SIMULATIONS OF GAS CLOUDS IN INTERACTING GALAXIES

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1. Introduction

A companion can induce a varitey of morphological changes in a galaxy. I use N-body simulations to study the effects of different kinds of perturbations on the dynamics of a disk galaxy. The model is two-dimensional, with a disk consisting of about 60,000 particles. Most of the particles (80 %) represent the old stellar population with a high velocity dispersion, while the rest (20 %) represent gas clouds with a low velocity dispersion. Initially, the velocity dispersion corresponds to $Q = 1$ for the "star" particles, and $Q = 0$ for the "gas" particles, where Q is Toomre's (1964) stability parameter. The gas clouds can collide inelastically. The disk is stabilized by a rigid halo potential, and by the random motions of the old "star" particles. To simulate the effect of an encounter on the disk, a companion galaxy, modelled as a point mass, can move in a co-planar orbit around the disk. A complete description of the N-body code is found in Thomasson (1989).

In this contribution, I first present the spiral structures caused by a companion in first a direct and then a retrograde (with respect to the rotation of the disk) parabolic orbit. The associated velocity fields suggest a way to observationally distinguish between leading and trailing spiral arms. I then study the stability of the gas component in a disk in which tidally triggered infall of gas to the center occurs. Finally, I show how a ring of gas can form in a disk as a result of a co-planar encounter with another galaxy.

2. Leading and trailing spiral patterns

The galaxy model used in this section is that of a Mestel disk stabilized by a fixed halo potential of the same form as that of the axisymmetric disk. This model has a flat rotation curve and a finite radius.

Surrounded by a halo with the same mass as the disk, the unperturbed disk after a while looks like in Fig. 1. A spiral pattern with many arms, or rather fragments of arms, has developed in the gas population, while no structure is seen in the stellar disk.

A perturber in a direct parabolic orbit induces a *grand design two-armed trailing spiral pattern* in the disk (Sundelius *et. al.* 1987). In the example shown in Fig. 2, the perturber has a mass of 20 % of the disk + the halo, and a closest approach of about two disk radii. Two long arms dominate the picture, although there are also some other structures caused by the inelastic collisions between the clouds, and not found in runs without collisions. If the perturbation is strong enough, the global pattern can be seen both in the gas and the star component, contrary to the more fragmentary pattern in the unperturbed case. This is in general agreement with observations of flocculent and grand design galaxies (Elmegreen & Elmegreen 1984). The

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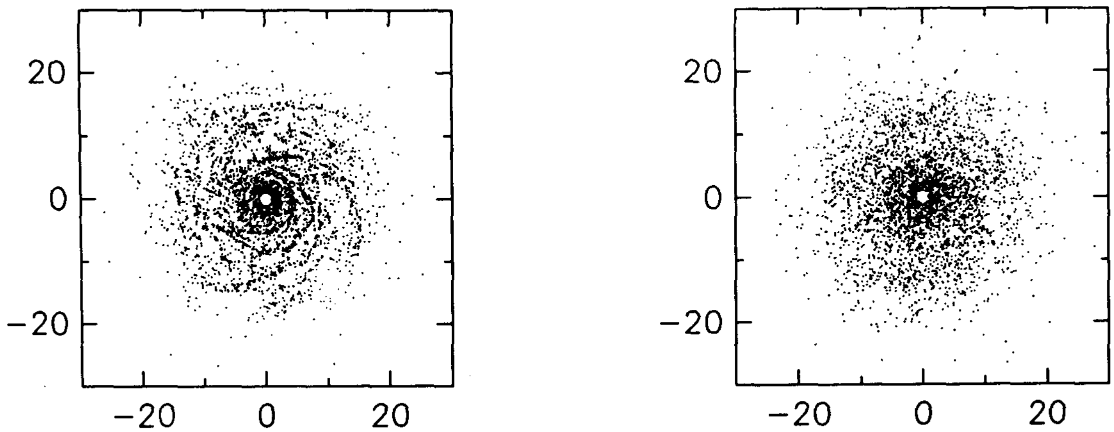

Fig. 1. Fragments of spiral arms in the gas (*left*), but no structure among the stars (*right*) after 2.5 revolutions of a particle at the edge of the disk, at $r = 20$.

