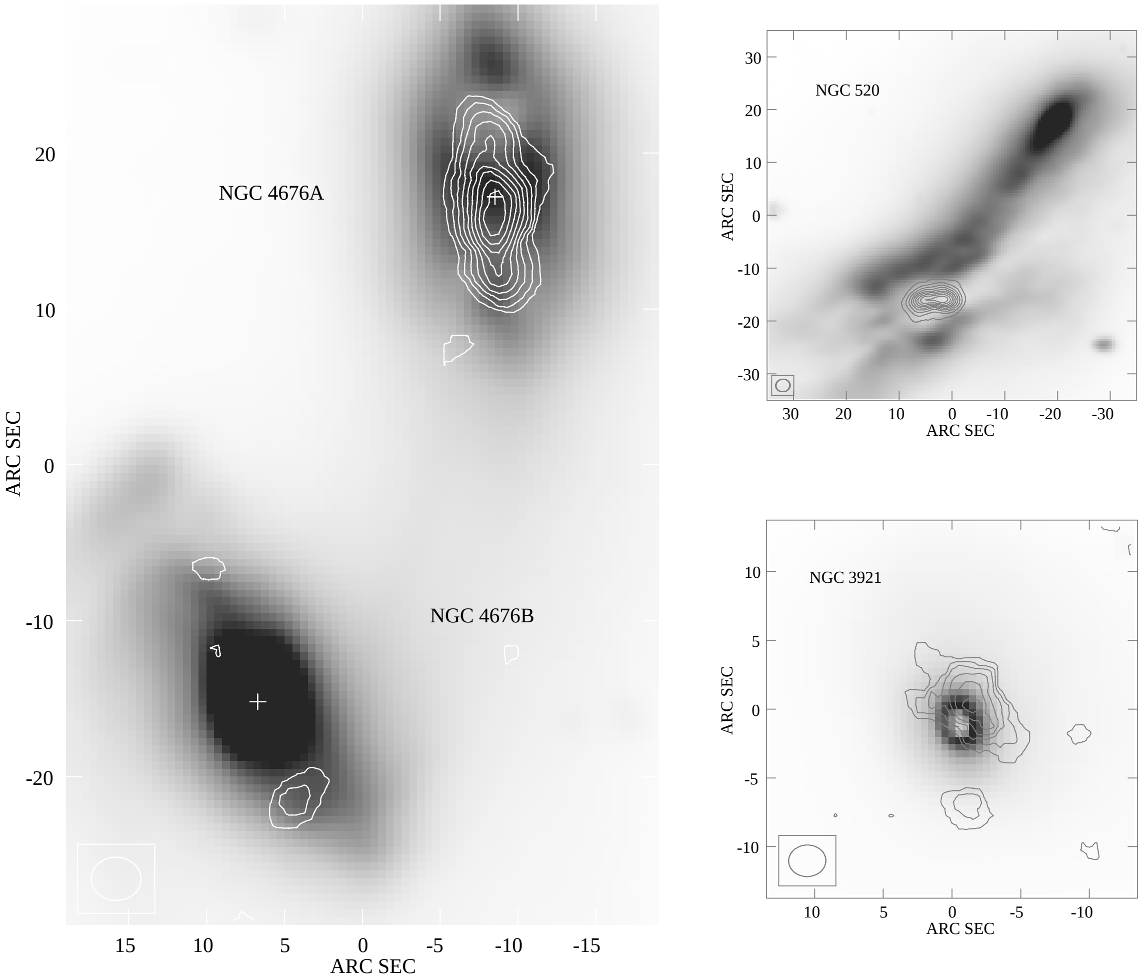


**Figure 1.** CO (1–0) maps of "Toomre sequence" of merging galaxies (Toomre 1977) are shown in linear contours over the gray scale optical images. All three galaxies are displayed at the same linear scale so that the plot frame for NGC 520 corresponds to 10 kpc on each side. The synthesized beams for each objects are plotted on lower left hand corner.

