

## GAS IN MERGING GALAXIES

John E. Hibbard, Jacqueline H. van Gorkom, Steve Kasow, Columbia University.  
David J. Westpfahl, New Mexico Institute of Mining and Technology.

## SUMMARY

We present observations of the neutral hydrogen, ionized hydrogen, and starlight of galaxies chosen from the "Toomre Sequence" of merging galaxies (Toomre, 1977, in "The Evolution of Galaxies and Stellar Populations"). This sequence is meant to represent the progressive stages of the merger of two disk galaxies into a single elliptical-like remnant. The galaxies in this study span the full range of this sequence.

The stars and atomic gas are very differently distributed, with the stars more widely distributed at early stages, and the gas much more widely distributed at later stages. Large quantities of neutral gas are sent to large radii ( $\gtrsim 100 h^{-1} \text{kpc}$ ), and still persist even after the central remnant has relaxed to an  $r^{1/4}$  light profile.

There are a few times  $10^9 M_{\odot} h^{-2}$  of both molecular and atomic gas in each of these systems. Throughout the different stages, about half of the total gas mass lies within the galaxies' optical bodies. The fraction of this mass that is in neutral hydrogen drops rapidly in the later stage mergers, suggesting that atomic gas is processed into molecular gas, stars, and hot gas during the merger and resulting star burst.

Star formation occurs at all stages of the interaction, both within the tails and in the central bodies. In the early stages, the  $H\alpha$  shows many arcs and plumes. In the late stages, there are large H II regions in the tails which are associated with large quantities of neutral hydrogen. There is always a very good correlation between optical,  $H\alpha$ , and H I peaks, with  $N_{HI} \gtrsim 3 \times 10^{20} \text{cm}^{-2}$  at the location of the H II regions in the tails.

## TRENDS

Early Stages: Arp 295 (fig. 1a), NGC 4676 = "The Mice" (fig. 1b).

Selection: Clearly separated disks bodies; Connecting luminous bridge; Tails or counterarms reaching a few optical diameters ( $D_{opt}$ ) in length.

Optical: Fainter, thicker optical "plumes" out to several  $D_{opt}$ . More widely distributed than H I. **H $\alpha$ :** Found mostly in main bodies, with loops and plumes, especially along the minor axis (see Arp 295 north, NGC 4676 north). Almost no  $H\alpha$  found in bridges.  $H\alpha$  clumps in tails. **H I:** Confined to bodies and brighter tidal features. Less extended than optical. Reaches a few times  $D_{opt}$ .  $N_{HI} \gtrsim 3 \times 10^{20} \text{cm}^{-2}$  at regions with optical and  $H\alpha$  clumps. We note that the break in the tail of NGC 4676 south and subsequent clump in H I is very similar to the H I morphology of NGC 4038/9 = "The Antennae" (Mahoney, van der Hulst, and Burke, in preparation). The later has a very blue dwarf at the end of the arm, whereas in NGC 4676S we find several H II regions.

Middle Stages: NGC 520 + UGC 957 system (fig. 1c).

Selection: Distinct optical bulges embedded in a common luminous envelope; Long, luminous tails. (Note: NGC 4038/9, referenced above, and NGC 3256 and NGC 1467 (English, in preparation) also fall in this category and have similar data available).

Optical: Optical tails end long before H I. Sharp optical cutoffs. Extremely IR luminous. **H $\alpha$ :** Again, find most  $H\alpha$  in the bodies, with plumes and loops and emission along the minor axis. Also in the regions between the two bulges. Still seen in clumps in tails. **H I:** Gaseous arm is much, much longer than the optical features, with a total H I cross-section 20 times the optical. Central H I absorption. H I minimum along the minor axis, possibly related to the  $H\alpha$  plumes. Column densities  $\gtrsim 4 \times 10^{20} \text{cm}^{-2}$  at regions with optical and  $H\alpha$  clumps (southern tail, at location of UGC 957).

Late Stages: NGC 3921 (fig. 1d), NGC 7252 (fig. 1e).

Selection: Two tails, but only one body.  $r^{1/4}$  luminosity profile in the remnant.

