WING GALAXIES: A FORMATION MECHANISM OF THE CLUMPY IRREGULAR GALAXY MARKARIAN 297

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In order to contribute to an understanding of collision-induced starburst activities, we present a detailed case study on the starburst galaxy Markarian 297 (= NGC 6052 = Arp 209; hereafter Mrk 297). This galaxy is classified as a clumpy irregular galaxy (hereafter CIGs) according to its morphological properties (cf. Heidmann, 1987). Two major clumps and many small clumps are observed in the entire region of Mrk 297 (Hecquet, Coupinot, and Maucherat 1987). A typical major clump of CIGs has a diameter of a few hundred pc and its dynamical mass is estimated as an order of 10^8 $M_\odot$ (Taniguchi and Tamura 1987).

Since Mrk 297 looks like an isolated system, Schweizer (1983) included it as a candidate of mergers. On the other hand, Alloin and Duflot (1979) proposed another idea that Mrk 297 is just a colliding system between two late-type spiral galaxies because this galaxy has two kinematically distinct components (*the two major clumps*). Following their suggestion, we try to consider a possible geometry and orbit of the interaction in Mrk 297.

The overall morphology of Mrk 297 is highly chaotic and thus it seems difficult to determine possible orbits of galaxy-galaxy collision. However, we have serendipitously found a possible orbit during a course of numerical simulations for a radial-penetration collision between galaxies. The radial-penetration collision means that an intruder penetrates a target galaxy radially passing by its nucleus. This kind of collision is known to explain a formation mechanism of ripples around disk galaxies (Wallin and Struck-Marcell 1988). Here we show that the radial-penetration collision between galaxies successfully explains both overall morphological and kinematical properties of Mrk 297.

We made two kinds of numerical simulations for Mrk 297. One is N-body (1×10^4 particles) simulations in which effects of self gravity of the stellar disk is taken into account. These simulations are used to study detailed morphological feature of Mrk 297. The response of gas clouds are also investigated in order to estimate star formation rates in such collisions. The other is test-particle simulations, which are utilized to obtain a rough picture of Mrk 297

https://doi.org/10.1017/S0252921100005947 Published online by Cambridge University Press

and to analyze the velocity field of Mrk 297. The techniques of the numerical simulations are the same as those in Noguchi (1988) and Noguchi and Ishibashi (1986). In the present model, an intruding galaxy with the same mass of a target galaxy moves on a rectilinear orbit which passes the center of the target.

