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N-body simulations of galaxy collisions

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Abstract. The tidal effects of close collisions between two spherical galaxies of different mass and mass distributions are studied by numerical simulations. The galaxies are represented by polytropes of indices n = 4 and n = 0 which represent a wide range in mass distribution of high central concentration and uniform mass distribution respectively. The initial relative velocity of the galaxies in a hyperbolic orbit is taken to be 700 kms^{-1}. It is found that the tidal effects are quite sensitive to the mass ratio and the mass distribution of the galaxies. The results show that in a collision between identical centrally concentrated galaxies relatively more spin is imparted to the galaxies compared to collision between identical homogeneous galaxies. The dependence of tidal capture and tidal disruption on the choice of the model and mass ratio is also investigated.

Key words : galaxies, interactions, numerical simulations

1. Introduction

The tidal effects of encounters between galaxies have been studied extensively by numerical simulations in different scenarios by a number of workers (see Namboodiri, Sastry and Narasimhan, 1998; Alladin and Narasimhan, 1982 and Struck, 1999 and the references therein). We feel that collisions between galaxies that differ in their mass distributions need to be studied in greater detail. In this paper we attempt to get further insight into the stickiness of galactic collisions by performing a number of N-body simulations. We have chosen the galaxies in such a way that they have (i) the same mass distribution and (ii) differing mass distributions, having same/different mass and dimensions in order to get qualitative estimates for the upper and lower limits to the tidal damage caused by the encounters. The galaxies are represented by polytropes of indices n = 4 and n = 0. The density in them are typical of a globular cluster or an elliptical galaxy and a homogeneous galaxy of radius R respectively. Although the polytrope n = 0 for a galaxy is not realistic, we have chosen this model as it represents the extreme case of homogeneity as was done earlier by Alladin et al., (1975). We describe the model in Section 2 and the results are discussed in Section 3.

2. The model

The model consists of galaxies that contain 4096 equi-mass particles. The units of distance, mass and velocity are 10 kpc, 10^{12} $M_\odot$ and 700 kms^{-1} respectively. In these units the gravitational constant G=1 and the unit of time is 1.5×10^7 year and the simulations lasts for more than 10^9 year. The primary galaxy (more massive) of mass M_1 is separated from the secondary of mass M_2 by 20 units initially and at closest approach they are about 0.9 units apart. The initial relative velocity in a hyperbolic orbit is about 700 kms^{-1} in all collisions. The various model are denoted by P1, P2, P3, ..., P10. The computation was performed using the GRAPE computer system.

3. Model parameters and collision results

In table 1, we give the collision model P (with corresponding polytropic indices in brackets), the masses M_1 and M_2 in units of $10^{12}M_\odot$, half-mass radii Rh_i and Rh before and after collision, the fractional change $\Delta U/|U|$ in the binding energy, the mass loss $\Delta M/|M$ of the pair after the collision, the spin parameter λ of the primary, L/L_{orb}, where L is the modulus of the angular momentum of the primary and L_{orb} is the initial orbital angular momentum of the pair. The entires in the first row in any model refer to the primary (denoted by p) and those in the second to the secondary (denoted by s). $\Delta U/|U|$ is a convenient order of magnitude estimate of the intensity of the tidal effects. A galaxy disrupts considerably when $\Delta U/|U| \sim 1$, on the other hand if loss $|\Delta E|$ in the orbital energy is of the same order as its initial energy E, tidal capture or merger takes place.

The rotation of the galaxies is measured by $\lambda = |U|^{0.5}L/GM^{2.5}$ where L is the modulus of the angular momentum of the primary, M is its bound mass and U its internal energy. The values of λ and L/L_{orb} for non-disrupting collisions as in P1, P3, P5, P9 and P10 are given in table 1. An examination of the values of $\Delta U/|U|$, $\Delta M/M$, λ, and L/L_{orb}, suggests that the tidal effects are quite sensitive to the mass ratio and mass distribution of the galaxies. We draw the following conclusions based on the simulations that lasted upto T=70 units i.e., about 10^9 year.

(i) λ decreases with decreasing central concentration in mass distribution of the galaxies while Vergne and Muzzio (1995) noticed decrease of λ with decreasing mass ratio. Thus it appears that in a collision between identical galaxies relatively more spin is imparted to the galaxies if they are centrally concentrated than if they are homogeneous. This aspect needs to be studied in greater detail in order to give a physical explanation. The typical value of rotation obtained in centrally concentrated galaxies (i.e., model P1) is about 80 kms^{-1}.

(ii) A slight increase in the mass ratio of the galaxies of different mass distributions as in P5 and P7 alters the collisional effects drastically from being moderate as in P5 to severe leading to disruption of the less massive homogeneous galaxy as in model P7.

It will be interesting to study the effects of interactions in more realistic models, viz. with polytropic indices n = 4 to n = 2 which is planned for our future studies.

Table 1. Collision parameters and results.

Model		M	Rh_i	Rh	$\frac{\Delta U}{\lvert U \rvert}$	$\frac{\Delta M}{M}$	λ	$\frac{L}{L_{orb}}$	Remarks
P1(4,4)	p	1	0.82	1.3	0.72	0.19	0.067	0.49	Both galaxies survive
	s	1	0.82	1.2	0.69	0.17	0.078	0.46	and remain bound
P2(4,4)	p	2	0.82	0.9	0.29	0.015			Capture and disruption
	s	1	0.82	5.1	2.3	0.065			of M_2
P3(0,0)	p	1	0.95	1.2	0.6	0.14	0.052	0.38	Both galaxies survive
	s	1	0.95	1.2	0.6	0.14	0.036	0.27	and remain detached
P4(0,0)	p	3	0.95	0.85	0.14	0.001			Capture and disruption
	s	1	0.95	5.5	2.9	0.76			of M_2
P5(0,4)	p	1	0.95	1.3	0.63	0.14	0.041	0.35	Both galaxies survive
	s	1	0.82	1.2	0.62	0.17	0.061	0.53	and remain detached
P6(0,4)	p	7	0.95	0.86	0.034	0.0			Capture and disruption
	s	1	0.82	18	4.7	0.9			of M_2
P7(4,0)	p	1.4	0.82	1.1	0.50	0.062			Capture and disruption
	s	1	0.95	4.5	1.7	0.51			of M_2
P8(4,4)	p	2	1.2	2.2	0.8	0.065			Capture and disruption
	s	1	0.82	2.4	1.4	0.4			of M_2
P9(0,0)	p	3	1.9	2.1	0.29	0.005	0.011	0.17	Both galaxies survive
	s	1	0.95	1.2	0.86	0.19	0.033	0.301	and remain detached
P10(0,4)	p	7	8.1	8.6	0.17	0.005	0.0008	0.14	Both galaxies survive
	s	1	0.82	0.82	0.07	0.016	0.017	0.055	and remain detached

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