Optical: Long, fainter tails, several times  $D_{opt}$  in length, which end abruptly. Many loops and shells surrounding the remnant body. **H $\alpha$ :** The ionized gas in the central remnant is much more smoothly distributed than in the earlier stages, though there are still many knots. There is either  $H\alpha$  or blue colours at the base or spine of the tails. The end of the optical tails coincides with a bright H II region in each of these systems. **H I:** Most, if not all, of the neutral hydrogen is in the tails (the gas which appears near the central regions

can be kinematically associated with the outer regions). Central regions HI poor, CO rich. The end of the optical tails, with the H II regions, have large neutral gas enhancements, with  $N_{HI} \gtrsim 4 \times 10^{20} \text{ cm}^{-2}$ . The gaseous tails, however, extend up to twice as far as the optical tails beyond these points.

fig 1a: Arp 295  
early stage

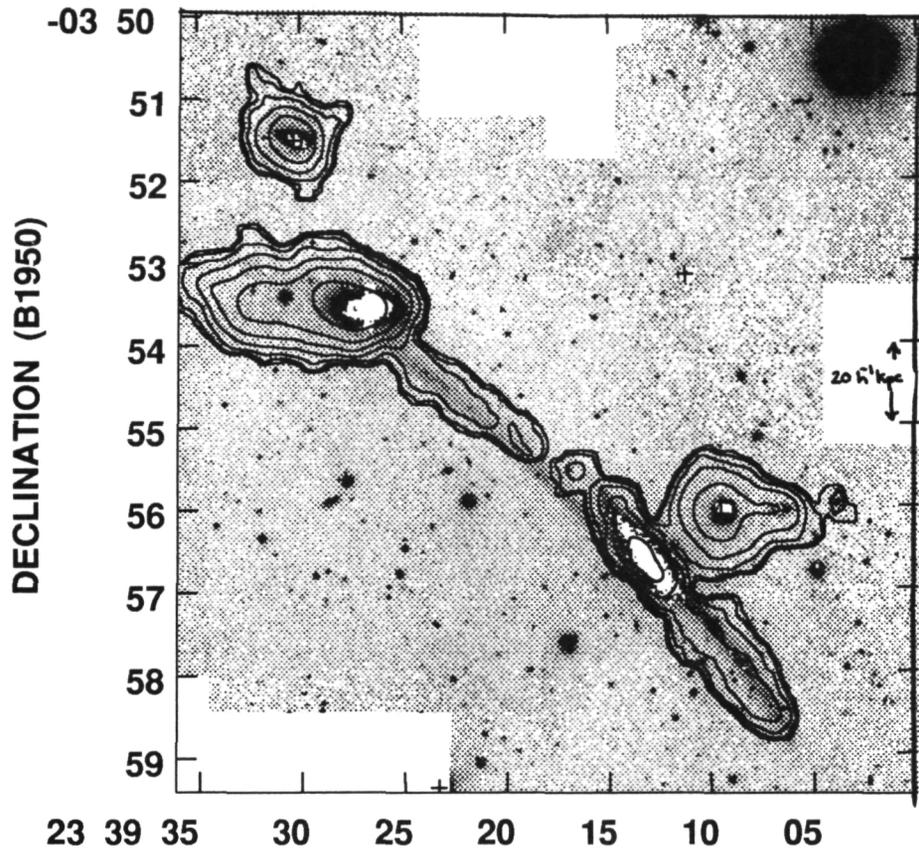


Figure 1 a-e: The 5 interacting systems: Arp 295, NGC 4676, NGC 520, NGC 3921, and NGC 7252. The greyscale shows the deep *KPNO* and *CTIO* broad band *R* images delineating the faint stellar structures, the white shows *KPNO* narrow band  $H\alpha$  imagery, and the contours show *VLA* C+D array observations of the neutral hydrogen.  $N_{HI}$  contours are drawn at the following levels, in intervals of  $10^{19} \text{ cm}^{-2}$ : 1a,b: (5,10,20,40,80,160); 1c: (2,4,8,16,32); 1d-e: (5,10,15,20,25,30,40).

