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A DYNAMICAL STUDY OF THE FORMATION OF PECULIAR GALAXIES

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RESUMEN. Un estudio de la formación de diferentes tipos de galaxias peculiares (interactuantes) es conducido en base de la dinámioa de la colisión llevando a su formación usando la aproximación impulsiva. Los resultados indican la existencia de una relación característica en base del cambio de la energía interna durante la colisión, cual determina el tipo de la galaxia peculiar formado. La relacion es analisada y valores críticos del cambio de la energía interna, llevando a la interacción entre galaxias de varias intensidades y la formación consecuente de varios tipos de sistemas peculiares es discutido.

ABSTRACT. A study of the formation of different types of peculiar (interacting) galaxies is conducted based on the dynamics of the collision leading to their formation, using the impulsive approximation. Results indicate the existance of a characteristic relationship, based on the internal energy changes during the collision, governing the type of peculiar galaxy formed. The relationship is analysed and critical values of internal energy changes, leading to galaxy interaction of varying intensities and consequent formation of different types of peculiar galaxies is discussed.

Key words: GALAXIES-DYNAMICS -- GALAXIES-FORMATION

I. INTRODUCTION

Galaxies interact gravitationally during a close approach. The gravitational interaction caused the formation of peculiar galaxies. The interpretation of multiple interacting systems (known as peculiar galaxies) as the relics of gravitational interaction between galaxies is now established. In a series of previous papers we conducted a dynamical study of the frequency of such galaxies (Chatterjee 1987a, 1987b, 1987c). A subsequent detailed study of the dynamics of colliding galaxies indicated that the nature of the peculiarity imparted to the colliding system is almost solely determined by the fractional change in internal energy incurred during the collision, provided the same is measured relative to the fractional internal energy changes corresponding to merger (corresponding to the same impact parameter). This last mentioned quantity leads to a fundamental measure of energy changes. Hence in this work we have studied the dynamics of colliding galaxies leading to the formation of peculiar galaxies, in the light of the fractional internal energy changes incurred and the type of the peculiarity imparted to the system. An inspection of photographs of interacting galaxies from the catalogues (e.g. Arp 1966, Vorontsov-Velyaminov 1959) show that the majority of these systems consist of a disk and a spherical system in interaction. Sphere-sphere and disk-disk systems are not so frequent, comparatively.

Moreover in most of the disk-disk pairs cases one of the disks is found to be seriously affected and is much larger in size than the intruder disk, which is only slightly affected. In such cases, the intruder disk can be approximated as a centrally concentrated galaxy, because of its small size. Hence in subsequant work, we have studied the formation of peculiar galaxies on the basis of collisions involving a disk and a spherical galaxy.

II. THEORY

The theory is discussed in detail in Chatterjee 1984 (hereafter referred to as Paper I). Basically, using the impulsive approximation, we study the velocity changes acquired by the stars of one galaxy due to the perturbation of the other galaxy and vice versa. From tke velocity changes acquired by the stars, we calculate the new orbits of the stars using the Bottlinger method (Bottlinger 1932, 1933), as discussed in Paper I. Subsequently we assess the shape of the resulting peculiar galaxy. We study the effects on the disk galaxy, which is the test galaxy, due to the spherical perturber. We also calculate the fractional change in internal energy, due to the collision, incurred by each galaxy, and characterise the collision as a function of the fractional internal energy change acquired by the disk galaxy (as it is the galaxy which is seriously affected and in principle determines the nature of the peculiarity imparted to the system). The fractional change in internal energy of a galaxy due to a collision, is given by (as in Paper I),

$$\Delta U/|U| = \beta \gamma$$

where,

$U \equiv$ Initial internal energy of the galaxy;
$\Delta U \equiv$ Change in internal energy due to the collision;
$\gamma \equiv$ Fn. (Masses and radii of the two galaxies, relative velocity of the collision);
$\beta \equiv$ Fn. (Integral of motion I, density distribution of the two galaxies);
I $\equiv$ Fn. (p, density distribution of the two galaxies);
p $\equiv$ Distance of closest approach between the two galaxies (measured in terms of the radius of either galaxy).

The details of these functions are given in Paper I. As in Paper I, we model the disk galaxy as an exponential model disk and the spherical galaxy as a polytrope of index n = 4.

