VLA OBSERVATIONS OF NEUTRAL HYDROGEN IN COMPACT GROUPS

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Abstract. VLA images of the neutral hydrogen (HI) in the direction of HCG 2, 16, 33, 88, and 92 (Stephan's Quintet) are examined. In HCG 2 and 16, the HI gas is bound to the individual galaxies but shows definite signs of tidal interaction; while in HCG 92, the more compact configuration, the HI gas is contained within a few prominent cloud features well displaced from the optical positions of any of the spiral members. In every case, the motions of the gas are consistent with the motions of the galaxies within the Hickson groups. A range of kinematical properties is observed for the HI gas, from well-ordered rotation, to small-scale systematic gradients within the cloud features.

1. Introduction

We have successfully imaged about a dozen of the Hickson (1982; HCG) groups in a long-term program to observe with the Very Large Array (VLA) all the Hickson groups detected by Williams and Rood (1987). The debate

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over the true nature of compact groups still continues. Their existence, age, and state of dynamical evolution have been and continue to be the subject of controversy. If these systems are real, then they are truly interesting objects because of their dynamical properties, i.e., short crossing and collision times, large space densities, low velocity dispersions, and short time scale for loss of orbital energy due to dynamical friction. Compact groups would be ideal places to study the evolution of galaxies as well as the entire group.

Two models have been proposed to explain their existence; they are truly compact systems/configurations, or they are chance alignments within larger systems (Rose 1977; Mamon 1986) or unbound galaxies along filaments (Hernquist, Katz, and Weinberg 1995). It is reasonable to assume that the objects in the Hickson catalog are not of a single nature but represent some heterogeneous mixture including physically dense systems, the cores of large groups, (HCG 58; Williams 1985), chance alignments in either loose groups or along edge-on filaments of galaxies, and even single galaxies (HCG 18; Williams and van Gorkom 1988). Given this potpourri of objects, what observational tests can be made to distinguish between the two basic models presented above? Diffuse gas trapped within the gravitational potential of a group provides a means of determining which systems are real and which are chance superpositions (Ostriker, Lubin and Hernquist 1995). Since all of the compact groups with an extended intragroup medium have high percentages of early-type galaxies (Mulchaey et al. 1996), X-ray emission is a poor observational test for the spiral-dominated Hickson groups. Clearly a better observational test for the spiral-rich groups would be the distribution and kinematics of the neutral hydrogen (HI) gas in the spiral galaxies. HI aperture synthesis could be used to distinguish between the real and illusory objects. Disk galaxies are normally more extended in HI than in starlight, so that the HI gas is suspectable to tides and direct collisions and ought to be more sensitive to recent interactions. In most cases, observations with the VLA can provide the spatial resolution needed to confirm the dynamical interactions suspected in the spiral-rich groups if they are indeed physically dense. The distribution and kinematics of the HI gas can give clues about the dynamical state and evolution of the spiral-rich groups.

2. Distribution and Kinematics of the Neutral Hydrogen Gas

Based on their HI morphology, the Hickson groups that we have imaged thus far fall into three basic categories. There is a class of Hickson groups that display evidence of physical compactness. The HI distribution shows signs of tidal tails, severely warped HI disks, and complex HI velocity fields, all suggestive of ongoing interactions between the members of the group.

The second category includes groups that display normal HI morphologies and kinematics. The HI emission is distributed about the optical centers of the spiral members and the overall patterns of the velocity field are consistent with motions generated by rotating disks of gas viewed at various inclinations. Most of the spiral galaxies in these groups have global HI kinematics, i.e., velocity widths, consistent with their absolute blue luminosities. The third category is the one that includes compact groups that have been misidentified and are in fact single galaxies. The new images that we present here of HCG 2, 16, 33, 88, and 92 (Stephan's Quintet) have HI morphologies that are consistent with the first two categories described above.

