N91-16940

ENERGY AND ANGULAR MOMENTUM TRANSFER IN BINARY GALAXIES

P.M.S.Namboodiri and R.K.Kochhar

Indian Institute of Astrophysics

Koramangala Bangalore 560034 India

Abstract

We have numerically studied tidal effects of a massive perturber on a satellite galaxy. The model consists of a spherical satellite galaxy and a point mass perturber and the encounter is non-penetrating. A wide range of density ratios and eccentricities of the relative orbits have been considered. The disruption of the satellite galaxy has been observed when the numerical value of the fractional change in the energy is greater than two. The changes in the energy and angular momentum show smooth variation in the case of unbound orbits and irregular variation in the bound orbit cases. It is shown that for a constant pericentric distance, increasing the density ratio decreases the tidal effects; and for a given density ratio an increase in the eccentricity decreases the tidal effects.

1. Introduction

Tidal disruption and merger are two important processes in the dynamical evolution of a binary stellar system. Many earlier simulations concentrated either on the merger of two galaxies or on the tidal effects on slow hyperbolic collisions. We have performed numerical simulations using Aarseth's N-body 2 code of non-penetrating stellar systems to study the tidal effects on a satellite galaxy due to the passage of a heavy perturber.

2. Numerical simulations

We consider two model galaxies of which the more massive one is a point mass called the primary (or the perturber) and the less massive, the satellite (or the test galaxy). The mass of the test galaxy is denoted by M and that of the primary by M_1. The test galaxy is a spherical cluster of 250 particles having an initial radius R = 20 units. The gravitational constant G is set equal to unity. Aarseth's N-body 2 code is used to integrate the orbits of the particles. The details of the simulations are given in Namboodiri & Kochhar (1990). We consider three models in which the relative orbit of the perturber is parabolic (model P) elliptic (model E) and circular (model C). The initial eccentricity in elliptic case is e = 0.5. In all models the distance of closest approach p = 100. The mean density ρ_h of M within a sphere of radius R_h is

$$\rho_h = \frac{M/2}{4/3\ \pi\ R_h^{\ 3}} \quad , \qquad (1)$$

where R_h is the half-mass radius of the satellite. The Roche density ρ_R is defined as

$$\rho_R = 2\rho_1 = 2\left[\frac{3\ M_1}{4\ \pi\ p^3}\right] \quad . \qquad (2)$$

The collision parameters are given in Table 1.

3. Results and discussion

The fractional change in the energy $\Delta U/|U|$ is plotted as a function of time by solid lines in figures 1 a, b and c. Here $\Delta U = U_f - U$ where U_f is the energy of the satellite after the encounter and U its unperturbed initial energy. The variation of the fractional angular momentum $\Lambda = J_T/J_{orb}$ is also shown by dashed lines in figures 1 a, b and c. Here J_T is the spin of the test galaxy after the encounter and J_{orb} is the initial orbital angular momentum of the pair. It can be seen that the changes in energy and angular momentum are smooth in unbound orbit encounters. Due to the partial reversal of the tidal acceleration, the changes in energy and

Table 1. Collision parameters and similation results

Model	ρ_h/ρ_R	M_1/M	$\Delta U/\lvert U\rvert$	$\Delta U/\lvert U\rvert_{IA}$	Λ	Λ_B	$\Delta M/M$
P4	5.34	166.7	2.297	1.021	0.142	9.43E-4	0.272
P5	10.68	83.3	0.970	0.507	0.115	1.09E-3	0.124
P6	21.36	41.7	0.449	0.251	0.058	2.64E-3	0.068
P7	42.71	20.8	0.066	0.122	0.014	1.05E-3	0.024
P8	85.41	10.4	0.051	0.059	0.024	2.32E-3	0.008
P10	341.63	2.6	0.003	0.012	0.002	2.86E-3	0.000
E4	5.34	166.7	8.711	2.420	0.582	7.84E-4	0.396
E5	10.68	83.3	3.774	1.202	0.381	1.08E-3	0.236
E6a	21.36	41.7	1.035	0.595	0.205	1.13E-3	0.140
E6b			1.754		0.419	1.30E-3	0.196
E7a	42.71	20.8	0.396	0.290	0.122	1.66E-3	0.076
E7b			0.838		0.363	8.68E-4	0.156
E8	85.41	10.4	0.167	0.139	0.060	5.02E-3	0.044
E10	341.63	2.6	0.026	0.028	0.070	9.53E-3	0.016
C6	21.36	41.7	11.470	2.008			1.000
C7	42.71	20.8	1.610	0.978	0.297	2.36E-3	0.172
C8a	85.41	10.4	0.553	0.467	0.163	5.44E-3	0.084
C8b			0.539		0.199	1.91E-3	0.128
C10a	341.63	2.6	0.032	0.093	0.029	7.41E-3	0.016
C10b			0.062		0.087	0.011	0.036

angular momentum show irregular variation in bound orbit cases. Disruption of the satellite occurs when $\Delta U/|U| > 2$, which approximately corresponds to a mass loss of 30 - 40 % . Miller (1986) has shown that the condition for a satellite not to be disrupted is $F_T/F_I < 1/4$ where F_T is the maximum tidal force and F_I is the internal force at median radius. The ratio F_I/F_T is nearly equivalent to the density ratio ρ_h/ρ_R and we note that disruption occurs when $\rho_h/\rho_R < 4$. The values of $\Delta U/|U|$, Λ and fractional mass loss $\Delta M/M$ are given in Table 1.

