Morphology and Molecular gas fractions of local luminous infrared galaxies as a function of infrared luminosity and merger stage

K. L. Larson[1,2], D. B. Sanders[1,3], J. E. Barnes[1,4], C. M. Ishida[1,5], A. S. Evans[6,7,8], V. U[9], J. M. Mazzarella[2], D.-C. Kim[7], G. C. Privon[10,11], I. F. Mirabel[12,13], and H. A. Flewelling[1]

Background

- LIRGs have strong IR emission due to star formation and active galactic nuclei (AGN)
- Galaxies increase in mass over time through interactions and mergers
- Observations show that all ULIRGs and many LIRGs in the local universe involve strong tidal interactions and mergers between molecular gas-rich disk galaxies
- LIRG morphology studies are important for determining the role of interactions and mergers in the evolution of IR luminosity and molecular gas fraction (MGF)
- The total amount of molecular gas is readily available fuel to form new stars

Visual Morphological Classification Scheme

- Single galaxy (**s**): No current sign of an interaction or merger event.
- Minor merger (**m**): Interacting pairs with estimated mass ratios >4:1.
- Major merger—stage 1 (**M1**): Galaxy pairs with $\Delta V < 250 \, \mathrm{km \, s^{-1}}$ and $n_{sep} < 75$ kpc, which have no prominent tidal features. These galaxies appear to be on their initial approach.
- Major merger—stage 2 (**M2**): Interacting galaxy pairs with obvious tidal bridges and tails (Toomre & Toomre 1972) or other disturbances consistent with having already undergone a first close passage.
- Major merger—stage 3 (**M3**): Merging galaxies with multiple nuclei. These systems have distinct nuclei in disturbed, overlapping disks, along with visible tidal tails.
- Major merger—stage 4 (**M4**): Galaxies with apparent single nuclei and obvious tidal tails. The galaxy nuclei have $n_{sep} \lesssim 2$ kpc.
- Major merger—stage 5 (**M5**): Galaxies which appear to be evolved merger remnants. These galaxies have diffuse envelopes which may exhibit shells or other fine structures (Schweizer & Seitzer 1992) and a single, possibly off-center nucleus. These merger remnants no longer have bright tidal tails.

Data

- 65 LIRGs from Great Observatories All-Sky LIRG Survey (GOALS) sample (northern sample)
- This sample spans the full range of infrared luminosities and Galactic stellar masses observed in the GOALS sample
$L_{IR} = 10^{11} - 10^{12.6} L_\odot$, $M_* \sim 10^{9.5} - 10^{11.6} M_\odot$
- All objects were visually classified using I-band images from the Hubble Space Telescope, the University of Hawaii 2.2m telescope and the Pan-STARRS 1 survey
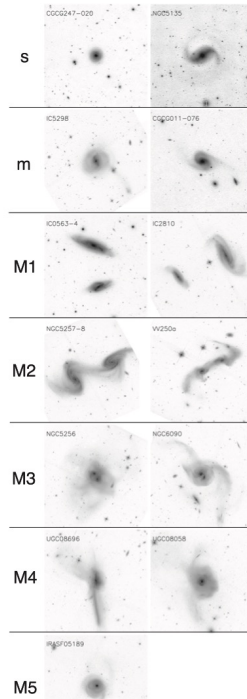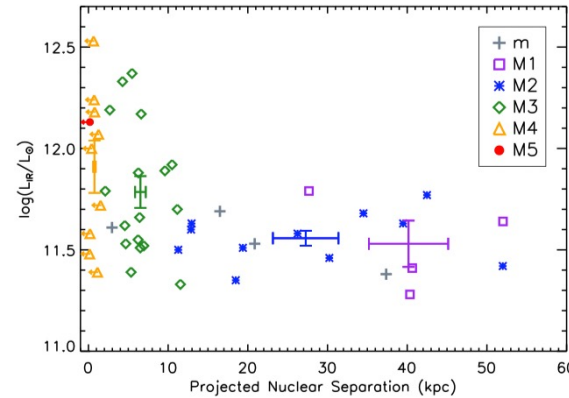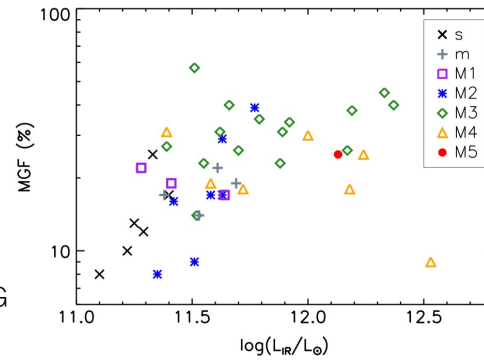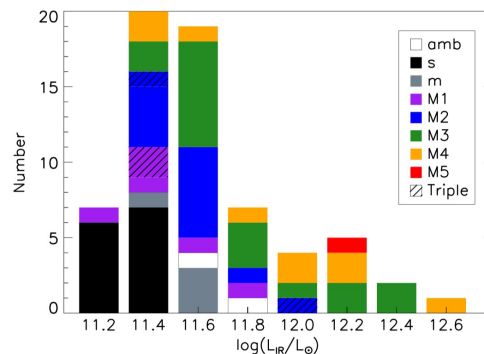