The integrated HI emission detected in the direction of HCG 2 *(fig. 1a)* can be clearly associated with the two spiral galaxies, *a* and *c*. In at least eight channel maps, the HI is elongated along a line connecting galaxies *a* and *b*. The HI contours of galaxy *a* in figure 1a are distorted in the direction toward galaxy *b*. This may be suggestive of some mild tidal interaction between the two members. In general, the velocity fields of both galaxies are well-ordered and are consistent with the motions associated with rotating disks. Figure 1b shows the global profiles that have been reconstructed from the channel maps. The total integrated flux measured

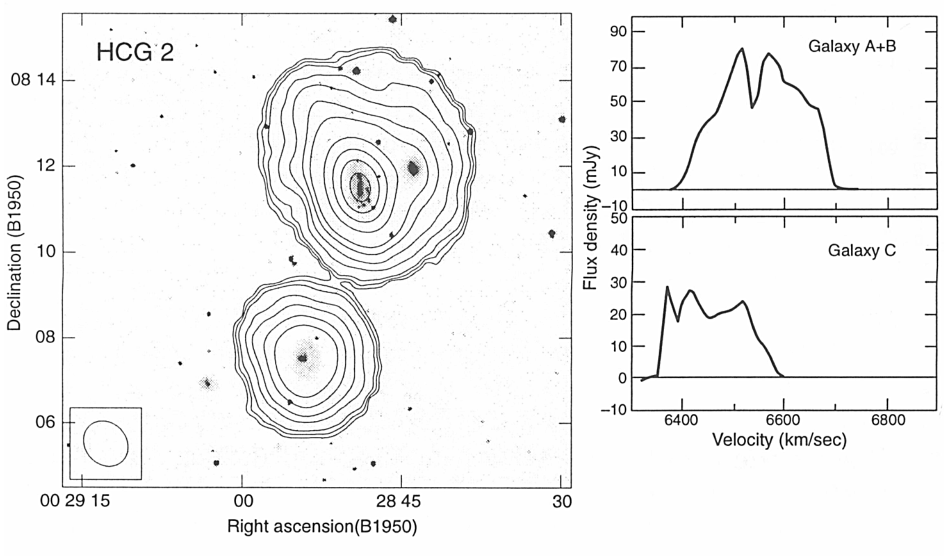

Figure 1. *a*) VLA integrated map of the HI emission in HCG 2. The lowest contour level is 0.05 Jy km s^{-1}. The peak emission is 7.6 Jy km s^{-1}. The beam size is 67.2″ × 57.9″. *b*) The global profiles reconstructed from the channel maps for galaxies *a*, *b*, and *c*.

by the D-array is 22.6 Jy km s^{-1} which is larger than that measured, by the NRAO 300-ft telescope (Williams and Rood 1987). Galaxies *a* and *c* have a hydrogen mass of $1.5 \times 10^{10} M_\odot$ and $3 \times 10^9 M_\odot$, respectively. We have assumed that most of the neutral hydrogen in the direction of galaxies *a* and *b* is contributed by galaxy *a*. The velocity field appears too uniform to be produced by more than one galaxy. There is no strong evidence of tidal interaction between the two hydrogen-rich galaxies, *a* and *c*.

HI emission *(fig. 2a)* detected in the direction of HCG 16 is contained within a single cloud feature that is centered between galaxies *c* and *d* and elongated toward the southeast companion, NGC 848. At the resolution of the D-array, the emission from the individual galaxies cannot be determined but a comparison of the VLA integrated flux with that measured at Green Bank (Williams and Rood 1987) shows good agreement. Systematic motions are observed along two different gradients, none of which aligns with the major axis of any galaxy. It is difficult to interpret the D-array results with the present angular resolution. HCG 16 is clearly one group that needs to be reobserved with the higher angular resolution provided by the C-array. The global profiles of the three features resolved by the D-array are shown in figure 2b. NGC 848, the companion detected to the southeast,

