RevMexAA (Serie de Conferencias), **49**, 33–36 (2017)

XV Latin American Regional IAU Meeting (Cartagena de Indias, Colombia, 3-7 October 2016)
Editors: Mario Armando Higuera Garzón & Santiago Vargas Domínguez

UPDATE ON THE INTERACTION EFFECTS OF MINOR MERGER SYSTEMS: KINEMATICS, STAR FORMATION AND METALLICITY

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RESUMEN

En este trabajo se revisan las propiedades fotométricas, cinemáticas y químicas de los pequeños sistemas que se fusionan, a fin de comprender mejor los efectos que la interacción puede jugar en la evolución de sus componentes. A pesar de su importancia, las fusiones menores han sido menos estudiadas que las interacciones de las fusiones mayores. Sin embargo, se reconoce que las fusiones menores son agentes potenciales para impulsar la evolución galáctica. La interacción con una compañera pequeña puede generar los mismos fenómenos que ocurren en las fusions mayores, como colas de mareas, puentes, anillos, así como la formación o destrucción de barras o brazos espirales, y desencadenar la formación estelar. Uno de los principales efectos es la pérdida de momento angular del gas debido a la torca ejercida por la galaxia compañera. Esto da como resultado una cantidad significativa de flujo de gas hacia la parte interna del disco y la región nuclear. Como consecuencia, los elementos químicos pueden ser desplazados afectando su distribución y gradiente de metalicidad y/o alimentar la actividad del núcleo. Además, el campo de velocidad de la galaxia principal a menudo muestra asimetrías e irregularidades debidas a la interacción con la compañera más pequeña.

ABSTRACT

In this work, we review photometric, kinematic and chemical properties of the minor merger systems, in order to better understand of the effects that interaction may play on the evolution of their components. Despite their importance, the minor mergers have been less studied than major merger interactions. However, minor mergers are recognized as potential agents to drive the galactic evolution. The interaction with a small companion can generate all kinds of phenomena seen in major cases, such as tidal tails, bridges, rings, as well as the formation or destruction of bars or spiral arms, and triggering the star formation. One of the main effects is the loss of angular momentum of the gas due to the torque exerted by the small companion galaxy. This results in a significant amount of gas inflows into the inner part of the disk and the nuclear region. As consequence, the chemical elements can be stirred up affecting their distribution and metallicity gradient and/or feed nuclear activity. In addition, the velocity field of the main galaxy often shows asymmetries and irregularities due to the interaction with the smaller companion.

Key Words: galaxies: abundances — galaxies: interactions — stars: formation

1. INTRODUCTION

Relevant works on colliding galaxies were done by Holmberg (1940) and Zwicky (1942) before 1950. Spitzer and Baade (1951), working on Zwicky's ideas, observed that collision between galaxies are more frequent in dense clusters. During collision, stellar distribution may be moderately disturbed. However, the interstellar gas can be pushed out from the interacting galaxies over the collisional process. This could explain the predominant number of S0 galaxies in galaxy clusters. After these seminal works collisions between galaxies were seen to have an important role in galactic evolution. In an early review on multiple galaxies, Zwicky (1959) described the coexisting galaxies, which are several individual galaxies that may form permanent double or multiple dynamic systems like the Whirlpool nebula M 51 (NGC 5194), a blue normal and a yellow-green barred spiral galaxy and their "elliptical" companion NGC 5195. The Fig. 1 shows a sketched drawn by Zwicky (1959) to illustrate all type of connection between neighbouring galaxies. They are present in normal and barred spiral galaxies, this fact indicates that these configurations would be the result of double or multiple encounters between the components of the system.

The first evidence of radio sources associated with colliding galaxies was given by Baade and Minkowski (1954), they reported that the radiosource in Cassiopeia, Cignus A, is associated with