### Optically Selected Less Luminous Mergers ("Toomre Sequence")

High infrared luminosity, disturbed optical morphology, and presence of large amounts of central molecular gas (Scoville et al. 1991 and references therein) have led to a widely held belief that luminous IR galaxies are the results of mergers involving one or more gas-rich galaxies (Joseph & Wright 1985, Sanders et al. 1988a, Scoville et al. 1994 and references therein). In this scenario, the interaction delivers large quantities of cold gas into the central regions of the merger remnant (Toomre & Toomre 1972, Negroponte & White 1983), where the increased column densities and/or shortened gas-cloud collision time lead to a concentrated, energetic burst of star formation.

An important challenge to this merger scenario is that not all strongly interacting or merging galaxies show the same high levels of activities seen in the IRAS selected sample. Many clear disk-disk mergers have levels of activity and gas content, as measured by the infrared to blue luminosity ratio ($L_{IR}/L_B$), molecular gas to blue luminosity ratio ($M_{H_2}/L_B$), and the IR luminosity per unit molecular gas ratio ($L_{IR}/M_{H_2}$), that are closer to normal spirals than the extreme values found for the ultraluminous IR galaxies (Schweizer 1986, Sanders et al. 1988b, Hibbard 1994). And it is not certain if all ultraluminous IR galaxies result from major mergers of pre-existing disk galaxies or if all mergers of gas-rich galaxies will go through an ultraluminous phase.

In an effort to better understand the nature of the ULIR phenomenon and to scrutinize the details of the merger scenario, we have mapped the CO emission in an optically selected sample of on-going mergers with

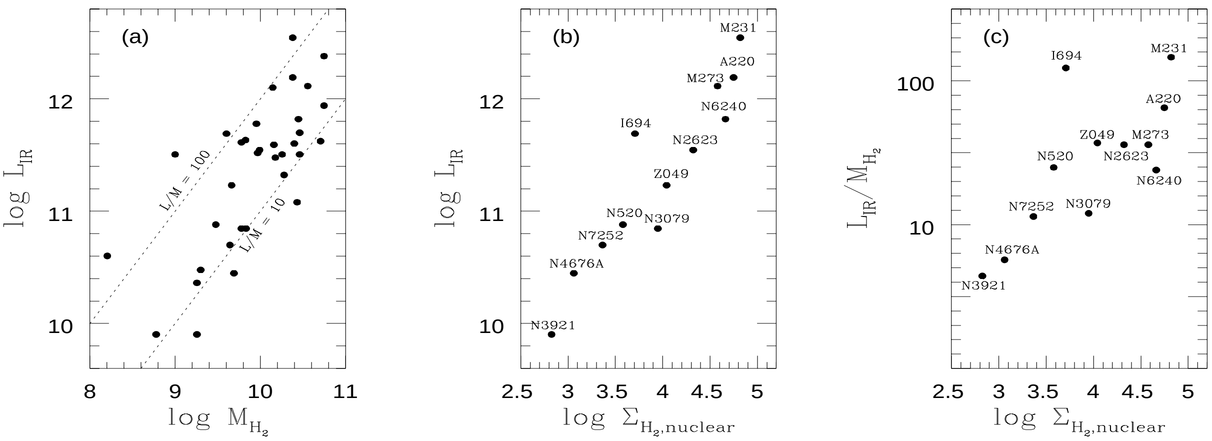


**Figure 2.** (a) Total IR luminosity is plotted against the total derived $H_2$ mass for all objects observed at OVRO to date. A good correlation has been noted previously (see Young & Scoville 1991 and references therein), and most of these IR bright galaxies lie between $L_{IR}/M_{H_2} = 10$ and 100 lines. (b) An extremely tight correlation is seen between the total IR luminosity and surface molecular gas mass density ($\Sigma_{H_2}$) for the 12 objects that are observed with sufficient spatial resolution. $\Sigma_{H_2}$ is derived to be average gas mass inside central 1 kpc diameter region. (c) Luminosity conversion efficiency ($L_{IR}/M_{H_2}$) is plotted against $\Sigma_{H_2}$. As suggested by Scoville et al. (1991), there is also a good correlation here. Notable departures such IC 694 may be due to extra IR emission associated with the central AGN.