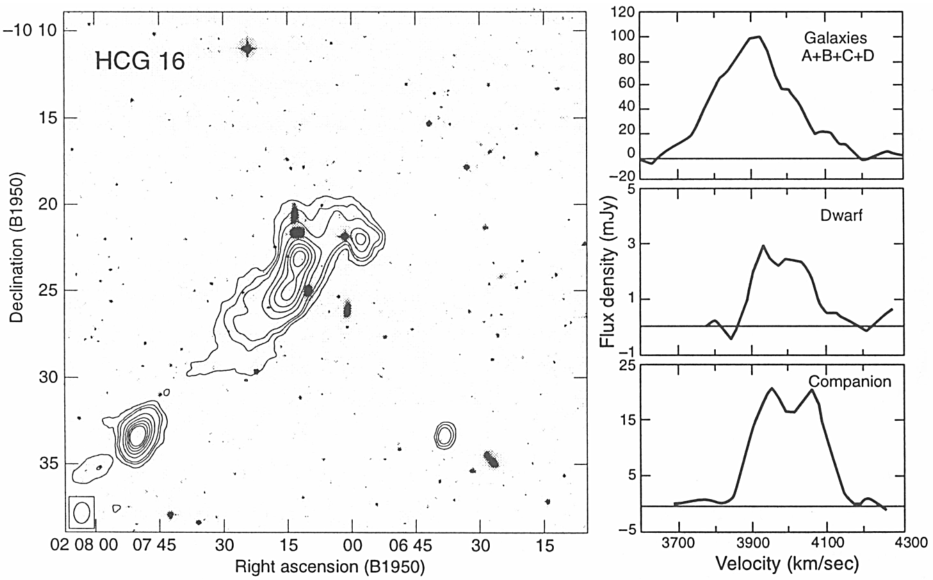

Figure 2. *a*) VLA integrated map of the HI emission in HCG 16. The lowest contour level is 0.25 Jy km s^{-1}. The peak emission is 3.9 Jy km s^{-1} and the beam size is $73.3'' \times 54.6''$. *b*) The global profiles reconstructed from the channel maps for the group, NGC 848, and the dwarf member.

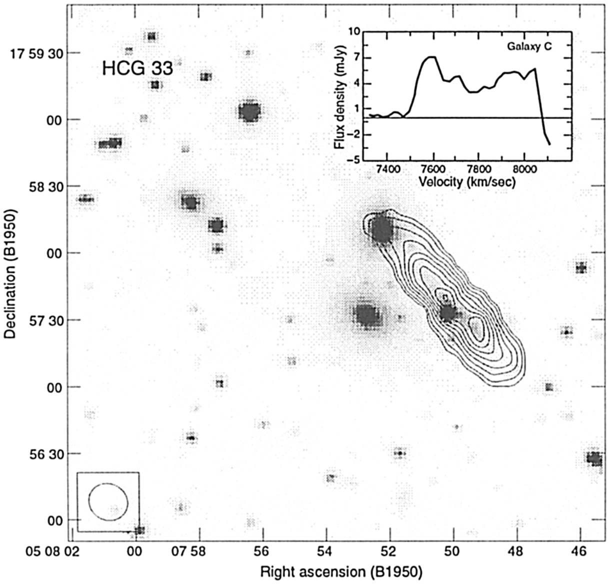

Figure 3. *a*) VLA integrated map of the HI emission in HCG 33. The lowest contour level is 0.05 Jy km s^{-1}. The peak emission is 0.83 Jy km s^{-1} and the beam size is 17.8″ × 16.4″. *b*) The global profiles reconstructed from the channel maps for galaxy *c*.

has a total hydrogen mass of $5 \times 10^9 M_\odot$, and the newly discovered dwarf member, southwest of the group, has a total hydrogen mass of $3 \times 10^8 M_\odot$.

The HI emission detected in the direction of HCG 33 is clearly identified with the only spiral member in the group, galaxy *c*. Measurements of the integrated flux with the C-array observations *(fig. 3a)* yield a value that is 40% of the integrated flux measured by the NRAO 300-ft telescope. Large amounts of extended emission are missing from the map shown in figure 3a. A lower limit of $6 \times 10^9 M_\odot$ can be set on the amount of HI in galaxy *c*. Given its luminosity, galaxy *c* is hydrogen-rich. The systematic motions observed in the velocity maps occur along the optical disk and are consistent with optical velocities measured by Rubin et al. (1991). As noted by Rubin et al. (1991), this low luminosity spiral has a peculiarly large internal velocity dispersion. The global profile shown in figure 3b has a velocity width (at 20% of peak emission) of 570 km s^{-1}. Given the luminosity of galaxy *c*, the predicted velocity dispersion is about half the measured value.

The HI emission *(fig. 4a)* is clearly associated with the individual galaxies in HCG 88. The total integrated flux (C-array) is consistent with the NRAO 300-ft measurement (Williams and Rood 1987). There are no obvious signs of tidal interaction in the HI distribution or the velocity field.