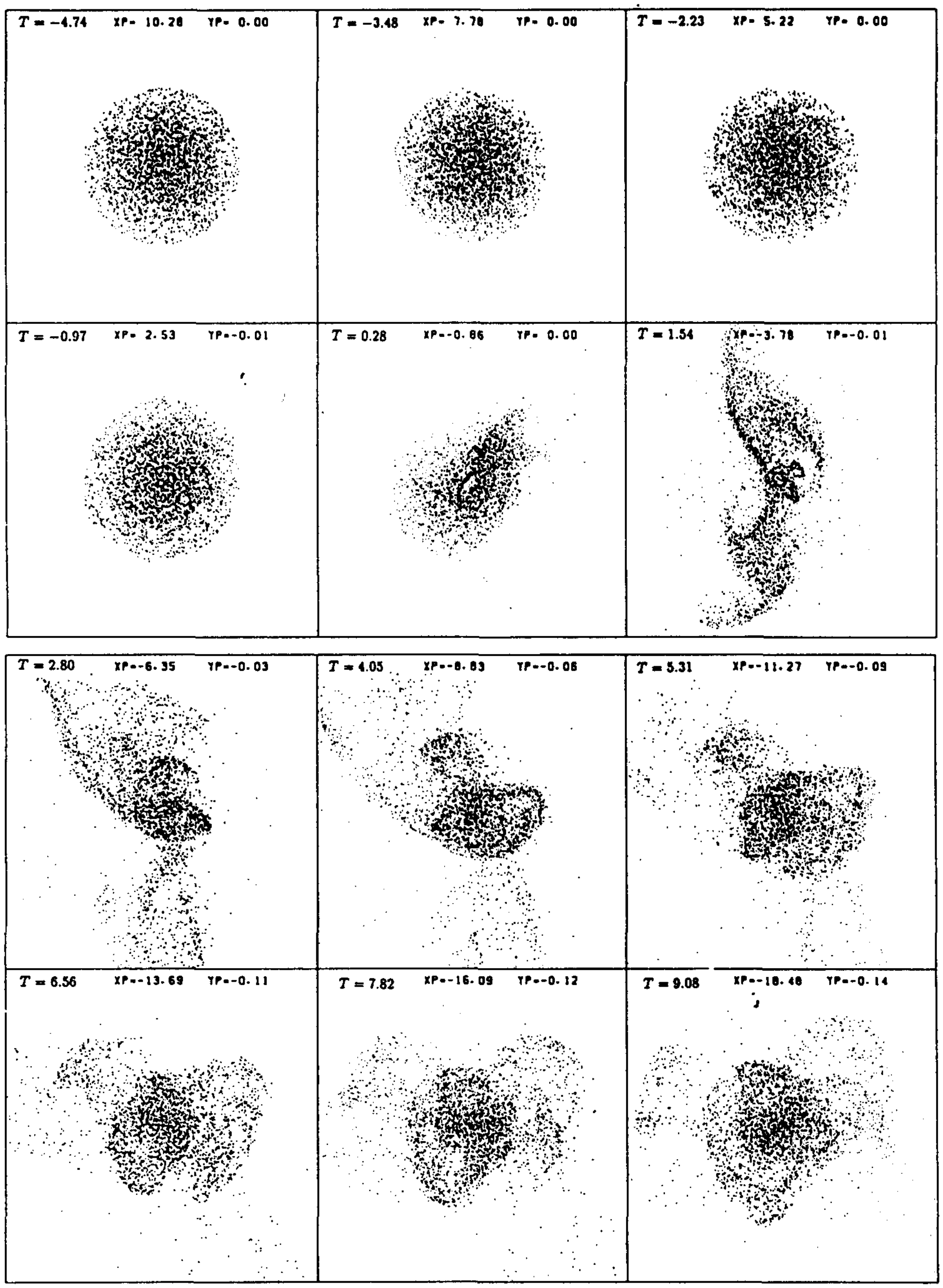

Fig. 1. The radial-penetration collision between galaxies. The morphological evolution of the target galaxy during the period of about two disk rotation time is shown. The wing phase discussed in this paper corresponds to the sixth panel ($T = 1.54$). This galaxy evolves into a barred galaxy, finally.

In Fig. 1, we show a morphological evolution of the radial-penetration collision based on the N-body simulation taking account of self gravity of the stellar disk. Nearly just after the impact (a few 10^7 years later), the target galaxy is deformed into a "*wing*"-like structure shown in the sixth panel of Fig. 1. This wing structure resembles with the eastern part of Mrk 297 in morphology. To demonstrate this, we compare the model result with the observation in Fig. 2. Our interpretation implies that the western part of Mrk 297 is an intruding galaxy. Although the morphological feature of this part is very complex, the basic structure appears to be a nearly round one with many clumps. Therefore, we may consider that the intruder is nearly observed from a face-on view. In the case that the colliding partner is deformed to a ring galaxy, the projected image of the two galaxies is quite similar to the observed shape of Mrk 297 (a rough sketch of given in Fig. 3, which is obtained with a test-particle simulation). Our analysis shows that a possible orbital plane of the collision is nearly parallel to the line of sight. Note that the intruder locates at a distance of twice of the galaxy diameter from the target when the wing structure is formed. Therefore, it is suggested that Mrk 297 is not a merger although it looks like a single object.