Figure 1. Visual morphological classification scheme.

Result of classification

2 : ambiguous
4 : triple nuclei major merge
4 : minor merger
14 : single galaxies
3 : M1, 11 : M2, 17 : M3
9 : M4, 1 : M5

Visual classification – IR luminosity (Fig 3)

$L_{IR} \geq 10^{11.5} L_\odot$ all galaxies are interacting system
$L_{IR} \geq 10^{11.7} L_\odot$ all galaxies are major merger
Almost all ULIRG are late-stage merger (M3,4,5)

MGF – IR luminosity (Fig 4)

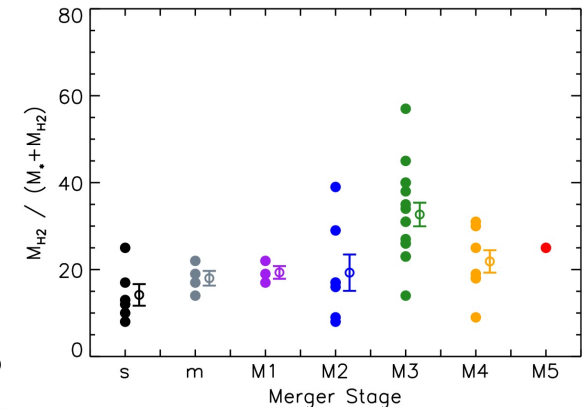MGFs calculated from CO observations of 47 galaxies conversion factor
$$X_{CO} = 3.0 \times 10^{20} \, \mathrm{H_2 \, cm^{-2} (K \, km \, s^{-1})^{-1}}$$
$$MGF = M_{H_2} / (M_* * M_{H_2})$$
Almost all galaxies are rapidly increasing and fluttering above $L_{IR} \sim 10^{11.5} L_\odot$
Mean MGF of lower IR luminosity 12.7%
Mean MGF of LIRG above $L_{IR} \sim 10^{11.5} L_\odot$ 23.8%

M3 : mean MGF 33%
M4, M5 : 22%

Table 3
Mean Properties of Galaxies vs. Merger Stage

Type	log(L_{IR}) ($L_\odot$)	log(M) (M_*)	N_{sep} (kpc)	MGF (%)
s	11.29 ± 0.03	10.59 ± 0.10	⋯	14.2 ± 2.5
m	11.55 ± 0.07	10.79 ± 0.08	19.4 ± 7.1	18.0 ± 1.7
M1	11.53 ± 0.11	10.88 ± 0.04	40.2 ± 5.0	19.3 ± 1.5
M2	11.56 ± 0.04	10.86 ± 0.08	27.2 ± 4.1	19.3 ± 4.2
M3	11.79 ± 0.08	10.71 ± 0.06	6.52 ± 0.67	32.7 ± 2.7
M4	11.91 ± 0.13	10.79 ± 0.11	<0.76 ± 0.16	21.4 ± 2.9
M5	12.13	10.91	<0.19	25