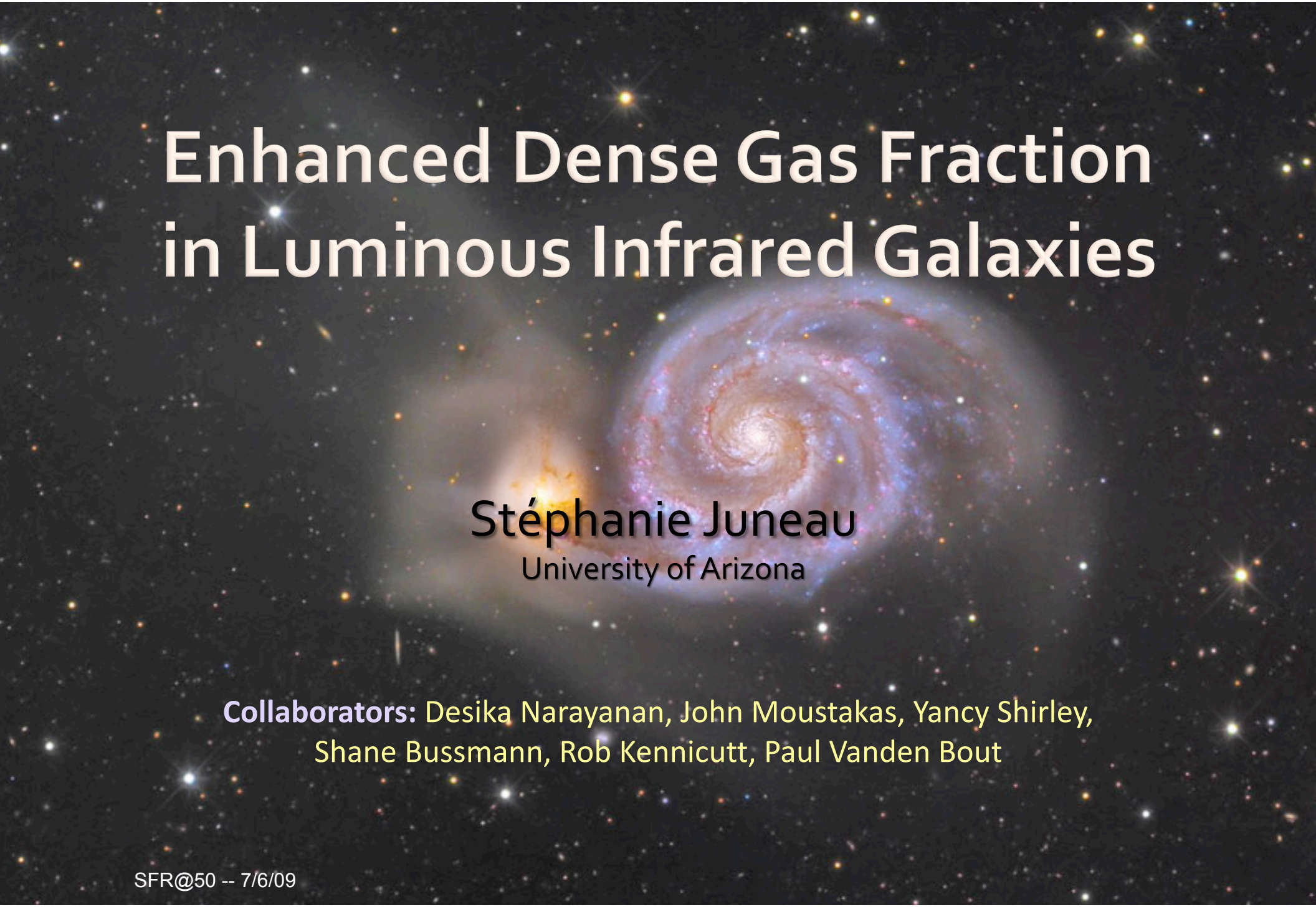
# Enhanced Dense Gas Fraction in Luminous Infrared Galaxies



