

## VLA Neutral Hydrogen Imaging of Compact Groups

B. A. Williams

University of Delaware

P. M. McMahon

Columbia University

J. H. van Gorkom

Columbia University/NRAO

We present images of the neutral hydrogen (H I) in the direction of the compact groups of galaxies, HCG 31, HCG 44, and HCG 79. We find in HCG 31 and HCG 79, emission contained within a cloud much larger than the galaxies as well as the entire group. The H I emission associated with HCG 44 is located within the individual galaxies but shows definite signs of tidal interactions. We have imaged the distribution and kinematics of neutral hydrogen at the two extremes of group sizes represented in Hickson's sample. HCG 44 is at the upper limit while HCG 18, HCG 31, and HCG 79 are at the lower end. Although the number of groups that have been imaged is still very small, there may be a pattern emerging which describes the H I morphology of compact groups. The true nature of compact groups has been the subject of considerable debate and controversy. The most recent observational and theoretical evidence strongly suggest that compact groups are physically dense, dynamical systems that are in the process of merging into a single object (Williams and Rood 1987, Hickson and Rood 1988, Barnes 1989). The neutral hydrogen deficiency observed by Williams and Rood (1987) is consistent with a model in which frequent galactic collisions and interactions have heated some of the gas during the short lifetime of the group. The H I disks which are normally more extended than the luminous ones are expected to be more sensitive to collisions and to trace the galaxy's response to recent interactions. Very Large Array observations can provide in most cases the spatial resolution needed to confirm the dynamical interactions in these systems.

Spectral-line observations of HCG 31 and HCG 79 were made with the VLA in the C-array and of HCG 44 in the D-array. In the C-array, the angular resolution is 20 arcsec and the velocity resolution is  $21 \text{ km s}^{-1}$ . The rms

noise in the channel maps of HCG 31 and HCG 79 is 0.6 and 0.9 mJy per beam, respectively. The limiting column density ( $3\sigma$ ) is  $\approx 10^{20}$  H cm $^{-2}$ . In the D-array, the angular resolution is 60 arcsec and the velocity resolution is 40 km s $^{-1}$ . The rms noise in the channel maps is 0.4 mJy per beam which gives a limiting column density ( $3\sigma$ ) of  $2 \times 10^{19}$  H cm $^{-2}$ .

The H I emission detected in the smaller groups, HCG 31 and HCG 79 is shown overlaid on POSS photographs in figure 1. As is the case with HCG 18 (Williams and van Gorkom 1988), the integrated H I emission from HCG 31 and HCG 79 is far more extended than the optical group, and peaks at the position of the galaxies or at bright luminous clumps associated with the group. The total amount of hydrogen detected is  $2.1 \times 10^{10} M_{\odot}$  and  $2.3 \times 10^9 M_{\odot}$  for HCG 31 and HCG 79, respectively.

The H I emission from HCG 79 is strongly peaked in an elliptical-shaped cloud centered on the only late-type galaxy (Sbc) in the group. At this position, the column density is  $5 \times 10^{21}$  H cm $^{-2}$ . Extended emission is also distributed in a relatively narrow tail which curves as far as 2' from the center of the cloud where the column density drops to  $2 \times 10^{20}$  H cm $^{-2}$ . Approximately 18% of the total hydrogen detected is associated with the emission from the tail structure.

Figure 1b shows the systematic variation in the radial velocity across the main portion of the cloud centered on the edge-on galaxy. The radial velocity gradient runs along the same direction as the disk of galaxy d. If we interpret the systematic motions as due to rotation, at least  $2.5 \times 10^{10} M_{\odot}$  is needed to stabilize the inner regions of the cloud. The optical plume of galaxy b and the curved gas feature are good reasons to suspect tidal interactions between the galaxies.

The H I emission in the direction of HCG 31 is contained within two cloud structures: a) the 3' linear feature superposed on the brighter members and b) the diffuse feature located 2' northwest of the group. The peak emission has a column density of  $4 \times 10^{21}$  H cm $^{-2}$  and is coincident with the two interacting galaxies a and c. In the southern part of the ridge structure, both emission peaks with column densities greater than  $3 \times 10^{21}$  H cm $^{-2}$  are located at the newly identified H-alpha emission-line objects (Rubin et al. 1988). The diffuse cloud to the north also contains several condensations ( $10^{21}$  H cm $^{-2}$ ) that upon close inspection of the POSS print are coincident with very faint extended optical emission.

