THE FATE OF THE MOLECULAR GAS FROM MERGERS TO ELLIPTICALS

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1. From Disk Galaxies to Ellipticals

Because of their mutual gravitational interactions, galaxies do not live forever. In extreme collisional events, galaxy pairs can merge into single spheroidal systems. Numerical simulations (Barnes 1988) indeed support the suggestion that the formation of some ellipticals does result from the merging of two disk galaxies (Toomre and Toomre 1972). However, one must then explain the *very low molecular-gas content of ellipticals* compared to that of spiral galaxies. Could the burst of star formation triggered during the merging exhaust the molecular material of the disk progenitors ? In order to test this hypothesis, data must be collected on the gas content of mergers at various stages of evolution and of "genuine" ellipticals as well. We here report on multi-line ^{12}CO and ^{13}CO observations of a sample of such objects. Our aims were (i) to contribute to a better knowledge of the molecular content of elliptical galaxies, and (ii) to help understand *when and how the molecular gas of a merging system is consumed on its way towards an elliptical.* The detailed presentation and discussion of the results are to be found in Casoli *et al.* (1988 : Paper I ; 1990 : Paper III), Dupraz *et al.* (1990 : Paper II), and Dupraz and Casoli (1990).

2. Four Ongoing Mergers and an Old Merger Remnant

We have already presented ^{12}CO J=1–0 and J=2–1 observations of two ongoing mergers, Arp 220 and NGC 2623 (Paper I), and of the old merger remnant NGC 7252 (Paper II). Recently, we have mapped two other merging systems, NGC 1614 and NGC 3256, in the same lines ; additional ^{13}CO (1–0) and (2–1) spectra of the centre of NGC 3256 were also obtained. The observational procedure and data are described in Paper III. For NGC 1614 some of the results are displayed below (Fig. 1) ; for NGC 3256, our data appear in excellent agreement with those presented by Aalto *et al.* (1990) in this volume.

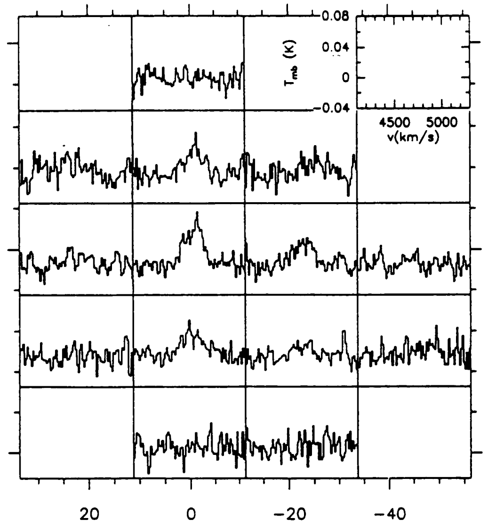
These observations suggest that the molecular-gas component of ongoing mergers is more concentrated than that of disk galaxies. It is unresolved in NGC 1614 and 2623 with a maximum diametre of 7 kpc for both objects. Besides, interferometric observations have shown that 30% of the single-dish flux of NGC 1614 is emitted from a region less than 2 kpc in size (Scoville *et al.* 1989). Such a behaviour is the consequence of the mechanical agitation which accompanies the merging. Frequent collisions make gas clouds efficiently dissipate their energy, and sink towards the centre of the system. However, *the molecular distribution is bound to remain extended*, as the free-fall time of the outer material exceeds the duration of the violent relaxation phase (a few 10^8 yrs for the inner regions). The other

F. Combes and F. Casoli (eds.), Dynamics of Galaxies and Their Molecular Cloud Distributions, 373–375.

galaxies, for instance, are actually resolved in CO, with diametres of ≈ 7 kpc for Arp 220 (Paper I) and 3–4 kpc for NGC 3256 (Paper III, Aalto *et al.* 1990).

The large L_{IR}/L_B and $L_{IR}/M(H_2)$ ratios of the four systems reveal their intense star-formation activity (superposed to an active nucleus for Arp 220). Nevertheless, it is most unlikely that these starbursts can affect regions that extend over several kiloparsecs. This hypothesis is in particular ruled out by the measured values of the CO(2–1)/CO(1–0) ratio. Ranging from 0.6 in Arp 220 to 1.2 in NGC 1614, they are intermediate between what is found in disks and nuclei of spirals – much lower than in the starburst regions of M82 or NGC 1808 where they reach 2–3 (see Paper III). A dominant contribution from hot, thin CO-emitting gas is thus precluded. It suggests that the central starburst regions of ongoing mergers are enshrouded within the bulk of their molecular material, *which physical conditions are not radically different from those measured in spiral galaxies*. This may account for the self-absorption feature found in the CO(2–1) spectrum of NGC 2623 (Paper I).