Stéphanie Juneau
University of Arizona

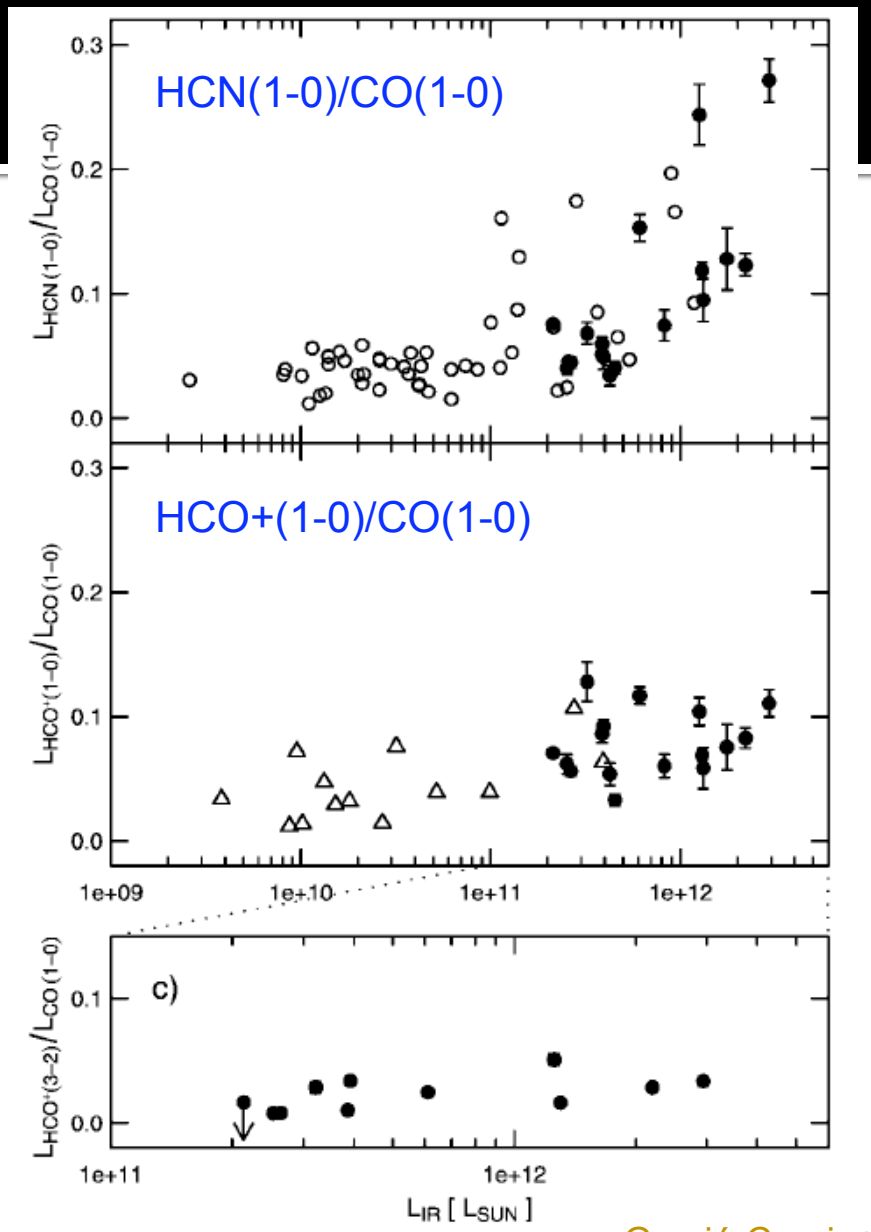
**Collaborators:** Desika Narayanan, John Moustakas, Yancy Shirley, Shane Bussmann, Rob Kennicutt, Paul Vanden Bout

# Motivation

- How do galaxy SFR and gas content relate?
  - Kennicutt-Schmidt Law: $\Sigma_{SFR} \alpha \Sigma_{gas}^{1.4\text{-}1.5}$
  - Models (e.g. Narayanan+08, KT07): SFR α (gas density)$^{1.5}$
- Observations & history
  - CO(J=1-0) traces total molecular gas
    - Traditional relation between $L_{IR} - L'_{CO(1\text{-}0)}$
  - HCN(J=1-0) traces dense molecular gas, responsible for star formation
    - Linear relation between $L_{IR} - L'_{HCN(1\text{-}0)}$ (Gao & Solomon '04)