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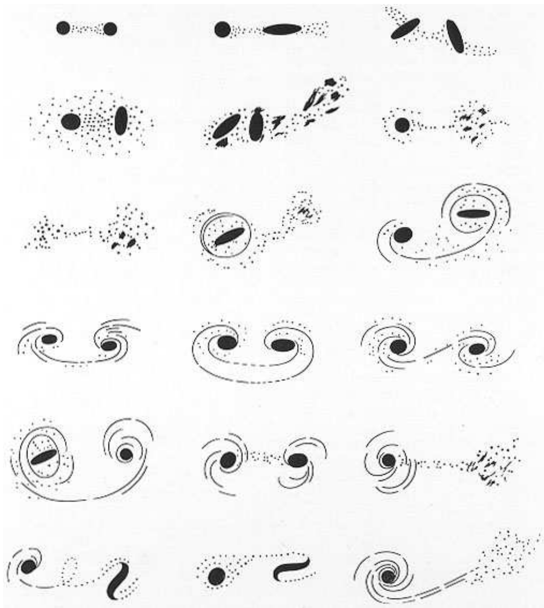

Fig. 1. Sketches made by Zwicky (1959) to illustrate all type of connections between neighbouring galaxies. Image taken from Zwicky (1959).

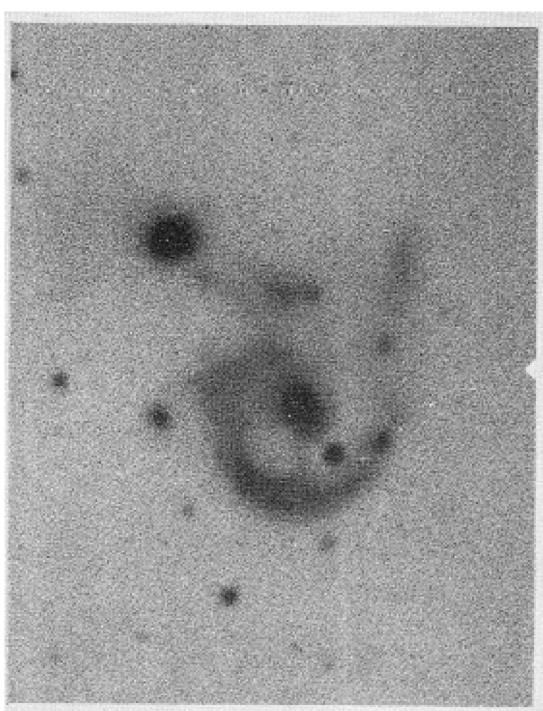

Fig. 2. Interacting pair arp 107. Image taken from Arp (1966).

an extragalactic nebula, which has very large internal random motion. In 1966, Halton Arp published *the Atlas of Peculiar Galaxies* (Arp 1966), which presents the result of 4 years of photographic obser-

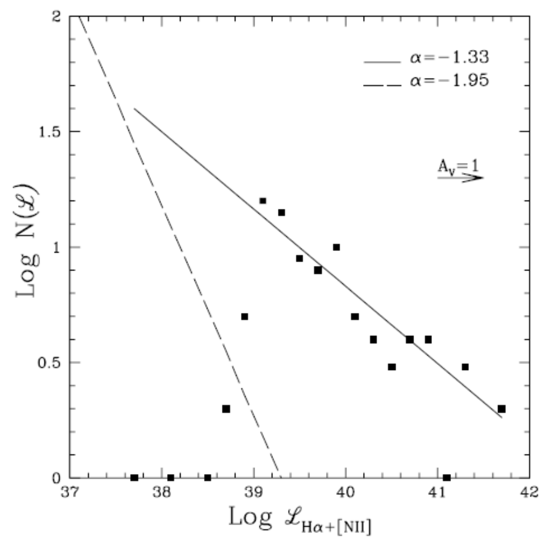

Fig. 3. The luminosity function of sample of HII regions studied by Ferreiro et al. (2004). The solid line is the power-law with index $\alpha = -1.33$ fitted to the data; dashed line is the fit obtained by Crocker from HII regions of ringed galaxies with index $\alpha = -1.9$. Image taken from (Ferreiro et al. 2004).

vations of unusual individual galaxies taken from the Vorontsov-Velaminov list and from objects selected from the Palomar and Mount Wilson plates. The Fig. 2 shows the interacting system ARP 107. A southern extension of this survey was *the Catalogue of Peculiar galaxies and Association* (Arp 1987). In this catalogue the objects were classified according to degree of perturbation, comparative sizes between galaxies, and number of interacting galaxies. The 9th category was given for the "the minor mergers", which are formed by a luminous spiral associated with a small galaxy, the mass of the primary is 3 times larger than the mass of the secondary galaxy. This type of systems are very common in the universe, in fact they are at least an order of magnitude more frequent than major mergers (Hernquist and Mihos 1995).

