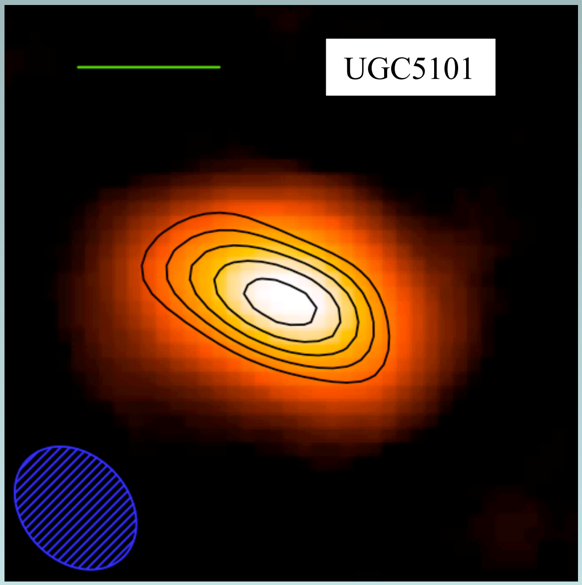
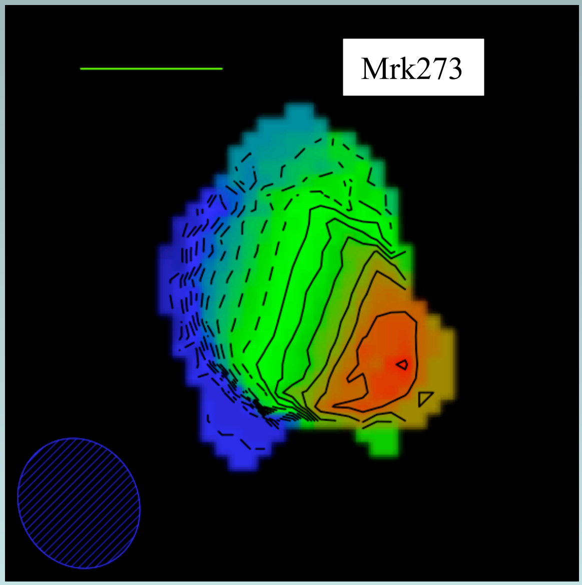
Molecular gas dynamics in luminous infrared galaxies observed with the SMA

Chris Wilson, McMaster University



1. What are luminous infrared galaxies?
2. The SMA Legacy Project
3. Comparison to high redshift sources



The SMA U/LIRG Legacy Survey

- Chris Wilson, Brad Warren, Adam Atkinson, Jen Golding (McMaster)
- Glen Petitpas, Melanie Krips, T. J. Cox (CfA), Daisuke Iono (NAOJ), Alison Peck (ALMA)
- Andrew Baker (Rutgers), Lee Armus (IPAC), Paul Ho, Satoki Matsushita (ASIAA), Mike Juvela (U. Helsinki), Chris Mihos (Case Western), Ylva Pihlstrom (New Mexico), Min Yun (UMass)
- This talk based on Wilson et al. 2008 (ApJS, in press) and Iono et al. 2008 (ApJ, submitted)

ULIRGS are galaxy mergers

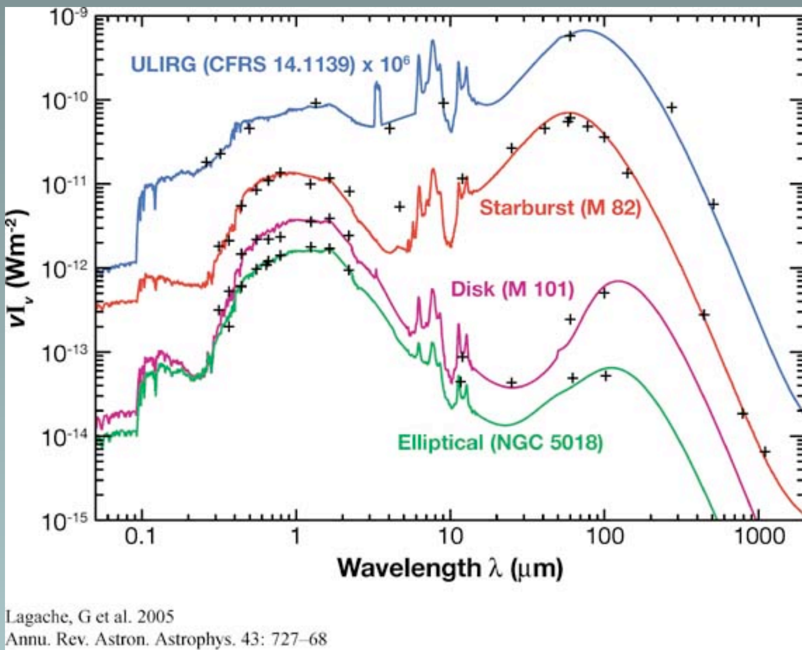
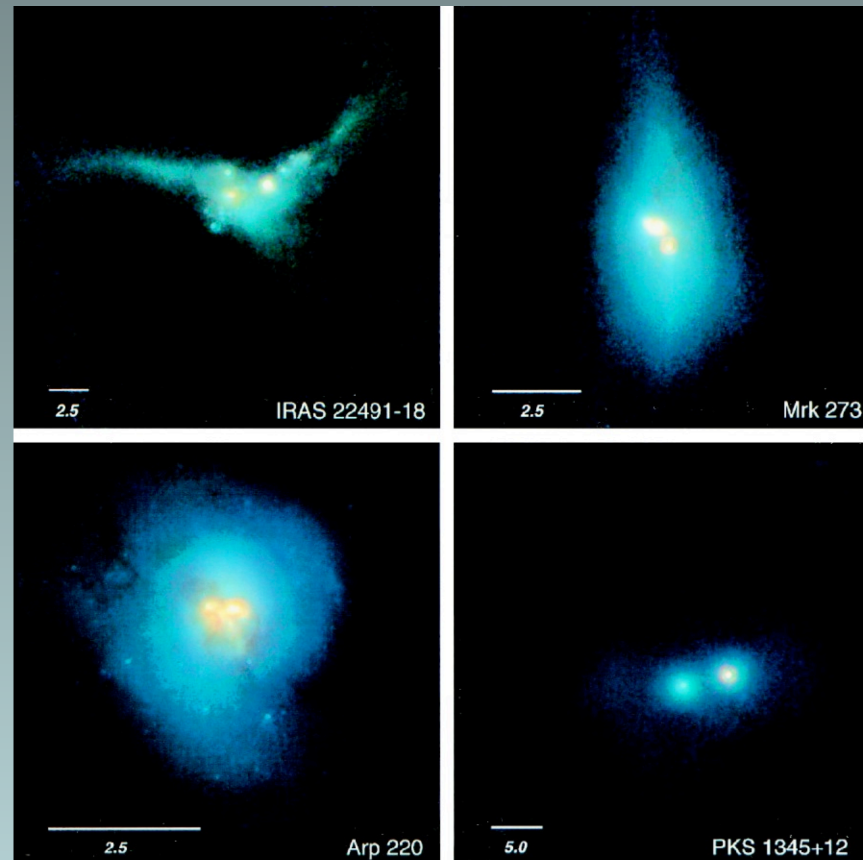