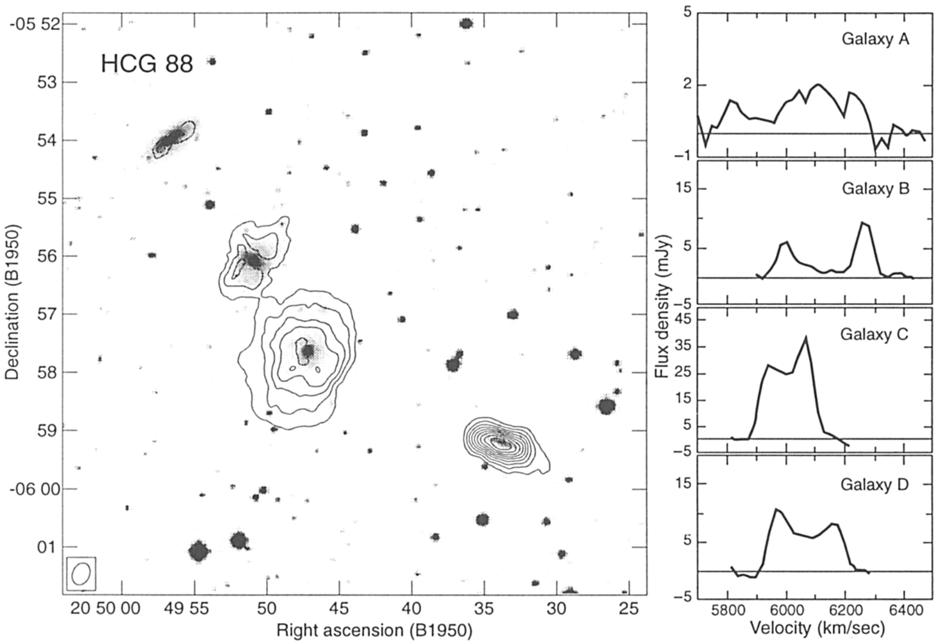

Figure 4. *a*) VLA integrated map of the HI emission in HCG 88. The lowest contour level is 0.074 Jy km s^{-1}. The peak emission is 0.74 Jy km s^{-1} and the beam size is $23.5'' \times 17.3''$. *b*) The global profiles reconstructed from the channel maps for galaxies *a*, *b*, *c*, and *d*.

Note that the HI disk associated with galaxy *a* is comparable in size to that of the optical disk. In the other galaxies, the HI disks are clearly much larger than the stellar ones. The integrated properties of galaxies *a* and *b* are worth noting. The hydrogen mass-to-light ratio of galaxy *a* and *b* is ~ 0.007 and ~ 0.05, respectively. For Sb-type galaxies, both are relatively deficient in neutral hydrogen. The measured velocity widths (20% peak) of their global profiles *(fig. 4b)* exceeds 560 km s^{-1} which are much broader than would be predicted from their luminosities. The amounts of hydrogen measured in galaxies *a*, *b*, *c*, and *d* is $3 \times 10^8 M_\odot$, $2 \times 10^9 M_\odot$, $9 \times 10^9 M_\odot$, and $4 \times 10^9 M_\odot$, respectively.

HI emission detected in the direction of HCG 92 (Stephan's Quintet), shown in *fig. 5a*, is displaced from any galaxies identified as members of the group. A similar distribution was observed by Shostak, Sullivan and Allen (1984). Where their observations detect emission between NGC 7320 and NGC 7319 and between NGC 7319 and NGC 7318A/B, ours do not. Most of the extended emission detected by Shostak et al. (1984) is missing from the C-array observations. The integrated flux detected with the VLA represents only $\sim$ 40% of the integrated flux measured by Shostak et al.

