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A Numerical Experiment of a Triple Merger of Spirals

Héctor Aceves

IAA-CSIC. Apdo. Postal 3004. Granada 18080, Spain.

1. Introduction

Several studies have addressed the topic of spiral interactions in pairs or in small groups (Barnes 1998). However there is no specific study, to our knowledge, of interacting triplets of spirals. Here we present a preliminary report of ongoing research on the dynamics of triplets that includes galaxies of different morphology. In particular we follow a triplet of equal-mass spirals until a merger remnant that resembles an elliptical-like galaxy has been formed.

It is known that the H I component of spirals is a good tracer of interactions. Indeed, several triplets (e.g. in M81 group) that do not appear to be perturbed in optical images do so in H I maps. Although a self-consistent treatment of gas requires the inclusion of e.g. pressure forces, we use here a test-particle approach to study it during a triple interaction of spirals; this can yield information about the large-scale kinematical features of gaseous tails.

2. The Numerical Experiment

We use Milky Way-like spirals with total mass $M \approx 5.8 \times 10^{11} \mathrm{M}_{\odot}$, dark halo radius $R_{\mathrm{halo}} \approx 135$ kpc, and disc mass $M_d \approx 4.4 \times 10^{10}$ $\mathrm{M}_{\odot}$ (Kuijken & Dubinski 1995, Model B). For computational economy, the number of particles used for each spiral were: $N_{\mathrm{bulge}} = 1000$, $N_{\mathrm{disc}} = 5000$ and $N_{\mathrm{halo}} = 12000$. In isolation the spiral was relatively stable for a few orbital periods. Disc orientations were obtained from three random sets of Euler angles (some animated gifs of the simulations are at `http://www.iaa.es/ae/triplets.html`).

The initial positions and bulk velocities of galaxies were obtained from one cold-collapse simulation of spherical galaxy triplets, in which a relatively rapid triple merger was found (Aceves 2000). We started the simulation at $t_0 \approx 2$ Gyr from turn-around, when two of the galaxies G1 and G2 had their halos just overlapping. These galaxies were approaching at a relative velocity of ~ 140 $\mathrm{km\,s^{-1}}$; the third galaxy's (G3) halo had not yet 'touched' the binary's common halo and was infalling at ~ 40 $\mathrm{km\,s^{-1}}$. In the following, times quoted will be the elapsed time since t_0. The simulation lasted for another ≈ 12 Gyr.

The 'gas' particles were distributed uniformly in the plane of the discs extending twice the stellar component. Forces on them were calculated using the mass interior to their position, with respect to each galaxy centre. The distribution of mass in galaxies was assumed to remain the same throughout the simulation and that it had a radial dependence. We consider this a somewhat better approximation than assuming that all the mass of a galaxy resides at its centre; no important extra computational effort was required in this approach.

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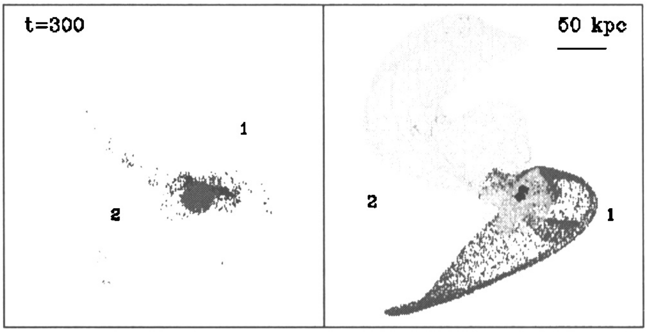

Figure 1. (*left*) XY-projection of disc particles of galaxies G1 and G2 at ≈ 4 Gyr from t_0. (*right*) Gas particles of galaxies, as well as the bulges, are shown. The numbers track each galaxy.

3. Results

In Fig. 1 we show a projection of the discs of galaxies G1 & G2 interacting at ≈ 4 Gyr; galaxy G3 has not yet come close enough for its halo to be perturbed. The discs are greatly disturbed and a long stellar tidal tail has developed in G2 (~ 150 kpc, in projection). The gaseous tails generated reach ~ 200 kpc in projection. Some stars and gas particles are *returning* to the 'binary' galaxy due to conservation of angular momentum and because they do not have enough kinetic energy to leave the local potential well of the binary. At ≈ 10 Gyr galaxies G1 & G2 have already merged with G3; see Fig. 2. Galaxy G3 shows a very large projected stellar tidal tail of ~ 350 kpc, which is about the same size as its gaseous one. At this time the tidal tail of G2 has almost disappeared, although important traces of it exist as a more diffuse component.

The configuration at the end of the simulation is shown in Fig. 3. Enormous gaseous tails ~ 1 Mpc long are present and the stellar tidal tail of G3 seen in Fig. 2 is still present. Since gas thermodynamics has not been considered, it is probable that some 'H I gas' has been ionized by shocks developed during the interaction and, hence, this extension is an upper limit; also, the initial size of the gaseous discs and the spiral matter profile determine the tail extent. After removing all unbound particles the shape of the merger was found to be prolate. No disc or bulge particles were formally unbound, but galaxies G1 and G2 had lost $\approx 3\%$ of their halo mass and G3 $\approx 10\%$. The merger remnant shows a luminous profile that resembles that of an elliptical, although with a rather isothermal core, its phase-space has retained more information about its spiral past; see Fig. 4. The physical size of the stellar tails reach ~ 500 kpc!

