Galaxy dynamics with small computers : Some results on tidal interactions

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> **"We haven't the money, so we've got to think."**
>
> [Lord] Ernest Rutherford (1877-1957)

Abstract

Numerical simulations with a small computer have been performed to investigate the tidal influence of a larger galaxy on a smaller companion. A criterion is developed for disruption of the satellite galaxy. The behaviour of energy and angular momentum has also been investigated.

1. Introudction

Ever since the discovery of galaxies, astronomers have struggled with the dynamical problems posed by large aggregates of stars. The notion that the galaxies are island universes evolving silently in isolation has been shown to be untenable by the discovery of binary and multiple systems, groups and clusters of galaxies. The discovery of peculiar galaxies points towards the importance of the role of environment in shaping the structure of a galaxy. It is conjectured that many galaxies approach each other, crash with a great splattering of stars and either merge into one galaxy that soon settles down or separate and proceed on their way with more or less damage done to each of them. Galaxy interaction can alter the morphological types of galaxies, trigger star formation and produce active

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galactic nuclei. There is considerable evidence that cD galaxies may form by the merger process.

Tidal disruption and merger are two important processes in the dynamical evolution of a binary stellar system. The first self-consistent studies of merging galaxies focused on the collision between spherical single component systems. (e.g; Toomre, 1977; van Albada & van Gorkom, 1977; White, 1978, 1979, 1980; Roos & Norman, 1979; Miller & Smith, 1980; Villumsen, 1982 etc). These simulations showed that tidal effects cause rapid merging of two similar galaxies, within only one orbital period whenever they overlap significantly at closest approach. The simulations also gave insight into the collective mechanisms which transfer energy and angular momentum from the relative motion of galaxies to the internal degrees of freedom of each galaxy.

Following the studies of encounters between spherical galaxies, several workers tried to model collision between disk galaxies (eg;Gerhard, 1981; Farouki & Shapiro, 1982; Negroporote & White, 1983 etc). These experiments proved much more difficult essentially because self-gravitating disks are more fragile than spherical system. When a disk is modelled as an N-body system containing a few hundred particles, $\sqrt{}$ N fluctuations are amplified to the point where they can largely ruin the disk in only a few dynamical times. In spite of these serious problems, the simulations yielded satisfactory results concerning merger of disk galaxies.

The aim of this work is to study interacting galaxies by N-body simulations, using a small computer. Several numerical experiments have been performed to study the tidal effects of a larger galaxy on a smaller companion. The description of the numerical method is given in section 2. The results are presented and analysed in section 3. The conclusion are given in section 4.

2. Numerical method

The model consists of two galaxies in which the more massive one is a point mass called the primary (perturber) and the less massive one is called the satellite (test galaxy). The test galaxy is a spherical cluster of radius R = 20 units containing 250 particles, with unit mass for each particle. We use a system of units in which G = 1. If we take R = 20 Kpc and the mass of the test galaxy M = $10^{11} M_{\odot}$, unit of time is nearly equal to

Table 1

Model	ρ_h/ρ_R	M_1/M	$\Delta U/\mid U\mid$	$\Delta U_B/\mid U\mid$	$\frac{\Delta M}{M}$	λ
H1	0.75	1186.2	2.080	0.716	0.420	-
H2	1.50	593.1	1.260	0.576	0.316	0.05
H3	2.67	333.3	0.986	0.450	0.260	0.02
H4	5.34	166.7	0.514	0.265	0.148	0.04
P1	0.75	1186.2	6.203	0.956	0.812	-
P2	1.50	593.1	5.357	0.771	0.548	-
P3	2.67	333.3	4.100	0.594	0.388	-
P4	5.34	166.7	2.297	0.403	0.272	0.04
P5	10.68	83.3	0.970	0.209	0.124	0.03
P6	21.36	41.7	0.449	0.131	0.068	0.04
P7	42.71	20.8	0.066	0.037	0.024	0.01
P8	85.41	10.4	0.051	0.024	0.008	0.02
P10	341.63	2.6	0.003	0.009	0.000	0.01
E1	0.75	1186.2	14.095	-	1.000	-
E2	1.50	593.1	13.222	-	1.000	-
E3	2.67	333.3	10.236	-	1.000	-
E4	5.34	166.7	8.711	0.514	0.396	-
E5	10.68	83.3	3.774	0.290	0.236	0.03
E6a	21.36	41.7	1.035	0.168	0.140	-
E6b	-	-	1.754	0.227	0.196	0.02
E7a	42.71	20.8	0.396	0.089	0.076	-
E7b	-	-	0.838	0.152	0.156	0.02
E8a	33.21	10.0	0.248	0.111	0.080	-
E8b	-	-	0.574	0.185	0.188	0.03
C6	21.36	41.7	11.470	-	1.000	-
C7	42.71	20.8	1.610	0.196	0.172	0.02
C8a	85.41	10.4	0.553	0.093	0.084	-
C8b	-	-	0.539	0.159	0.128	0.03
C10a	341.63	2.6	0.032	0.024	0.016	-
C10b	-	-	0.062	0.050	0.036	0.02