At the positions of the brighter galaxies with measured optical velocities (figure 1d), the agreement between the motions of the gas and that of the galaxies is remarkable. Systematic motions are observed along two directions within the ridge-like feature. Between 4120 and 4150 km s<sup>-1</sup>, systematic motions are aligned with the disks of the brightest members. For radial motions below 4100 km s<sup>-1</sup>, systematic motions occur along a position angle of 120°. This configuration suggest that the major cloud structure can be resolved into two kinematical systems 2-6 times larger than the individual galaxies within the group. The relative position of the two gas systems may indicate a recent collision which probably initiated the current episode of star formation (Rubin et al. 1989) along their interface.

In contrast, the neutral hydrogen gas in HCG 44 is located within the individual galaxies as shown in figure 2a. Although the location of the gas is normal, its asymmetric distribution suggest that the galaxies have experienced tidal interactions. The warping clearly visible in the luminous disk of galaxy d is also followed by the distribution of the gas which flares above and below the principal plane. An even better case is shown in figure 2c where a bridge of very weak (at the 2 sigma level) H I emission can be seen connecting galaxies a and c.

Although our sample is still very small, there may be a pattern emerging which describes the most compact systems. The morphology of the neutral hydrogen in compact groups may be correlated with their stage of evolution, i.e., more evolved groups have a single cloud of emission while the least evolved groups have their gas still associated with the individual galaxies. This correlation would be similar to that proposed by Forman and Jones for the X-ray morphology of early and 'evolved' clusters of galaxies. By observing more groups, eventually all of the Hickson compact groups, it should be possible to determine if such a correlation exist.

#### References

- Barnes, J. E. (1989). *Nature* **338**, 123.
- Rubin, Ford, and Hunter, 1989, STScI Workshop, May 1989.
- Hickson, P. and Rood, H. J. (1988). *Astrophys. J.* **331**, L69.
- Williams, B. A. and Rood, H. J. (1987). *Astrophys. J. Suppl.*, **63**, 265.
- Williams, B. A. and van Gorkom, J. H. (1988). *Astron. J.* **95**, 352.

