

Triplets of Galaxies: Some Dynamical Aspects

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1. Introduction

In celestial mechanics the 3-body problem has a long and rich history, yet the particular problem of 3-galaxy systems has been rather less studied (see review by Valtonen & Mikkola 1991). Most of the up-to-date works have addressed the 3-galaxy problem using a point-like approach, although some explicit-physics simulations have been performed to simulate dynamical friction effects and merging processes (Zheng et al. 1993). These studies have provided important understanding on the general behaviour of observed galaxy triplets (Karachentsev 2000), and some accordance with observations has been obtained.

However galaxies are not point-like particles, but rather consist of a large number of stars which can be approximated as point-like particles. Qualitative and quantitative differences result in the dynamics when the 3-galaxy problem is addressed self-consistently; *i.e.* when galaxies are able to redistribute energy and angular momentum among their stars. Since not using self-consistent galaxies necessarily casts some doubts on earlier results, we address here the 3-galaxy problem self-consistently and compare some results with observations. A full report on this work is in preparation.

2. Numerical Experiments

Galaxies were modeled as Plummer spheres with $N = 3000$ particles each. No explicit difference was made as to particles being luminous or dark. The units used here are such that $G = M = R_0 = 1$, where M is the mass of each galaxy and R_0 its scale-length. To transform N -body results ('n') to astronomical ones ('a') we need to choose a real galaxy. We use here a galaxy similar to ours with $M \approx 5.5 \times 10^{11} M_\odot$ and $R_{\text{halo}} \approx 135$ kpc (Kuijken & Dubinski 1995, Model B). The following transformations follow:

$$\frac{r_a}{r_n} \approx 13.5 \text{ kpc}, \quad \frac{m_a}{m_n} \approx 5.5 \times 10^{11} M_\odot, \quad \frac{t_a}{t_n} \approx 32 \text{ Myr}, \quad \frac{v_a}{v_n} \approx 420 \text{ km s}^{-1}. \quad (1)$$

Initial positions of the centres-of-mass of the three galaxies were randomly generated within a homogeneous spherical distribution of radius R_{max} . The evolution of the triplet depends, obviously, on the size of this sphere. R_{max} is taken here as an approximate turn-around radius of a density perturbation with the mass of a triplet; galaxies are assumed to be already formed. We consider an initial virial ratio of $2T/|W| = 1/4$ for this perturbation with velocity dispersion $\sigma = V_0/2\sqrt{3}$, where $V_0 = \sqrt{3GM_t/5R_{\text{max}}}$ and $M_t = 3M$ (e.g. Barnes 1985).

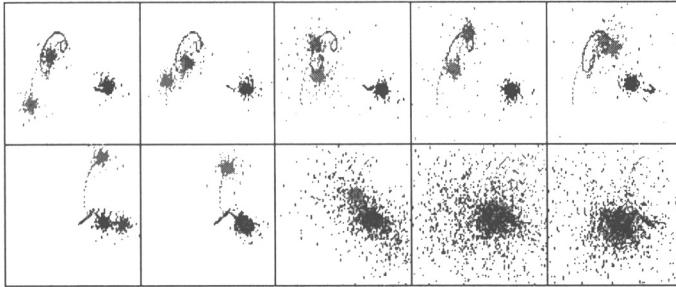


Figure 1. Outcomes of two triplet simulations, from initial conditions to ≈ 20 Gyr in steps of ≈ 5 Gyr. (*top*) The formation of a binary and a single galaxy, (*bottom*) a triple merger. Lines indicate the path of the centre of galaxies. Frames are 100×100 length units.

Numerical simulations of galaxy formation tend to indicate that the dark matter background at turn-around had $\sigma \sim 20 \text{ km s}^{-1}$ (Lake & Carlberg 1988). We take this as a fiducial value for σ in triplets at maximum expansion. Hence for three Milky Way-like spirals we obtain $R_{\text{max}} \sim 1 \text{ Mpc}$. No common dark matter halo has been used in the present simulations. Note that if we increase the mass of the triplet by introducing a common dark matter halo, and retain cold initial conditions, this will increase R_{max} proportionally. The collapse time is taken here as $\tau_{\text{coll}} = \pi \sqrt{R_{\text{max}}^3 / 2GM_t} \approx 20 \text{ Gyr}$ (or 794 time units). These initial conditions are more appropriate for triplets turning around at this epoch.