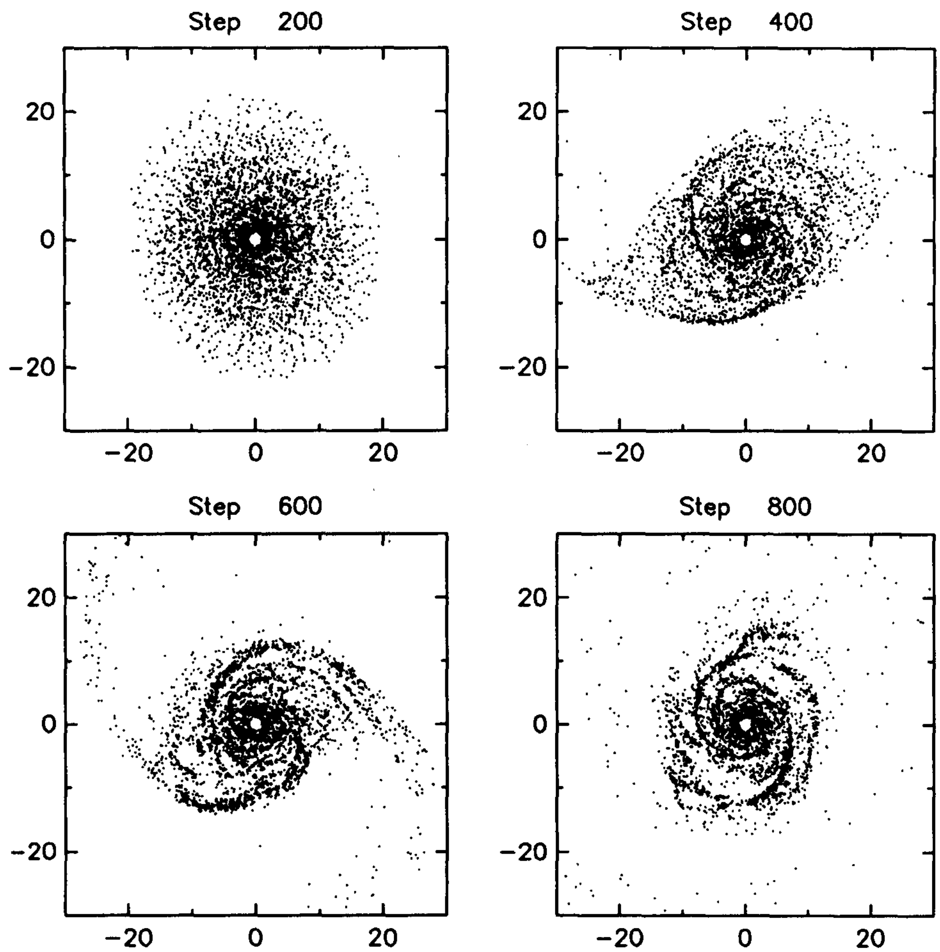

Fig. 2. The evolution of the gas population in a disk perturbed by a companion in a direct parabolic orbit. One revolution at the edge of the disk corresponds to 314 time steps.

rotation curve shows the usual "bumps", i.e. it has positive velocity gradients at the locations of the arms. The radial velocity is negative for objects in the arms.

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A large retrograde perturber causes a *one-armed leading spiral pattern* to form in the disk (Thomasson *et. al.* 1989). A leading spiral arm is an arm who's tip points in the direction of rotation. Since leading arms are more clearly seen in galaxies with a large halo, I have increased the halo mass from 0.5 to 0.6 of the total mass of the primary galaxy in the example shown in Fig. 3. The perturber has here the same mass as the primary galaxy, and a closest approach just outside the disk. The rotation curve has the familiar "bumps" also in this case, but the radial velocities are now negative in the arms.

