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A DYNAMICAL PROXIMITY ANALYSIS OF INTERACTING GALAXY PAIRS

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ABSTRACT. Using the impulsive approximation to study the velocity changes of stars during disk-sphere collisions and a method due to Bottlinger to study the post collision orbits of stars, the formation of various types of interacting galaxies is studied as a function of the distance of closest approach between the two galaxies.

INTRODUCTION

The interpretation of multiple interacting systems as the relics of gravitational interaction between galaxies is now strongly favored (see Toomre, 1974, for a review). Observations indicate that the proximity of the constituent galaxies in different types of interacting galaxies (eg., mildly perturbed galaxies, galaxies with bridges and tails, ring galaxies) is different. There seems to be a relation between the proximity of the constituent galaxies and the intensity of interaction between them. To study this relation it is necessary to study the formation of peculiar interacting systems, on the basis of the collision theory, as a function of the distance of closest approach between the constituent colliding galaxies.

An inspection of photographs of interacting galaxies from catalogues (eg. Voronotsov-Velyaminov, 1959; Arp, 1966) show that the majority of these systems consist of a disk and a spherical galaxy lying close to each other. Moreover the basic criteria determining the type of the interacting galaxy bears a strong relationship to the degree of perturbation encountered by the disk galaxy. Sphere-sphere collisions are important in a study of merging galaxies and do not lead to a variety of interacting galaxies, but rather to a particular variety. Hence, in subsequent work, we have studied the formation of peculiar interacting galaxies on the basis of collisions involving a disk and spherical galaxy, as our aim is a functional analysis of the type of peculiar interacting galaxy and the proximity of the constituent galaxies.

THEORY

In a previous paper (Chatterjee 1984; hereafter referred to as Paper I) the conditions of the formation of ring galaxies, during head-on collisions between disk and spherical galaxies, was studied. Using the same method we study in this paper both head-on as well as off-center and non-vertical collisions between disk and spherical galaxies and determine approximately the range of impact parameters favorable for the formation of different types of interacting systems.

The spherical galaxy is modeled as a polytrope of index n=4. The spiral galaxy is modeled as an exponential model disk, thickened by a method indicated by Rohlfs and Kreitschmann (1981), with a polytropic n=4 bulge superposed on this disk. The model is discussed in detail in Chatterjee 1989.

The theory is essentially the same as in Paper I. Using the impulsive approximation, the change in velocity ($\overrightarrow{\Delta v}'$) of the representative star in the disk galaxy, due to the collision is given by, (case $R_S=R_D=R$),

$$\overrightarrow{\Delta v}' = -\,[GM_S/(VR)]\,\vec{I} \tag{1}$$

$$I_x = -\,x_D \int_{-\infty}^{\infty}(1/s'')(d\phi_S/ds'')[s'/(s'^2-p^2)^{1/2}]ds' \tag{2}$$

$$I_y = (p-y_D) \int_{-\infty}^{\infty}(1/s'')(d\phi_S/ds'')[s'/(s'^2-p^2)^{1/2}]ds' - p\int_{-\infty}^{\infty}(1/s'')(d\chi_{DS}/ds'')[s'/(s'^2 - p^2)^{1/2}]ds' \tag{3}$$

$$I_z = 0 \tag{4}$$

where the symbols have the same meaning as in Paper I, except for p, which is the distance of closest approach between the colliding galaxies, measured in units of the radius of either galaxy; and χ_{DS}, which a measure of the mutual potential due to the gravitational interaction between the disk and the spherical galaxy and is defined as the mutual potential function for the disk-sphere pair (Ballabh, 1975).

$\vec{I}$ and $\overrightarrow{\Delta v}'$ are functions of both the distance of closest approach between the two galaxies, p, and the angle of inclination, i, of the disk to the direction of relative motion between the two galaxies (see Paper I). Using equations (1) to (4), we calculate the velocity perturbations of the representative stars for different collisions, each collision being characterized by a value of p and i. We then apply a method due to Bottlinger (Bottlinger, 1932, 1933) as discussed in Paper I, to study the post-collision orbits of the stars, the orbits of the innermost and outermost stars being studied by numerical integrtion due to the validity of the Bottlinger force law within a limited range of distance only. For convenience we define the angle $\alpha = 90° - i$, so that for $\alpha=0$ we have a collision whose trajectory is normal to the plane of the disk.

We increase p and α in small steps (of 0.05 and 5°), and find $\Delta v'$ for the representative stars for each collision and scale its value for different values of the collision parameters (M_S, M_D, R, V). Then we determine the final density distribution of disk galaxy for each collision, approximately, and test whether the rearrangement of stars leads to the formation of a peculiar galaxy (and if so, its shape and form, which determine its type).

NUMERICAL RESULTS AND DISCUSSION

We find that, for central or near central impacts, ring galaxies are formed provided the angle of inclination does not exceed about 45°. If $\alpha \lesssim 30°$ and the impact is central, or nearly so, we get very symmetrical and bright rings whose intensity distribution is almost uniform. If α is increased beyond 45°, we get messy, ill-defined structures. If p is increased the rings become asymmetrical and acquire non-uniform intensity distributions. Beyond $p \sim 1/3$, fairly well defined and prominent rings do not form. Messy ill-defined rings form up to $p \sim 2/3$.

Beyond $p \sim 2/3$, we get one-armed structures which do not close on themselves, but end abruptly. Beyond $p \sim 1$ we get very faint bridges and tails and extremely faint ring-like structures which do not close on themselves, resembling embryonic spiral arms, and are embedded in the background of the victim disk (see Chatterjee, 1986, for details).

Prominent bridges and tails start forming only when $p \sim 1\ 3/4$. Bridges and tails form for all orientations of the colliding galaxies to the trajectory of the collision, only they are better formed when the trajectory of the collision does not make a large angle with the plane of the disk, being most prominent when this angle is quite small but not zero (i.e., $i > 0°$ but $< 15^0$).

As the impact parameter is increased, we find that bridges and tails cease to form when p is slightly greater than 2 (about 2.1). However the shapes of the galaxies are affected due to tidal forces up to $p \sim 2\ 1/2$. Beyond this value of p the colliding galaxies do not affect each other enough to produce observable distortions.

CONCLUSIONS

As expected a dynamical study of the formation of peculiar interacting galaxies, on the basis of the collision theory, indicates that, as the distance of closest approach between the colliding galaxies increases, the interaction fades off rapidly but what is interesting is the existence of an almost continuous series of subtypes of different types of peculiar interacting galaxies as a function of the proximity of the constituent galaxies. Each subtype seems to have a characteristic range of values of the distance of closest approach, which leads to the conclusion that different subtypes should have different ranges of values for the proximity of the constituent galaxies. This may play an important role in the subjective classification of interacting galaxies. More observational surveys should be conducted in the light of these facts, to enable comparisons with the theoretical conclusions.

Finally we would like to mention that the various parameters which determine the degree of interaction between galaxies can be expressed in terms of the fractional change in internal energy incurred by either galaxy, $\Delta U/|U|$, where U is the initial internal energy and ΔU is its change due to the collision. If we define $\Delta U=(\Delta U/|U|)/(\Delta U/|U|)_M$, where $(\Delta U/|U|)_M$ is the fractional internal energy change for which merger is affected for the same value of p, then the ratio δU has characteristic values which determine the degree of interaction between the colliding galaxies and hence the peculiarity imparted to the system. It is interesting to note that these characteristic values of δU define the interaction in terms of a two parameter family, e.g., p and V, for a given pair of galaxies (for details see Chatterjee, 1989b).

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