Notes Col.(1) Model identification (2) density ratio (3) mass raio (4) fractional change in energy of total system. (5) fractional change in energy of bound system. (6) fractional mass loss (7) dimensionless spin parameter λ of the bound system. Models E6, E7, E8, C8 and C10 have been followed for two orbital periods.

1.3 $\times 10^8$ yr and unit of velocity 147 Kms $^{-1}$. The initial mass distribution is M (r) α r . Each particle is given a velocity equal to circular velocity appropriate to its position with random directions. It has initially no net angular momentum and is approximately in virial equilibrium. We use a softened potential where the softening lengthg ϵ = 0.1 R (See Namboodiri & Kochhar, 1990).

The test galaxy is evolved for about eight crossing times to obtain a dynamically stable system. This evolution produces a test galaxy with higher concentration toward the centre and expansion in the outer regions. Its half-mass radius is R_h = 6.6 units, and the entire galaxy extends to about 37 units. A point-mass perturber is introduced at a distance where tidal effects are negligible. Several experiments have been performed in which the relative orbit of the perturber is hyperbolic (model H), parabolic (model P), elliptic (model E) and circular (model C). The closest approach distance p for all the models is kept constant at p = 100.

3. Numerical results and discussion

The mean density ρ_h of the test galaxy with mass M within a sphere of radius R_h is

$$\rho_h = \frac{M/2}{\frac{4}{3}\pi R_h^3} \tag{1}$$

The Roche density ρ_R is defined as

$$\rho_R = 2\rho_1 = 2\frac{3M}{4\pi p^3} = M_1 \tag{3}$$

We consider density ratios ρ_h/ρ_R = 0.75, 1.5, 2.67 5.34, 10.68, 21.36 42.71, 85.41; and 341.63 and use Aarseth's N-body 2 code for integration of the equation of motion (see Aarseth, 1985). This selection of the initial condition is such as to avoid merger between the galaxies. The time evolution of the mass-loss, energy and angular momentum transfer have been computed at selected time intervals. The various models and the important results are given in Table 1. In models E6, E7, E8, C8 and C10, the evolution of the satellite has been followed for two orbital period.

It is well known that energy and angular momentum from the orbit are transferred to the internal degrees of freedom in the galaxies in a collision between them. Consequently the galaxies will expand in size and some particles will receive enough energy to escape from the system. The fraction of these particles will give an idea about the mass loss $\frac{\Delta M}{M}$. The fractional change in mass loss is shown in figure 1,2, 3 and 4. The percentage of mass loss is almost 40 or more in models H1, P1 - P3, E1 - E4 and C6 as a result of which the test galaxy undergoes significant disruption. Miller (1986) performed computations with60,000 particles in a galaxy orbiting within a cluster and obtained the strength of the interaction in terms of the ratio of the maximum tidal force F_T and the internal gravitational force F_I at median radius of the satellite. Miller's condition for the disruption of a galaxy $\mathrm{F}_T/F_I < \frac{1}{4}$. The ratio F_I/F_T is nearly equivalent to the density ratio ρ_h/ρ_R and thus disruption of a satellite occurs when $\rho_h/\rho_R < 4$. This is in agreement with Miller's result. It is also seen that the maximum mass loss occurs during the first contact.