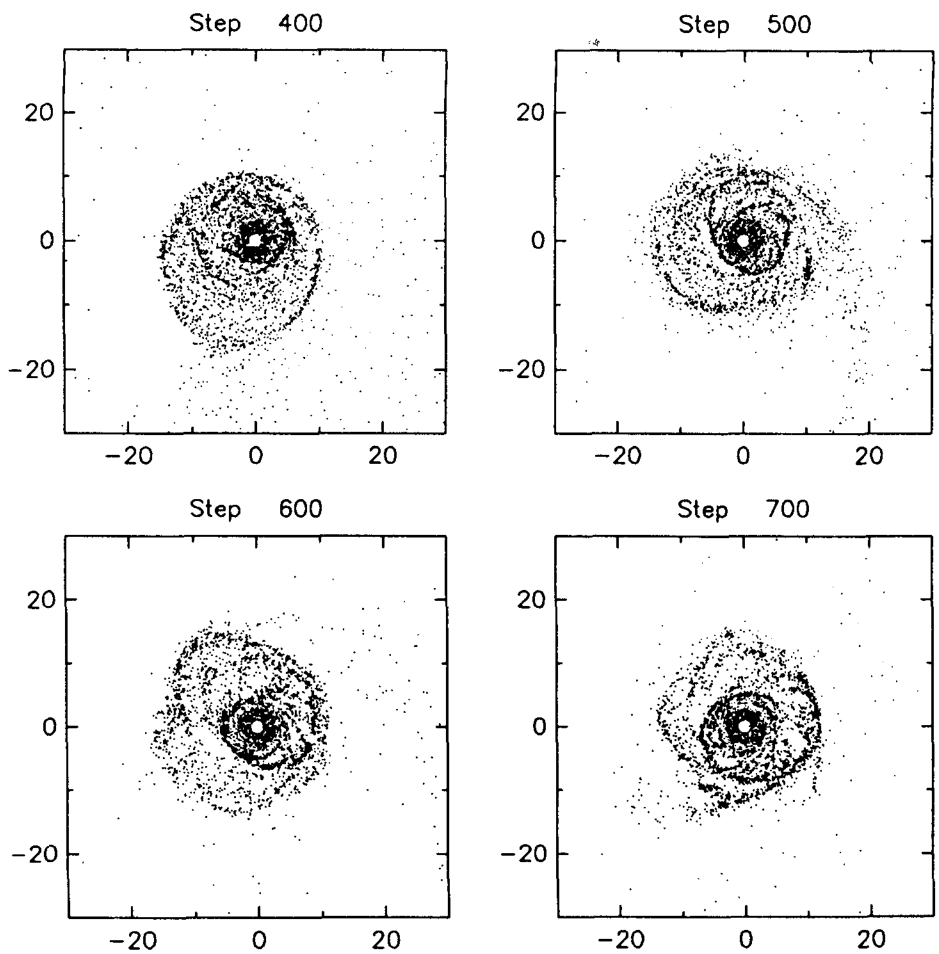

Fig. 3. The evolution of the gas population in a disk perturbed by a companion in a retrograde parabolic orbit.

The radial velocities in the arms suggest a possible way to observationally distinguish between leading and trailing spiral patterns. As mentioned above, the objects in a trailing spiral arm have *negative* radial velocities (inside co-rotation), while they in a leading arm have *positive* radial velocities. Also, since gas enters a trailing arm from the inner side, and a leading arm from the outer side, shocks and dust lanes should be found on different sides of the arms in trailing and leading patterns.

3. Infall of gas and activity in the center

(The work presented in this section was done in collaboration with Dr. B. G. Elmegreen.)

A tidal perturbation can also trigger infall of gas to the center of the disk. How this process can be responsible for the activity in the center of e.g. Seyfert galaxies has been studied by Byrd *et. al.* 1986, 1987. They used a Mestel disk in their simulations. Just to try something different, I used a Kuzmin disk ("Toomre's model 1") stabilized by a halo (of the same kind as the disk) with a mass of 0.7 of the total mass of the galaxy, and I found the same effect. The Kuzmin disk has a rotation curve that rises steeply to a maximum and then falls off slowly at larger radii. The "gas" particles were initially given a small velocity dispersion. A perturber with a mass of 0.2 moved past the galaxy in a parabolic orbit with a pericentre at somewhat more than twice the half mass radius of the galaxy.

Because of the tidal perturbation, gas starts to fall towards the center of the disk. If the gas disk is very unstable at medium and large radii, there is a risk that much of the gas will be used up in star formation before it reaches the center. In Fig. 4, Toomre's stability parameter Q is shown with a grey scale at a time step when the companion has moved far away from the disk. Q gives a rough measure of the stability of the gas. During the infall process, Q is large (white or light grey in the figure) except for in the central parts. A small region with very low Q (black) is found close to the nuclues of the galaxy. This means that the gas disk is unstable only in the most central parts, and we can expect a large amount of star formation there. The central region is just were most of the star formation activity in interacting galaxies take place (Bushouse 1987, Laurikainen *et. al.* 1989, Wright *et. al.* 1988).

4. Formation of a ring of gas clouds

If the Kuzmin model galaxy above is perturbed by a massive object in a retrograde orbit, a ring can form in the component of the disk consisting of colliding gas clouds. The ring shown in Fig. 5 was formed after the passage of a perturber as massive as the primary galaxy. A large number of cloud-cloud collisions occur in the ring. The stellar disk shows no ring structure at all.