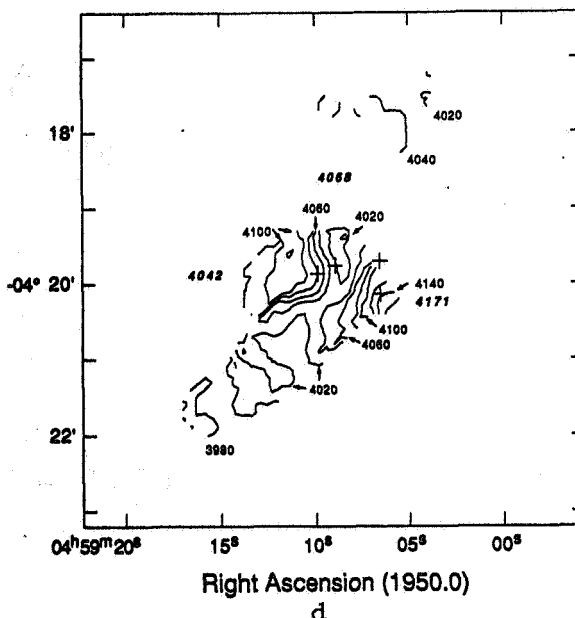
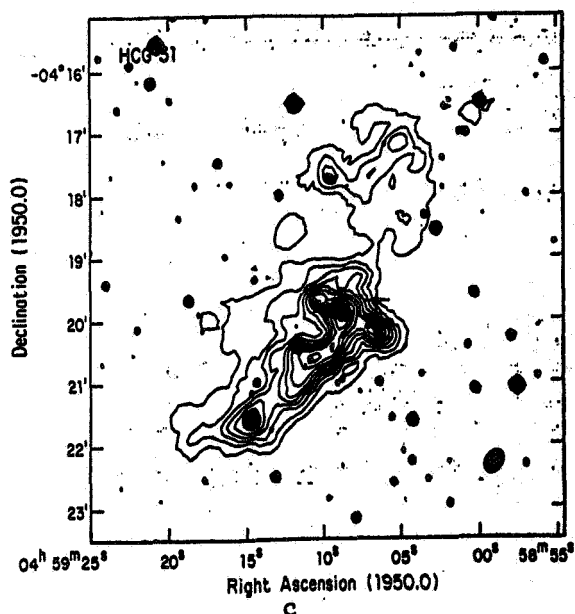
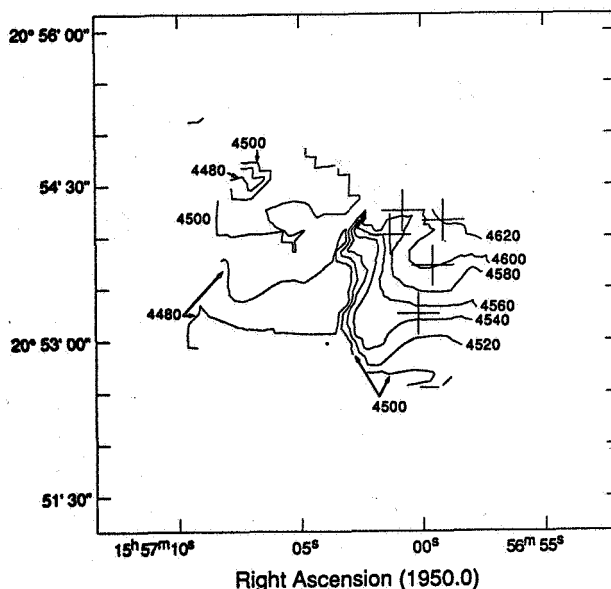
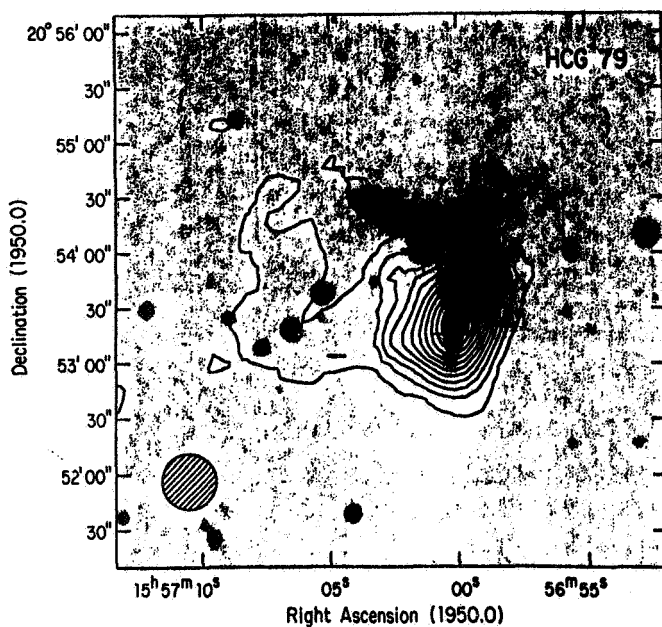
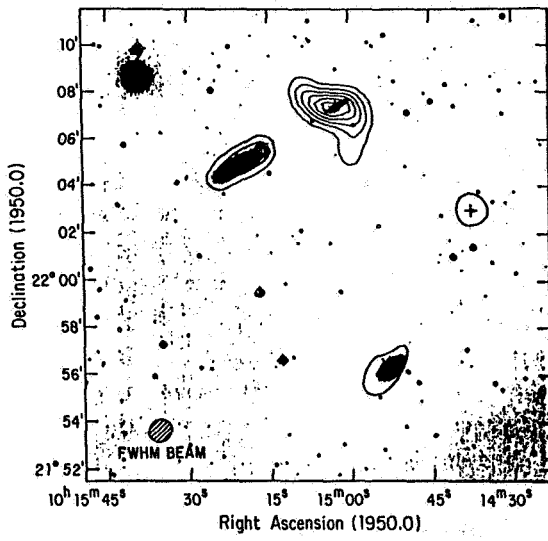


Figure 1a. VLA integrated map of the H I emission in HCG 79. The lowest contour is 0.04 Jy km s<sup>-1</sup> per beam and the contour interval is 0.11 Jy km s<sup>-1</sup> per beam.