The energy gained by the stars in a satellite during an encounter is a measure of the damage done to it. The variation of the fractional change in energy $\frac{\Delta U}{|U|}$ as a functioning of time is shown in figures 1,2,3 and 4. Here U is the unperturbed energy of the satellite and Δ U, its change during the course of an encounter. Most of energy change occurs after the perturber crosses the perigalactic point. It is interesting to see that the variation of $\frac{\Delta U}{|U|}$ is smooth in H and P models. This is due to the fact that the amount of energy transferred decreases monotonically as the perturber moves away from the satellite. For models E6, E7, E8 and C8, the variation shows oscillatory behaviour. This is because in these models the perturber is moving in closed orbit as a result of which the direction of tidal acceleration gets partially reversed. It can also be seen that the disruption of the satellite occurs when $\Delta U/\mid U \mid > 2$, as earlier indicated by Miller (1986)

The escaping particles from the satellite carry away a large fraction of the induced spin of the satellite. The behaviour of the angular momentum variation is similar to that of energy change (see Namboodiri & Kochhar, 1991). The tidally induced spin is in the same direction as that of the initial orbital angular momentum. The dimensionless spin parameter $\lambda = J \mid U \mid^{1/2} /(GM^{5/2})$ where J is the angular momentum, U the total energy and M, the mass of the remnant system is given in Table 1.

4. Conclusions

We have used self consistent N-body simulations to study the effect of a large perturber on a smaller satellite galaxy. The main conclusions are as follows:

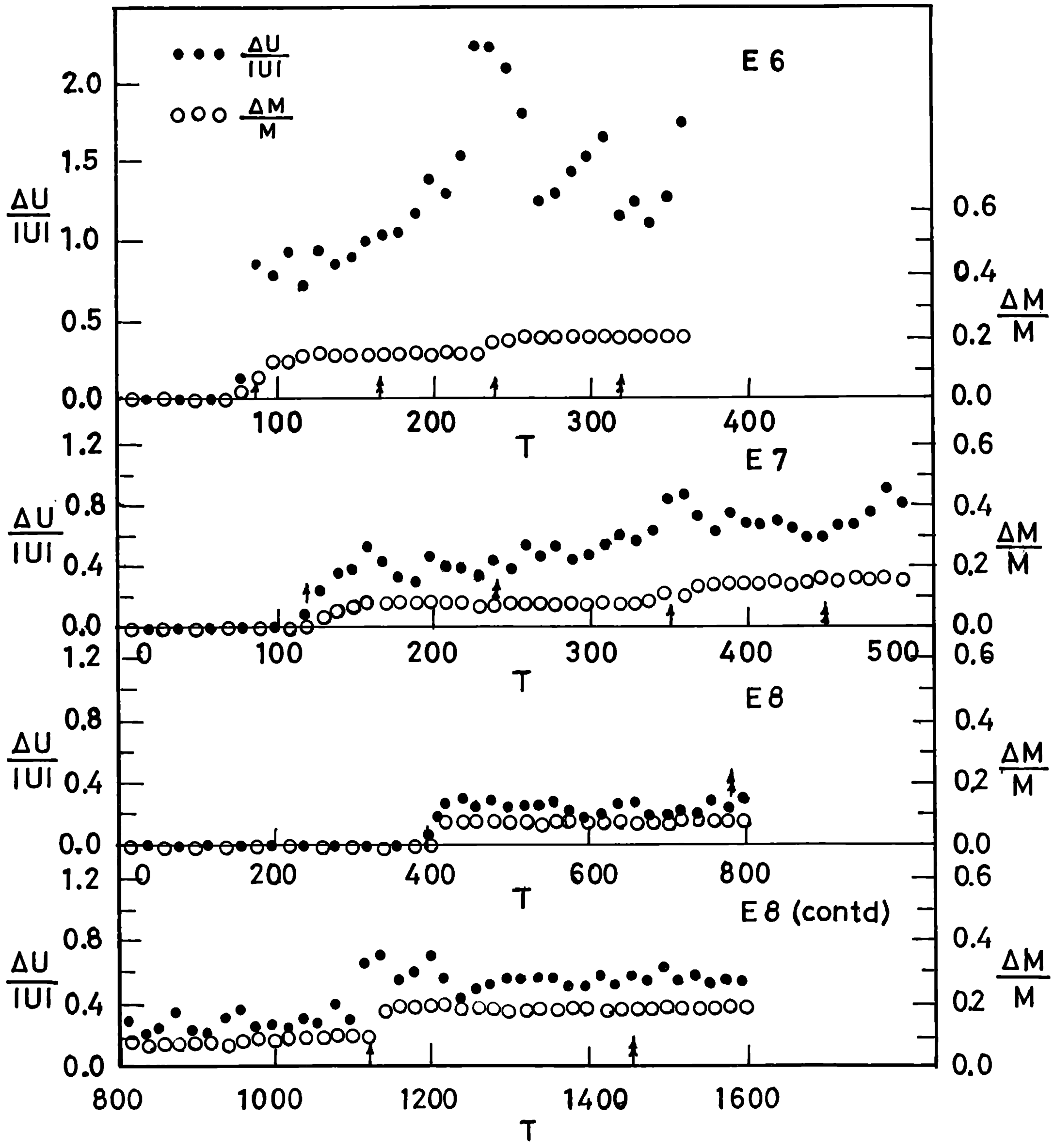

Fig.1 Fractional change in energy and mass loss as a function of time for H models.

