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GALAXY INTERACTIONS AND STAR FORMATION

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RESUMEN

A partir de resultados observacionales, revisamos la idea de que las interacciones entre galaxias producen brotes de formación estelar. Se consideran tres tipos de interacciones: "encuentros distantes" (interacción de marea entre pares), "encuentros cercanos" (donde se atraviesan una galaxia a la otra) y la fusión de galaxias. Se discuten los procesos físicos de la detonación de brotes estelares producidos por perturbaciones dinámicas, asíi como su relación con los Núcleos Activos de Galaxias.

ABSTRACT

We review, from observational results, the idea that galaxy interactions trigger starburst activity. Three types of interactions are considered: "distant encouters" (tidal interactions between isolated pairs), "close encounters" of interloping or piercing galaxies, and "mergers" or fussion of galaxies. We also describe the theoretical basis to explain induced SB processes as well as their connection with Active Galactic Nuclei (AGN).

Key words: **GALAXIES: INTERACTIONS — GALAXIES: NUCLEI — STARS: FORMATION**

1. INTRODUCTION

Hints and evidences suggesting some connections between galaxy interactions and the enhancement of star formation (SF), date back to the late fifties and early sixties. In 1958, Morgan discovered what he called "hotspots" in galaxies, and Vorontsov-Velyaminov (1959) published the first catalog of interacting galaxies. Later, the Atlas of Peculiar Galaxies was published by Arp (1966), and Sersic & Pastoriza (1967) made a catalog of "hotspots" in the centers of galaxies. They found one important property in all the centers of galaxies harboring hotspots: extreme blue colors. This was also a distinctive property of most galaxies in both Vorontsov-Velyaminov's and Arp's catalogues. The only other wavelength accessible for observations at that time was radio, and Sulentic (1976) found evidence of excess radio emission in interacting galaxies (see also Condon & Dressel 1978; Hummel 1980). Larson & Tinsley (1978) were the first ones to point out that tidal forces in interacting galaxies could trigger "***bursts of star formation***", in which up to 5% of the total mass of a galaxy could be converted into stars in a short time, 10^7 to 10^8 yrs. On the theoretical side, after the first gravitational simulation by Holmberg (1941), and the work of Alladin (1965), the early seventies were the start point for the development of theoretical models describing interacting galaxies. In 1972 the famous Toomre & Toomre (hereafter TT) paper was published, but others preceded and followed (e.g., Yabushita 1971; Eneev et al. 1973). Observational evidence supporting the link between interactions of galaxies and enhanced star formation rates (SFR) has been accumulating at an amazing pace during the last twenty, and particularly ten years. The precise nature of this link for different types of interactions —and between different types of galaxies—, as well as a deep understanding of the physical phenomena involved in such processes, advances more slowly. The advent of CCD detectors, and access to new observing windows from space —particularly in the infrared bands— together with the development of supercomputers, has produced an authentic "Super-Burst of paper formation" on this subject!. The task of reviewing the field is appalling, and we shall focus this review mostly on observational aspects. The last section will be devoted to the most recent results from the *Hubble Space Telescope (HST)*. Several excellent reviews —and contributions— on various topics related to this subject, can be found in Wielen (1990), Sulentic et al. (1990), and Shlosman (1994). For a deeper insight into various theoretical aspects which we shall barely touch in this paper, we refer the reader to Barnes & Hernquist (1992) and Combes & Athanassoula (1993). This is, by no means, a complete list of references.

