TIDAL INTERACTIONS BETWEEN THE GALAXY AND THE MAGELLANIC CLOUDS

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The merging time and the disruption time in a binary galaxy system are analytically obtained under the Adiabatic Approximation (AA). Applications are made to the Galaxy-LMC (Large Magellanic Cloud) pair.

Estimates for the time of merging of the Magellanic Clouds with the Galaxy were made earlier by Tremaine (1976) using the standard dynamical-friction formula, and by Alladin and Parthasarathy (1978) under the Impulsive Approximation (IA). In the latter case, it is assumed that the speeds of the stars in the galaxies may be neglected in comparison with the orbital speed of the pair. Although this assumption is good when the relative motion of the galaxies is hyperbolic, it becomes worse as the orbital motion becomes slower. In the present paper, we have considered the other extreme case wherein the motion of the galaxies is neglected (AA). In the case of Galaxy-LMC pair, we find that even the outermost star in LMC has an angular speed, ω_s, larger than the orbital angular speed, ω_g, of the pair assuming circular orbits. Hence the approximation $\omega_s >> \omega_g$ (AA) is better than $\omega_s >> \omega_g$ (IA).

Using the geometry given in Avner and King (1967), who used this approximation earlier in their study of the galactic warp, the velocity increment of a star is obtained by integrating the tidal force on it over a period of the star. Analytical expressions are derived from it for the average increase in the binding energy/unit mass $dU(R_h)/dt$ at the median radius, R_h, of a galaxy and the average decrease in the orbital energy of the pair dE/dt, assuming that the two galaxies are spherically symmetric, non-penetrating, the stars move in circular orbits and have a circularly symmetric distribution of velocity vectors. The first term in the tidal force which contributes to $dU(R_h)/dt$ in the case of IA, contributes nothing to it secularly. However, the subsequent term does contribute a small amount.

We obtain from the dominant non-zero term in the tidal force, the disruption and merging times:

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$$t_d = \frac{|U|}{dU(R_h)/dt} = \frac{0.0136}{\sqrt{G}} \frac{M^{1.5}}{M_1^2} \frac{D^8}{R_h^{6.5}}$$

$$t_m = \frac{E}{dE/dt} = \frac{0.048}{\sqrt{G}} D^7 \left[\frac{M_1}{M} \int_0^R \frac{r^{5.5}}{\sqrt{M(r)}} \frac{dM}{dr}\, dr + \frac{M}{M_1} \int_0^{R_1} \frac{r_1^{5.5}}{\sqrt{M_1(r_1)}} \frac{dM_1}{dr_1}\, dr_1 \right]^{-1}$$

where M_1 and M are masses of the perturbing and the test galaxies, D the separation of the galaxies assumed constant, r the distance of the star from the galactic centre, and U is the binding energy/unit mass. Thus the times of merging and disruption increase rapidly with increasing D, as expected from the numerical work of Lin and Tremaine (1982) and T.R. Bontekoe (private communication).

We take the mass of LMC as 5×10^9 $M_\odot$ within 5 kpc (Feitzinger, 1980) and the mass distribution as that of a polytrope n=2. We obtain for the Galaxy-LMC pair, with D=55 kpc, $t_m \sim 6 \times 10^9$ yrs with mass models of Rohlfs and Kreitschmann (1981), and Ostriker and Caldwell (1979) truncated at 50 kpc, for the Galaxy. Schmidt's (1965) model for the Galaxy which does not have such a massive halo gives $t_m \sim 6 \times 10^{10}$ yrs. The merging rate at this distance is considerably faster than the disruption rates of the galaxies. The ratio of the tidal force to the main force indicates that the outermost parts of the Galaxy will be more affected than the outermost parts of the LMC.

A comparison of the results obtained in the present treatment with those obtained under IA leads to the conclusion that as the orbital motion of the galaxies becomes slower, the density ratio of the galaxies becomes more important than their mass ratio in determining the effects of mutual disruption. That a small satellite galaxy can appreciably influence the structure of a big, extended galaxy is also being suggested by the fact that galaxies with spectacular spiral structure are generally accompanied by companions (Toomre, 1981).

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