A DYNAMICAL STUDY OF THE FREQUENCY OF MERGING GALAXIES

I. Mergers Involving Spherical Galaxies in a Single-Crossing Time

TAPAN K. CHATTERJEE
Instituto Nacional de Astrofísica, Optica y Electrónica, Tonantzintla, Puebla, México

(Received 20 May, 1987)

Abstract. A study of the expected frequency of merging galaxies, involving spherical systems, is conducted, using the impulsive approximation. Results indicate that the expected frequency of such galaxies is several orders of magnitude smaller than the observational value, if mergers taking place only in a single crossing time are considered. This aspect will be further investigated in the continuing series of papers.

1. Introduction

Ever since the death of the ancient idea that galaxies are born, live and die in splendid isolation, the subject of interaction between galaxies gained considerable momentum. This was followed by a growing interest in binary and merging galaxies. Later on ideas on tidal disruption and cannibalism among galaxies to explain cD galaxies became extremely popular as they were supported by observational evidence (Ostriker, 1977; Ostriker and Tremaine, 1975; Ostriker and Hausman, 1977; Hausman and Ostriker, 1978; McGlynn and Ostriker, 1980; Morgan and Lesh, 1965; White, 1976; Jenner, 1974; Dressler, 1980, 1981). Then it was questioned whether all, or at least a majority, of the elliptical galaxies are nothing but remnants of mergers between spiral galaxies (see Toomre, 1977 and Tremaine, 1977; for a review). Finally the idea of merger, became so popular that the question arose whether all galaxies have not experienced one or more mergers, during their lifetime (Toomre, 1977; Tremaine, 1980; White, 1978; Aarseth and Fall, 1980; Dekel et al., 1980; White and Sharp, 1977).

However, Holmberg's (1940) introduction to this subject never seems to lose its appeal. To quote him, "The average space separation of extragalactic objects is rather small compared to the dimensions of single objects. In a stationary Universe, we expect a large number of encounters. Every close encounter between two objects will create large tidal disturbances and the resulting loss of kinetic energy may be sufficient to affect a capture — i.e., to change the hyperbolic orbits of the objects into elliptical ones. Immediately after the capture, the elliptical orbits may be assumed to have rather large eccentricities. Every subsequent passage of a component through the pericenter of a relative orbit will, however, create new tidal effects and thus tend to decrease the eccentricity. The general result will be the gradual contraction of the relative orbit, which may continue until the two components form practically one object." Given long enough the components of a double galaxy will form a single stellar system (Alladin et al., 1975).
If galaxies are formed without large peculiar velocities, then it is natural to suppose that in many cases a galaxy and its nearest neighbour will form a bound pair. In the absence of tidal torquing, the galaxies will fall together and collide; if the collision is close enough to head-on, then mergers will occur (Toomre and Toomre, 1972; Toomre, 1977). Aarseth and Fall (1980), observed many mergers of loosely bound binaries in their cosmological N-body simulations. In the real Universe, the importance of merging may be enhanced by correlations in the galaxy distribution, and may lead to a high frequency of collisions between pairs which have always been bound and are on long skinny orbits with almost zero-angular momentum (White, 1982).

The universality of the idea of merging creeps from the fact that such skinny orbits and pairing and clustering of protogalaxies arise naturally from some of the theories of galaxy formation.

Modeling of the growth of structure from white noise initial conditions, using N-body simulations, show that as the simulated system expands, first pairs, then groups, and finally cluster of objects condense out in regions where the statistical fluctuations led to a density enhancement in initial conditions (Peebles, 1970; White, 1976; Aarseth et al., 1979; Efstathiou et al., 1979; Efstathiou and Eastwood, 1981). In these simulations, the large-scale objects are found to consist of condensations and subsequent evolution proceeds by inhomogeneous aggregation leading to ever increasing structures, which bear a resemblance to the observed galaxy distribution. Thus the theory of hierarchical clustering predicts merger as an extremely common phenomena.

The realization that merging galaxies form important blocks of the Universe, was followed by an avalanche of papers on the subject. Preliminary studies, involving impulsive approximation calculations, were made for the numerical estimates of escape and capture velocities of colliding galaxies (Sastry, 1972; Alladin et al., 1975; Sastry and Alladin, 1981). Richstone (1975, 1976) used the restricted three-body approach. After the advent of the N-body method, the work on galaxy mergers gained an ever increasing impetus, as these involved slow interpenetrating collisions, which can be suitably studied by this method. The results of the N-body simulations have demonstrated the vehement nature of the tidal friction in slow close collisions and have shown that the merging process is very rapid in such cases (Toomre, 1974; van Albada and van Gorkom, 1977; White, 1978, 1979; Dekel et al., 1980; Roos and Norman, 1979; Aarseth and Fall, 1980; White and Sharp, 1977; Villumsen, 1982). Tidal coupling is greatly enhanced if the direction of revolution of the constituent stars and the orbital motion of the merging galaxies coincide (White, 1978). These results also show that the merger remnant bears a striking resemblance to an elliptical galaxy and support the existence of massive halos surrounding the luminous parts of the galaxies.

For the study of the merger of satellite galaxies, the standard dynamical friction formula (Chandrasekhar, 1942, 1943) has been found to be very useful (Tremaine, 1976, 1980; Lin and Tremaine, 1983; Tremaine and Weinberg, 1984; Bontekoe and van Albada, 1987), though its validity – for all ranges and conditions is questionable (White, 1983). Studies of orbital decay of satellites leading to consequent mergers, have also demonstrated the rapidity of the sinking of the satellite, accompanied by disruption.