fig 1b  
NGC 4676  
early stage

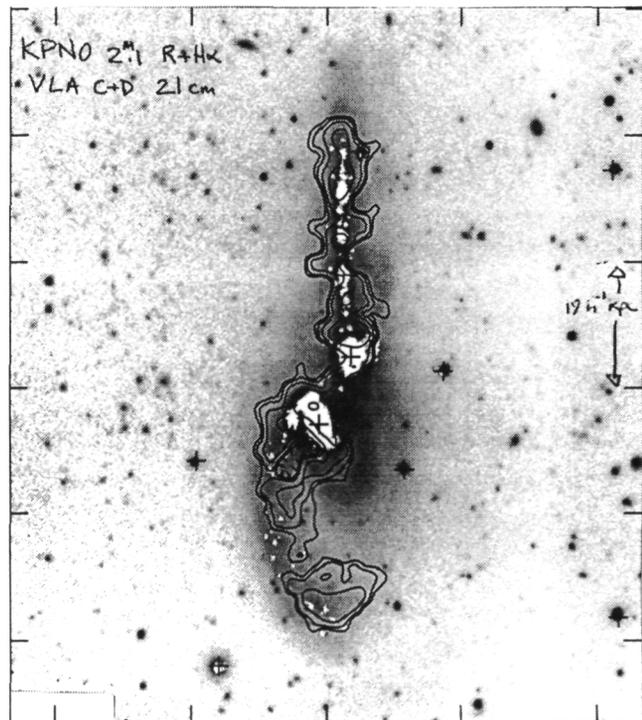


fig 1c: NGC 520 + UGC 957 middle stage

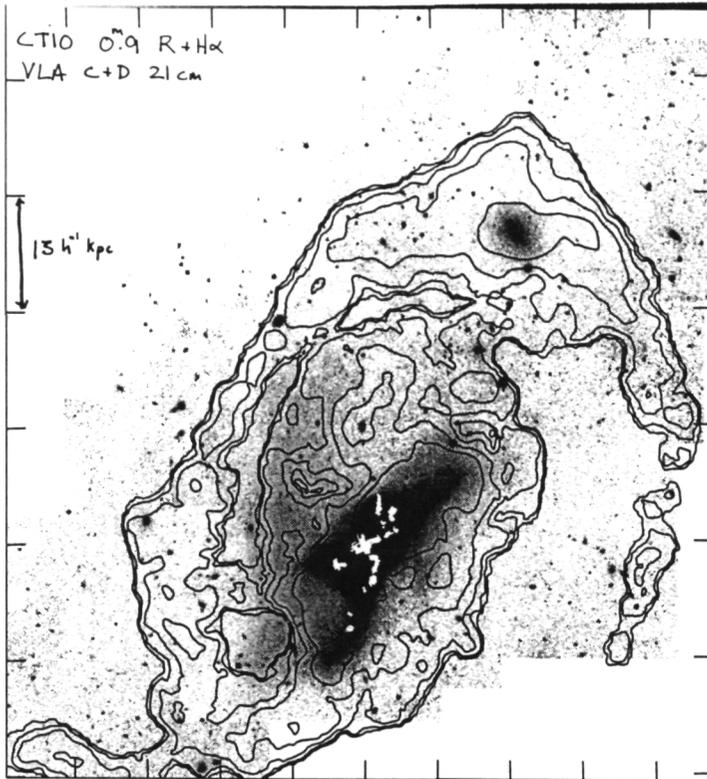


fig 1d: NGC 3921 = Mkn 430 late stage

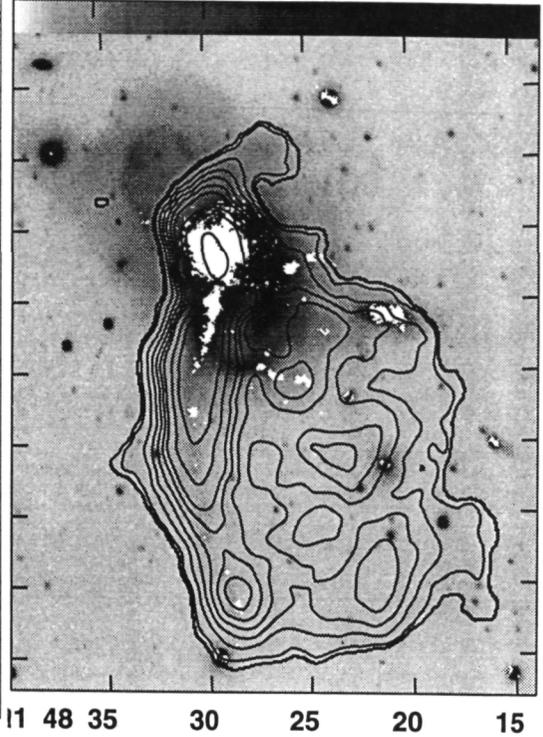


fig 1e: NGC 7252 late stage