# Motivation II

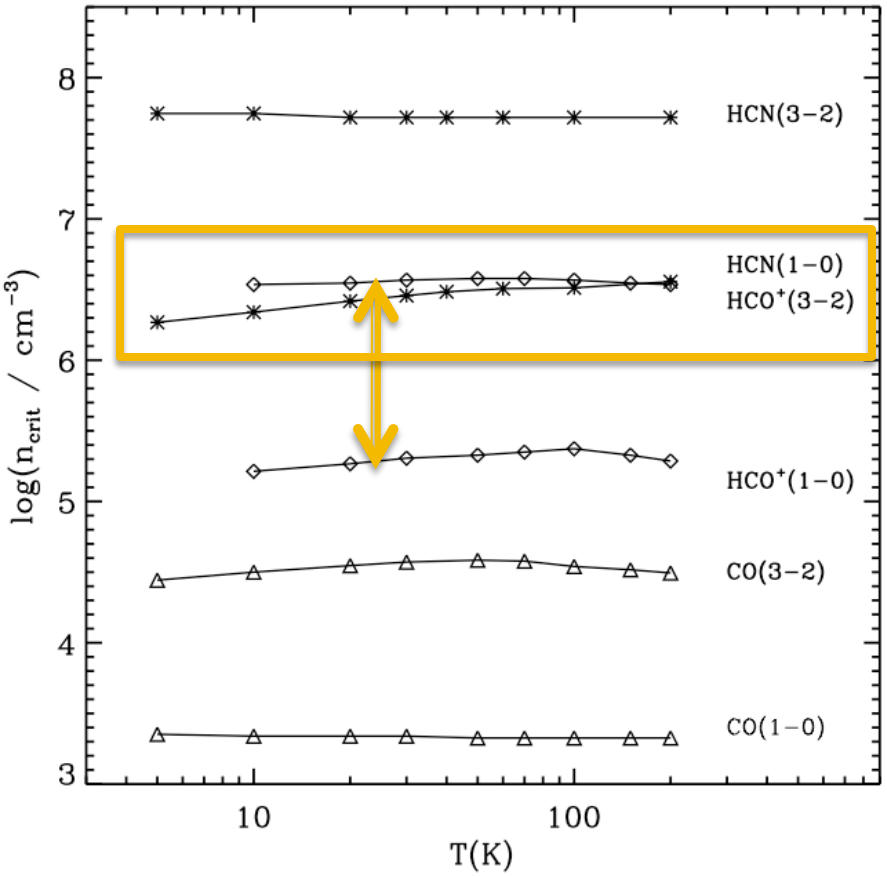
- However, recent work questions the robustness of HCN(J=1-0) as a dense gas tracer in AGNs
  - Observations of higher HCN(1-0)/CO(1-0) in ULIRGs (most of which host an AGN)
  - Does AGN influence chemistry/abundance of HCN?
  - Does the higher HCN(1-0)/CO(1-0) reflect a higher dense gas fraction?




Graciá-Carpio+ 06

# Critical Densities

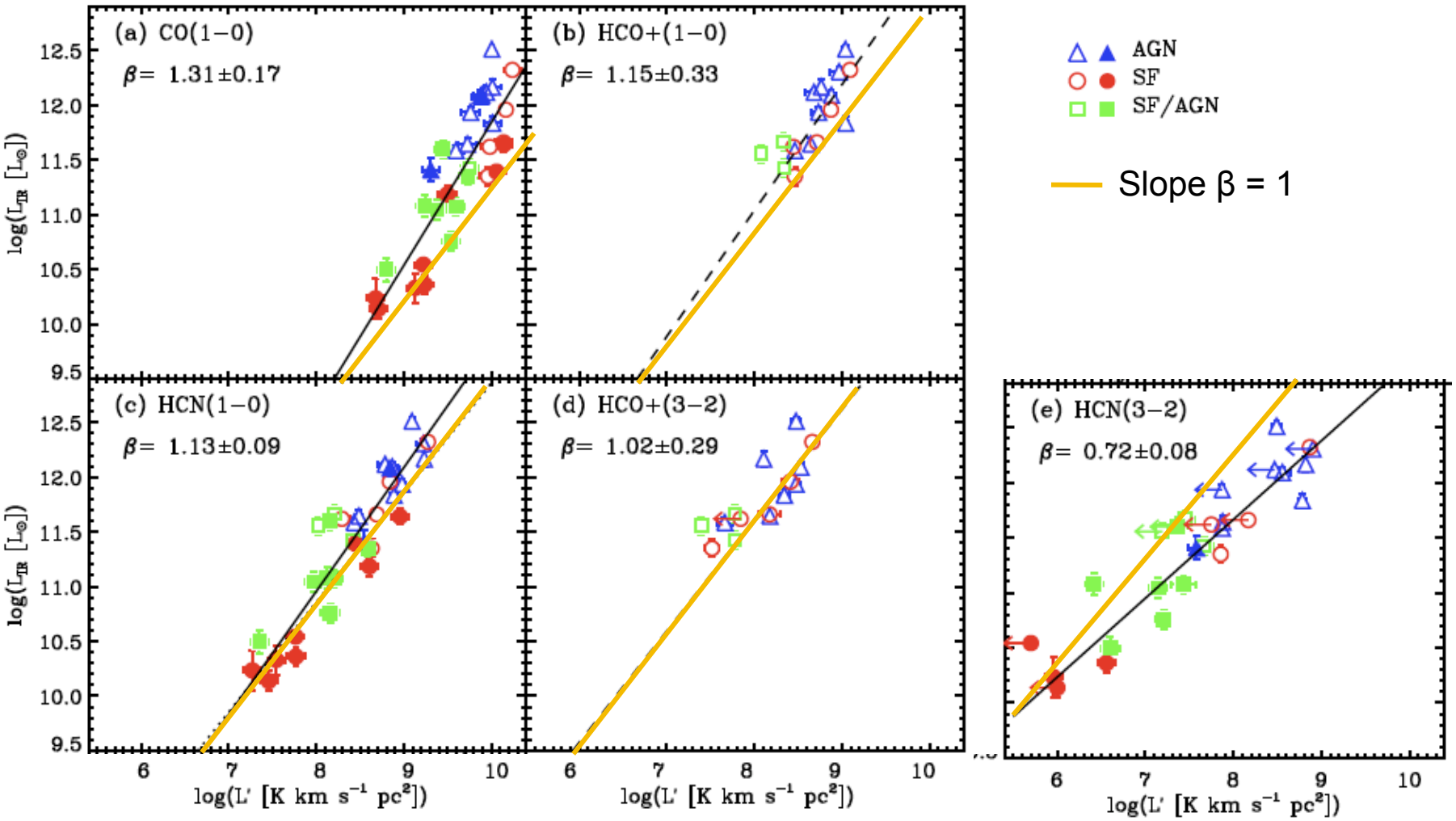
- Density of the gas probed by molecular lines (in LTE): $n_{crit} = A_{ul} / \Gamma_{ul}$
  - $n_{crit}$[HCN(1-0)/HCO+(1-0)] > 10
  - $n_{crit}$[HCN(1-0)]≈ $n_{crit}$[HCO+(3-2)]



