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Hidden Interaction in SB0 galaxies

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Botany of Interactions

Galaxies, like plants, show a large variety of grafts: an individual of some type connects physically with a neighborhood of same or different type. The effects of these interactions between galaxies have a broad range of morphologies depending, among other quantities, on the distance of the closest approach between systems and the relative size of the two galaxies. A sketch of the possible situations is shown in Table 1. This 'botanical' classification is just indicative, because the effects of interactions can be notable also at relatively large separations, when additional conditions are met: as for example low density of the interacting systems or the presence of intra-cluster gas. In spite of the large variety of encounters and effects, in the literature the same terms are often used to refer to different types of interactions.

Table 1: Indicative classification of different types of interaction between galaxies as a function of their closeness and of their relative mass. The phenomenon implied is indicated in the table, with the possible results of the interaction suggested in parenthesis. Three cases of mass ratio are considered: *i*) galaxies with same mass, *ii*) comparable masses between the *primary* galaxy and its *satellite*, *iii*) mass of the companion negligible (*point-mass*).

$\frac{M_{companion}}{M_{primary}}$	Closeness		
	In contact	**Close to very close**	**Bound**
$\simeq$**1**	merging (*E galaxy*)	tides (*bridges, tails distortions*)	clustering (*double or multiple systems*)
<0.1	accretion (*gas rings, kinematical decoupling, counterrotation*)	perturbation (*warps, bridges, tails, shells*)	capture (*satellite*)
$\ll$**1**	evaporation (*increase of bulge or halo size*)	capture (*halo star cluster*)	capture (*intergalactic star cluster*)

As can be seen from Table 1, only few of the situations show evident signs of interaction. They appear to be most relevant when the size of the two galaxies is comparable. Bridges and tails, like the well known case of NGC 4038/39, *the Antennae*, are only observed for a very low percentage of all galaxies (~0.38%, Arp & Madore 1977). In most cases of gravitational bond between two galaxies, the effects of interactions are not relevant or evident. For instance, the detection of stellar shells (Malin & Carter 1983), which have been attributed to the accretion of gas stripped from another galaxy or to the capture and disruption of a small stellar system (Quinn 1984), requires particular observing and reduction techniques. Besides these difficulties of detection, time plays an important role in erasing, within a massive galaxy, the effects of interactions with smaller objects. This can happen on a timescale shorter than the Hubble time, so the number of systems now showing signs of interaction suggests a lower limits to the *true* frequency of interactions in the life-time of a stellar system.

Hidden interactions

In this paper we want to discuss one type of interaction whose effects are not manifest, but hidden within the main body of the galaxy. In Table 1, the last two items of the first column describe this type of interaction. Differently from merging, which implies the complete absorption of the components of the galaxies into one another, accretion of a small quantity of matter (gas or a whole stellar system) does not alter the structure of the original galaxy. The evidence for this kind of interaction should be easier to detect than a complete merging, since the residuals of the acquired galaxy do not lose their identity within the host galaxy for a long time. In addition, we must expect that a destructive merging, like that of two equal-sized galaxies, should yield configurations trending toward dynamical and structural entropy, like elliptical galaxies. On the contrary, the above mentioned accretion process could be sought within both ellipticals and S0 galaxies, increasing the number of candidates. We shall discuss later what morphology the phenomenon could assume when accretion involves spiral galaxies.

Keeping in mind these differences, a more or less recent accretion of gas (and possibly stars) could produce irregularities in the galaxy kinematics or in the gas distribution. For example, the existence of elliptical galaxies with dust and gas rings along the apparent minor axis (Bertola & Galletta 1978) could be a clue of accretion, especially if this gas exhibit a kinematics independent from that of the stars (Sharpless *et al.* 1983, Caldwell 1984, Bertola *et al.* 1985, Wilkinson *et al.* 1986). A similar kinematical decoupling has been also observed in some S0's, where a gas ring extending far out the stellar body rotates perpendicularly to the stellar disk (polar ring galaxies, see Schweizer *et al.* 1983). Such kinematical decoupling is not a prerogative of dust-lane ellipticals or polar-ring S0's, but is also present in normal elliptical galaxies with emission lines (see Bettoni 1984 for a collection of cases). In the context, the observations of some galaxies where gas and stars rotate in opposite directions (Bettoni 1984, Caldwell *et al.* 1986, Galletta 1987, Rubin 1988, Bertola *et al.* 1988, Bertola & Bettoni 1988, Schweizer *et al.* 1989) is another tessera completing the mosaic of galaxy interactions.