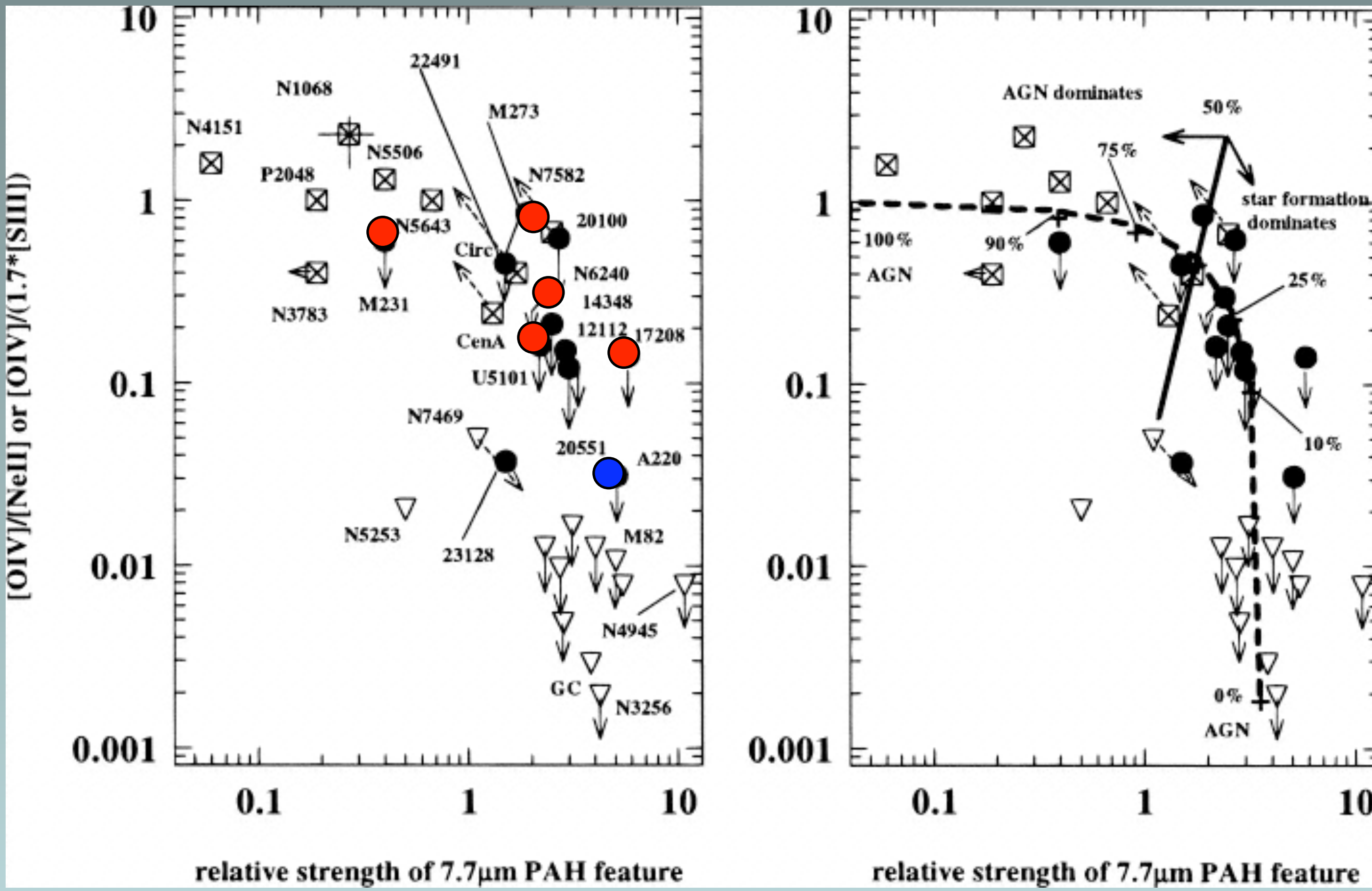
Figure from Galliano 2004



Scoville et al. 2000

All galaxies with $L_{FIR} > 5x10^{11}$ L_o are interacting or close pairs *(Sanders et al. 1987)*

