ON THE TIDAL ORIGIN OF M51-TYPE SYSTEMS

B. Vorontsov-Velyaminov

We established M51 systems as a class of interacting pairs of galaxies in 1959. In 1975 I showed that among 160 systems with this appearance the ratio of luminosities (and hence masses) of the components varies from 1:1 to 1:0.01. In the latter case, the companion is comparable in mass and dimension to an isolated H II region. The number of such M51-type systems increases as the luminosity of the companion decreases. Small companions cannot draw spiral arms from the primary companions by means of tides. Yet, they are observed at the tips of spiral arms. Thus, they must originate at the same time as the spiral or form within them. In some cases, these companions emanate from the spiral arm, as is shown by comparison of observations and calculations.

There are cases, such as VV 20, 21, 244, 247 and others, in which the components have bridges or tails, possibly of tidal origin, much fainter than the original spiral arms. They form large angles with real spiral arms and probably lie in another plane.

There are some "twice M51-type" galaxies with two similar components at the ends of opposite arms. It is impossible to believe that this resulted from their simultaneous arrival from infinity or from very elongated closed orbits to symmetrical, very close positions relative to the primary. In VV 470 the relative dimensions of the components are equal to those in the case of M51.

It is noteworthy that there are cases (M51, VV 19, VV 20 and others) where, besides a curved filament, really or only apparently connecting the components, there is also a straight and more massive filament connecting them which is not predicted by the tidal theory.

The fine tidal arms ingeniously obtained by this theory disappear in a more realistic treatment in which there is self-gravitation and small dispersion of velocities (modelled by F. Hohl). The hypotheses of collisions to explain ring galaxies and "Mergers" fails on the grounds of statistics and because of the existence of tight nests of galaxies.

THE FREQUENCY OF RING GALAXIES AND THE PROBABILITY OF THEIR FORMATION BY COLLISIONS

V. Dostal and V. Metlov

A survey of ring galaxies which were discovered in 1960 by B. Vorontsov-Velyaminov has been carried out using the Morphological Catalogue of Galaxies. Clusters of galaxies were also included. Such galaxies without spiral arms constitute 0.7% of all galaxies down to $15^{m}_{.}0$, and are 100 times less frequent than spiral galaxies. This percentage is the same for clusters, but there are fields where ring

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galaxies are 3-5 times more frequent than the average. The probability of nearly central chance collisions of galaxies as proposed by some theories has been calculated. It was assumed that a ring galaxy is formed from the encounter of a spiral galaxy with another galaxy if its mass or luminosity is not less than 1% of that of the principal galaxy. The minimum separation of their centres was taken to be less than 2.7 kpc, but the angles between the vectors of the relative velocity and the planes of galaxies were not restricted. The lifetime of the rings once they are formed was assumed to be 10^9 years and the distribution of the galactic velocities was calculated according to a Maxwellian distribution. The number of galaxies of given absolute magnitude per unit volume was taken from Holmberg (*Stars and Stellar Systems*, 9, 123). The curvature of the trajectories was taken into account. So conditions were chosen to be most favourable for nearly central collisions.

The mathematical expectation of the ratio of the number of rings with apparent magnitude less than a given value to the corresponding number of spiral galaxies is only 10^{-5} percent. This figure cannot be changed more than one order of magnitude depending on the adopted parameters of the velocity distribution which were changed within its permissible limits. The calculated value of N_r/N_s thus is 10^3 times smaller than the observed ratio of rings to the number of spirals.

Collisions in double and multiple galaxies which have been dynamically connected since their formation are also of very small probability. In the case in which the deceleration of one of the galaxies occurs, the eccentricity of its orbit becomes smaller. The study of globular clusters has shown that increase in the ellipticity of orbits only takes place in some cases for orbits in the rather dense parts of the Galaxy.

If the companion had a radial orbit from the beginning, then according to Toomre (IAU Symposium No. 58, 360, 1974), after 2 or 3 oscillations it must coalesce with the primary. If we observe the first collision of this system, the components must have been formed with very small relative tangential velocity (less than 1 km s^{-1} for a mass of 10^{11} $M_\odot$ and an orbital period of 10^{10} years).

The fact that all these types of collision are of very small probability suggests that the mechanism of formation of the ring must be inherent in the galaxy. Perhaps the frequent presence of a companion plays some role in its development.

