MAKING SPIRALS WITH COUNTER-ROTATING DISKS

The case of NGC 4550

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Abstract. A single merger scenario for making galaxies such as NGC 4550 possessing equal coplanar counter-rotating stellar disks is investigated by collisionless N-body technique. The scenario is successful in producing an axisymmetric disk made of two almost equal counter-rotating populations. The final disk shows a clear bimodal line profile in the outer part, which demonstrates that disk-disk mergers do not always produce ellipticals.

1. The Puzzle of NGC 4550

The galaxy NGC 4550, an E7/S0 lenticular galaxy in the Virgo Cluster, was discovered by Rubin et al. (1992) to be a galaxy consisting of two coeval, coplanar, and counter-rotating stellar disks. Many other cases of counter-rotation are now known in ellipticals and also in spirals, but what makes the case of NGC 4550 particular (Kuijken, Fisher, & Merrifield 1996) is that the mass ratio of the counter-rotating disks is nearly 1/1. In the case of ellipticals counter-rotation is so frequent (e.g. Schweizer 1998) that the merger or accretion origins seem the most likely explanations for such kinematic misalignments.

The difficulty with a merger scenario for NGC 4550 is that strong disk mergers usually lead to ellipticals and the destruction of the disks, a "truth" often believed to be general since the seminal paper of Toomre & Toomre (1972). Thakar & Ryden (1996) have shown that over several Gyr a series of well correlated small *gaseous* merger events can lead to a massive counter-rotating gaseous disk. But then this scenario requires to preserve special correlations over several Gyr, contrary to a single event. Thus, it remains open whether a single merger of two equal mass spirals can result in some circumstances to a galaxy like NGC 4550.

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In a forthcoming paper (Pfenniger & Puerari 1998) we will present in more details the general conditions leading to moderate heating. In addition to mass and energy, one must also consider the angular momentum in the final budget. An input of specific angular momentum tends to cool the system, while inputs of specific energy and mass tend to heat it.

2. Simulations

2.1. MERGER SCENARIO

Since NGC 4550 is a rare object, a generic process is not required; exceptional conditions can be acceptable and should be expected. After various considerations we have retained: **1.** A nearly circular orbit of the initial disks, supposing that the excess energy of galaxies coming from infinity has already been absorbed by some outer matter. **2.** Initial disks with opposite spins (see Fig. 1). Counter-rotating disks are ideal for minimizing shocks in outer gaseous disks. Also the retrograde disk is less affected by tidal interactions. **3.** Nearly or exactly coplanar disks in the orbital plane. This may look a rather improbable situation, but a favorable factor to align the disk spins is to have initially flattened dark matter (the torques on misaligned disks is then high). Several arguments, such as the high frequency of warped outer HI disks with straight line of nodes, do suggest flattened dark mass distributions in spirals (see Pfenniger & Combes 1994).

2.2. INITIAL CONDITIONS AND RUNS

The simulations presented here were run in Geneva. Independently, Puerari run similar simulations in Mexico. We intend to publish jointly both sets of simulations since they lead to the same conclusions despite different choices of initial parameters. In particular Puerari's simulations include round massive halos, showing that the shape of the halos does not change the qualitative results, and his disks start on more elongated orbits.

In view of the poor understanding of gaseous processes in galaxies leading to exaggerate viscosity with the SPH technique (see Thakar & Ryden 1996), we simulate first only the collisionless gravity part. Obviously the resulting heating is enhanced with respect to simulations including gas.

Our two initial disks are identical, except for the initial coordinates. They consist of a bulge, with a scale-length of 1 kpc, an exponential disk with horizontal and vertical scale-lengths of 3 and 0.5 kpc, and a flaring ($h_z = 0.03R$) massive "dark" disk with a constant surface density up to 10 kpc, decreasing as R^{-1} between 10 and 30 kpc, and as R^{-2} between 30 and 60 kpc. The mass ratios of the three components are respectively (0.25:1:5), and the particle masses are all equal. The particle velocities