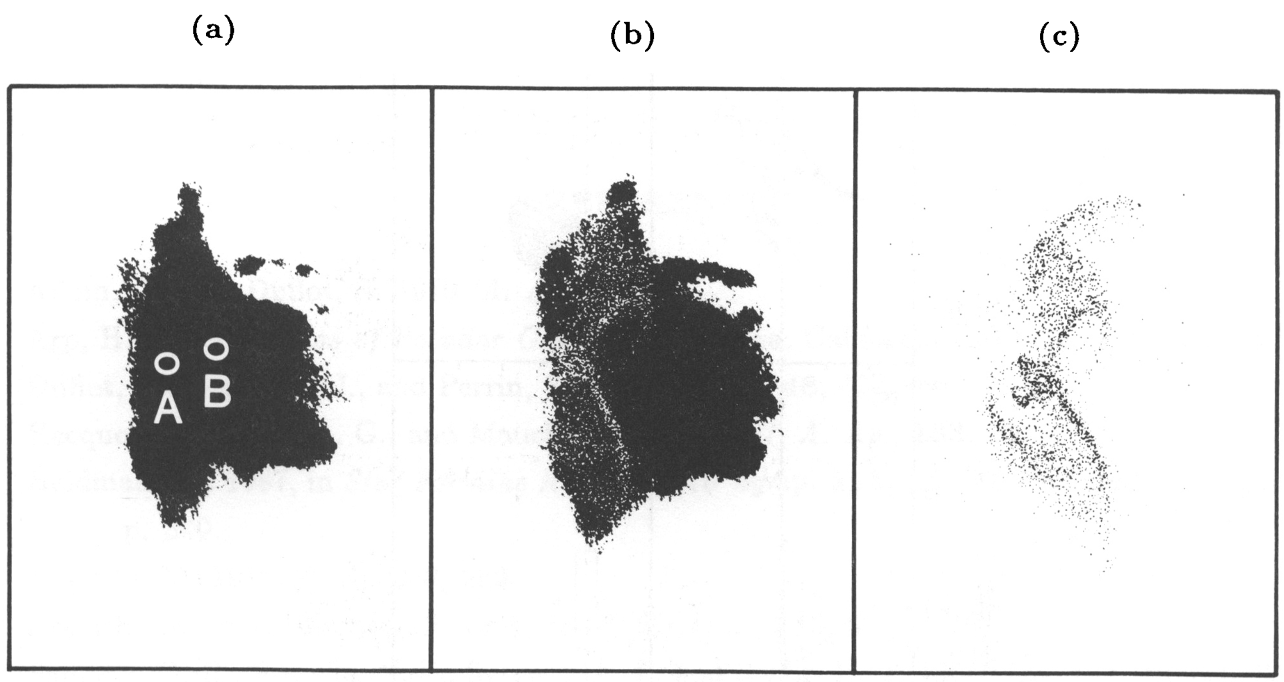

Fig. 2. A comparison of the morphology of Markarian 297 between (a) the observation (Arp 1966) and (c) our model (the sixth panel of Fig. 1). In the middle panel (b), the overlapped image of (a) and (c) is shown. Note that the wing structure corresponds to the eastern part of Mrk 297. The clumps A and B corresponds to the nuclei of the intruder and the target galaxies, respectively.

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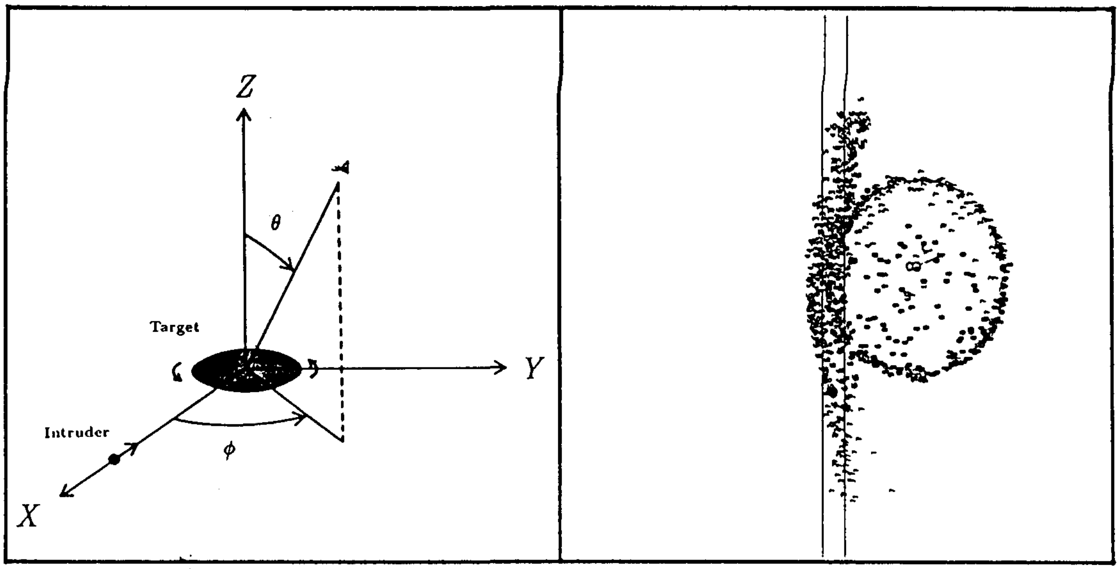