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2. OBSERVATIONAL BACKGROUND

The evidence relating starbursts (SBs) to interactions is now overwhelming, even from optical wavelengths only. Both spectrophotometric and imaging works indicate that: a) there are more galaxies with enhanced SFR in interacting systems, as compared to isolated galaxies; or vice versa, b)interacting galaxies have enhanced SFR (e.g., Petrosian et al. 1978; Condon et al. 1982; Kennicutt & Kent 1983; Keel et al. 1985; Madore 1986; Kennicutt et al. 1987; Bushouse 1987; Hummel et al. 1990; Keel & van Soest 1992). All these observations show that two, out of three —and sometimes all three— of the following properties are highly correlated in galaxies: blue colors (from young stars), emission-line spectra (from the associated H II regions), and perturbed morphologies (or other more or less obvious signs of ongoing or past interactions). These findings are corroborated in recent works, such as that by Liu & Kennicutt (1995) who found that even far-infrared ultraluminous galaxies tend to have blue colors in optical bands, typical of Star-Forming-Galaxies (SFG); see also Couch et al. 1994; Wirth et al. 1995. Subsequent studies of the hotspots (e.g., Kenicutt et al. 1989) reveal that they are indeed, sites of recent bursts of SF. These spectacular star-forming regions are usually found in a ring or ringed-shaped structure that lies from a few hundred to a few thousand parsecs from the nucleus. The most common interpretation is that they are the consequence of huge gas inflows that probably occur in strongly barred galaxies. The rings always lie close to the expected locations of the Inner Lindblad Resonance (ILR) of the bar (e.g., Kenney et al. 1992; Roy & Belley 1993; Friedli this volume), and theoretical works convincingly account for the formation of such gas rings (e.g., Combes & Gerin 1985), and their subsequent fragmentation into stars (e.g., Elmegreen this volume). Examples also exist, however, of hotspots rings in galaxies which are not clearly barred. Interactions may also trigger SB rings and/or hotspots outside the nuclear regions. There is, of course, another more subtle, yet additional line of evidence from optical wavelengths relating bursts of SF to interactions. This is the so-called Butcher-Oemler effect: galaxies in rich clusters are bluer than field galaxies (Butcher & Oemler 1978; Oemler 1992). Subtle evidence becomes compelling, if we link this effect to the discovery that blue galaxies in rich clusters have indeed enhanced SFR, with more and closer neighbors than galaxies in the field or in looser groups (Lavery & Henry 1994; Keel & Wu 1995). Another line of evidence comes from the discovery of enhanced supernovae rates in interacting systems (e.g., Smirnov & Tsvetkov 1981; Keel et al. 1985; Petrosian & Turato 1995)

UV radiation from young massive stars not only ionize the surrounding gas, but can also be absorbed and re-radiated by heated dust in the mid-infrared band. The fact that some galaxies emit as much energy in the infrared as in the optical wavelengths was established with the first mid-infrared observations of extragalactic sources (e.g. Low & Kleinman 1968). Observations at wavelengths 2–25 μm disclosed several objects, including luminous SBs, Seyferts and QSOs, that appeared to emit most of their luminosity in the mid-infrared. By the mid eighties, surveys of interacting galaxies in the mid-infrared (Joseph et al. 1984; Lonsdale et al. 1984; Curty & Mc Alary 1985) had clearly revealed an enhancement of infrared emission in interacting systems compared to isolated galaxies. Joseph & Wright (1985) identified a subset of advanced mergers in the Arp atlas with extremely strong mid-infrared emission, and they attributed this radiation to super-SBs that could occur during the merging process. We shall come back to this issue below.

The first all-sky survey at far-infrared wavelengths was carried out in 1983 by the *Infrared Astronomical Satellite (IRAS)*. *IRAS* was the first telescope with sufficient sensitivity to detect large numbers of extragalactic sources at mid- and far-infrared wavelengths. A survey of $\sim$ 96% of the sky, produced an initial *IRAS* Point Source Catalog (1988) that contained $\sim$ 20 000 galaxies, the majority of which had not been previously cataloged. It also revealed a new type of objects in the Universe: The *IRAS* Luminous, Ultraluminous and Hyperluminous (!) Infrared Galaxies (LIGs, ULIGs & HyLIGs). All these galaxies have infrared luminosities, $L_{IR} > 10^{11} L_\odot$, and the last emit more that $10^{13} L_\odot$. An excellent and extensive review on this new class of objects is currently in press (Sanders & Mirabel 1996). For a complete flux-limited sample of 86 infrared selected galaxies, Soifer et al. (1984a) found a fraction of interacting galaxies as high as one-fourth. Initial cross-correlation of larger *IRAS* source lists with galaxy catalogs has produced only one or two objects with the most extreme known ratios $L_{IR}/L_B > 50$, most notably the ULIG NGC 6240 (Joseph et al. 1984) and Arp 220 (Soifer et al. 1984b), both advanced mergers (see below). *IRAS* discovered mid- and far-infrared emission to be present in practically all spirals and irregulars (de Jong et al. 1984). Various models for the infrared emission (e.g., Helou 1986; Rowan-Robinson 1986), have convincingly shown that for lower luminosity "normal" galaxies, the peak in the spectral energy distribution seen in the mid-infrared is due to the emission of small dust grains near hot stars, while a stronger peak that appears around 100 μm represents emission dominated by dust from infrared cirrus heated by the older stellar population radiation field. In more infrared luminous galaxies a "SB component" emerges around 60 μm, plus in Seyfert galaxies and stronger SBs, an even warmer component peaks near 25 μm.

