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Spin angular momentum of tidally affected galaxies

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SUMMARY

Numerical experiments have been performed to study the transfer of angular momentum to an initially non-rotating spherical galaxy as it undergoes a collision with a point mass perturber moving in a relative orbit of constant pericentric distance. The variation of the acquired spin of the galaxy with time is smooth in the case of open orbit encounters, whereas it is irregular in the case of bound orbit encounters. The induced rotation of the test galaxy is in the same sense as that of the initial orbital angular momentum of the pair.

1 INTRODUCTION

The end result of a tidal encounter between galaxies is that the energy from orbital motion is transferred to the internal energy of the test galaxy. The tidally affected galaxy thus acquires not only additional kinetic energy of random motion but also angular momentum. In an earlier paper (Namboodiri & Kochhar 1990, hereafter Paper I) we have numerically studied the response of an initially spherical galaxy to a mild encounter with a massive perturber. The point mass perturber can choose from a number of orbits, open as well as closed, all at a fixed pericentric distance of about three times the size of the test galaxy. In some cases, the test galaxy is totally disrupted. In general, the galaxy survives the ordeal if the mass loss is less than 30–40 per cent, corresponding to a value of $\Delta U/|U|$ of about 2. Here U is the total internal energy of the galaxy before the encounter, and ΔU is the tidal increase in it.

Recently Som Sunder, Kochhar & Alladin (1990) considered the case of a rigid ellipsoidal model galaxy involved in a fast impulsive encounter with a point mass perturber moving in a straight line. They obtain an expression for the component of the angular momentum acquired by the test galaxy:

$$\Delta J_i = \frac{2GM_1}{p^2 v}\,\alpha_{jk}(I_{kk} - I_{jj}), \qquad (1)$$

where M_1 is the perturber mass, p the pericentric distance with a corresponding velocity v, $I_{jj} = \frac{1}{5}Ma_j^2$ is the moment of inertial tensor of the test galaxy, and the angular dependence is determined by α_{jk}.

Note that angular momentum transfer takes place because of the presence of the gravitational quadrupole moment. In particular, if any two axes of the ellipsoid are equal, ΔJ_i does not have a component in the perpendicular direction. In addition, $\Delta J_i = 0$ if the orbit of the perturber lies in the equatorial plane of the test galaxy.

In this paper we examine, by numerical methods, the question of the transfer of angular momentum to an initially spherical galaxy.

2 THE MODEL

Our model consists of a test galaxy of mass M and a point mass perturber with mass M_1. The test galaxy is modelled as a spherical cluster containing 250 particles subject to a softened potential (see Paper I). The orbit of each particle is integrated using Aarseth's NBODY 2 code. One-half of the mass of the test galaxy is confined within $R_h \approx 6.55$, 90 per cent within about $3R_h$ and 100 per cent within about $6R_h$ (see Paper I).

We have considered a number of relative orbits: hyperbolic (model H), parabolic (model P), elliptic (model E) and circular (model C). The orbital plane coincides with the X–Y plane with the X-axis pointing in the direction of closest approach. In all but one model, the distance of closest approach p is 100. In hyperbolic encounters, the perturber is assumed to move in an orbit of eccentricity $e = 2$, whereas in the elliptic case $e = 0.5$. For model ES we $p = 72$ and $e = 0.8$

Ideally we should start the integration at a separation appreciably larger than the size of the galaxy. The initial separation r_0 in H and P models was taken as $r_0 = kp$ where $k = 3$ and 2, respectively. For bound orbits the perturber was placed initially at the apocentre (see Paper I for further details).

The number of particles in our test galaxy is small at 250. We have run our H4 model with 500 (model H I) and 1000 (model H II) particles in the test galaxy. The essential similarity of results gives us confidence that the 250-particle galaxy is capable of bringing out the physics of the phenomenon involved.