Luminosity Source: Starbursts and AGN



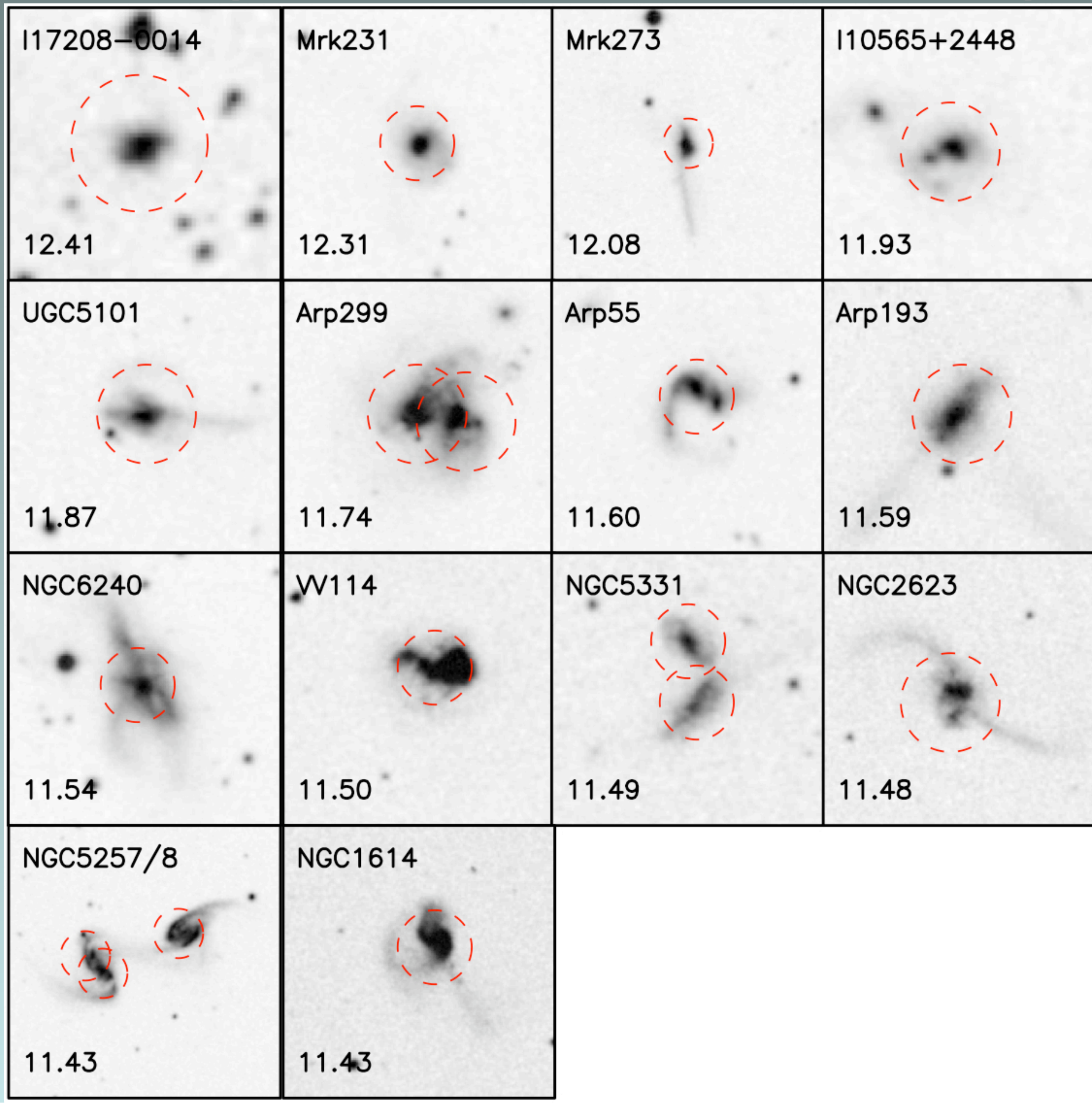
- 70-80% predominantly starbursts
- 20-30% predominantly AGN