Several authors have shown that both mid- and far-infrared emission of Sy 2s is dominated by dust re-emission of starlight (e.g., Dultzin-Hacyan et al. 1988, 1990; Mouri & Taniguchi 1992; Vaceli et al. 1993; Dultzin-Hacyan & Benitez 1994). There has been more controversy about the source of dust heating in Sy 1s. Already in 1987, Rodriguez-Espinoza et al. found evidence that even for Sy 1s, the dominant source may be starlight, and more evidence was found recently by Gu et al. (1996). The link to interactions —our main topic in this review— is quite straightforward for Seyferts, since there is ample statistical evidence that they tend to have more companions than "normal" spirals (e.g., Laurikainen & Salo 1995 and references therein), and the link to induced circumnuclear SF in Seyferts is reviewed in Dultzin-Hacyan (1995). The *IRAS* survey and subsequent optical identification of *IRAS* galaxies, marked a turning point in the establishment of the role of interactions and collisions of galaxies in triggering activity. On the other hand, the development of panoramic detectors for near- and mid-infrared ground-based imaging and spectroscopy, have given fundamental information on the dynamical and physical conditions of the induced SF bursts (e.g., Doyon et al. 1994; Prestwich et al. 1994; Smith et al. 1995).

Single-dish observations of millimeter-wave emission from rotational transitions of CO and the 21-cm line of H I now exist for the majority of objects in the *IRAS* Bright Galaxy Survey. They show that the total neutral gas content, and in particular the total mass of molecular gas, appears to play a particular role in the genesis of LIGs. More recently, interferometer maps have provided dramatic pictures of the redistribution of the H I and H_2 gas that occurs during interactions and mergers. Millimeter wave interferometer measurements of CO emission for approximately two dozen LIGs —nearly all of which are advanced mergers— show that from 40 to 100% of the total CO luminosity is contained in the central $r < 0.5 - 1$ kpc (e.g., Scoville et al. 1994; Aalto et al. 1995; Sander & Mirabel 1996, and references therein). Last but not least, is the detection of megamasers in nearly 50 LIGs (Baan 1993), which is also used to probe the circumnuclear high density interstellar gas in distant infrared galaxies.