This kinematical feature, *gas counterrotation*, is particularly interesting when observed in S0 galaxies. The complex structure of such stellar systems supports, as stated before, the hypothesis of acquisition of a small quantity of gas that is unable to perturb the global structure of the host galaxy. The two SB0s studied by us, NGC 4546 and NGC 2217, do indeed not reveal any particular anomaly in the distribution or in the kinematics *of the stars*. Their main peculiarity is only apparent in long-slit spectra, that show emission and absorption lines inclined in opposite directions.

In the cases of NGC 4546 (Galletta 1987, Bettoni *et al.* 1990b) and of another S0 galaxy, NGC 1216 (Rubin 1988), both galaxies are seen relatively edge-on and simple geometrical considerations imply that the opposite inclination of the emission- and absorption lines in the spectra arise from two almost coplanar disks of gas and stars rotating in opposite sense. An Hα knot, possibly the residual of the accreted object, has been detected near the bright Hα nucleus of NGC 4546 (Bettoni *et al.* 1990b). When the gas entered the galaxy, it settled in the plane of the galaxy following the global potential. An estimate of the time needed by the gas to completely settle in the equatorial plane is of order of hundred million years (Galletta 1987), while possible interactions with stars by dynamical friction would take $\sim 10^{10}$ years to become effective. This would not be the case if some appreciable amount of gas pre-existed in the galaxy (as in the case of spiral galaxies). Since the velocity differences between gas and stars are, for NGC 4546, $\sim$400 km s^{-1}, it is possible to imagine that a collision between existing clouds and newly entering gas would have enough energy to create high-energy radiation. The shock-heated gas could diffuse within and around the galaxy, eventually *evaporating* in a low density halo. On the contrary, also the H I observed in NGC 4546 has the same sense of rotation as the ionized gas, and none of the galaxies with counterrotating gas are known to be luminous at X-ray wavelengths.

In other words, we think that it is unlikely that a relatively stationary disk of counterrotating gas can occur in spiral galaxies, and that galaxies showing gas counterrotation, Ellipticals and S0s, were gas free at the epoch of last accretion. To support this statement, we note that neither counterrotating gas nor polar rings have been observed in (gas-rich) Spirals. The unstable structures resulting from such accretions should probably be searched among the many irregular objects existing in the Universe or in something similar to the H I clouds with anomalous velocities detected in M101 or in other spirals (van der Hulst & Sancisi 1988).

To complicate the picture, not all cases where in long-slit spectra the lines of gas and

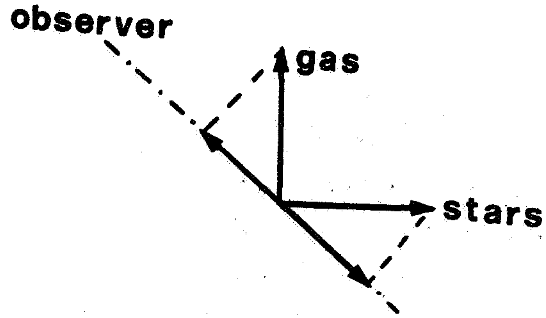

Figure 1: Two motions reciprocally perpendicular could be observed as opposite, generating an *apparent* counterrotation

