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

N-body Simulations of Two-Component, Bar-Unstable Disks

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Abstract. We present results of numerical simulations of bar-unstable disks that include a dissipative gas component. The simulations have been carried out using a two-dimensional polar grid for the force calculations. The gas component has been modelled as a collection of finite-sized particles that dissipate a fraction of their relative motion during collisions.

1. Introduction

Many previous studies have focussed either on the formation of bars in collisionless models of disk galaxies (e.g., Combes & Sanders 1981, Sellwood 1981, Sparke & Sellwood 1987) or on the response of gas to realistic but imposed bar potentials (e.g., Schwarz 1981, 1984, Combes & Gerin 1985). In comparison, many fewer have dealt with the combined stellar and gas dynamics of bar-unstable disks by means of fully self-consistent simulations. Notable exceptions are recent papers by Combes & Elmegreen (1993) and Friedli & Benz (1993). In order to understand better the dynamical evolution of such two-component disks, and in particular to see under what conditions ring-formation might take place, we have run a number of models of bar-unstable disks that include both a stellar and a gaseous component.

2. Models and Methods

Our models consist of an active disk of stars and gas whose self-gravity is supplemented by that of an inert spherical bulge component. The stellar surface density Σ_s is that of a Kuz'min-Toomre disk,

$$\Sigma_s(r) = \frac{M_d(1-f_g)}{2\pi a^2}(\frac{r^2}{a^2}+1)^{-3/2}, \tag{1}$$

where M_d is the total (stellar + gaseous) disk mass, f_g is the mass fraction of gas, and a is the disk scale parameter. In half of the models the gas mass $M_d f_g$ is distributed according to this same law, while in the other half a uniform distribution is used. In all cases we truncate the particle distribution at a radius $r \approx 5a$. The inert bulge component is modelled as a Plummer sphere of mass M_b and scale parameter b. The particles are initially given tangential velocities sufficient to put them into centrifugal equilibrium with the calculated radial force field plus small random radial and tangential velocities parameterized by

https://doi.org/10.1017/S025292110005034X Published online by Cambridge University Press

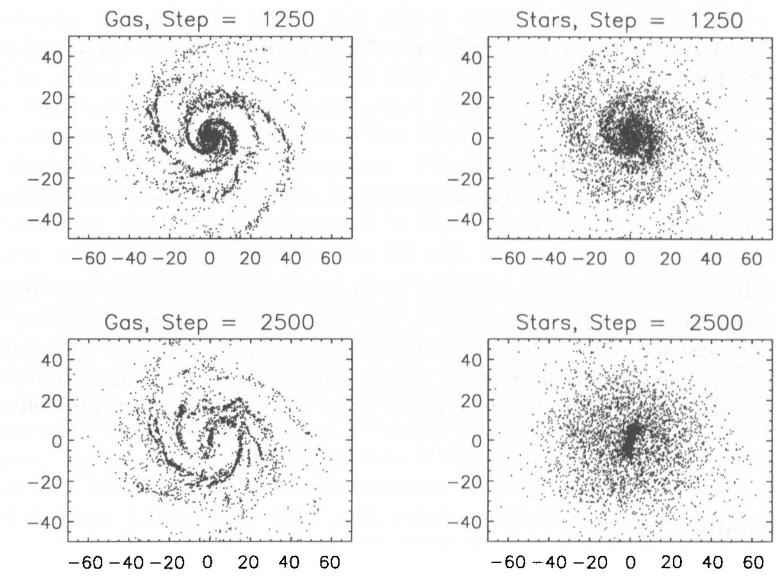

Figure 1. Typical evolution of a model with $b/a = 0.2$.

Toomre's Q. In all our runs we have used $Q_{stars} = 1$ and $Q_{gas} = 0$. Also, in all of our runs we have taken $M_b/(M_d + M_b) = 0.3$, while $b/a = 0.2$ for most of the runs (a few used the value $b/a = 0.5$).

Our gas particle collision scheme is precisely that used by Schwarz (1981, 1984). At each time-step we overlay a cartesian grid whose cell size is the specified collisional cross-section of the particles (in all our simulations we take this to be $0.03a$). The gas particles within a given cell collide if they are approaching each other, though a given particle can only collide with one other particle per time-step. In a collision the relative radial velocity is multiplied by a coefficient of restitution, c_r, and the sign of this relative velocity is reversed. In the runs shown here we have taken $c_r = 0.2$.

3. Results

Figure 1 shows the evolution of a very typical model with $b/a = 0.2$ and $f_g = 0.1$. The gas in this particular run was initially distributed according to the Toomre-Kuz'min density profile. At time-step 1250 (a particle at $r = a$ takes about 250 time-steps per rotation) the model displays a pronounced spiral structure in both the stars and gas. By time-step 2500, though, a strong stellar bar has formed, the stellar spirals have faded considerably leaving a broken spiral structure in the gas only, and much of the gas interior to the bar radius has accumulated in a dense nuclear ring. Significant alteration of the azimuthally averaged gas density profile does not take place until between time-step 1750 and 2000. This is precisely the epoch of the formation of the strong bar.

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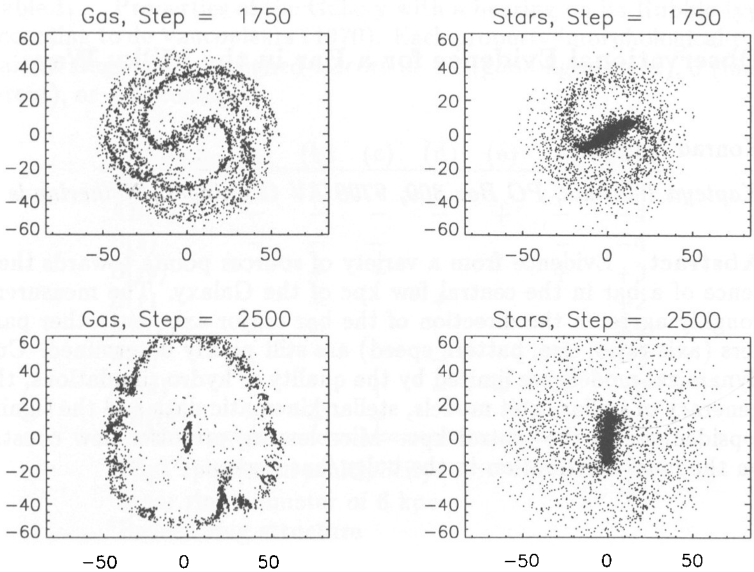

Figure 2. Evolution of an outer ring-forming model with $b/a = 0.5$.

Figure 2 shows the evolution of a typical model with $b/a = 0.5$ and $f_g = 0.1$. The larger value of the bulge scale length leads to a longer, more slowly rotating bar than in the previous case. The initial gas density in this case was uniform. In this run the formation of the bar is accompanied by a much shorter period of spiral activity and the gas in the outer disk is rather quickly torqued out to a ring near the OLR of the bar. Notice also that in this case the gas inside the bar radius has again accumulated in a nuclear ring inside the bar.

Acknowledgments. I would like to thank the government of France and l'Institut d'Astrophysique de Paris for a one-year stay there during which the polar grid code was written. Also, I would like to thank Magnus Thomasson, Maria Sundin and Björn Sundelius for their help and advice in this endeavor.

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