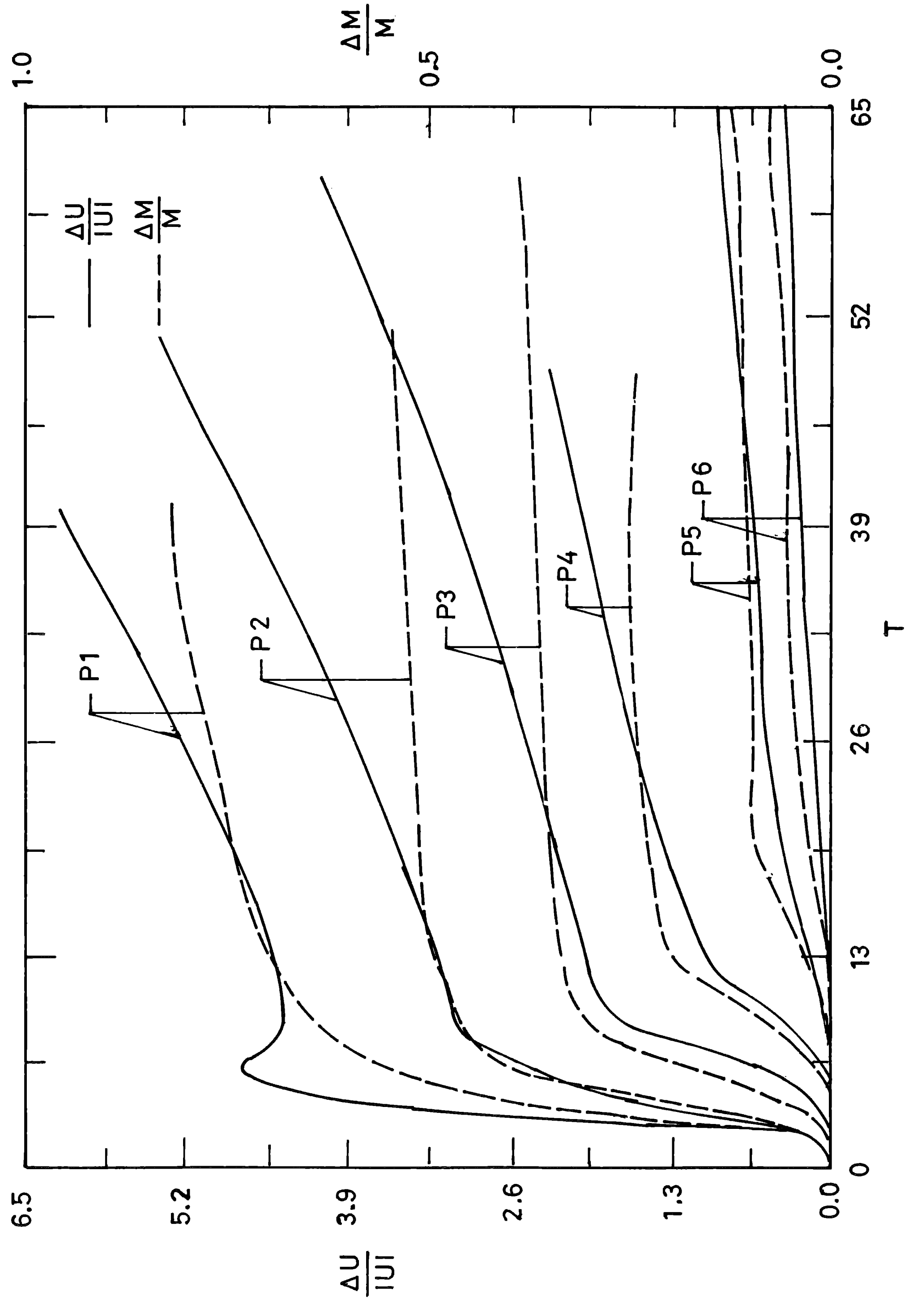

Fig.2 Same as Fig.1. but for P models.