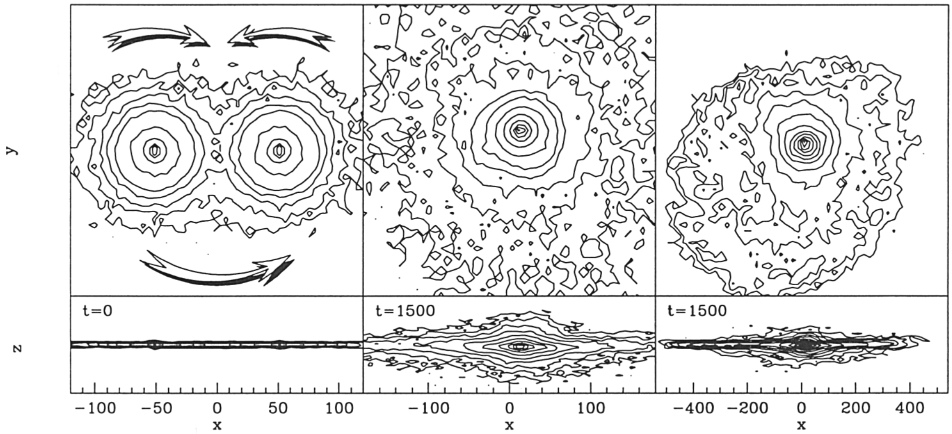

Figure 1. Merging of coplanar disks. The particle density is shown with iso-contours separated by 2 mag. The arrows indicate the disk spins and the disk sense of rotation.
Left: Initial conditions at t=0 Myr.
Middle: After the disk merging (t=1500 Myr), the remnant disk with counter-rotation.
Right: Large-scale view of the particle distribution with marked asymmetries.

are found by solving the Jeans equation for each component in the total potential, assuming velocity dispersions ellipsoids parallel to cylindrical coordinates. The potential of the mass distribution is calculated with a set of $1.25 \cdot 10^6$ particles on the Geneva PM polar grid code.

A rapid run of coplanar counter-rotating disks merger is performed with the PM code with $2.5 \cdot 10^6$ particles. The result is positive but not fully convincing since during the merging process substantial changes of positions of the mass distribution occur within the grid, which has a position dependent resolution. Therefore, we select out a subset of $1.25 \cdot 10^5$ particles, the mass of which is multiplied by a factor 20 to keep the same total mass. The particle subset is then run with the Barnes-Hut (1989) TREECODE (with an opening angle of θ=0.5), which does not imply any geometrical assumptions. In several experiments we verify that slight initial disk inclinations with the orbital plane (5–10°) still lead to counter-rotating coplanar disks.

2.3. RESULTS

Here we just describe the strictly coplanar disk merger. Fig. 1, left, shows the initial particle distribution with the senses of rotation. The disks are on a prograde near circular orbit. The tidal perturbation creates immediately (at ∼200 Myr) a bar in each disk, persisting until the disks merge. The merging process conserves the disks fairly well, the less damaged one being the retrograde one. Fig. 1, middle, shows the inner remnant disk at t=1500 Myr, still containing 80% of the initial total mass, almost circular and barless. Fig. 1, right, shows the large-scale particle distribution, at

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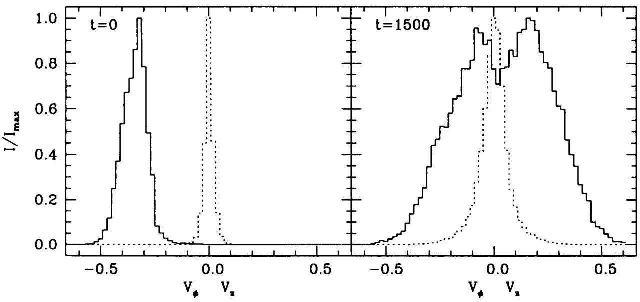

Figure 2. Tangential (solid) and vertical (dotted) line profiles, averaged in the interval 30<R<100.
Left: In the initial retrograde disk, **Right:** In the final remnant.
The final bimodal tangential velocity dispersion is clearly visible.

t=1500 Myr. The excess angular momentum is transported by 10-20% of the mass, mostly of the prograde disk, to large distances, 100–500 kpc.

Fig. 2 shows how the average line profiles as seen in the edge-on disks change from unimodal to bimodal. The bimodal distribution is crucial in order to distinguish counter-rotating disks from a hot population with a zero net rotation. The ratios of final to initial velocity dispersion amount to ~2.4 in the radial direction, and ~2 in the vertical direction. The final mass distribution follows well a $R^{1/4}$ profile. With a relatively limited heating the final disk resembles both in shape and kinematics a typical S0/E7 galaxy, with, in addition, marked counter-rotating populations.

At some moments during the merging process the system as seen edge-on looks like a single galaxy but with two bulges. Such a case of "two-bulge" looking galaxy is PGC 57064 in the Hercules cluster.

3. Conclusions

We have shown that counter-rotating co-spatial disks can be made by a single spiral-spiral merger. The required initial conditions are somewhat peculiar, but favored if the dark matter distribution is flat; however, this is not a necessary condition. The strong reaction of the disks, expelling 10–20% of the mass to 100–500 kpc, means that dark matter in such systems must be distributed in a pronounced asymmetric way for several Gyr. Thus, in many spirals the outer (dark) mass distribution should still be chaotic.

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