that fast bars are produced by instabilities that are eventually due to disk fast rotation, while slow bars result from mutual attraction and capture of slowly precessing stellar orbits.

2. Analysis

Let us consider the following initial distribution functions:

$$f_0 \sim L^{\beta}(E_0 - E)^{\alpha}\theta(L), \tag{1}$$

where L and E are the star angular momentum and the energy, respectively, E_0 the dimensional model parameter, α and β the dimensionless parameters; $\theta(L) = 1$ for $L > 0$, $\theta(L) = 0$ for $L < 0$. The ratio of transversal to radial dispersions for the models (1) can be expressed as $\overline{v_\varphi^2}/\overline{v_r^2} = \beta + 1$. It follows from this relation that values of β close to (-1) result in models with an arbitrarily large excess of radially elongated orbits; $\beta = 0$ corresponds to the isotropic models. We restrict ourselves to only the subset of functions (1), for which

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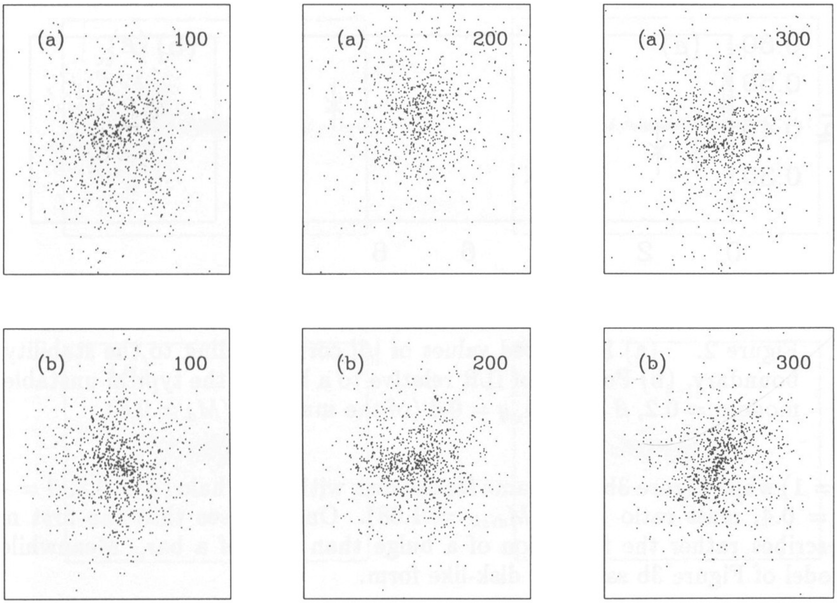

Figure 1. Evolution of the system for model (1) with (a) $\alpha = 0.2$, $\beta = -0.4$, $q = 1$ (no halo) and (b) $\alpha = 0.2$, $\beta = -0.4$, $q = 0.4$ (a halo of the mass $M_h = 1.68 M_d$).

$\beta/2 + \alpha = 0$. We used one more parameter (q) which determines the mass ratio M_{halo}/M_{disk}, $q = 1$ being the model without a halo. We assume that the halo potential is proportional to the disk potential. The results are presented in Figures 1-4. Figure 1a shows the in-plane evolution of the model $\alpha = 0.2$, $\beta = -0.4$, $q = 1$ (no halo, $\overline{v_\varphi^2}/\overline{v_r^2} = 0.6$); it is apparent that this model is stable. The stability boundary for disks without halos occurs at $\beta = -0.5$ (Polyachenko & Polyachenko 1994).

Figure 1b shows the in-plane evolution of the model $\alpha = 0.2$, $\beta = -0.4$, $q = 0.4$ ($M_{halo}/M_{disk} = 1.68$,$\overline{v_\varphi^2}/\overline{v_r^2} = 0.6$); this model is apparently unstable (recall that the same model without halo was stable! - see Fig.1a).

Figure 2a gives our estimations of the parameter $|\beta|$ at the stability boundary, in dependence on the ratio M_{halo}/M_{disk}. From Figure 2a follows that this dependence is non-monotonic, the presence of a halo being favorable for the instability if $M_{halo}/M_{disk} < 5$; it leads to occurrence of the unstable systems with almost isotropic velocity distribution.

Figure 2b shows a typical location of the ILR relative to the bar.