Genzel et al. 1998

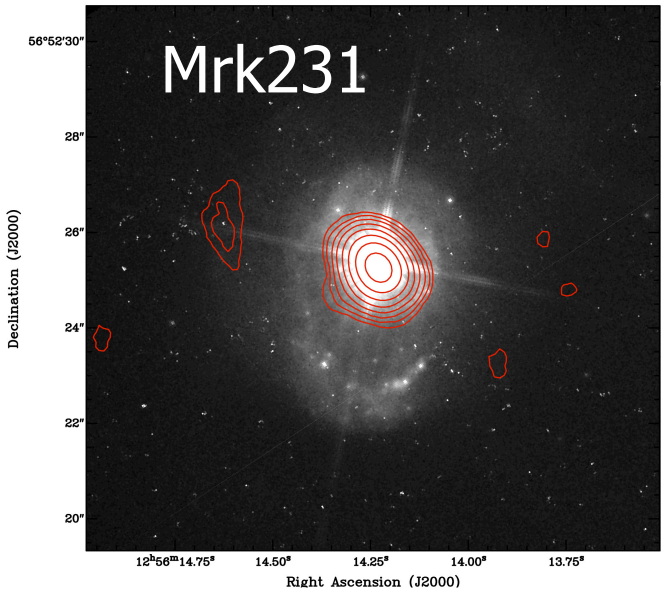
Gas Morphology and Dynamics in Luminous Infrared Galaxies: Sample Selection

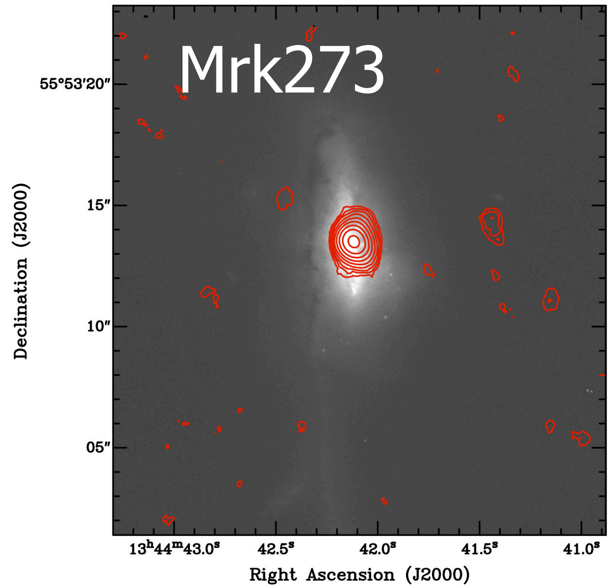
- Representative sample of 14 luminous ($\log(L_{FIR}) > 11$) and ultraluminous ($\log(L_{FIR}) > 12$) infrared galaxies
- $D_L < 200$ Mpc (resolution 1″ ~ 1 kpc)
- $\log(L_{FIR}) > 11.4$
- All with previous interferometric observations in the CO J=1-0 line

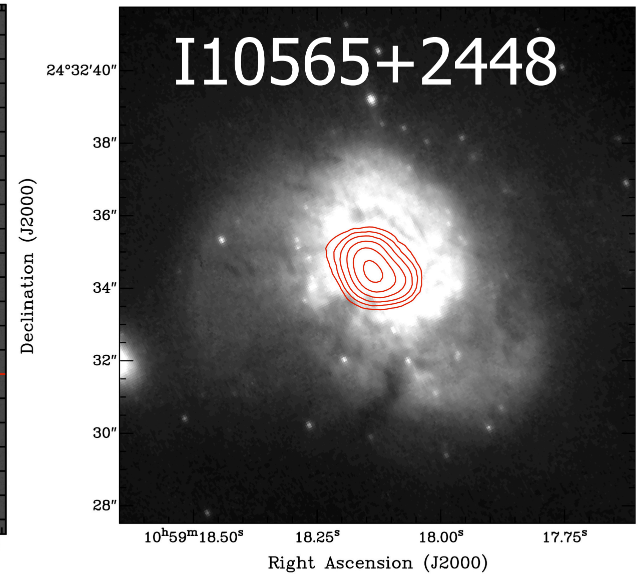
The Nearby Luminous Infrared Galaxy Sample