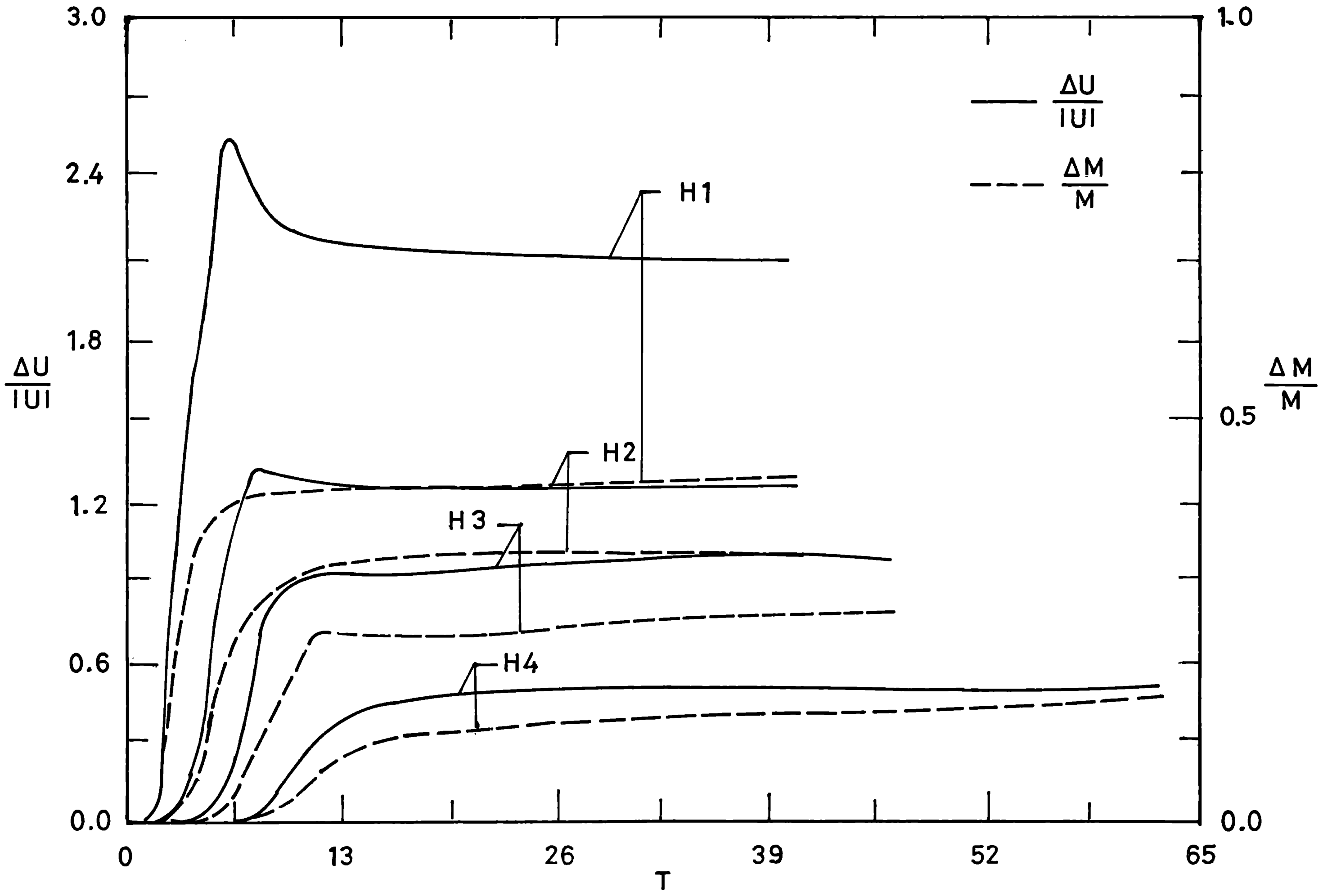

Fig.3 Same as fig.1, but for models E6, E7 and E8. Symbols ↑ and respectively ↑ denote times of minimum and maximum separation.

