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## NGC 4438: RAM PRESSURE SWEEPING OF A TIDALLY DISRUPTED GALAXY.

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## ABSTRACT

NGC 4438 is the highly HI deficient peculiar spiral in the center of the Virgo cluster. ~~In this paper we present observations~~ of the neutral hydrogen emission obtained with the VLA in the D-array configuration. These observations map out the total HI as determined from single dish measurements, and show the hydrogen to be confined to a region about one third the size of the optical disk and displaced to the side of the galaxy opposite M87. The hydrogen content of the galaxy is over an order of magnitude less than that expected for a galaxy of its type.

The data suggest that the HI deficiency is a result of ram pressure stripping of the gas in the outer regions of the galaxy by the hot intracluster medium after being tidally perturbed.

## I. INTRODUCTION

It is well known that the central galaxies in clusters with high X-ray luminosities are deficient in HI in comparison with galaxies in less volatile environments (Giovanelli and Haynes, 1985), suggesting that the hot intracluster medium plays a crucial role in removing the gas from these galaxies. This effect is most strikingly illustrated in figure 23 of Cayette et al. (1989) of HI observations of the galaxies within  $5^\circ$  of M87, a bright X-ray source. All of the galaxies within  $2^\circ$  of M87 have greatly reduced HI disks sizes.

NGC 4438 is in projection the closest spiral to M87 ( $50' = 150$  kpc, assuming a distance to Virgo of 12 Mpc, used throughout this paper). If it is physically close to M87, it moves through that galaxy's X-ray halo at supersonic speeds, and is therefore a prime candidate to study for the effects of the sweeping of its interstellar medium (Kotanyi, van Gorkom and Ekers, 1981). Optically the galaxy looks disturbed, possibly caused by an interaction with NGC 4435, which is close in projection ( $4.3'$ ) to NGC 4438. Yet the neutral hydrogen observations of NGC 4438 are not typical of tidally involved galaxies: clearly interacting systems with HI show the gas to be almost always extended, either in narrow tails or diffuse envelopes, and to have roughly the gas content expected for their morphological type.

The intent of this observation was to recover the full velocity width profile of NGC 4438, which previous synthesis observations failed to do. With the HI fully located it is now possible to address the cause of the peculiar hydrogen extent and content.

## II. OBSERVATIONS

NGC 4438 was observed with the VLA of the NRAO\* in the compact D-array configuration. The spatial resolution is  $60''$  and the velocity resolution is 21 km/s. The rms noise in the channel maps is 0.75 mJy/beam. These observations are sensitive to hydrogen emission on scales less than  $15'$  and column densities greater than  $8.3 \times 10^{17}$  atoms/cm<sup>2</sup> per channel ( $3\sigma$ ). We recover the full profile width of  $412 \pm 21$  km/s found from single dish observations, and find a total hydrogen content of  $1.7 \times 10^8 M_\odot$ .

## III. DISTRIBUTION AND KINEMATICS OF THE GAS

The intensity distribution from the zeroth order moment is given in figure 1 overlaid upon the optical photograph from Arp (1966) and the CO observations of Combes et al. (1988).

The maximum has a peak of  $4.9 \times 10^{20} \text{ cm}^{-2}$  and is displaced to the northwest of the galaxy, anti-correlated with the CO peaks. A secondary peak of  $1.2 \times 10^{20} \text{ cm}^{-2}$  occurs towards NGC 4435 and coincides with the end of the swept back stellar arm. Similar peaks are found in the tail features of other interacting galaxies. The HI disk is only a third the size of the optical disk.

The line emission was detected in 21 channels, from 300 to -112 km/s. These channel maps are presented in figure 3. The intensity-weighted velocity field is given in figure 2. The velocity field is disturbed, but regular.

#### IV. DISCUSSION

The HI deficiency parameter, DEF, is defined by Haynes and Giovanelli (1983) as the difference in the logarithm of galaxy's observed HI mass from that expected for a normal galaxy of similar morphological type and optical diameter. Figure 4 plots the HI flux (which is proportional to HI mass) versus the corrected photometric diameter,  $D_0$ , for late type galaxies of the comparison field sample used by Haynes and Giovanelli, as well as for several classes of interacting and peculiar galaxies from data presented by Davis and Seaquist (1983). It is found that the interacting and peculiar samples follow the same relationship as the comparison sample, albeit with a wider spread. NGC 4438 is found to lie over an order of magnitude off of the relationship, with a DEF of  $1.44 \pm 0.20$ . This makes it one of the most hydrogen deficient galaxies measured.