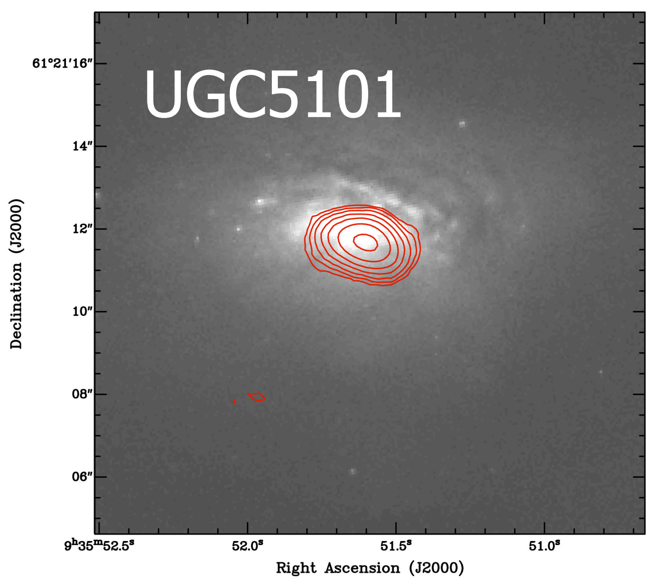


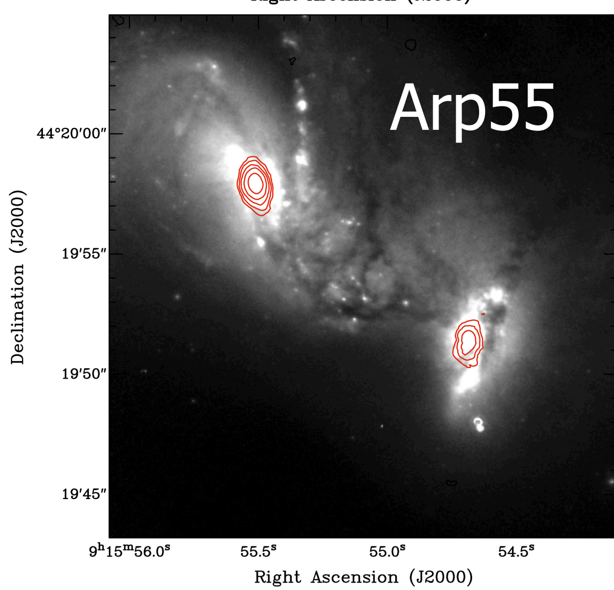
Centrally compact CO 3-2 emission











(HST images of Arp55 and I10565+2448 from Evans, Vavilkin, et al., 2008, in prep.)

Extremely high central gas surface densities

- Peak gas surface densities range from 10^3 to 10^4 M_o/ pc^2 inside 0.5-1.2 kpc^2 area
  - $6x10^{22}$ - $6x10^{23}$ H_2/cm^2
  - A_V=70-700 mag
- Average volume density at peak range from 1 to 15 M_o/pc^3
  - n_H = 20 - 300 cm^{-3}
  - Estimated as (gas surface density) / (beam radius)

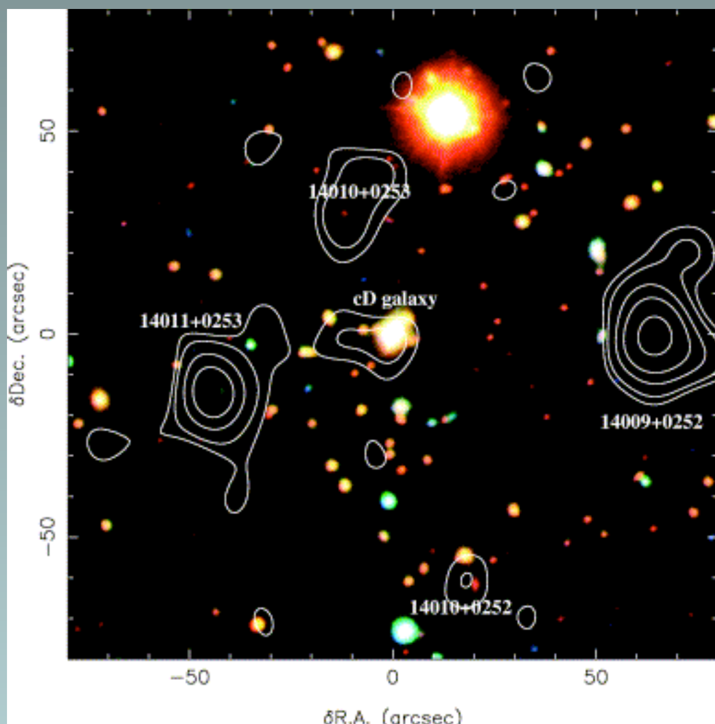
➢ Average volume density is comparable to a GMC, but volume is 10^3-10^6 times larger
  ➢ 1 kpc versus 10-100 pc

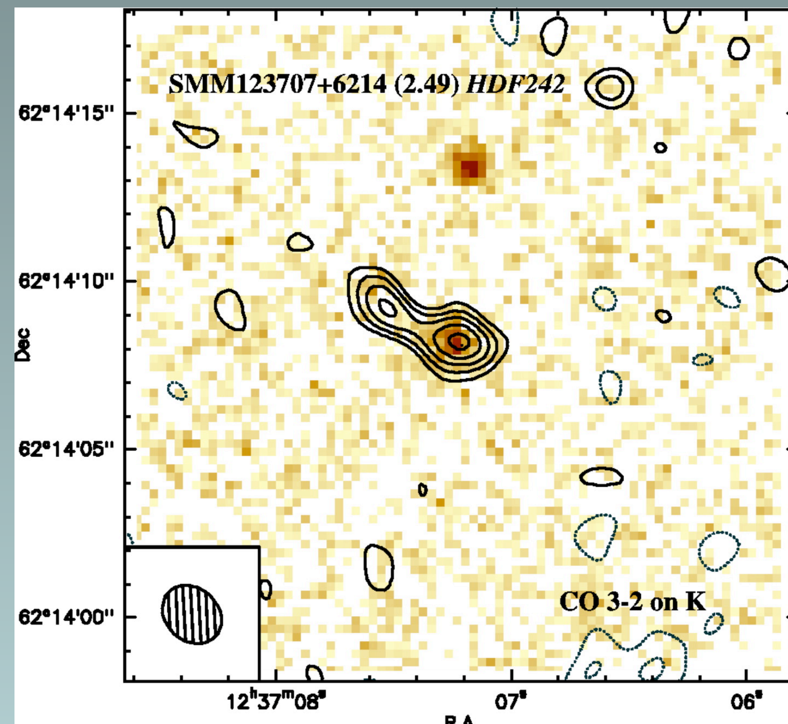
Star formation rates and efficiencies

- $L_{IR}/M(H_2)$ ranges from 30 to 600 L_o/M_o
  - Total LIR divided by total SMA $M(H_2)$ …
- $Log(L_{IR})$= 11.43 -12.41 implies star formation rates of 50 - 450 M_o/yr
  - Kennicutt 1998, ARAA
  - Caution: some L_{IR} could be from AGN
- gas depletion times of $1x10^7$ to $2x10^8$ yr
  - Note naïve calculation, does not include possibility of gas recycling