It is evident beforehand that the disk models of negligible thickness should be unstable relative to the bending instability. So, we have also carried out the simulations with small initial z-velocities of particles. Figure 3a presents two states (intermediate and final) for the disk without a halo ($\alpha = 0.3$, $\beta = -0.6$,

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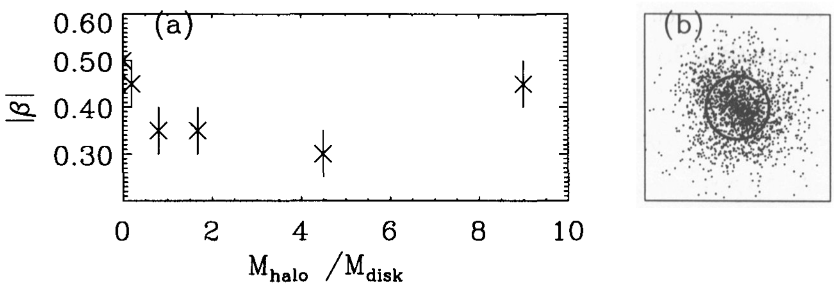

Figure 2. (a) Estimated values of $|\beta|$ corresponding to the stability boundary. (b) Position of ILR relative to a bar for the typical unstable mode $\alpha = 0.2$, $\beta = -0.4$, $q = 0.6$ (of the mass $M_h/M_d = 0.8$).

$q = 1$) while Figure 3b - the same for the disk with some halo ($\alpha = 0.3, \beta = -0.6$, $q = 0.4$, mass ratio $M_{halo}/M_{disk} = 1.68$). One can see that the first model describes rather the formation of a bulge than that of a bar. Meanwhile the model of Figure 3b saved its disk-like form.

3. Conclusions

Thus, the effect of a halo on the slow bar instability was studied; for the models considered, it turns out that the presence of a halo is favorable for the instability at $M_{halo}/M_{disk} < 5$, and conversely at $M_{halo}/M_{disk} > 5$. Also, we ensured in passing that a halo mass stabilized successfully the bending instability of rather 'hot' disks considered. It is clear from the physics of the bending instability that slow bars should be thicker than fast bars, all things being equal (first for the same halo mass).

In our opinion, the problem of origin for slow bars is not more difficult and dim than that for the fast bars. On the assumption that slow bar formation requires very elongated orbits, such a statement might appear to be rather strange. Then it would indeed be difficult to see how such disks could be formed (it is reasonably agreed that the formation of flattened disks requires the presence of gas, and, consequently, a high amount of rotation). However, the point is that the relevant bar formation mechanism, which is akin to the radial orbit instability, does not in general require nearly radial orbits, especially for disks without high density concentration to the center (in this regard, the name of the instability is not quite appropriate). But the necessary elongation of orbits can be reasonable, even though disks have a high central density concentration (for example, at the expense of a halo effect, as is shown above). Besides, one should recall Noguchi's tidal way of the slow bar formation (Noguchi 1988). By the way, the tidal interaction could at times lead to highly elongated orbits.

At last, we should mention that a slow bar could form from an initially fast bar, if the latter slows down afterwards; just this picture is assumed by Combes & Elmegreen (1993).

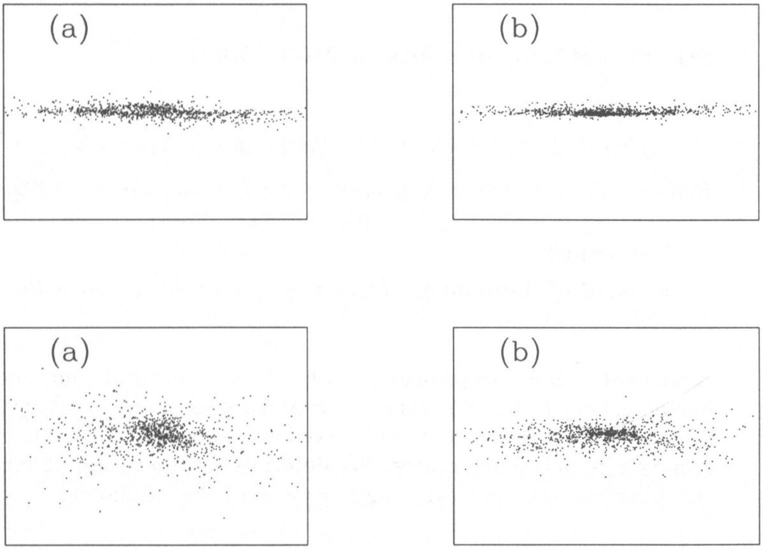

Figure 3. Intermediate (top) and final (bottom) states of two systems (side view): (a) $\alpha = 0.3$, $\beta = -0.6$, $q = 1$ ($M_h/M_d = 0$), and (b) the model $\alpha = 0.3$, $\beta = -0.6$, $q = 0.4$ ($M_h/M_d = 1.68$).

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Polyachenko, V. L. & Polyachenko, E. V. 1995, to appear