3. THEORY

The galaxy M51 enjoys a special place in the history of extragalactic astronomy. It was the first galaxy whose grand design spiral shape was modeled, using the first high-speed computers by the Toomres (TT). TT examined the kinematics of the M51/NGC 5195 system, using a restricted three-body method. The study was further refined by Toomre (1978). Despite the amazing (external) morphological resemblance between the restricted three-body simulation of Toomre (1978), and a composite image of M51 (e.g., Hernquist 1990), the model faces severe problems. The main problem became evident with the discovery of an extended H I tail in M51 by Rots et al. (1990). While this observation strongly supports the view that nearly all the structure in M51 originates as a consequence of its tidal interaction with NGC 5195 (as opposed to models based on long-lived waves generated internally), it also implies a much longer time since pericenter than the one used by Toomre (1978). According to Hernquist (1990), the difference is at least a factor of 8. What was the main problem of the model? *the lack of gas.* The recent advances in both computational capacity and techniques have made it possible to perform sophisticated 3D numerical simulations including both particles and gas. A recent example of a very successful model for the M51-type galaxy Arp 86, that is able to reproduce both external and internal morphology, as well as velocity fields, can be found in Salo & Laurikainen (1993), and preliminary results of a collaboration with these authors is given in Cruz-González et al. (this volume). What we want to stress here is, that the role of gas is *crucial* in interactions between galaxies because: a) it is dissipative, b) it responds irreversively to dynamical perturbations, and c) it is an active component to fuel both SBs and "monsters" (accretion disks around supermassive black holes). From the models we learn that when galaxies interact —either colliding or through a strong tidal perturbation— stellar bars tend to form that help to channel gas into the central regions by the loss of angular momentum due to friction. The gas may "pile-up" at the ILR, if present, or proceed further inwards where it fragments and clumps, forming ring-shaped or nuclear SBs (e.g., García-Barreto et al. 1996). Extranuclear, extended fragmentation into starbursts may also be induced by interactions. The stages that proceed beyond a few kiloparsecs towards an innermost possible accretion disk, are poorly understood, although recent progress has been made to model this final stage (e.g., Shlosman & Heller 1994; Bekki 1995) needed to "feed the monster" —if present—. A reference to a hybrid model for active galaxies, where the inter-relation between a circumnuclear SB and a "monster" are dealt with, can be found in Perry (this volume).

In what follows, we will divide interactions between galaxies into three types, according to the degree of maximum proximity of the galaxies: a) tidal interaction between "non-obviously-touching" galaxies, or "distant encouters"; b) "close encouters" of intruding or interloping galaxies, and c) "mergers", defined as collisions that end in the complete fusion of galaxies. This is by no means a rigorous classification, as it obeys pure didactical purposes (in the mind of the author), in order to illustrate various types of dynamical perturbations, and their effect in inducing SF.

4. DISTANT ENCOUNTERS

Typical examples of this type of interactions are physical pairs of galaxies. Larger ensembles of close enough galaxies for gravitational forces between them to be important, are the Compact Groups of galaxies (e.g., Hickson 1993). The mere physical reality of these groups, and the occurrence of interactions within them, is controversial (e.g., Tovmasian & Shahbazian 1981; Sulentic 1996); yet there seem to be examples of tidally enhanced SF activity within such systems (e.g., Menon 1995; Zheng-Long et al. 1995). In what follows we shall restrain to isolated pairs of galaxies.

We begin with mixed morphology (E + S) pairs, systems whose origin is controversial. According to many schemes of galaxy formation, one expects to find members of similar morphological type in pairs of galaxies (e.g., Dressler 1980; Yamagata 1990). And yet, there is a strong over representation (about 150 out of nearly 600) of mixed-morphology pairs among binary galaxies in the Catalog of Isolated Pairs (CPG, Karachentsev 1972) compared to expectations from randomly selecting galaxies from the general distribution of Hubble types in regions of similar surface density. Numerous structural peculiarities (Rampazzo & Sulentic 1992), and far-infrared luminosity function studies (Xu & Sulentic 1991) suggest that most of these pairs are physical binaries. Moreover, there is at least one documented example (to our knowledge) of mass transfer and induced SF in the early (!) member of the system: AM 0327-285 (de Mello et al. 1995).

The E + E systems, represent nearly 10% of all binaries. For a long time they were thought to be nearly gas free. However, X-ray observations have revealed that large amounts of hot gas may be associated to these systems (e.g., Colina & Borne 1995; Bonfati et al. 1995). The gas is so hot however, that there are no expectations to find any tidally induced SF in this type of binaries.

