Molecular gas dynamics in luminous infrared galaxies observed with the SMA

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

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All galaxies with $L_{\text{FIR}} > 5 \times 10^{11} \, L_\odot$ are interacting or close pairs \citep{Sanders1987}.

\textit{ULIRGS are galaxy mergers}

\textit{Figure from Galliano 2004}

\textit{Scoville et al. 2000}
• 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($L_{\text{FIR}}$) > 11) and ultraluminous (log($L_{\text{FIR}}$) > 12) infrared galaxies
- $D_L < 200$ Mpc (resolution 1″ ~ 1 kpc)
- log($L_{\text{FIR}}$) > 11.4
- All with previous interferometric observations in the CO J=1-0 line
# The Nearby Luminous Infrared Galaxy Sample

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<th>Name</th>
<th>Image</th>
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<td>Mrk273</td>
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<td>I10565+2448</td>
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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 $10^4$ $M_\odot$/pc$^2$ inside 0.5-1.2 kpc$^2$ area
  - $6 \times 10^{22}$ - $6 \times 10^{23}$ $H_2$/cm$^2$
  - $A_V=70$-700 mag

- Average volume density at peak range from 1 to 15 $M_\odot$/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

- \( \frac{L_{\text{IR}}}{M(H_2)} \) ranges from 30 to 600 \( \frac{L_\odot}{M_\odot} \)
  - Total LIR divided by total SMA \( M(H_2) \) ...
- \( \log(L_{\text{IR}}) = 11.43 - 12.41 \) implies star formation rates of 50 - 450 \( M_\odot/\text{yr} \)
  - Kennicutt 1998, ARAA
  - Caution: some \( L_{\text{IR}} \) could be from AGN
- gas depletion times of \( 1 \times 10^7 \) to \( 2 \times 10^8 \) \( \text{yr} \)
  - Note naïve calculation, does not include possibility of gas recycling

- Very high star formation rates and efficiencies compared to normal galaxies or GMCs
ULIRGs are best local analogs to dusty galaxies at high redshift

- 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_\odot

Ivison et al. 2000
Tacconi et al. 2006
Slope (0.92+/-0.03) is similar to HCN (Gao & Solomon 2004) and significantly steeper than CO(1-0) (Yao et al. 2003)
Gas surface densities in $M_\odot/pc^2$:
- 1400 ± 350 U/LIRGs
- 2290 ± 890 SMGs
- 4280 ± 600 quasars

Surface density correlates with far-infrared luminosity
- $L'_{\text{CO}(3-2)}$ to $M(H_2)$ using $M(H_2) = 0.8L'_{\text{CO}(3-2)}$
- 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

- $L'_{\text{CO}(3-2)}$ and $L_{\text{FIR}}$ 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
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:
  - LBGs: Baker et al. 2004, Coppin et al. 2007