We have studied many collisions with different values of the collision parameters, each collision being chacterised by the distance of closest approach, p, and the fractional change in internal energy, $\Delta U/|U|$. In each case, from the velocity impulse received by the stars, we find the post collision orbits of the stars and thus the shape or type of the peculiar gslaxy formed.

Theoretically $\Delta U/|U|$ can vary from 0 to ∞, but for practical purposes we find it to vary from 0 to $(\Delta U/|U|)_M$, where $(\Delta U/|U|)_M$ denotes the fractional change on internal energy at which merger takes place, along with strong disruptive effects, for a given value of the distance of closest approach p.

III. NUMERICAL RESULTS AND DISCUSSION

We find that if we exprees the fractional change in internal energy in terms of the value for the same parameter for merger (and consequent strong disruptive effects), corresponding to the value of p for which the collision is being studied, then it becomes quite an independent criterion whioh determines the collision. First, keeping p constant, we have determined the fractional change in internal energy due to various collisions and compared them with the corresponding value of this property for which merger takes place. Subsequently we also vary p. Results indicate that, in general, a peculiar galaxy is formed when $\Delta U/|U| \geq 1/8\ (\Delta U/|U|)_M$. A subsequent study of many collisions, with different values of p, indicate that for all values of p a peculiar galaxy is formed more or less when $\Delta U/|U| \geq 1/8\ (\Delta U/|U|)_M$. As far as the upper limit is concerned a collision always leads to the formation of a peculiar galaxy; only if $\Delta U/|U|$ is too high capture will take place and disruption will set in. We measure the fractional change in internal energy in terms of the same value corresponding to merger and disruption and denote it by $\delta = (\Delta U/|U|)/(\Delta U/|U|)_M$

Different types of peculiar galaxies are formed for different values of δU. For interpenetrating collisions, with $p \leq 1$, if $1/8 \leq \delta U \leq 1/2$, we get galaxies with faint structures embedded in them, eg. faint rings or one armed structures embedded in the disk galaxy. (See Chatrerjee 1986, for details). For grazing or nearly grazing collisions, with $p \geq 1$, $1/4 \leq \delta U \leq 1/2$, we get galaxies with appendages — bridges and tails. For $1/2 \leq \delta U \leq 3/5$; ring galaxies are formed, such high values of δU imply deep interpenetration. If $\delta \geq 3/5$, merger takes place and disruption sets in.

Though p and δU are dependent upon each other, the interesting thing is that each type of peculiar galaxy is characterised by a range of values of the fractional change in internal energy, measured with respect to the corresponding value at merger, δU. Within this range, different values of δ will correspond to different subtypes of peculiar galaxies, leading to a continuous gradation between δU and the peculiarity imparted to the colliding system. This may also help in the search for new types of peculiar galaxies, as some values of δU may correspond to yet unknown type of peculiar galaxies.

IV. CONCLUSIONS

Tbe fact that the internal energy changes determine the nature of the peculiarity imparted to the colliding system seems to be quite obvious as these changes determine the structural changes which the system undergoes. But what is interesting is that if the fractional change in internal energy is measured in terms of the corresponding value for merger (for a given value of the distance of closest approach, p), it becomes quite an independent criterion which determines the character of the collision. This leads to the conclusion that the fractional change in internal energy corresponding to merger as a function of the distance of closest approach between the two galaxies, p, plays a part of paramount importance in close encounters between galaxies, as it leads to a fundamental unit for measuring energy changes.

For a given value of the distance of closest approach, the fractional internal energy change corresponding to merger determines the point at whioh the internal energy imparted to the constituent stars, extracted from the orbital energy of motion of the colliding galaxies, exceeds a critical limit. At this critical limit the constituent stars of the galaxies acquire a velocity which enhances disruptive effects tremendously and causes a severe loss of orbital energy of the galaxies rendering a mutual escape of the two galaxies impossible. An analysis of this parameter can throw considerable light on all aspects of the merger phenomenon, in particular the expected number of mergers at various epochs and their consequences on the structure of the universe. If galaxias 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 (Toomre 1977). 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). Suoh skinny orbits and pairing and clustering of protogalaxies arise naturally from some of the theories of galaxy formation. Thus the theory of hierarchical clustering predicts merger as an extremely common phenomena. Hence a statistical analysis ef the expected local distributions (for various regions of the universe) as well as the expected overall distribution of this parameter δU, with respect to the separations between neighbouring galaxies may throw considerable light on the substructures of the universe as well as on the large scale structure of the universe, respectively.

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