Ablation processes, such as ram pressure sweeping (Gunn and Gott, 1972) and thermal evaporation (Cowie and Songaila, 1977) are expected at the gas densities and X-ray temperatures appropriate to NGC 4438, if it is within the X-ray halo of M87 (Kotanyi, van Gorkom and Ekers, 1981, Chincarini and de Souza, 1985). Yet these processes cannot mechanically affect the stellar component of the galaxy. The tidal encounter scenario of Combes et al. (1988) nicely reproduces the stellar and molecular features of NGC 4438, as well as the general distribution of the HI which is found. But simulations and observations show that interactions do not remove the HI, and they extend rather than truncate the size of the disk.

The best explanation of the data is that both effects are important in this case. We believe that NGC 4438 underwent a tidal encounter with NGC 4435 which displaced the hydrogen and molecular features and produced the sweptback arm. The hydrogen disk was extended, moreso nearest NGC 4435, where it became clumped along the northern arm. Since the galaxy was within the halo of M87 during or shortly after the encounter, this extended gas was easily removed by the hot IGM, since both the column densities and the gravitational pull of the galaxy were lower.

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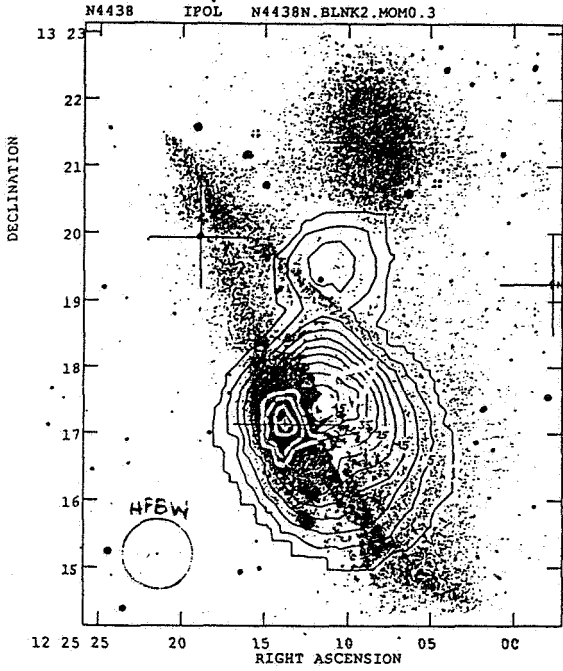


Figure 1: Hydrogen contours (black) for NGC 4438 superposed on the photograph from Arp (1966) and the CO(1→0) contours (white) from Combes et al. (1988). The Hydrogen contours are in units of  $10^{19}$  atoms/cm<sup>2</sup>, and the CO contours are at levels of 8, 20, and 50 \*K km/s.

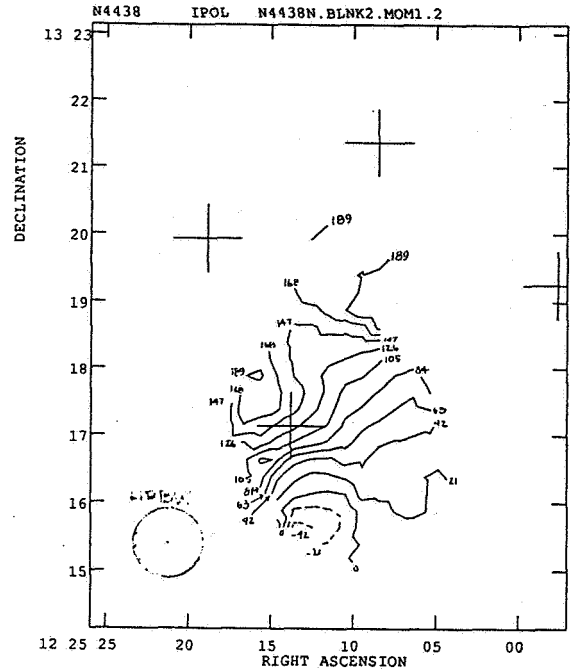


Figure 2: Intensity-weighted HI velocities (km/s) for NGC 4438. Crosses mark the optical centers of NGC 4438 and NGC 4435 and two reference stars.