➢ Very high star formation rates and efficiences compared to normal galaxies or GMCs

ULIRGs are best local analogs to dusty galaxies at high redshift



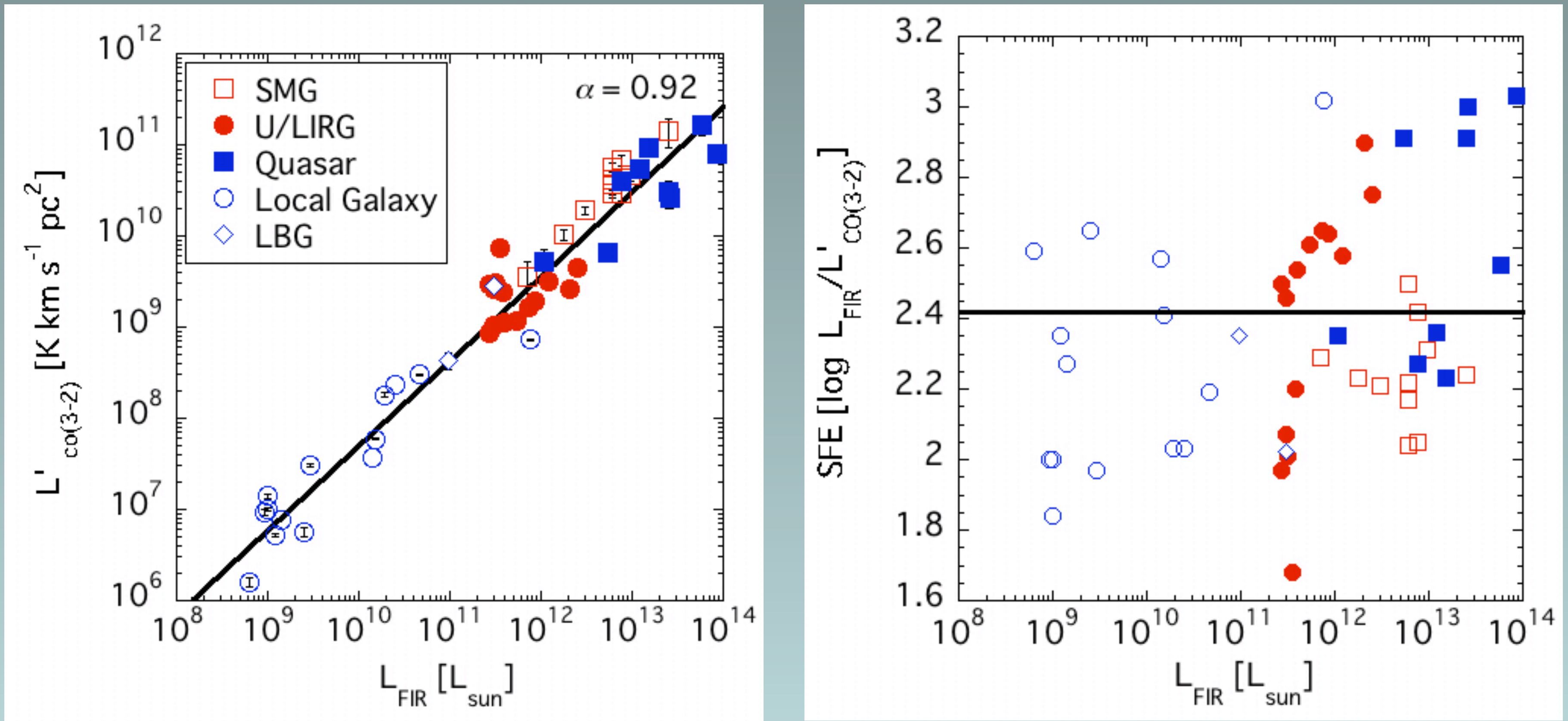


Ivison et al. 2000

Tacconi et al. 2006

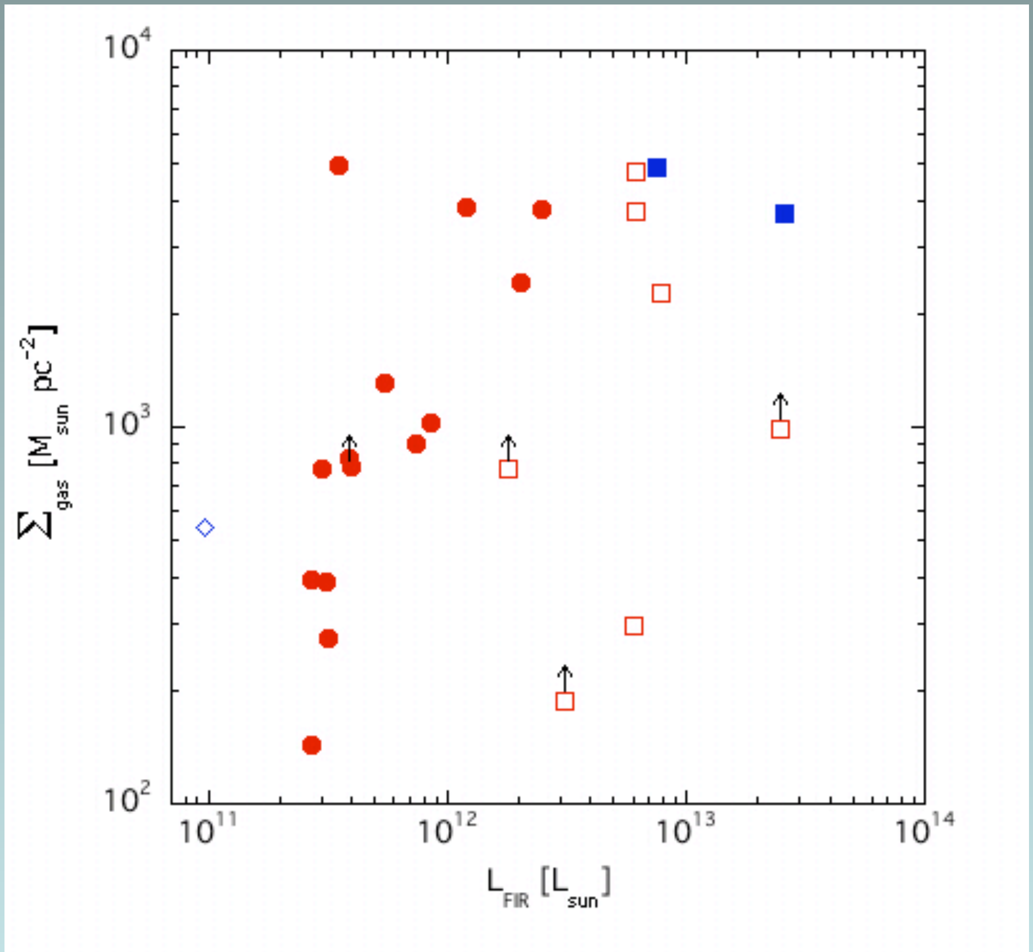
- Cosmologically significant population of very luminous dusty galaxies discovered at submm wavelengths
- For z>0.5, 5 mJy at 850 μm implies $L > 8x10^{12}\ L_o$

CO(3-2) traces dense star forming gas



- Slope (0.92+/-0.03) is similar to HCN (Gao & Solomon 2004) and significantly steeper than CO(1-0) (Yao et al. 2003)