We also considered virialized initial conditions, obtained by assuming galaxies to be point-masses. We made 30 simulations and estimated the 1-D velocity dispersion σ , mean harmonic radius R_{H} , crossing time t_{c} , and virial mass M_{v} (Nolthenius & White 1987), along three orthogonal projections; *i.e.* 90 ‘triplets’ are simulated for each of the initial conditions considered. Simulations lasted $\approx 20 \text{ Gyr}$ from turn-around, and energy was conserved for all the runs to $\lesssim 1.5\%$.

3. Results

In Figure 1 we show two typical outcomes of the simulations performed. Qualitatively situations where binaries are formed first, some of them leading to a rather quick triple merger (*bottom*) and others taking a much longer time to even form a binary merger (*top*), predominate the simulations. This resembles the same instability found in the 3-body problem to form initially a binary. However, when self-gravity is considered effects such as the sling-shot mechanism are not common due to the galaxies’ ability to absorb orbital energy.

In Table 1 we show quantitative results for both types of initial conditions, taking out mergers. Numbers are given in N -body units. The first row, for each time, are average values while in the second median values are given. Times correspond respectively to $\approx 0.5, 5, 10, 13, 15,$ and 20 Gyr . As expected, initially virialized triplets evolve much slower than cold ones. Collapsing triplets yield a significant number of mergers in the time interval (10 – 13) Gyr; *i.e.* $\sim \tau_{\text{coll}}/2$.

The average or median mass values *never* overestimate the true mass of the system; in collapsing triplets. The underestimate in the median is a factor of $\lesssim 3$ than the true mass during the wide time interval of $\approx (5 - 15)$ Gyr for collapsing triplets; the agreement is much better for initially virialized systems. Some triplets provided an overestimate in mass along a particular line-of-sight.

Table 1. Results for Triplets in Isolation

| t | σ | Cold-Collapse | | | Virial | | | |
|--------|----------|---------------|--------------------------|-------|----------|-------|--------------------------|-------|
| | | R_H | t_c/τ_{coll} | M_V | σ | R_H | t_c/τ_{coll} | M_V |
| 17.24 | 0.036 | 82.86 | 3.70 | 0.58 | 0.071 | 82.92 | 1.85 | 2.28 |
| | 0.033 | 86.35 | 3.75 | 0.59 | 0.067 | 86.03 | 1.81 | 2.28 |
| 159.42 | 0.063 | 73.21 | 2.91 | 1.64 | 0.102 | 73.93 | 1.41 | 4.08 |
| | 0.050 | 71.06 | 1.71 | 1.04 | 0.087 | 71.95 | 1.28 | 3.46 |
| 314.54 | 0.098 | 59.66 | 1.90 | 2.26 | 0.090 | 75.71 | 1.67 | 3.45 |
| | 0.090 | 50.12 | 0.86 | 1.45 | 0.077 | 75.36 | 1.39 | 3.13 |
| 409.33 | 0.091 | 58.26 | 1.88 | 2.18 | 0.086 | 74.38 | 1.77 | 3.39 |
| | 0.065 | 52.62 | 1.71 | 1.65 | 0.082 | 68.39 | 1.41 | 2.82 |
| 469.65 | 0.105 | 49.76 | 1.31 | 2.46 | 0.090 | 71.90 | 1.92 | 3.68 |
| | 0.081 | 39.22 | 0.58 | 2.07 | 0.074 | 67.44 | 1.27 | 2.41 |
| 642.00 | 0.066 | 43.27 | 1.62 | 1.04 | 0.058 | 67.71 | 2.45 | 1.32 |
| | 0.065 | 30.88 | 0.70 | 0.84 | 0.054 | 63.09 | 1.50 | 1.17 |