Spiral galaxies are by far the most abundant. 80% of all galaxies are spirals, and thus S + S systems are common. Since in these galaxies the gaseous component is very important, disturbed morphologies and induced activity is also more easily detected in binaries. However, understanding the connection between dynamical perturbations, activity and morphological type is not straightforward. Mihos & Hearnquist (1994) found from simulations, that the rate of gas infall towards the nucleus depends on the size of a dense central bulge; in other words, on morphology. From the observational point of view, this is discussed in the work by Moles et al. (1995) and neatly illustrated with the study of the system Arp 298 (Benítez et al. 1995; Márquez & Moles 1994). This physical system consists of an early + late type spirals: NGC7469 + IC5283. Benítez et al. (1995) obtained deep images in the V and R bands under exceptional seeing conditions, and were able to show that while in IC 5283 there is a knotty structure of star-forming regions distributed along the whole galaxy, in the case of NGC 7469 the main star-forming region is confined to a ring around the (Seyfert) nucleus, situated at approximately the ILR (see also Genzel in this volume). The authors interpret their result as follows: On early-type galaxies, the effects of interactions are not disrupting; on the contrary, galaxies seem to respond coherently, being able to accommodate large scale perturbations by producing a global response, for example, in the form of a bar that drives gas into the center. On the other hand, a late type spiral, which lacks a massive bulge, could not produce a global coherent response, and thus could not prevent the onset of local fragmentation, producing SF all along the galaxy. The dependence on morphology can be traced even in some mergers (Liu & Kennicutt 1995).

5. CLOSE ENCOUNTERS (INTRUDING GALAXIES)

Linds & Toomre (1976) first suggested that “transient ring galaxies are caused by near central head-on collisions of a small galaxy (or S bulge)”. The event is certainly uncommon, and if we add that the observable effects (ring-shaped SBs) of such an intrusion last no more than about 10^8 years, we understand that we are speaking of a rare event to be observed. We include this class of so-called “ring galaxies” for three main reasons: first, they are incredibly spectacular!; second, they provide an example where the SF burst is produced in one or more rings, far (several kiloparsecs) away from the nucleus; and third, it is probably the case for which the physics of the process that triggers enhanced SF is better understood. Recent work on the evolution of ring galaxies can be found in Mazzei et al. (1995); Higdon et al. 1995, and Lamb (this volume). In a few words, the phenomenon occurs when there is a nearly central, head-on intrusion of a relatively small and compact galaxy (often referred to as the inter-loper galaxy) through the disk of a spiral. The passage creates a density wave that propagates outward along the disk of the perturbed galaxy. Actually, several successive waves may form. Since the impact parameter is not exactly zero, the rings are not exactly concentric with respect to the nucleus of th spiral. The interloper is usually seen as a nearby companion visible along the minor axis of the spiral. We d not include here other types of rings, such as "polar rings", "shell galaxies", wound spirals or "pseudo-rings".

The "super-example" of a ring galaxy is the Cartwheel galaxy (VV 784). A magnificent composite imag of this galaxy taken by K. Borne with the WFC1 (Wide Field Camera 1) on board of the *HST* can be foun in the popular book by Petersen & Brandt (1995; see also Borne in this volume). This collision produce a SB ring with a radius of about 10 Kpc. This is an example of a "slow intrusion". Kar 29 (VV 347), o the other hand, is an example of a "fast intrusion". This is a case of a mixed morphology physical pair o galaxies, where there are clear indications that the small elliptical made a nearly head-on passage through th disk of the spiral, producing at least two SB rings at 4 and 10 Kpc (Marziani et al. 1994). What makes i particularly interesting, is the fact that Horellow & Combes (1993) carried out independent three-dimensiona N-body simulations involving both stars and gas, to examine the effect of the perpendicular fast passage of companion on the vertical gaseous and stellar extension of a target disk galaxy. Without knowledge of the worl on Kar 29, they chose very similar parameters to the ones observed in Kar 29, and the simulation reproduce the observations extremely well. Although the simulation did not take SF into account, gas was found to pil up and form rings at about 4 and 10 Kps from the center.