The origin of the galactic bridges and tails observed in minor mergers were explicated by Toomre and Toomre (1972) as the result of close encounters. After the passage of the small companion, the primary disk galaxy is deformed both in an inner spiral arm or a bridge extending to the satellite. As an example see the model for Arp 178 (Fig. 19 of Toomre and Toomre (1972)), which suppose a parabolic passage of the small galaxy with their disk inclined 15° with respect to the primary disk. In their initial models they did not consider the effect of Chandrasekhar's dynamical frictions, however, in a pos-

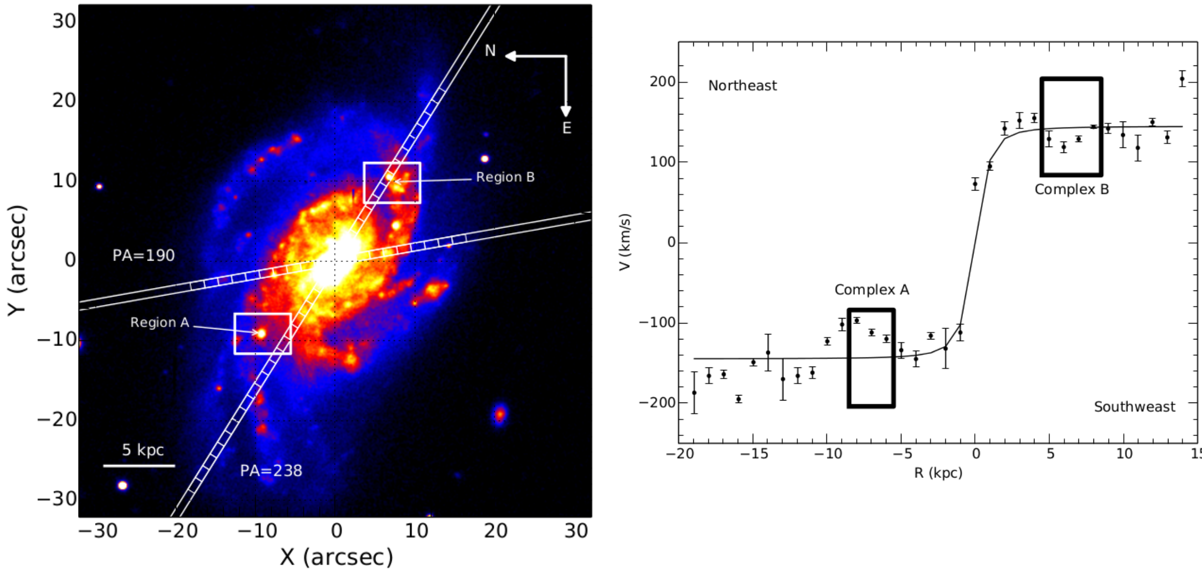

Fig. 4. **Right:** the r' image of the main galaxy of the AM 2326-721, the boxes show the FOVs of Gemini GMOS-IFUs. The long-slits used to build the velocity field model for the main galaxy are also plotted. **Left:** the observed velocity curve profile along the long-slit at PA=238, the continuous line is the projected curve fit model taken from Krabbe et al. (2008). The boxes delineate the projected area of FOVs of IFUs of the complexes.

terior Yale Conference, Alar Toomre (1977) showed that if this effect is taken in consideration the colliding galaxies would merge. Collision between large spirals could lead to the formation of an elliptical galaxy. Toomre showed the possibility that collision were the dominant factor in the evolution of an important class of galaxy from Spiral to Elliptical.

Normal and peculiar galaxies present different distribution in the color diagram (U-B, B-V) (e.g., see figure 9 of Larson and Tinsley (1978)). The peculiar galaxies are bluer and have a large dispersion in colors. In order to interpret these differences, Larson and Tinsley (1978) built a grade of galaxy models with decreasing star formation rate and different time scale of the burst. They found that the peculiar galaxies have colors consistent with a time scale burst $< 10^7$ years and that the large dispersion of colors are associated with galaxies showing different degree of interaction. This diagram provide evidence for a burst mode of star formation associated with violent dynamical phenomena. Later, Sanders et al. (1987) report that IRAS survey of the local universe revealed the existence of ultra luminous infrared galaxies, optical images show that almost all of this type of galaxies are in advanced merger state.