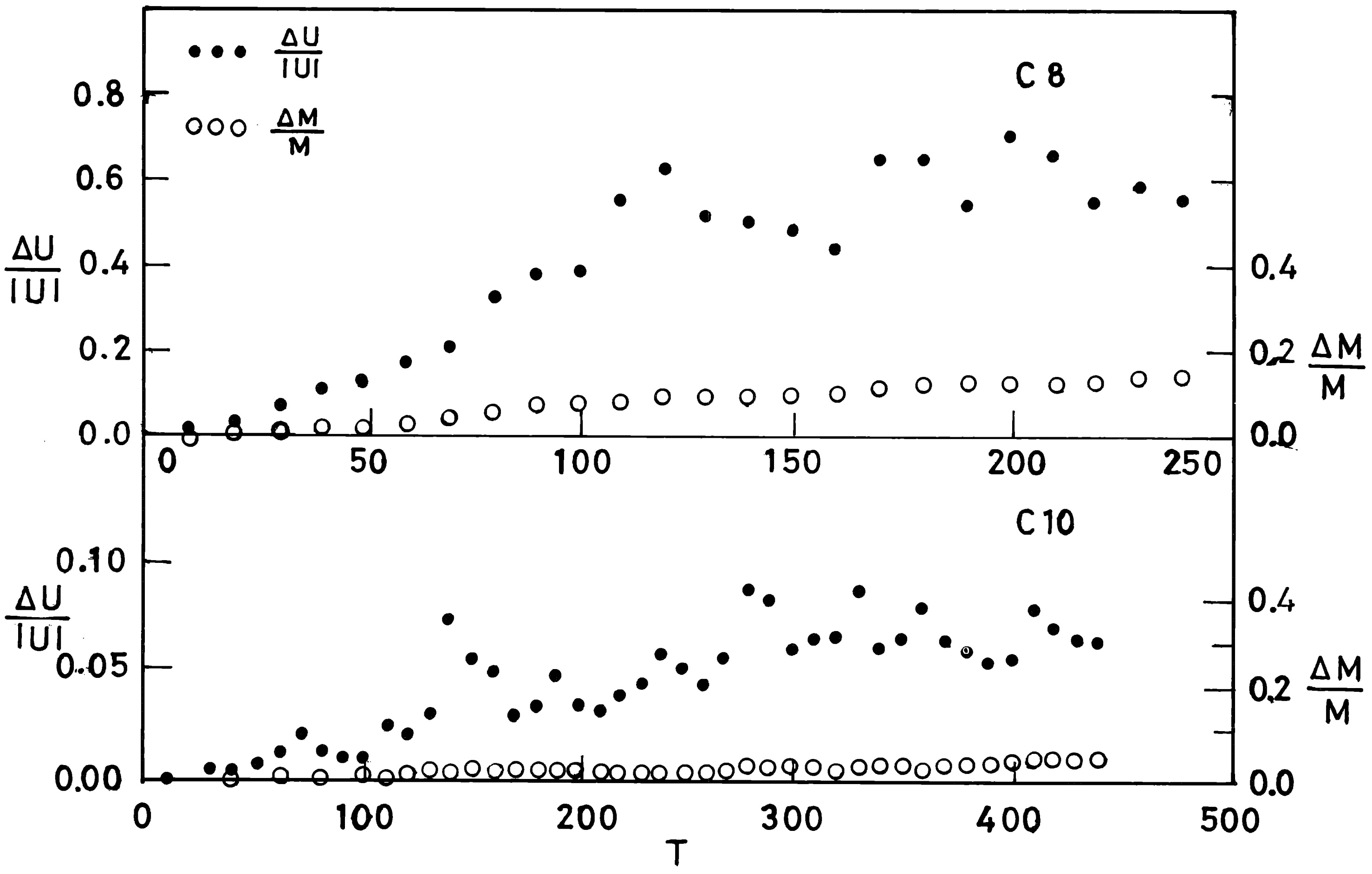

Fig.4 Same as fig.1 but for models C8 and C10.

(i) The disruption of a satellite galaxy occurs (in the sense that it looses more than 40 per cent of its mass) if the value of $\frac{\triangle U}{|U|} > 2$ or $\rho_h/\rho_R > 4$.

(ii) Most of the rearrangement in energy and angular momentum takes place after the perturber passes the perigalactic point.

(iii) The variation of energy and angular momentum shows oscillations is bound orbit cases which is due to the partial reveral of the direction of tidal acceleration.

We have used a modest number of particles to represent a galaxy and covered only a small region in the parameter space of collision of galaxy. Another draw back of our model is that we have used a point mass perturber and the collisions are distant ones. But still such situations are likely to occur in the outer parts of clusters of galaxies. Neverthless we have shown that useful results could be obtained by using small computers.

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