6. MERGERS

Mergers represent the most drastic phenomenon of galaxy interactions: a collision of galaxies that end up in the complete fusion of its original components into a "new" single galaxy. Although the development o infrared astronomy and of modern simulation techniques has drawn much attention, and has shed new ligh on the subject of merging galaxies, it is by no means a recent discovery. Already in 1977 Toomre propose a possible evolutionary sequence represented by four equal mass disk-disk merger's stage. Going from earl to late merger stage, he used the examples of the "Mice" (NGC 4676), the "Antennae" (NGC 4038/39), th "Atoms-for-Peace" galaxy (NGC 7252), and Arp 220. Today we still regard this sequence as basically correct If we include modern data on the gas (both atomic and molecular) distribution, which we have seen is crucia in the study of dynamical perturbations, we can describe the evolutionary sequence of a merger in the followin general terms (see also, Schweizer 1986; Scoville et al. 1994).

The early stages of merging are characterized by large ammounts of H I still observable in the disk; S is spread through the disk (and obviously, so is the Hα emission). Clearcut examples of this stage are th systems Arp 295 and the "Mice". Arp 295 has both a bridge and a tail indicating at least one passage of th two galaxies about each other, but both disks are still distinct. The system has also extended tidal tails and luminous bridge of material between the two galaxies. Approximately 65% of the total H I mass appears outsid the optical disk, and the Hα is widely distributed over both galactic disks and tidal tails (see Figs. 3 and 4 i Scoville et al. 1994). A slightly more advanced stage is illustrated by the system NGC 520/UGC 975 (Sander et al. 1988).

It is at the intermediate stages of a merger, that the strongest mid- and far-infrared, and CO luminositie are emitted. SF is enhanced in tails, and in the case of ULIGs, Blue Compact Dwarf (BCG) and irregula galaxies may be formed in the tip of the tails (see below). Molecular gas is observed to be highly concentrate in the center. Typical examples are: Mkn 430 (NGC 3921), which consists of a single nucleus with two tida systems —one stellar and one gaseous— suggesting the system may be the result of a merger of a spiral and a ga poor S0 galaxy. The presence of a large star-forming cluster in the southern tail suggests that self-gravitatin systems are forming there (Hibbard & van Gorkom 1993). The "Antennae" (e.g., Whitmore & Schweizer 1995 and its ULIG counterpart, the "Super-antennae" (Mirabel et al. 1991) are both spectacular examples of merger in progress. In the case of the "Super-antennae", the tails emanate from a merger of giant gas-rich galaxie that harbor two nuclei: one SB, and one Seyfert. Mirabel et al. (1992) found a BCG at the tip of the souther tail (see also Yoshida et al. 1994). These small SFGs of tidal origin resemble BCDGs, and are likely to becom detached systems. Because the matter out of which they are formed has been removed from the outer parts o giant disk galaxies, the isolated tidal dwarf galaxies thus formed have low metallicities.

The "Atoms-for-Peace" galaxy, and Arp 220 are very good examples of advanced mergers. The first on is probably an advanced merger of two disk systems. The optical light distribution indicates an $r^{1/4}$ law, an the merged galaxy may be well along towards forming an elliptical galaxy core (Schwizer 1982). Molecular ga (80% of the CO emission) is in the very central region (Wang et al. 1992), while most atomic gas is containe in the tidal features, and Hα emission is seen both from the nucleus, and also filling the gap between the C and innermost H I. Arp 220 is an example of a very advanced merger; the progenitor's morphology is totall indistinguishable, and it has only very faint tidal tails. Its infrared luminosity at $\lambda = 8-1000\ \mu$m is $1.5\times 10^{12} L_\odot$, exceeding that in the visual by two orders of magnitude, and placing it in the luminosity range of quasars. Both blue and redshifted velocity components are present in the CO distribution, indicating that the molecular gas has partially relaxed to a disk-like configuration (Scoville et al. 1994).

