Instability, Chaos and Predictability
in Celestial Mechanics and
Stellar Dynamics

ISBN 1-56072-054-9

ROCHE INSTABILITY IN BINARY STELLAR SYSTEMS

P.M.S. Namboodiri and R.K. Kochhar
Indian Institute of Astrophysics, Bangalore - 560034, India

ABSTRACT

The stability of a galaxy against disruption when it encounters a point mass perturber has been investigated by numerical simulations. The merging process dominates in the case of encounters of binaries of comparable mass and disruption is important in cases where the components have different masses. The disruption of a galaxy occurs when its mean density is less than a critical density - the Roche density. The change in the energy falls steeply near the Roche density in the case of encounters in which the relative orbit of the perturber is circular.

INTRODUCTION

Tidal interactions between galaxies result in an exchange and redistribution of energy mass and angular momentum. The survival of a test galaxy against disruption during the course of an encounter with a massive perturber can generally be predicted by estimating the ratio $\Delta U/|U|$ where U is the initial internal energy of the test galaxy and ΔU the increase in it. Numerical simulations have shown that if $\Delta U/|U| > 2$, the test galaxy suffers significant disruption whereas the disruption is considered negligible if $\Delta U/|U| < 2$ (Namboodiri and Kochhar, 1990). However $\Delta U/|U|$ gives an estimate of the changes in the internal structure of a test galaxy.

THE MODEL

Our model consists of a test galaxy of mass M and a point mass perturber with mass M_1. The test galaxy is modelled as a spherical cluster containing 250 particles subject to a softened potential. The test galaxy has a radius $R \sim 36$ where the units are chosen such that the gravitational constant G=1. One half of the mass is contained within $R_h = 6.55$, 90%, within about $3R_h$, and 100%, within about $6R_h$. A massive perturber is introduced at a distance of about 3R such that its initial relative orbit is circular and the orbital plane coincides with the X-Y plane.

The mean density ρ of M within a sphere of radius R is

$$\rho = \frac{M}{(4/3)\Pi R^3} \qquad (1)$$

The Roche density ρ_R is defined as

$$\rho_R = 2\rho_1 = 2\left[\frac{M_1}{(4/3)\Pi p^3} \right], \qquad (2)$$

where p = 100 is the initial distance of the perturber. We consider density ratios ρ/ρ_R = 0.25, 0.50, 1.0 and 4.0 and the corresponding models are denoted by C6, C7, C8 and C10 respectively. In models C8 and C10, the evolution of the test galaxy has been followed for two orbital periods. The parameters of the encounter and the essential results are given in Table 1. In this table, 'a' and 'b' denote the results at the end of the first and second encounter respectively. The integration of the orbit of each particle was performed using Aarseth's NBODY 2 code (see Ahmed and Cohen,1973 and Aarseth, 1987).

Table 1: Collision parameters and results of encounter

Model	ρ/ρ_R	M_1/M	$\Delta U/\lvert U \rvert$	$\Delta M/M$
C6	0.25	41.7	11.470	1.000
C7	0.50	20.8	1.610	0.172
C8a	1.00	10.4	0.553	0.084
C8b	4.00	10.4	0.539	0.128
C10a	4.00	2.6	0.032	0.016
C10b	4.00	2.6	0.062	0.036

NUMERICAL RESULTS

During an encounter, orbital energy is transferred to the internal energy of the test galaxy. Some stars gain energy such that their velocity exceeds the escape velocity and thus leave the system. The fractional change in the internal energy $\Delta U/|U|$ of the test galaxy and the mass loss $\Delta M/M$ are given in Table 1. The test galaxy is considered disrupted if the mass loss exceeds 30 - 40% (Miller, 1986) and $\Delta U/|U| > 2$. Total distruption is observed in model C6 whose density ratio is 1/4. The disruptive effects decrease drastically as we increase the density ratio. The disruption seems to be unimportant in models C7, C8 and C10.

DISCUSSION

The fractional change in the total internal energy $\Delta U/|U|$ of the test galaxy is a good measure of the damage done to it. If $\Delta U/|U| > 2$, the test galaxy suffers considerable disruption whereas the disruption is considered negligible if $\Delta U/|U| < 2$. The fractional change in the internal energy is plotted as a function of the density ratio for all models in figure 1. It is interesting to see that $\Delta U/|U|$ decreases drastically near $\rho/\rho_R \gtrsim 1$. Alladin et.al (1985)

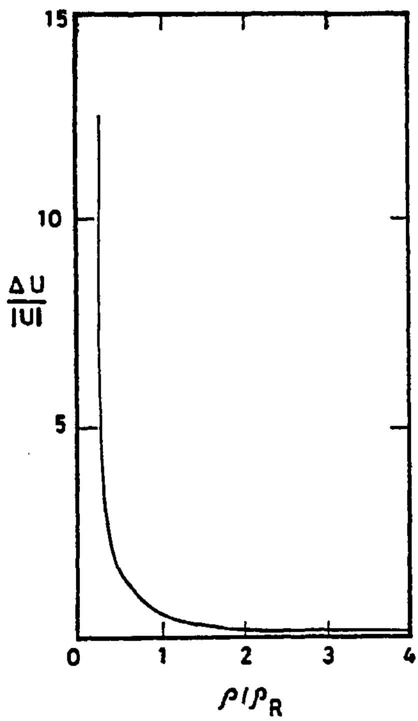

Figure 1: Variation of the fractional change in energy $\Delta U/|U|$ as a function of the density ratio ρ/ρ_R for all models.

made analytic estimates using adiabatic approximation and have inferred that there would be a sharp decrease in the disruption rate at $\rho_h = \rho_R$ where ρ_h is the mean density of the test galaxy within a radius R_h, the half-mass radius. Kurth (1957) has shown that for the stability of a cluster, its mean density must be at least twice as large as that of a sphere of radius equal to the distance of the cluster and being uniformly filled with its total mass. Our results agree with Kurth's estimate, The agreement of our results with that of Alladin et.al. is satisfactory if the full radius of the test galaxy is used and not the half mass radius.

CONCLUSIONS

We have performed self-consistent numerical simulations to investigate the stability of a test galaxy as it encounters a massive perturber which moves in an initial circular orbit. The test galaxy suffers severe disruption if its mean density is less than the Roche density and the disruption is observed to be insignificant if $\rho > \rho_R$. Further there is a sharp decrease in change in the energy of the test galaxy near $\rho \approx \rho_R$.

REFERENCES

1 Aarseth, S.J. (1985), In Multiple Time Scales, Academic Press, p.377.
2 Ahmed, A. and Cohen, L. (1973), J.Comp. Phys. 12,339.
3 Alladin, S.M., Ramamani, N. and Meinya Singh, T.(1985). J. Astrophys. Astr. 6,5.
4 Kurth, R. (1957), In Introduction to the Mechanics of Stellar Systems, Pergamon Press, p.88.
5 Miller, R.H. (1986), Astr. Astrophys., 167,41.
6 Namboodiri, P.M.S. and Kochhar, R.K. (1990), Mon.Not.R. astr. Soc., 243,276.