At each time interval, the centre-of-mass of N particles (excluding the perturber) is computed and particles with positive energy with respect to this centre-of-mass are identified as escapers. The centre-of-mass of the remaining particles is again evaluated and the escapers relative to this new centre-of-mass are identified next. This procedure is continued until convergence is reached (see Dekel, Lecar & Shaham 1980). The particles remaining in the system at the end of this iteration are identified as bound particles from which we readily obtain the number of escapers.

3 TRANSFER OF ANGULAR MOMENTUM

As expected, the tidal forces stretch the test galaxy in the orbital plane and compress it in the perpendicular direction, transforming the sphere into an ellipsoid. The resulting torques transfer a fraction of the orbital angular momentum into the spin of the test galaxy. The results for various models are given in Table 1. In this table, Column 1 gives the model designation, a and b denoting the first and second orbit, respectively; Column 2 gives the mass ratio; Columns 3 and 4 give the fractional change in the energy and mass after an encounter; Column 5 gives the fraction of the orbital angular momentum transferred to the internal spin of the test galaxy; Column 6 gives the fraction of the spin retained by the bound part; and Columns 7 and 8 give the angles made by the spin vectors of the total and bound system, respectively, with the Z-axis.

It can be seen that the spin acquired by the test galaxy increases as the mass ratio decreases. Further, a reduction in the eccentricity of the initial relative orbit increases the spin of the test galaxy, e.g., the spins acquired in models P7, E7 and C7 are in the ratio 1:13:33.

The escaping particles carry away a large fraction of the internal spin of the test galaxy. The tidally induced rotation, in the case of total system and the bound part is in the same sense, within statistical fluctuations, as that of the initial orbital motion (see Columns 7 and 8 of Table 1).

Table 1. Parameters of the test galaxy after tidal encounter.

Model	$\frac{M_1}{M}$	$\frac{\Delta U}{\lvert U\rvert}$	$\frac{\Delta M}{M}$	$\frac{J_T}{J_{orb}}$	$\frac{J_B}{J_T}$	θ°_T	θ°_B
H2	593.1	1.260	0.316	0.009	0.397	3	3
H3	333.3	0.986	0.260	0.012	0.451	3	4
H4	166.7	0.514	0.148	0.012	0.578	3	6
HI	166.7	0.522	0.150	0.011	0.570	2	3
HII	166.7	0.527	0.158	0.010	0.566	1	2
P5	83.3	0.970	0.124	0.117	0.428	0	2
P6	41.7	0.449	0.068	0.060	0.785	4	4
P7	20.8	0.122	0.024	0.014	0.974	11	11
P8	10.4	0.051	0.008	0.012	0.998	7	7
P10	2.6	0.003	0.000	0.002	1.000	9	9
E6a	41.7	1.035	0.140	0.220	0.667	0	1
E6b	41.7	1.754	0.196	0.449	0.628	2	1
E7a	20.8	0.396	0.076	0.126	0.696	2	2
E7b	20.8	0.838	0.156	0.410	0.714	1	3
E8	10.4	0.167	0.044	0.063	0.936	2	4
E10	2.6	0.026	0.016	0.061	0.996	6	6
ESa	10.0	0.248	0.080	0.212	0.677	4	4
ESb	10.0	0.574	0.188	0.587	0.611	4	5
C7	20.8	1.610	0.172	0.326	0.586	1	1
C8a	10.4	0.553	0.084	0.169	0.610	7	8
C8b	10.4	0.539	0.128	0.208	0.661	4	5
C10a	2.6	0.032	0.016	0.049	0.973	6	6
C10b	2.6	0.062	0.036	0.089	0.972	6	5

The angular momentum imparted to the test galaxy is shown as a function of time in Figs 1–3. If the orbit is open, J_T/J_{orb} shows smooth variation with time whereas, in the case of closed orbits, the variation is irregular. This is analogous to the behaviour of $\Delta U/|U|$ reported in Paper I.