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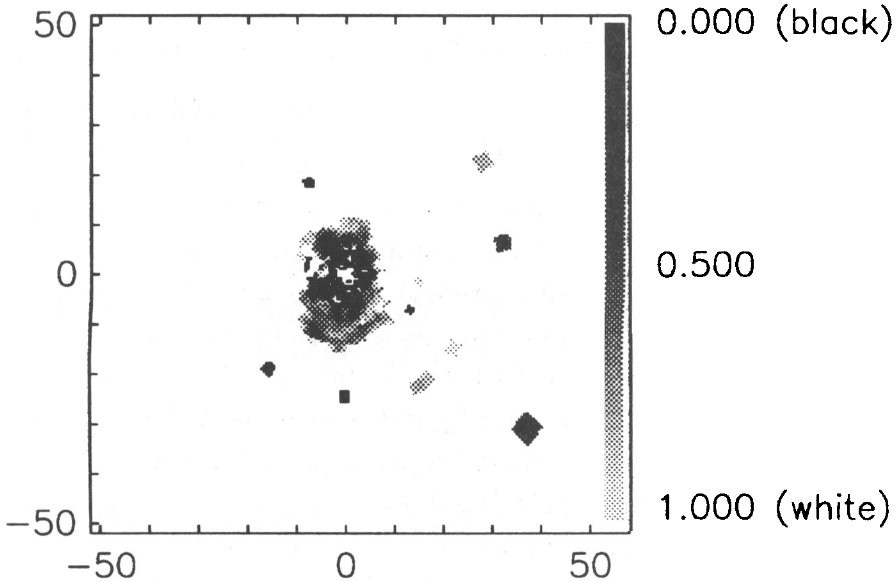

Fig. 4. A grey scale plot showing Toomre's Q for the gas (calculated using only the gas surface density) during the infall process. The half mass radius was initially 16, but particles filled the whole coordinate system. The black parts show where the gas is very unstable (Q is close to zero). White means either $Q > 1$ or zero surface density. In the very center of the disk, inside $r < 1$, there are no particles in the simulation.

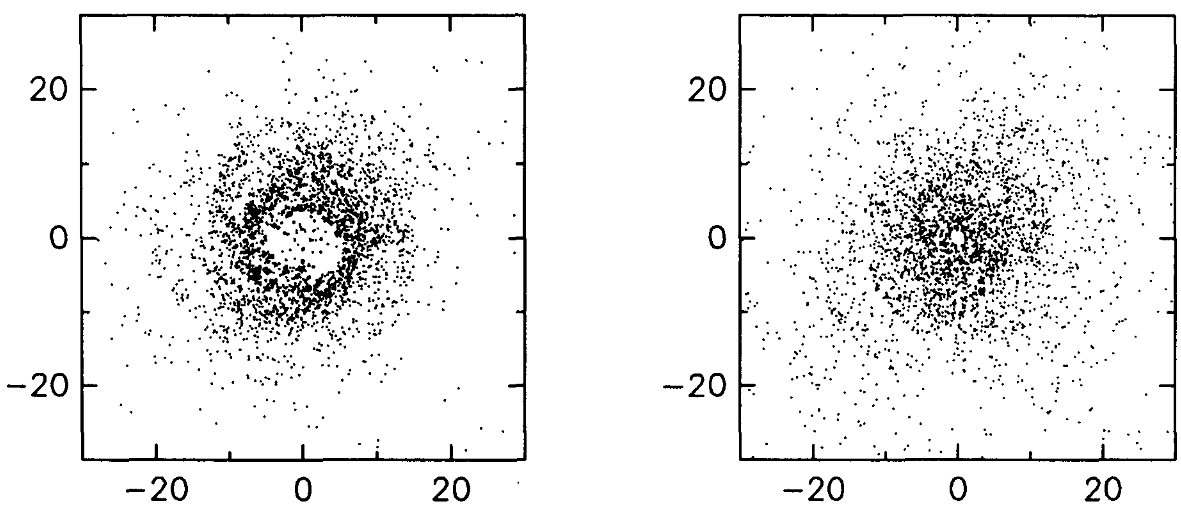

Fig. 5. The ring of gas clouds that formed after pericentre passage, at a radius of 28, of a massive perturber (*left*). No ring among the stars (*right*).

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