The fractional change in the energy of a galaxy undergoing collision can be obtained under impulse approximation using the following formula (Alladin & Narasimhan, 1982).

$$\left[\frac{U}{|U|}\right]_{IA} = \frac{2\,\Pi^2}{(1+e)^2}\;\frac{G^2\,M_1^{\,2}}{p^4\,V_p^{\,2}}\left[\frac{R_{rms}}{V_{rms}}\right]^2 . \qquad (3)$$

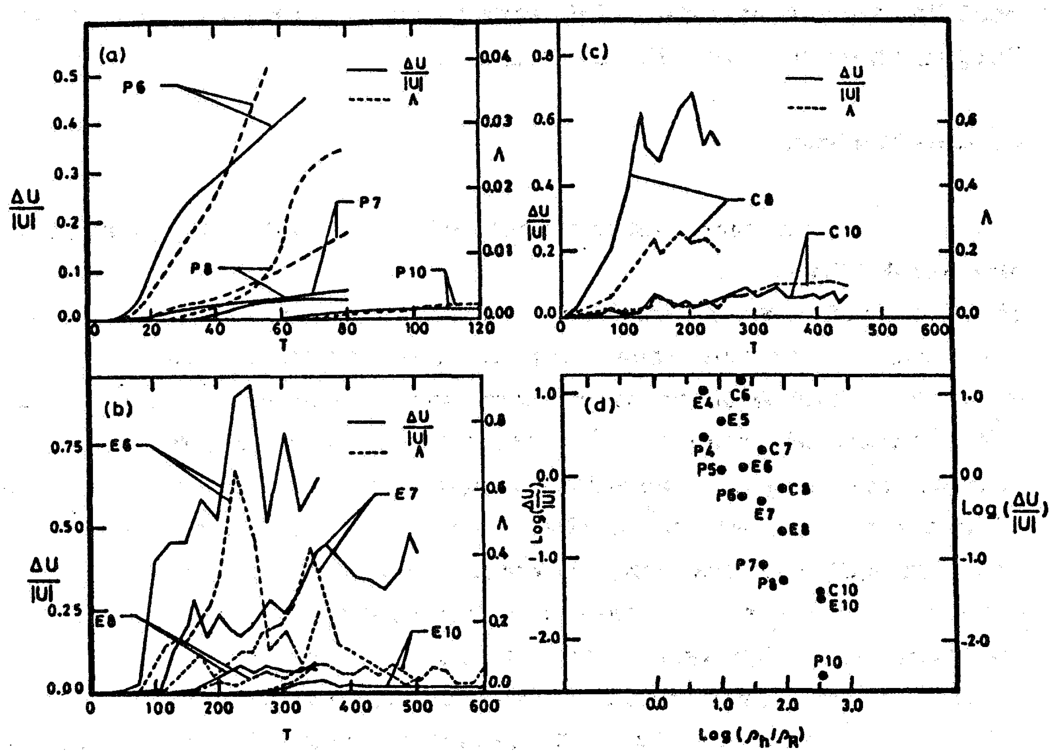

Figure 1. Time variation of $\Delta U/|U|$ and Λ for (a) P models, (b) for E models and (c) for C models. (d) variation of $\log(\Delta U/|U|)$ with $\log(\rho_h/\rho_R)$ for all models.

Here e is the eccentricity of the relative orbit; V_p is the velocity at closest approach; R_{rms} and v_{rms} are the root mean square radius and velocity of the satellite. The values of $\Delta U/|U|_{IA}$ are given in Table 1. The IA estimates agree with numerical results in the range $0.1 < \Delta U/|U| < 2$. The IA underestimates the tidal effects when $\Delta U/|U| > 2$ whereas it overestimates them when $\Delta U/|U| < 0.1$.

In figure 1d, we plot the variation of $\log(\Delta U/|U|)$ vs. $\log(\rho_h/\rho_R)$. It can be seen that for a constant pericentric distance the tidal effect decreases as the density ratio increases. We also note that for a given density ratio an increase in the eccentricity decreases the tidal effect. Our results show that the tidal effect in the parabolic case to be larger than that of the circular case.

4. Conclusions

The main conclusions of our numerical simulations are as follows.

i) Disruption of a satellite galaxy occurs if $\Delta U/|U| > 2$ and in this case the mass loss is greater than 30 - 40 % and $\rho_h/\rho_R < 4$. ii) Impulse approximation estimates of $\Delta U/|U|$ agree with numerical results in the range $0.1 < \Delta U/|U| < 2$. iii) Energy and angular momentum changes of the satellite galaxy show smooth variation in the case of unbound orbit encounters and irregular variation in bound orbit cases. iv) The tidal effect decreases as the density ratio increases and for constant density ratio the tidal effect decreases as the eccentricity of the relative orbit increases.

We thank Drs. S.J.Aarseth for kindly making his N-body code available to us and S.M.Alladin for many useful discussions.

References

Alladin,S.M. & Narasimhan,K.S.V.S. 1982. Phys. Rep. 92, 339.
Miller,R.H. 1986. Astr. Ap. 167, 41.
Namboodiri,P.M.S. & Kochhar,R.K. 1990. M.N.R.A.S.(in press).