moderate IR luminosity ("Toomre sequence", Toomre 1977) at resolutions and sensitivity comparable to those of the more IR luminous objects and traced the response of the material deep inside the potential of the colliding galaxies. The CO maps of the three Toomre sequence galaxies, NGC 4676 ("Mice"), NGC 520, and NGC 3921 are shown in Figure 1 in order of the suggested merger. Also including NGC 7252 (Wang et al. 1992), a general trend of more centrally concentrated CO emission is seen as merger progresses. As in the more IR luminous systems, the advanced merger remnants show a very compact molecular gas complex in the center, and the new observations extend the observed luminosity-density relation for IR luminous galaxies (Scoville et al. 1991) to a lower luminosity regime (see Figure 2).

Then what differentiates these objects from the IR luminous objects? These less luminous mergers have generally less total gas mass, but the more luminous systems also put out *more luminosity per mass* (see Fig. 2c). A tight correlation seen between total IR luminosity and central gas mass density (Figure 2b) makes a strong suggestion that gas dissipation may play a key role. Details of gas dissipation (e.g., presence of a massive bulge) may strongly effect evolution of total luminosity and gas reserve in gas rich mergers (Mihos & Hernquist 1994). Our observations of NGC 520 and NGC 4676 show only one of the merging galaxies currently possessing significant gas reserve, and such mergers may be indistinguishable from a single perturbed galaxy.

A tight correlation seen between total IR luminosity and central gas density may reflect a relation similar to the "fundamental plane" (see Djorgovski 1992 and references therein). Virial theorem and infall/spin-up theory suggest a scaling relation, $L \sim V_m^4 X$, and the tightness of Tully-Fisher relation suggests the constancy of factor $X \sim (M/L)^{-1}\Sigma_h^{-1} \sim (M/L)^{-2} I_o^{-1}\lambda^{-2}$ [$\Sigma_h$ is halo surface density, $I_o$ is disk central brightness, and $\lambda$ is a spin-up or collapse factor]. The tightness of the relationship seen in Figure 2b suggests a similar coupling is at work for both luminous and less luminous merger systems, perhaps because bulk of the luminosity (seen in IR) originates from the massive central gas complex which dominates the dynamics in the inner 1 kpc region in all on-going mergers.

**References**


Djorgovski, S. 1992, in *"Morphological and Physical Classification of Galaxies,*, eds. G. Longo, M. Capaccioli, & G. Busarello (Dordrecht, Kluwer), p.337.

Hibbard, J.E. 1994, PhD Thesis, Columbia University.

Joseph, R.D., Wright, G.S., 1985, MNRAS 214, 87.

Mihos, J.C., Hernquist, L., 1994, 431, L9.

Negroponte, J., White, S.D.M. 1983, MNRAS, 205, 1009.

Sanders, D.B., et al. 1988a, ApJ 325, 74.

Sanders, D.B., Scoville, N.Z., Sargent, A.I., Soifer, B.T. 1988b, ApJ (Letters) 324, L55.

Schweizer, 1986, Science 231, 193.

Scoville, N.Z., Sargent, A.I., Sanders, D.B., Soifer, B.T. 1991, ApJ (Letters) 366, L5.

Scoville, N.Z., Hibbard, J.E., Yun, M.S., van Gorkom, J.H. 1994, in *"Mass Transfer Induced Activity in Galaxies"*, ed. I. Shlosman (Cambridge University Press: Cambridge), in press.

Toomre, A. 1977, in *"The Evolution of Galaxies and Stellar Populations"*, eds. B.M. Tinsley & R.B. Larson, (Yale University Observatory: New Haven), p.401.

Toomre, A., Toomre, J. 1972, ApJ 178, 623.

Wang, Z., Schweizer, F., Scoville, N.Z. 1992, ApJ, 396, 510.

Young, J.S., & Scoville, N.Z. 1991, ARAA, 29, 581.