Interacting galaxies also show asymmetries and irregularities in the velocity field due to tidal force. (e.g., Rubin et al. 1991; Dale et al. 2001; Hernadez-Jimenez et al. 2013, 2015). On the other hand, an important finding confirmed that collision between galaxies can form and eject to the space dwarf galaxies, now, they are called as tidal dwarf galaxies (TDG). A beautiful example are the TDGs observed at the end of Antennae tails (Mirabel et al. 1992).

2. MINOR MERGERS

Interaction among galaxies may lead to a high star formation by increasing the formation rate per unit mass and by increasing the concentration of the gas in some regions of the galaxies (Combes 1993). Moreover, numerical simulations have shown that interactions between a disk galaxy and a small satellite result in a redistribution of substantial quantities of the material into the central regions of the galaxies inducing high star formation rate (Mihos and Henquist 1994) .

In order to probe the above effect, Ferreiro et al. (2004) studied the main properties of a sample of 116 HII regions of 11 minor mergers of galaxies and compared with HII regions observed in normal and isolated galaxies and TDG candidates. They found that most of the HII regions are brighter than $M_B \leq -15$, which is an upper limit for giant HII complexes observed in the spiral arms of Sa and Sb galaxies, the luminosity function of both samples is presented in Fig. 3. Five regions are as bright as the TDG candidates observed in the tidal tail of Arp 105 (Weilbacher et al. 1977). These giant HII regions

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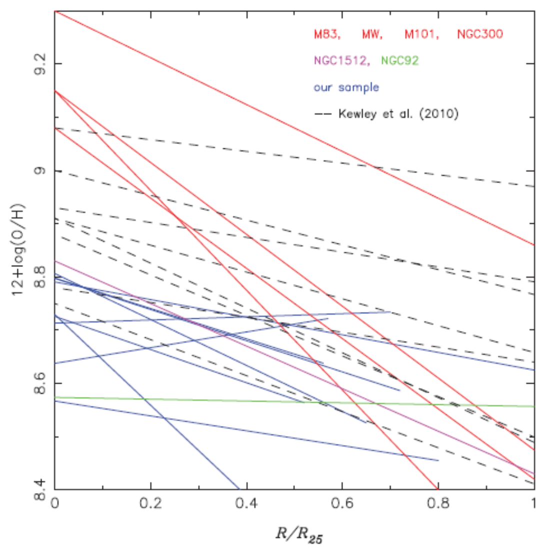

Fig. 5. Metallicity gradients for Rosa's et al. (2014) sample, some isolated galaxies, Kewley's et al. (2010) interacting galaxies sample, NGC 92 and NGC 1512. Image taken from Rosa et al. (2014).

can also affect the surrounding velocity field. For example, Hernadez-Jimenez et al. (2017) have found this effect in a kinematic study of two giant HII regions located at the spiral arms of the main galaxy of the minor merger AM 2306-721 by using Gemini GMOS–IFU observations. The Fig. 4 shows the galaxy together with their rotation curve, which has two bumps just in the place where are located the giant HII region.

The behaviour of metallicity in minor merger galaxies have been studied by Rosa et al. (2014). The oxygen abundance gradients from HII regions located in 11 interacting galaxies of their sample were obtained with the Gemini/GMOS (Rosa et al. 2014). Radial profiles were obtained using calibrations based on strong emission-lines (N2 and O3N2). They found that for their sample the oxygen gradients are significantly flatter than those observed in typical isolated spiral galaxies (see Fig. 5). The flattening in the oxygen abundance gradients could be the result of the gas motions produced by the interactions. The latter induces star formation along the disc of the interacting galaxies thus flattening the metallicity gradient.

3. CONCLUSION

In summary the galactic interactions are a major agent of galactic evolution. We can conclude that the main effects of the galactic interactions are:

- Enhancement of the ultra violet, optical, near infrared and radio emission.
- Increased of the star formation rate compared to that of isolated galaxies.
- Formation of the TDGs and giant HII regions.
- Perturbation of the velocity field of both stellar and gaseous components.
- Perturbation of the chemical state of the galaxies and flattening of the radial gradient of metallicity.

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