Not only the starburst concerns a very limited region of the system : its efficiency is also most unlikely to exceed, say, 50% because of the self-regulation of the star-formation process itself. Significant amounts of cold gas are thus expected to be left in post-starburst merger remnants. Our observations of NGC 7252 support this conclusion (Paper II). In



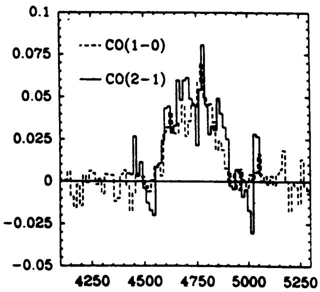


Figure 1. NGC 1614 – observations made with the SEST 15m telescope :
left : map of CO(1–0) spectra ; beamsize is 44" (13.4 kpc), sampling is 22" ;
above : CO(1–0) (dash) and CO(2–1) (full) spectra of the centre, convolved to 44" ;
– temperature scale : main-beam temperature
– systemic velocity : V_{hel} = 4730 km s^{-1}
– molecular mass : $M(H_2) \approx 6.5\ 10^9\ M_o$

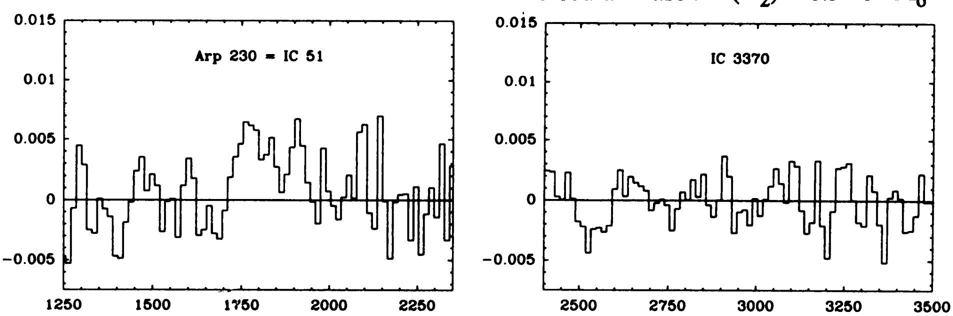


Figure 2. CO(1–0) spectra of two ellipticals ; *left* : Arp 230, $M(H_2) \approx 1.0\ 10^8\ M_o$; *right* : IC 3370 : $M(H_2) \leq 3.5\ 10^8\ M_o$; beamsize is 44", temperature scale is T_A^*.

this old merger / young elliptical, the starburst has not starved out by lack of fuel – its H_2 mass is still of 3.6 10^9 M_o – but because it became a relaxed stellar system. In Sect. 1, we asked when and how a merger gets fully rid of its gas. Parts of the answer seem to be : (i) it does not happen during the merging event, and (ii) it is not due to a burst of star formation. *Provided that its progenitors were gas-rich, a young elliptical galaxy should possess amounts of molecular gas much larger than what is present in "genuine" (older) ones.*

3. The Molecular Content of some Elliptical Galaxies

In order to complete this study, we observed a sample of such "genuine" ellipticals with SEST in $^{12}CO(1\text{–}0)$. The objects were selected in a highly biased way, so that they would possess as much molecular material as possible : (i) presence of shells or dust lanes indicating a recent accretion event (Arp 227, Arp 230, NGC 1947) ; (ii) recent activity of star formation evidenced by strong Balmer absorption lines (NGC 1700, NGC 3156 ; Schweizer 1989, priv comm) ; we also included the peculiar box-shaped elliptical IC 3370 (Jarvis 1987). The full sample is described in Dupraz and Casoli (1990). Although most galaxies are detected by IRAS, *we have only detected one, Arp 230* (Fig. 2), with an H_2 mass as low as $M(H_2) \approx 10^8$ M_o. For the other objects, upper limits of a few 10^8 M_o are derived (IC 3370 : see Fig. 2), which are actually comparable to the detections and limits found by other authors (see Wiklind 1990). More precisely, it seems that only those elliptical galaxies that have recently experienced a major accretion event still possess large amounts of cold material : for instance, $M(H_2) \approx 10^9$ M_o for Centaurus A (Phillips *et al.* 1987).

In conclusion : *elliptical galaxies are a very hostile environment to the molecular gas. Either by consuming this gas in normal star formation or heating it to X-ray temperatures, it prevents them for keeping or for developing a cold interstellar component.* Many non-exclusive processes can be invoked to make the cold material vanish, among which :
– normal star formation rates (to standards of spiral galaxies) without replenishment of the interstellar medium by cooled gas : in a nearly spherical potential, the gas expelled by the evolved stars does not return to the symmetry plane of the galaxy by lack of strong restoring force, and mixes with the X-ray emitting gas component ;
– erosion of molecular clouds by efficient H_2 photo-dissociation in an interstellar radiation field, again due to the 3D shape of ellipticals compared to the disk geometry of spirals ;
– dynamical destruction or dispersion of molecular clouds by star-cloud collisions, in the central regions of the galaxies where the stellar density and velocity dispersion are high.
Assuming a net gas consumption rate of a few M_o yr^{-1}, a molecular component as massive as several 10^9 M_o – such as the one of NGC 7252 (Paper II) – can disappear within 1 Gyr only : this could account for the low CO detection rate of elliptical galaxies.

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https://doi.org/10.1017/S0074180900244574 Published online by Cambridge University Press