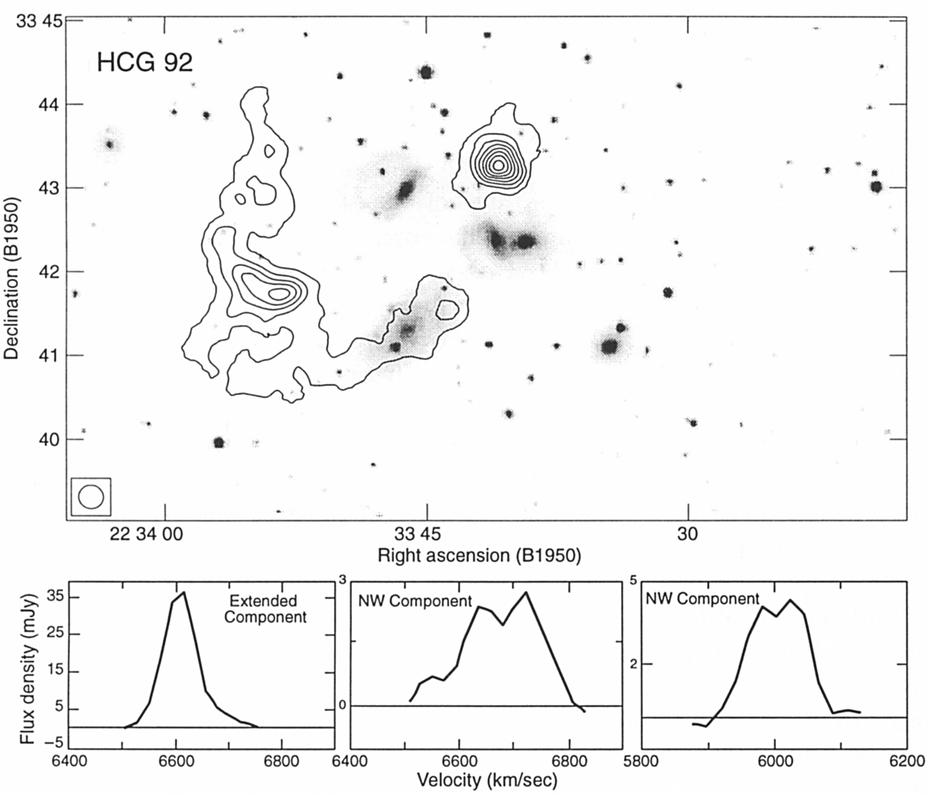

Figure 5. *a*) VLA integrated map of the HI emission in HCG 92. The lowest contour level is 0.030 Jy km s^{-1}. The peak emission is 0.48 Jy km s^{-1} and the beam size is $17.5'' \times 16.8''$. *b*) The global profiles reconstructed from the channel maps for the eastern cloud, and the northwest components.

(1984). HI is detected mainly in three cloud features, one near the end of the southeast tidal tail of NGC 7319 and two others north of NGC 7318A/B where Arp (1973) identified Hα regions at the same redshift as the group. The bulk of the HI is located in the curved eastern feature where the radial velocity of the gas is nearly constant *(fig. 5b)*. The compact emission north of NGC 7318A/B separates kinematically into two components, one at a systemic velocity of 6000 km s^{-1} and another at 6700 km s^{-1} *(fig. 5b)*. The peak emission in the northwest feature is 6×10^{20} H cm^{-2}, just at the threshold for OB star formation (Gallagher and Hunter 1984). There may be a physical connection between the compact HI emission and the underlying Hα objects identified by Arp (1973).

3. Summary

The HI morphology of HCG 2, 16, and 92 shows evidence that at least two or more galaxies in the groups are physically close. The galaxies are close enough for their gravitational fields to perturb the distribution and motions of the neutral hydrogen gas. In the case of HCG 92, it is the combination of the optical evidence of interactions both collisional and tidal, and the extraordinary HI distribution that present the most compelling case for physical compactness. If it is assumed that the HI detected in HCG 92 originally resided in the spiral members, then violent events must have caused the removal of large amounts of neutral hydrogen from these galaxies. HCG 2, 16, and 92 appear to be really compact systems. In contrast, the distribution and kinematics of HI in HCG 33 and 88 appear normal and show no signs of perturbations generated by the galaxies' tidal fields. As described by Hernquist, Katz, and Weinberg (1995), HCG 33 and 88 could be chance projections of unbound filaments of galaxies well separated along the line of sight.

If compact groups are in the process of merging, then we might expect to find them at different stages of the merging process. In the early stages, their properties should more closely resemble those of their progenitors, looser groups of galaxies. HCG 2 and 16 would be representative of an early stage in the merging process. The more evolved groups might appear more compact and more disordered in their optical and HI properties as a result of the dynamical interactions and major restructuring that is occurring within these systems, as observed in HCG 92. The imaged groups that show physical evidence of compactness have HI morphologies that are consistent with the model that describes compact groups as evolving objects.

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