# ENCOUNTERS OF SPHERICAL GALAXIES : N-BODY SIMULATIONS AND COMPARISON WITH THEORETICAL PREDICTIONS

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We have studied hyperbolic encounters of spherical galaxies by self-consistent N-body simulations. Each galaxy is represented by a Plummer model. A galaxy contains up to 250 'particles'. The force between the particles is properly softened in order to avoid an unrealistic internal evolution due to close encounters of the particles. The results of these numerical experiments, carried out by R.W., are compared with theoretical predictions based on the impulsive approximation, made by P.B. . In order to facilitate the assessment of such a comparison, the passing galaxy is here represented by a rigid gravitational field, moving on a straight line. In the table given below, we compare the relative mass loss, $\Delta M/M$, and the relative change in the total internal energy of a galaxy, $\Delta E/E$, for two cases. Both galaxies are of equal mass and size ; the impact parameter is equal to the median radius of a galaxy (containing 50% of its mass in projection) ; the initial relative velocity would correspond to the orbital excentricity e as given, if the galaxies were mass points. While the agreement is fair with respect to the energy transfer $\Delta E$, the theory predicts a mass loss of more than 10% (or 25 particles) in cases where no mass loss is observed in the N-body simulations The probable reason for this discrepancy is the failure of the impulsive approximation in these cases. A mass loss of the order of 1% or less cannot be ruled out in the N-body calculations, because of the limited number of particles. The significant increase of the internal energy of a galaxy during an encounter leads to an expansion of the outer parts of the galaxy. This expansion may finally lead to a mass loss as soon as the outer parts have expanded beyond the tidal radius of the galaxy caused by its cluster environment. The inelasticity of galactic encounters has implications for the dynamical evolution of groups and clusters of galaxies. The groups and clusters will shrink in radius because of the loss of orbital energy which is used to expand the individual galaxies. The final amount of collapse of the group or cluster is governed by the relative amount of the internal binding energies stored initially in the individual galaxies and released during the galactic encounters, in comparison to the binding energy of the group or cluster.

| | e=2.61 : | N-Body | Imp.Approx. | e=9.68 : | N-Body | Imp.Approx. |
|---|---|---|---|---|---|---|
| $-\Delta M/M$ | | 0 % | 10.6 % | | 0 % | 2.1 % |
| $-\Delta E/E$ | | 23.3 % | 20.4 % | | 6.9 % | 9.5 % |



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## DISCUSSION

*Ostriker:* Two comments on your interesting results may be appropriate:

(1) I quite agree that the relative change in energy per collision is usually large compared to the relative loss of mass. The energy change is typically concentrated near the half mass point, but the mass loss occurs only in the outermost regions. Thus, it is difficult for N-body integrations with a small N to have enough particles in these regions ($\Delta m/m \sim 5 \times 10^{-3}$) to give an accurate result.

(2) For galaxies like known galaxies (cluster or field objects), $V_{rms} \approx 200$ km $s^{-1}$, but great clusters have $V_{rms} \approx 1000$ km $s^{-1}$. Thus the maximum contraction would be 5% and quite generally one can show that a catastrophe will not, cannot, occur. The maximum density of the cluster is $1/N^2$ of the density of the initial galaxies, where N is the initial number of galaxies in the cluster.

*Wielen:* (1) My point of view is that the mass loss from galaxies in clusters occurs mainly "indirectly": galactic encounters 'excite' some stars in the galaxies to such energies that they can escape by crossing the tidal radius of the galaxy. Stars are usually not directly 'kicked out' of the galaxies by galactic encounters, i.e. they do not acquire positive energies from the encounter. Therefore, the (indirect) mass loss will strongly depend on the tidal radius and hence on the cluster environment of the galaxies.

(2) I have not claimed that the collapse of a cluster will be complete. The collapse will be stopped as soon as the binding energy, originally stored in the galaxies, is transferred to the cluster. This corresponds exactly to your density limitation. I agree that the Coma cluster will not contract significantly in the future. However, one can turn around that argument: Perhaps the inelasticity of galactic encounters was so effective in the past that most of the binding energy has already been transferred from the galaxies to the cluster, thus leading to the presently observed distribution of binding energies between the galaxies and the Coma cluster. In many groups and small clusters, the velocity dispersion in the cluster is smaller or equal to the velocity dispersion in the galaxies. These groups and clusters should be able to contract significantly in the future due to the inelasticity of galactic encounters.

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