Relation between gas surface density and far-infrared luminosity



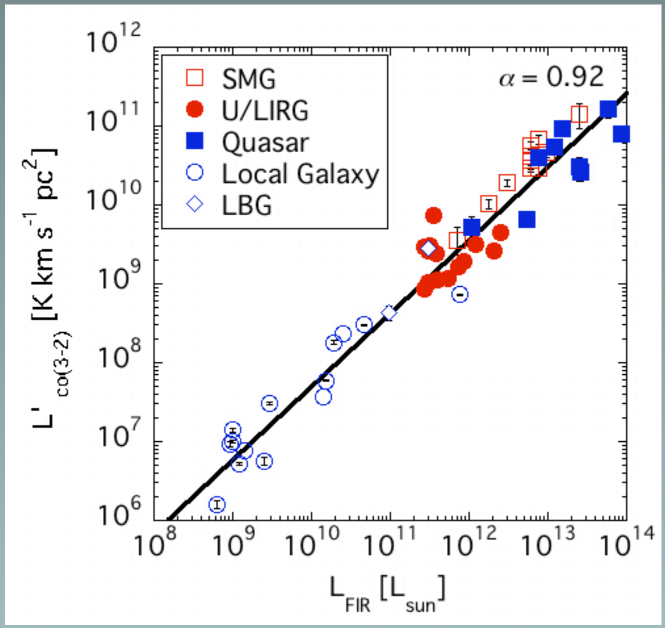
- Gas surface densities in M_o/pc^2:
  - 1400 ± 350 U/LIRGs
  - 2290 ± 890 SMGs
  - 4280 ± 600 quasars
- Surface density correlates with far-infrared luminosity
  - $L'_{CO(3-2)}$ to $M(H_2)$ using $M(H_2)=0.8L'_{CO(3-2)}$
  - assumes CO3-2/1-0=1
  - Note surface densities are not corrected for inclination

What will ALMA be able to do? Two examples …

- CO J=3-2
- 30 pc (0.06” at 100 Mpc)
- 4 hr, 5 km/s resolution gives 2 K rms
- Probe structure of molecular ISM on GMC scales