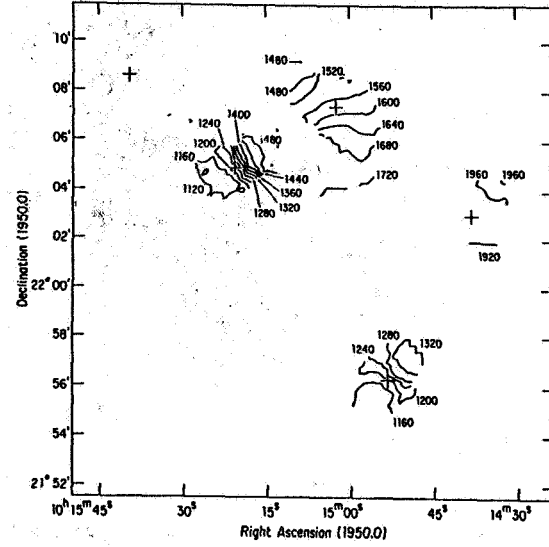
Figure 1b. Map of the H I velocity field (km s<sup>-1</sup>) of the inner third of the cloud in HCG 79.

Figure 1c. VLA integrated intensity map of the H I emission in HCG 31. The lowest contour is 0.05 Jy km s<sup>-1</sup> per beam and the contour interval is 0.11 Jy km s<sup>-1</sup> per beam.

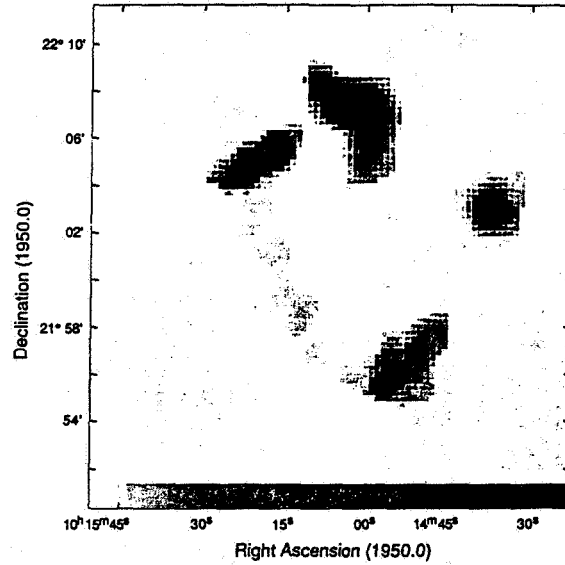
Figure 1d. Map of the H I velocity field (km s<sup>-1</sup>) of the gas in HCG 31.



a



b



c

Figure 2a. VLA integrated intensity map of the H I emission in HCG 44. The contour interval and lowest level are  $0.5 \text{ Jy km s}^{-1}$  per beam.

Figure 2b. Map of the H I velocity fields ( $\text{km s}^{-1}$ ) of the galaxies in HCG 44.

Figure 2c. VLA integrated intensity map of the H I emission in HCG 44 which reveals the weak bridge between galaxy a and c. The lowest grey scale is  $0.12 \text{ Jy km s}^{-1}$  per beam.

## DISCUSSION

**Carilli:** Do you find any difference between total HI observed with Arecibo versus that observed with the VLA?

**Williams:** No, except in Hickson 31.

**Heckman:** Paul Hickson showed an example of a compact group with hot diffuse inter-galactic material (X-ray emitting). You showed an example where the diffuse inter-galactic material was cold (HI). If these groups are produced by collision/interactions of gas-rich (spiral) galaxies, what determines whether the intra-group gas is virialized by shocks (collisions) to  $\sim 10^7$  K or remains as cold HI?

**Williams:** The velocity dispersion of the galaxies would determine whether the gas is heated to temperatures of  $\sim 10^7$  K after a collision. The energy for heating comes from the relative motion of the galaxies involved in the interaction. Hickson showed Stephan's Quintet which has a velocity dispersion of  $\sim 500$  km/s. This is much larger than the velocity dispersion of the galaxies in the groups that I have shown.

**Hutchings:** Is the HI deficiency consistent with ionization or stripping due to interactions?

**Williams:** All of the groups discussed here except for HCG 79 are significantly deficient in neutral hydrogen relative to the amount of blue light in the groups. Assuming these galaxies initially had normal neutral hydrogen gas contents, the observed deficiency is consistent with some form of heating of the gas either through tidal encounters or galactic collisions.

**Shlosman:** It seems you have shown that as a result of galaxy interactions in compact groups, the ISM is actually expelled from the galaxy. Is this a wrong impression?

**Williams:** We can only argue that the amount of mass needed to stabilize each cloud can be provided by the luminous mass associated with the galaxies. One obvious interpretation, and not the only one, is that the gas was originally bound to one of the galaxies in the group and has been stripped from the galaxies via collisions or tidal interactions. The interstellar medium has been removed from the galaxies rather than expelled by the galaxies.