DISCUSSION

Tovmassian: The movie and slides shown by Prof. Toomre were very impressive but I would still like to warn that one must be careful when discussing interacting systems. As an example I would like to mention the galaxy NGC 520 which has a very curious shape and which was considered an interacting pair by Toomre and Toomre. Radio observations of

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this galaxy made by myself and R. Sramek with the Green Bank interferometer revealed an unresolved radio source in the very centre of this object. In my opinion, this rules out the hypothesis of interacring galaxies. The results of our observations, and also a photograph of NGC 520, were published in the first issue of *Astrofisika* in 1976.

Toomre: You may be a little too pessimistic. Why couldn't that compact radio source be the nucleus of one of two almost overlapping systems? And maybe it was even "turned on" by some recent tidal accretion of gas from its neighbour? Anyhow, I do know that Stockton in Hawaii has recently measured the rotations of those two seemingly edge-on hulks in NGC 520. He finds both of their southeast ends to be receding, as indeed they should be on a simple tidal picture.

Ambartsumian: In the ring film by Reynolds you showed some results calculated for very close encounters. But since distant passages are much more probable, what are their effects?

Toomre: As several workers have found, passages of similar masses at distances greater than one or two disk diameters rapidly yield nothing remarkable or even very noticeable. Slightly deeper encounters where the outer parts of two systems indeed graze or mildly penetrate each other are the ones that tend to produce the nicest bridges or tails. Still deeper intrusions at, say, half a disk radius often result only in a great deal of tidal splatter - although the rings arising from the yet more accurate (but rarer) central hits are, of course, a delightful exception.

Sunyaev: Dr Toomre presented beautiful slides and films of the rings which appear in close encounters of galaxies. T. Eneev, N. Koylov and I have also made films of our simulations of encounters of galaxies which also demonstrate that ring features appear due to tidal interactions. I want to mention one interesting case. In some simulations, a point mass M passes by the "galactic" disk of massless particles in Keplerian orbits about a central mass of mass 2M. A significant fraction of the particles is captured by the point mass. A disk is formed around the point mass. The most interesting thing is that the plane of the newly-formed disk is <u>perpendicular</u> to the plane of the first galaxy. A smaller fraction of the particles is evaporated due to tidal effects.

Kiang: Your picture shows that the ring is a transient feature. It dissolves even as the satellite leaves the scene. Do you, then, find objects in the vicinity of the Cartwheel (and the like) that can plausibly be identified with the projectile?

Toomre: Yes indeed. Not only do we find those two candidates quite close to the Cartwheel (see Fig. 4), but it has been stressed by several observers since the late 1960's that good rings almost invariably have close companions. In his 1973 thesis, Theys went one step further: he noted that those companions often tend to lie near the minor axis.

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Morton: How do the spokes form in the Cartwheel?

Toomre: I am not sure, but I presume it is some intense shear-instability rather than just simple gravitational clumping that tends to make the interstellar gas extra uneven and lumpy in that outward-rushing zone of strong crowding. In any case, like Fosbury and Hawarden, I regard those spokes as gaseous and young stellar debris that has already been left behind by the main circular shock wave, and that is now falling back down toward that inner ring (like the intermediate trajectories in Figure 6).

Richter: A question about shock waves. I understand that the ring in the Cartwheel nebula may contain a shock front producing population I stars. However, from your movies it seemed to me that at the time when the ring is most prominent, most of the population II stars (except from near the nucleus) have themselves been swept into the ring. Hence the disk should contain nearly pure population I, whereas the population in the ring should be mixed. Therefore the disk spiral arms (or the "spokes") would need to be bluer than the ring. Is this right?

Toomre: No, I don't think so. All random motions were omitted in these simple simulations. Had they been included for population II stars, their "ring" would undoubtedly be much broader and less impressive.

Komberg: It was found by Smirnov and myself in a sample of nearby spirals that HII regions and OB associations are distributed in ringlike zones superposed on the spiral structure. In these ring structures the younger objects seem to be further from the nucleus. Also there are no visible companions. What does this mean from your point of view?

Toomre: I think the strong and sharp rings are a very special and rare class of galaxies. They are not at all to be confused with the faint and broad ringlike distributions of extra light seen fairly often in the exteriors of spiral galaxies with at least some hint of barred or oval structure. And of course the neutral hydrogen itself often tends to be depleted (used up?) near the centres of disks, as Roberts first stressed about a decade ago. I suspect your effect is related to the hydrogen.

Heidmann: Yesterday I showed a photograph of Markarian 271 where there appears to be a single one-armed spiral feature, like a whorl, connected to a small barred spiral. Do you think such a model could fit into your models for rings, with some special parameters?

Toomre: I won't know until I try! I doubt it will fit easily, though, since any deep-set spiral structure must need help from the self-gravity which my test particles simply omit.

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