Fig. 3. Definition of observing angles of the collision (*left*) and the rough sketch of the overlapped image of the two galaxies at $\theta = 70°$ and $\phi = 180°$ (*right*). The stripe shown in the right panel corresponds to a slit position of the spectroscopy by Duflot, Lombard, and Perrin (1976).

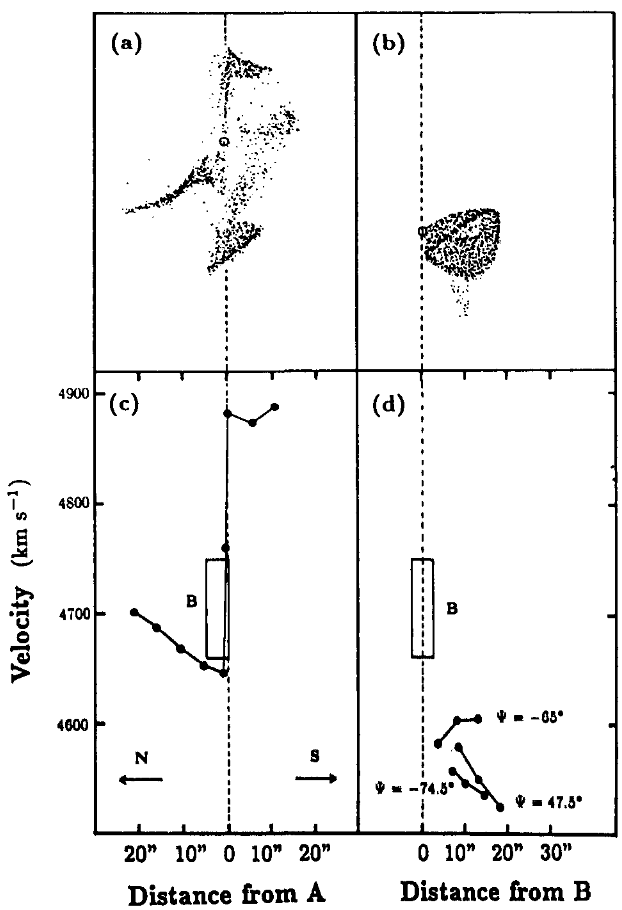

Fig. 4. A comparison of the velocity fields of Mrk 297 between the observation (*lower panels*) and our model (*upper panels*).

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Next, we compare the velocity fields of Mrk 297 between the observation (Duflot, Lombard, and Perrin 1976) and our model (Fig. 4). In the left panels, the comparison is made for the data at PA = 0° through the clump B. The component trapped by the intruder is also seen in the model result. However, this component is not discriminated from the intrude in the observation. In the right panels, we show the velocity field of the intruder. The distance is measured from the clump B (i. e., the nucleus of the intruder). It is shown that the observed velocity field of Mrk 297 is well reproduced on the basis of our model.

As noted above, in our scheme, Mrk 297 is not a merger but an only interacting galaxy. Very recently, Sofue *et al.* (1990) detected ^{12}CO ($J = 1 - 0$) emission in Mrk 297 using the 45-m radio telescope of the Nobeyama Radio Observatory. Their CO mapping showed that the CO emission comes from outer regions as well as from the nuclear one. It is, however, known that molecular gas clouds are highly concentrated in the circumnuclear regions in merger galaxies (*e. g.,* Sanders *et al.* 1988). This difference in molecular gas distributions between Mrk 297 and the mergers also support our modeling.

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