Results for the median R_H in collapsing triplets do not agree well with those of observations of present day compact triplets (≈ 65 kpc). This also occurs in virialized systems for which $R_H \gtrsim 400$ kpc. On the other hand, the velocity dispersions are always $\sigma \lesssim 50 \text{ km s}^{-1}$ for both types of initial conditions, a value which is about half of the observed median ($\approx 100 \text{ km s}^{-1}$). Nonetheless, about 10% of the simulated triplets have $\sigma \gtrsim 100 \text{ km s}^{-1}$ at $t \sim 10$ Gyr. Using a larger mass and halo size galaxy does not help much in increasing the astronomical median- σ since velocities scale as $v \propto \sqrt{M/R}$.

We recall that when comparing to observational data the assumption that Karachentsev's catalog of compact triplets forms an homogeneous and well defined sample is implicit, but this is not so since e.g. it includes galaxies of different luminosities (\sim mass) and morphological type. This needs to be considered in future studies to make more consistent comparisons with observations.

On other hand, however, there are some indications that triplets lie in the periphery of larger systems of galaxies. In a large-scale structure picture, triplets were probably not isolated from tidal perturbations before arriving at their present state. Hence it is of interest to estimate probable tidal effects on the dynamics of triplets in a Hubble time, even if only to first order. In Fig. 2 we present only the results of the σ -distribution under a tidal perturbation from a distant 'poor cluster'; the triplet was retained at the same initial distance to study the effects of a tidal force. The agreement of the median and average σ with observations is better when triplets are not considered 'island universes'; e.g., $\langle \sigma \rangle \approx 100$ at $t \approx 10$ Gyr when the perturber in Fig. 2 is at 3 Mpc. Although this value obviously depends on the perturber mass and distance, the results manifest the importance external fields can play in the dynamical properties of what otherwise were assumed to be isolated triplets. They also suggest that the environment could have introduced a 'selection effect' in allowing some initially

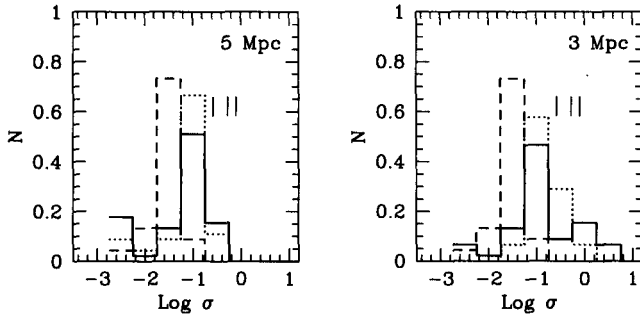


Figure 2. Velocity dispersion distribution for collapsing triplets under the action of tidal perturbation from a point-mass $M \approx 10^{14} M_{\odot}$. (left) Triplet 5 Mpc distant from the perturber, and (right) 3 Mpc distant. Dashed-lines are at $t = 0$, dotted at ≈ 10 Gyr, and solid-line at ≈ 15 Gyr. Bars correspond to $\sigma \approx 100, 200, 300 \text{ km s}^{-1}$, respectively. Some initially wide triplets get disrupted in $t \gtrsim \tau_{\text{coll}}/2 \sim 10$ Gyr.

wide triplets ($R_{\text{H}} \approx 630 \text{ kpc}$) to become compact, and disrupting others, in a Hubble time.

4. Final Comments

Simulations of *isolated* triplets show that on average rather low velocity dispersions are obtained when compared to observations. In this scenario an underestimate of mass will occur when using the bulk velocity and centre of galaxies, probably by a factor of ≈ 3 . This underestimate can be larger for particular triplets if strong signs of interactions are present and if galaxies have large dark halos; this situation could be similar for compact groups. Wide triplets could have evolved into compact triplets in a Hubble time, although their high σ remains to be explained.

Tidal perturbations on the evolution of a triplet, however, might have important effects on their dynamics over a Hubble time, and consequently on their mass estimation. We suggest that triplet dynamics is closely tied to cosmology, and that it is not direct to untangle internal effects from external ones. Observational studies that would search e.g. for possible correlations between σ and the density of the triplets environment could shed light on these issues.

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