An interesting debate has been going on for years in the literature, on the source powering this object. Is it a heavily enshrouded AGN or is it a "super SB"? Recent evidence shows that it is very probably *both*! (Prestwich et al. 1994, and references therein). Arp 220 is not the only case where both types of powering seem to be present. Another example is the well known "pre-*IRAS*" merger prototype: Arp 229 (Curti & McAlary 1985), with extremely strong mid-infrared and radio continuum, which seems to contain both a dust enshrouded AGN and various super-SB regions. These examples illustrate what we are now beginning to realize: that very often, it is not easy to separate one type of activity -SB- from the other —non-thermal (or properly AGN)—; the main reason being precisely the fact that galaxy interactions may trigger both types of activity, often simultaneously (e.g., Dultzin-Hacyan 1995, and references therein). Often the challenge is precisely to disentangle the relative contributions at different wavelengths of SBs from other sources of radiation —such as an accretion disk and/or jet— from the nuclei of galaxies (for a detailed analysis of the relative nuclear/circumnuclear contribution to radiation in the case of Seyferts, see Dultzin-Hacyan & Ruano 1996). The enormous gas concentrations, up to $10^{10} M_\odot$ within 0.5 kpc radius of the merger nucleus seen in LIGs, are an ideal breeding ground for a variety of powerful phenomena, including SBs, super-winds, formation of massive star clusters, and most likely, the formation and/or fueling of AGN. We cite one of the main conclusions in Sanders & Mirabel (1996): "LIGs very likely represent an important link between SBs and the AGN phenomena exhibited by QSOs and PRGs (powerful radio galaxies)".

7. WHAT HAVE WE LEARNED FROM *HST*?

Before *HST*, the observational data regarding the direct effect of galaxy collisions was limited primarily to the local universe, at $z \leq 0.1$, providing a very limited baseline over which to examine galaxy evolution. *HST* has provided the means to extend this baseline, with deep images of galaxies up to $z \leq 1.0$. The high spatial resolution and reduced sky background offered by *HST*, allows for accurate morphological typing of such galaxies often revealing multiple nuclei, tidal features and distorted isophotes. Using such morphological features, the effect of galaxy mergers at intermediate redshift may *in principle* be probed.

One particularly difficult problem is posed by the "E + A" systems (galaxies with spectral evidence for both an old stellar population and a recent SB). In an investigation of the intermediate redshift clusters AC 114 and Abell 370, Couch et al. (1994) found little or no evidence for mergers signatures among E + A galaxies, suggesting that other mechanisms may be responsible for triggering SBs in otherwise normal elliptical galaxies. Recently, however, Mihos (1995) used a combination of numerical simulations and synthesized *HST* images taken with *HST*/WFC1 to investigate this problem. Numerical calculations show that violent relaxation rapidly smoothes isophotal irregularities after the galaxies merge, leaving the very low surface brightness tidal debris surrounding the remnant as the only sign of peculiarity after a few hundred Myr. This debris becomes indistinguishable from the main body of the remnant after ≤ 0.2 ($z = 1.0$) to 1 ($z = 0.4$) Gyr. Using WFC1, all signatures of interaction become undetectable almost immediately once the galaxies merge, due to aberrated PSF (point spread function), and thus the fact that the above mentioned E + A systems appear morphologically normal in WFC1 images is not inconsistent with a merger origin for those galaxies. With the improved optics of WFC2, perhaps a more stringent test of the merger origin may be possible.

Taking into account the expansion of the Universe, the frequency of interactions should be higher in the past. The straightforward, naive dependence should be proportional to the peculiar velocities of the galaxies $\sim (1+z)$, and inversely proportional to their mean free path $\sim (1+z)^{-3}$, and thus the frequency of interactions should be proportional to $\sim (1+z)^4$. Due to various nuances whose discussion is outside the scope of this work, things are not so simple and several discrepant estimations have been obtained, that go from a constant value to $\sim (1+z)^4$ (e.g., Lacy & Cole 1992; Carlber 1992; Menci & Valdarini 1994). Recently, Keel & Wu (1995) took into account the new results of counts of pairs in deep *HST* fields (Burkey et al. 1994), and found that the frequency of interactions increases as $\sim (1+z)^{1.5}$. On the other hand, Mihos & Hernquist (1994) have shown that even relatively minor mergers (disk galaxies that accrete low mass dwarf companions) may trigger strong SBs (see also, Taniguchi this volume), and thus our main conclusion is, that *if* it is true that most galaxies have experienced one or more interaction-induced SB episode(s), or interaction-induced enhanced SF, this fact has profound implications for spectral, chemical, and morphological evolution of galaxies.

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