CO IN NGC4438 AND TIDAL STRIPPING IN THE VIRGO CLUSTER

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1. Background

It is now well established that the environment plays an essential role in the morphology and evolution of galaxies: in particular, the HI gaseous content is often deficient for galaxies in clusters, and the deficiency increases towards the cluster center (cf for the Virgo cluster: Chamaraux et al 1980, Cayatte et al 1988, in prep). The gas is mostly deficient in the outer parts of galaxies, which considerably reduces the size of HI disks (van Gorkom & Kotanyi 1985). However the central gaseous content, usually under the form of molecular hydrogen traced by CO emission, seems normal, at least in the Virgo cluster, the only one surveyed at millimetric wavelengths (Kenney & Young 1986).

Two main mechanisms have been proposed to explain the HI deficiency: either interaction with the hot intracluster medium (ICM), or tidal stripping during collisions with other cluster galaxies. The former process, which can be ram-pressure sweeping (Gunn and Gott 1972), thermal evaporation (Cowie and Songaila 1977) or viscous stripping (Nulsen 1982) has been favoured in Virgo and the other X-ray emitting clusters. In particular NGC4438, one of the closest galaxies to the Virgo center M87, has been considered as the archetype of galaxies swept out by the ICM (Kotanyi 1981): radio-continuum, X-ray and HI emissions reveal NW extensions, in the opposite direction to M87 (Kotanyi et al 1983).

The determination of the molecular gas distribution provides a crucial test for these mechanisms: indeed the molecular material is too dense to be easily swept out, and large perturbations in the CO emission are likely to be of tidal origin.

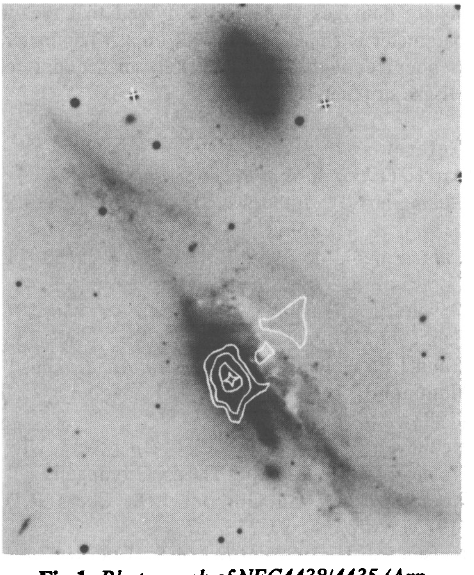

Fig.1: *Photograph of NFC4438/4435 (Arp 1966). Solid lines: contours of $\int T_R{}^* CO(1\text{-}0)\, dV$; levels 8, 20, 50 Kkm/s. The star is the radio continuum position.*

2. CO observations

We mapped the galaxy at 23" resolution in CO(1-0) with the IRAM 30m telescope at Pico Veleta (Spain). The contours of CO integrated emission are superimposed onto the Arp photograph in fig.1.

A strong, highly-concentrated component of diametre 25" (2.5 kpc at the adopted distance of 20Mpc) at half maximum is centered on the continuum source (Hummel et al 1983). Roughly elongated along the major axis, it appears associated to the unperturbed inner galaxian disk, and coincides with regions of non-thermal radio-continuum and X-ray emissions that are likely due to star

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formation. We derive a total H_2 mass of 2.9 10^9 M_0 for this central component, assuming a standard NH_2/I_{CO} of 4 10^{20}. The CO velocity field corresponds to a very regular rotation, in agreement with the Hα rotation curve (Chincarini and de Souza 1985).

We also mapped the NW-displaced component of CO emission up to more than 1' from the centre. This component reveals very unusual features, such as very large linewidths (300km/s at zero level), and almost no central velocity gradient. The total H_2 mass in this component is 1.2 10^9 M_0.

3. Theoretical interpretation

The discovery of molecular gas displaced in the same direction as HI, X-ray and radio emissions does not support the hypothesis of the ICM sweeping. Indeed, the average surface density of the molecular gas σ_{gas} = 200 M_0/pc^2 is too high for the ram-pressure to be efficient. Assuming a mean ICM density of 2 10^{-4} cm^{-3} (Fabricant and Gorenstein 1983) and a velocity through the ICM of 1200 km/s for NGC4438, a crude estimate of the ram-pressure exerted by the ICM on the galaxy is p_{ram} =6 10^{-12} dyne/cm^2. The ratio R of the gravitational restoring force (GM/r^2) to the ram-pressure force can then be estimated for r=10kpc at R= 100 >> 1. Also, the presence of two stellar tails (NE and SW), strongly suggests a tidal interaction with a nearby companion, which is only 4.'5 = 26kpc away in projection on the sky.

We therefore simulated the encounter with a test-particle code similar to that used by Toomre and Toomre (1972), the details of which are described in Combes (1978). We take a mass ratio of 1/2 between NGC4435 and NGC4438, according to their luminosities. Since their relative line of sight velocity is high (690km/s), we choose an hyperbolic orbit, of eccentricity *e* =4. The minimal distance of approach is 6kpc, since perturbations begin only beyond that distance in the CO emission. Only a retrograde passage can fit the observations.

Fig. 2 shows that the tidal-encounter model successfully accounts for the overall shape of NGC4438 and its companion. Contrary to previous arguments, even a highly hyperbolic retrograde collision can inflict severe damages to a disk, provided that the impact parameter is small. Such small impact parameters are frequent enough in rich clusters to account for the HI-gas stripping observed.

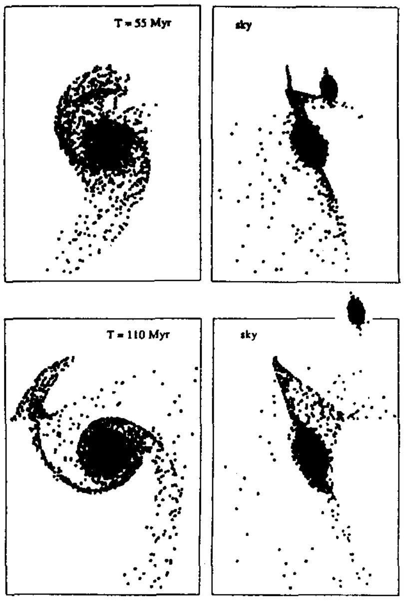

Fig.2: *Two snapshots of the simulation for t = 55 Myr and t = 110 Myr. Right panels: projection on the sky plane. Left panels: left-hand-side projection, for which the galaxies are almost seen face-on.*

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