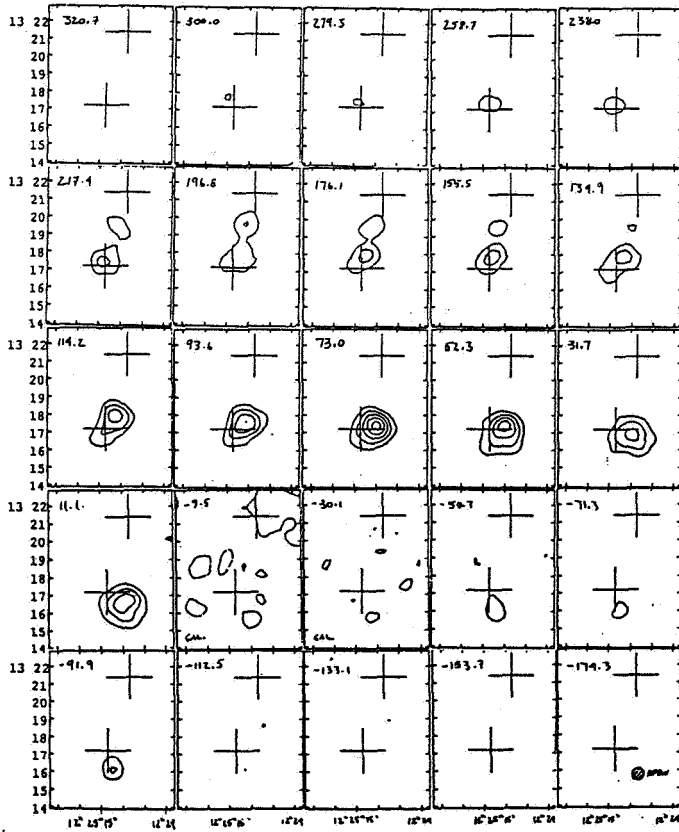


Figure 3: Channel maps of 21 cm-line radiation from NGC 4438. The contours are in steps of  $1.7 \times 10^{19}$  atoms/cm<sup>2</sup> ( $\Delta v$ ). Negative contours are dashed. The heliocentric radial velocity (km/s) of each channel is indicated at the top left of each frame. The channels at -9.5 and -30.1 km/s are contaminated by HI from the Galaxy. Crosses mark the optical centers of NGC 4438 and NGC 4435. The hatched ellipse in the final frame shows the size of the synthesized beam. (HPBW)

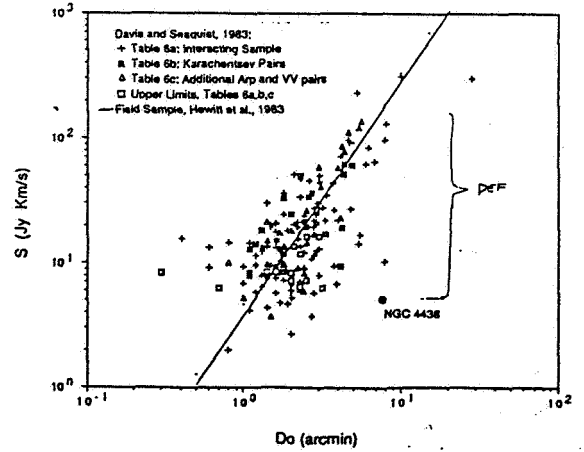


Figure 4: The relationship between single dish HI flux ( $S$  in Jy km/s) and corrected photometric diameter (arcmin) for the late-type interacting galaxies in the lists of Davis and Sequeit (1983) and for the field sample of Hewitt et al. (1983). Notice that the interacting sample follows the same relationship as the field sample for optical diameters above 1". HI deficiency is measured by the vertical distance off of the mean relationship. As can be seen, NGC 4438 is HI deficient compared to either sample.