Figure 5 shows velocity profiles for the gas, which would mimic the result of placing a narrow slit along the X-axis, both at ≈ 4 Gyr (*top*) and 12 Gyr (*bottom*). Velocities along the line-of-sight of ~ 100 km s^{-1} in the outer parts with a width of $\sim (50, 100)$ km s^{-1} are obtained, respectively, from G1 and G2

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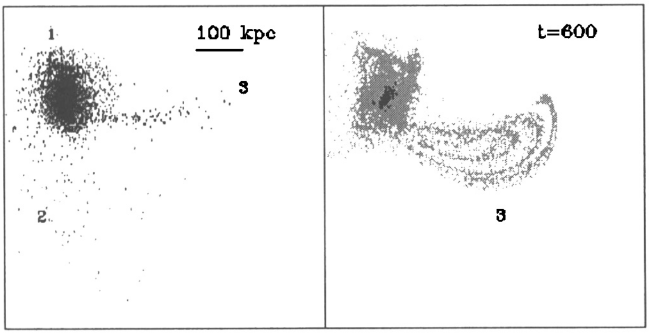

Figure 2. Similar to Fig. 1, but at $\approx$ 10 Gyr. Note the change of scale. The 'gas' tail is just separating from the stellar one in G3, as seen in some observations. The bulge of G3 is shown on the right.

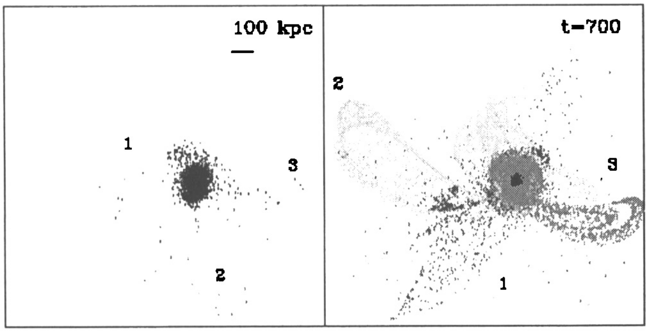

Figure 3. Final configuration. Note again the change in scale, and how some stars are very distant from the central region.

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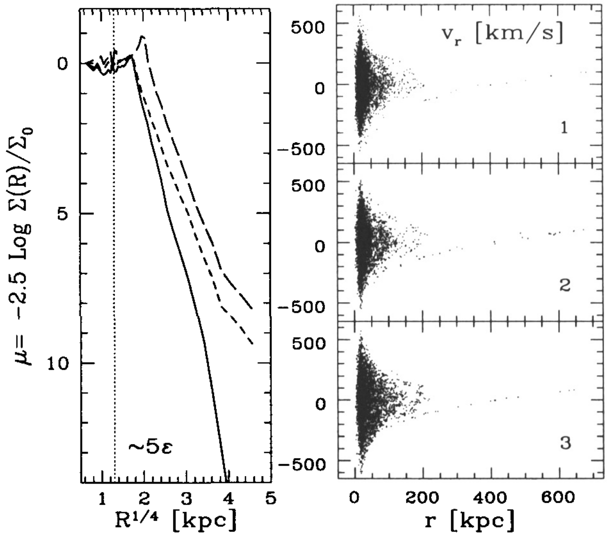

Figure 4. (*left*) Three orthogonal surface number density profiles of luminous matter at $t \approx 12$ Gyr. (*right*) Phase-space portraits of discs. Note that signatures of the encounter in the three galaxies persist.

at ≈ 4 Gyr. At the end of the simulation G1 shows a broad dispersion in the velocities, while galaxies G2 and G3 show a more well defined width of ~ 50 km s^{-1} in the XV_z-plane. Tidal tails in G3 developed very late in the merging process.

4. Final Comments

Some particular results suggested by the present simulation, with its specific cold-collapse initial conditions, tend to show that:

- Encounters of spirals can effectively destroy stellar discs in $\lesssim t_{\rm Hubble}$. Large projected stellar tidal tails ~ 200 kpc can develop during a binary formation, and up to ~ 350 kpc in the 3rd galaxy when it joins in. However, tidal tails are not eternal: they fall back to the remnant of their 'parent' galaxies in $\lesssim t_{\rm Hubble}$, although important traces of them remain for $\gtrsim t_{\rm Hubble}$.

- Diffuse light, due to stars stripped from the discs, is to be expected in deep imaging of spiral interactions and mergers. However if this stripping occurred more than a stellar evolution time-scale ago one may not detected it, but stellar remnants may be in the *field.*

- Gaseous tidal tails may extend to ~ 1 Mpc in radius, similar to the extent of the common dark halo formed, in a triple interaction in $\sim t_{\rm Hubble}$. This

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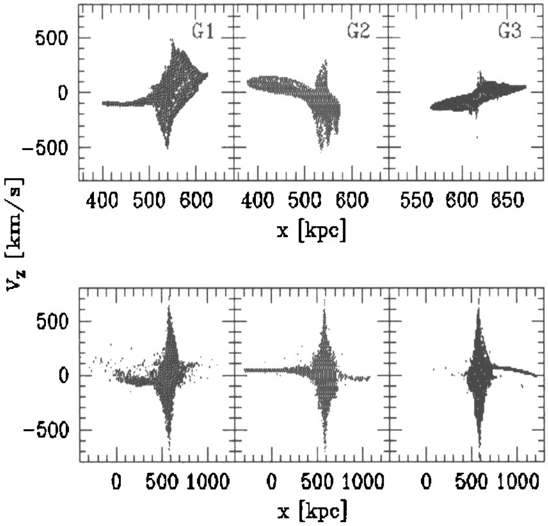

Figure 5. Velocity profiles of gas along the X-axis at ≈ 4 Gyr (*top*), and at ≈ 12 Gyr (*bottom*), for each spiral galaxy.

result suggests that gaseous halos may trace the size of a common dark halo developed during galaxy interactions.

- Although the stellar merger remnant shows an elliptical-like profile, it is more physically justifiable to look for merger signatures in velocity-space, although this would be an observational challenge.

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