MERGER CROSS-SECTIONS OF COLLIDING GALAXIES

K. Shankara Sastry and Saleh Mohamed Alladin
Centre of Advanced Study in Astronomy, Osmania University,
Hyderabad, India

ABSTRACT : The velocities of escape of colliding galaxies obtained under the impulsive approximation are compared to those obtained from N-body simulations.

A knowledge of merger cross-sections of colliding galaxies is very useful in the studies of interacting galaxies. Because of the inelastic nature of the galactic collisions, we have to distinguish between the parabolic velocity of escape, $V_e(1)$ and the more accurate velocity of escape $V_e(2)$ obtained by taking the tidal effects into account.
We designate the value of $V_e(2)$ at closest approach, p, by V_{crit} the critical velocity, obtained from the requirement that $|\Delta E|/E = 1$ where E is the total orbital (translational) energy of the pair initially at infinite separation, and ΔE is the change in this energy during the encounter due to tidal accelerations of the stars in the two galaxies and the consequent increase in their binding energies U_1 and U_2. Hence, $\Delta E = -(\Delta U_1 + \Delta U_2)$. The initial velocity for which $|\Delta E|/E = 1$ is designated as V_{cap}, the capture velocity. The two galaxies merge if $V_p < V_{crit}$ or $V_\infty < V_{cap}$, where V_p and V_∞ are the relative velocities of the galaxies at closest approach and at initial separation respectively.
It is the aim of the present paper to summarize the results of impulsive approximation for the aforementioned escape velocities and compare them with the results of N-body simulations.

The parabolic velocity of escape of a pair of polytropic model spherical galaxies of masses M_1 and M_2 (not necessarily of the same mass distribution) superposed on each other so that their centers coincide, $V_e^{(1)}(0)$, is obtained from

$$ {}^1/_2 M_1 M_2 (V_e^{(1)}(0))^2 / (M_1 + M_2) = - W(0) = G M_1 M_2 / \bar{R}_{12}(0) \quad (1)$$

where W(0) is the interaction potential energy of the galaxies at zero separation and $1/\bar{R}_{12} = \langle 1/r_{12} \rangle$ where r_{12} is the distance between a star in the galaxy of mass M_1 and a star in the galaxy of mass M_2. $\bar{R}_{12}(0)$ can be obtained from the function $(\psi/s)_{s=0}$ tabulated in Alladin (1965). If the separation r of the centers of the two galaxies is expressed in

E. Athanassoula (ed.), Internal Kinematics and Dynamics of Galaxies, 349–350.

units of $\bar{R}_{12}(0)$ and if the parabolic velocity, $V_e^{(1)}$ at this separation is expressed in units of $V_e^{(1)}(0)$, the relationship between $V_e^{(1)}$ and r is practically independent of the choice of models for the two galaxies. Let $x = r/\bar{R}_{12}(0)$ and $\nu_e = V_e^{(1)}/V_e^{(1)}(0)$. The following formulae describe the relationship quite well :

$$\nu_e = 1.00 - 0.00015\, x - 0.12\, x^2 + 0.025\, x^3 \; ; \; x \leqslant 3 \quad (2a)$$
$$= x^{-\frac{1}{2}} \; ; \; x \geqslant 3 \quad (2b)$$

Assuming for simplicity that the energy change ΔE is symmetric with respect to the position of closest approach, we obtain V_{crit} from

$$\frac{1}{2} M_1 M_2 V_{crit}^2/(M_1 + M_2) - \frac{1}{2} M_1 M_2 (V_e^{(1)}(0))^2/(M_1 + M_2) = \frac{1}{2} \Delta E \quad (3)$$

Following Tremaine (1981), the assumption of impulsive approximation gives for galaxies of root mean square radius R_{rms} :

$$\Delta E = 4\, G^2 M_1 M_2 (M_1 (R_{rms})_1^2 + M_2 (R_{rms})_2^2) \,/\, 3\, V^2 p^4 \; ; \; p \gg \bar{R}_{12}(0) \quad (4)$$

putting $V = V_{crit}$ in this equation and using it with Equation (3), we obtain V_{crit} for distant encounters. Sastry (1972) derived V_{crit} for penetrating collisions of spherical galaxies under the impulsive approximation. Let $\nu_{crit} = V_{crit}/\, V_e^{(1)}(0)$ and $y = p/(Rh_1 + Rh_2)$

where R_h is the radius containing half the mass of the galaxy. His results for identical polytropic n = 4 models of galaxies give :

$$\nu_{crit} = 1.15 - 0.42\, y + 0.06\, y^2 \; ; \; y \leqslant 3.5 \quad (5a)$$
$$= 0.79\, y^{-\frac{1}{2}} \; ; \; y \geqslant 3.5 \quad (5b)$$

Toomre (1977) obtained $V_{crit} = 1.16$ in a head-on collision of Plummer model galaxies under the impulsive approximation. Aarseth and Fall (1980) have summarized the results for V_{crit} obtained from N-body simulations. A comparison of our results with theirs shows that there is good agreement up to a distance of y = 1.6. Aarseth and Fall neglect merging beyond y = 2.

Capture velocities were derived by Alladin et al (1975) under the impulsive approximation for head-on as well as off-centre collisions. Let $\nu_{cap} = V_{cap} \,/\, V_e^{(1)}(0)$ and $z = p_\infty /(Rh_1 + Rh_2)$ where p_∞ is the impact parameter. We find :

$$\nu_{cap} = 0.54 - 0.079\, z + 0.0054\, z^2 - 0.00013\, z^3 \; ; \; z \leqslant 20 \quad (6a)$$
$$= 0.69\, z^{-\frac{3}{4}} \; ; \; z \geqslant 20 \quad (6b)$$

A comparison of these results with those of Roos and Norman (1979) shows that our values are somewhat higher.

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