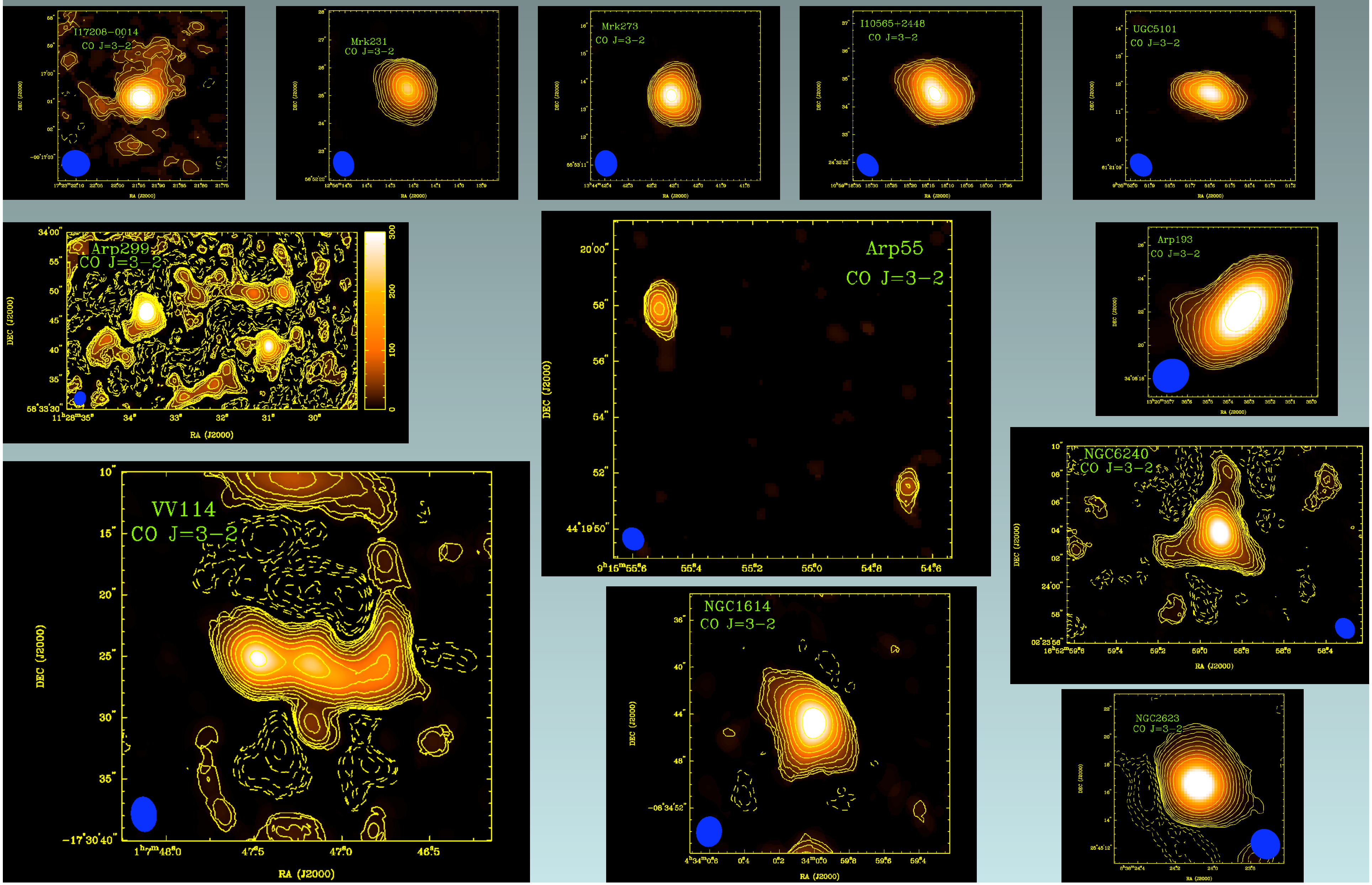
- Astrochemistry (HCN, HCO+ 4-3, etc.)
- 200 pc (0.2” at 200 Mpc)
- 4 hr, 20 km/s resolution gives 0.1 K rms
- Probe astrochemistry in starburst regions

Conclusions



- $L'_{CO(3-2)}$ and L_{FIR} correlated over 5 orders of magnitude
  - CO(3-2) traces dusty star formation activity
  - Star formation efficiency constant to within a factor of two in many galaxies
- ALMA:
  - Higher resolution studies of physics and chemistry of ISM in starbursts
  - Statistically complete samples to 200 Mpc or beyond
- Future work with SMA data:
  - Spatially and velocity resolved physical conditions in gas
  - Comparison with merger simulation

Molecular gas in merging galaxies



High-redshift comparison sample

- Select high-redshift objects with high resolution observations in CO(3-2) line
  - 12 submillimeter galaxies (SMGs) from z=2.2-3.1 (one at z=1.3)
  - 9 quasars from z=2.3-2.8 (one at z=6.4)
  - 2 Lyman Break Galaxies (LBGs) at z=2.7-3.1

- References for CO data:
  - SMGs: Genzel et al. 2003, Downes & Solomon 2003, Sheth et al. 2004, Greve et al. 2005, Tacconi et al. 2006, Iono et al. 2006
  - Quasars: Downes et al. 1995, Barvainis et al. 1998, Guilloteau et al. 1999, Weiss et al. 2003, Walter et al. 2004, Beelin et al. 2004, Hainline et al. 2004, Solomon & van den Bout 2005
  - LBGS: Baker et al. 2004, Coppin et al. 2007