4 CONCLUSIONS

We have numerically estimated the amount of angular momentum tidally transferred to an initially non-rotating

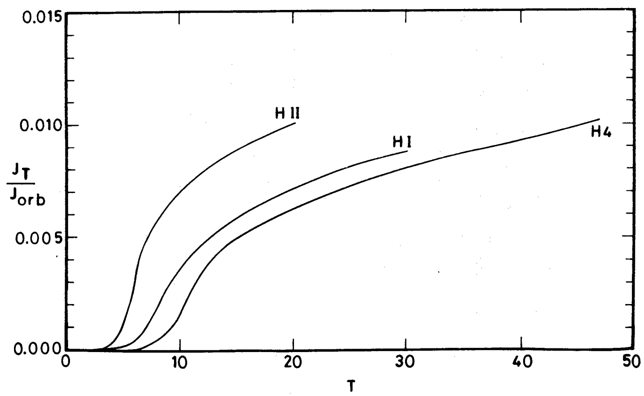

Figure 1. Variations of angular momentum of the total system as a function of time for H4, H I and H II models. J_T is the total internal angular momentum; J_{orb} the initial orbital angular momentum of the pair.

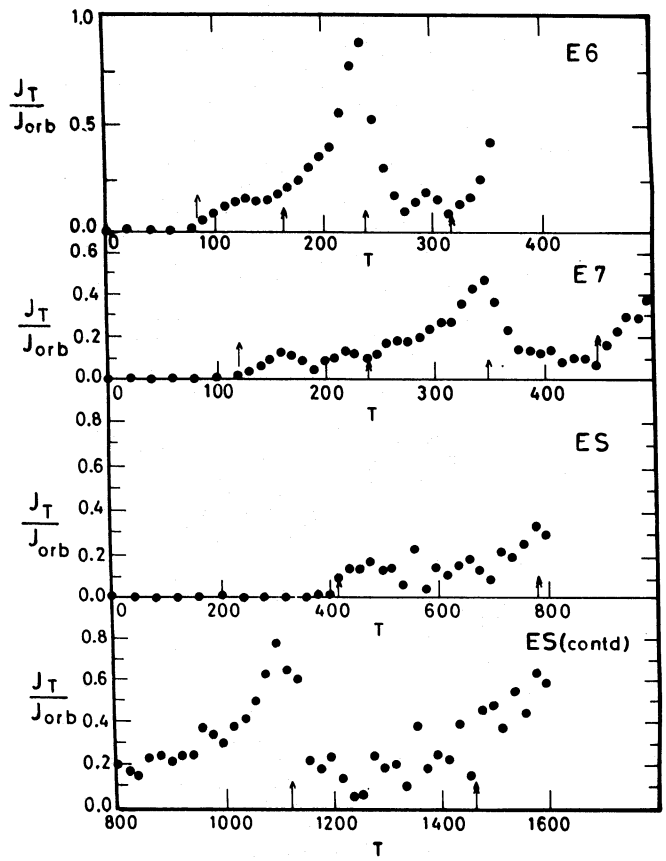

Figure 2. Same as Fig. 1 but for models E6, E7 and ES. Symbols ↑ and ↟, respectively, indicate the times of minimum and maximum separation.

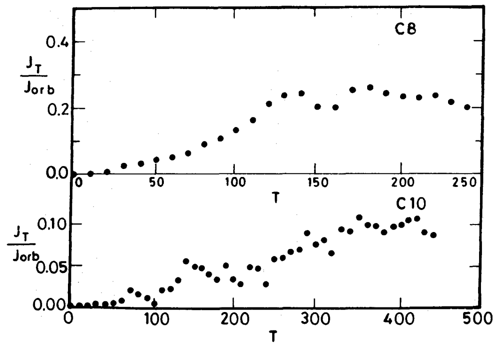

Figure 3. Same as Fig. 1 but for models C8 and C10.

spherical galaxy during the course of an encounter with a point mass perturber under a variety of initial conditions. Our models are restricted by a constant pericentric distance. The acquired spin shows smooth variation with time in open orbit encounters whereas the same shows irregular variation in bound orbit cases. As expected, the spins of the total system and of the bound part are aligned within statistical fluctuations with the direction of the initial orbital angular momentum of the pair.

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