stars exhibit an opposite tilts are examples of gas counterrotation. In fact, the opposite tilt of emission and absorption lines only imply that along the line-of-sight the rotational velocities are opposite, not necessarily that the gas and star disks have antiparallel spins. An example of this is the barred S0 galaxy NGC 2217 (Bettoni *et al.* 1990a): Contrary to the previous edge-on cases, this galaxy is seen almost face-on, but the stellar rotation is still clearly observable. Near the nucleus of the galaxy, a gas disk, perpendicular to the (stellar) equatorial plane, is projected on the sky almost edge-on. So we observe two disks rotating almost perpendicularly, as in polar-ring galaxies. It is possible to show that the motions of two such disks, rotating perpendicularly in space, have opposite velocity components along the line-of-sight when seen from particular viewing angles (see Fig.1). In NGC 2217 we are observing a case of perpendicular spins and not a true case of counterrotation. In fact, in the outer regions, where, driven by the bar, the inclination of the gas-disk changes and it coincides with the galactic plane, gas and stars show the same direction of motion. This pretty peculiarity is important when one is dealing with elliptical galaxies, where the orientation with respect to the line-of-sight is unknown. The existence of a projection effect similar to that observed in NGC 2217, as also discussed by Bertola & Bettoni (1988), would reduce the *true* frequency of occurrence of the counterrotating gas in elliptical galaxies. But no statistics could be done with the small number of cases known until now.

As a final consideration, we note that over 15 SB0 studied by us in a long-term project on the dynamics of this type of galaxies, 4 of them show emission lines. Among these four cases, for three there is clear evidence that this gas has been accreted: NGC 4546, with counterrotation, NGC 2217, with perpendicular and unstable disk, and NGC 4684, with filaments and irregular gas kinematics. This high occurrence of peculiarities poses the question, appearing sometimes in the literature, if all the gas in early-type galaxies has been accreted.

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DISCUSSION

R.Kennicut: Do you know anything about the ionization properties of the counterrotating gas?

G.Galletta: Our spectra were taken at intermediate resolution, to investigate in detail the velocity field, and the emission lines present are only [O III] and Hβ. Our requests to ESO for observing time in order to study the chemical composition of the counterrotating gas were never accepted until now. If done, they could reveal if this gas really comes from the accretion of a late-type system or if we are dealing with primordial material falling on the galaxy from the environment.

R.Kennicut: Do your galaxies show any other evidence of recent mergers, such as tidal tails, etc.?

G.Galletta: No tidal tails are visible from our images. Features more difficult to detect, like shells, need a technique that we have not applied to our frames. A warped and twisted gas layer is present in NGC 2217.

A.Zasov: What do you think about the fate of the counterrotating gas in the galaxies considered?

G.Galletta: Following the current theories, the fate of the gas accreted by the SB0 galaxy strongly depends on the impact angle. If this is close to the plane of the disk, the gas forms before a warped plane, than settles on the same plane of the stars in a short time. If the impact direction is very inclined with respect to the disk plane, the external part slowly settles on it, while the inner part, perpendicular to the bar, could precess differentially and finish later to collapse toward the center. Only almost perpendicular orbits could form a polar ring in equilibrium configuration.

A.Zasov: It is possible to obtain some restriction on the density of "native" gas in galaxies which should actively interact with the counterrotating gas?

G.Galletta: Since the velocity differences between gas and stars are very high, but no X-ray emission caused by collisions between native and accreted gas has been detected, I can estimate the native gas density to be very low. But I cannot quantify this estimate.

A.Fridman: Did you try to estimate the damping-time of gas component because of interaction with stellar component in NGC 4546?

G.Galletta: In the literature, there are some estimates of the time the gas settles in the plane of the disk. In a case like NGC 4546, it is expected this phenomenon takes place in a time of few 10^8 years.

A.Fridmann: What do you think about the possibility of a gas disk with two counterrotating parts?

G.Galletta: Contrary to the stars, the gas strongly interacts with pre-existing gas. I am expecting two counterrotating disks of gas cannot co-exist in the same galaxy. Two masses of gas could eventually survive as two concentric rings, if dissipation or differential precession do not destroy this peculiar configuration. But we have no indications that a galaxy with such configuration exists.

Khachikian: What is the distance between the two nuclei of NGC 4546?

G.Galletta: The projected separation between the two nuclei is $\sim$350 kpc.