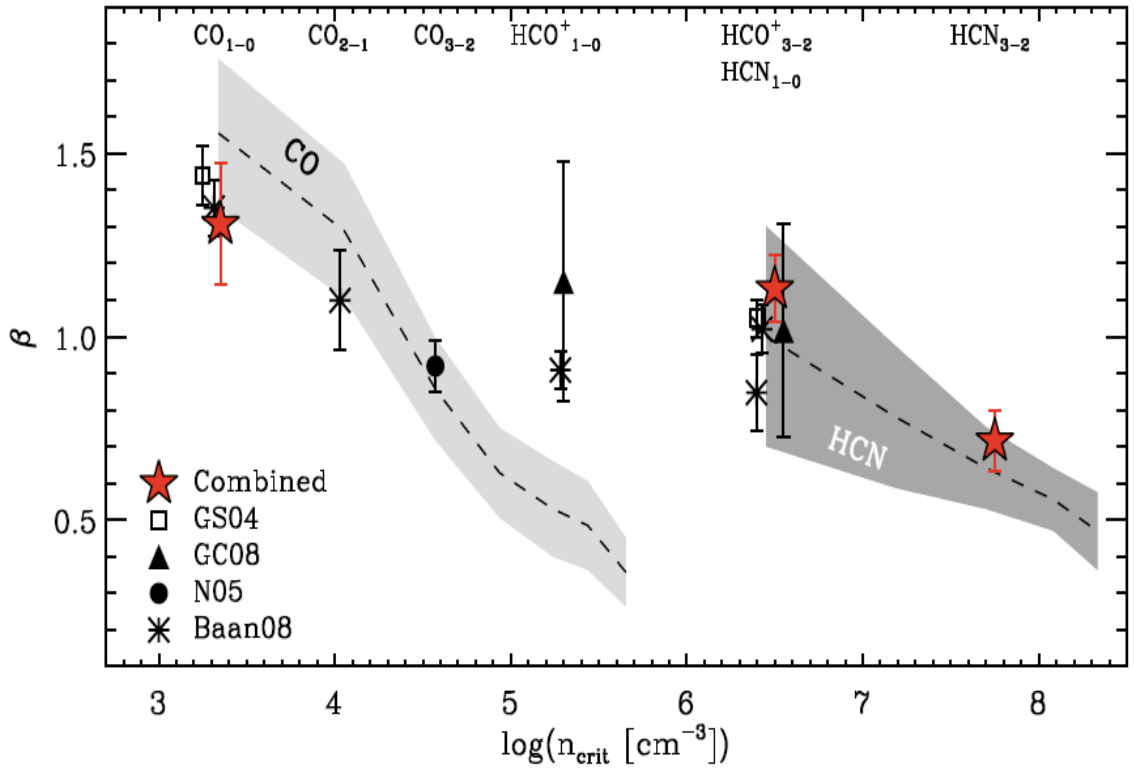
# Sample

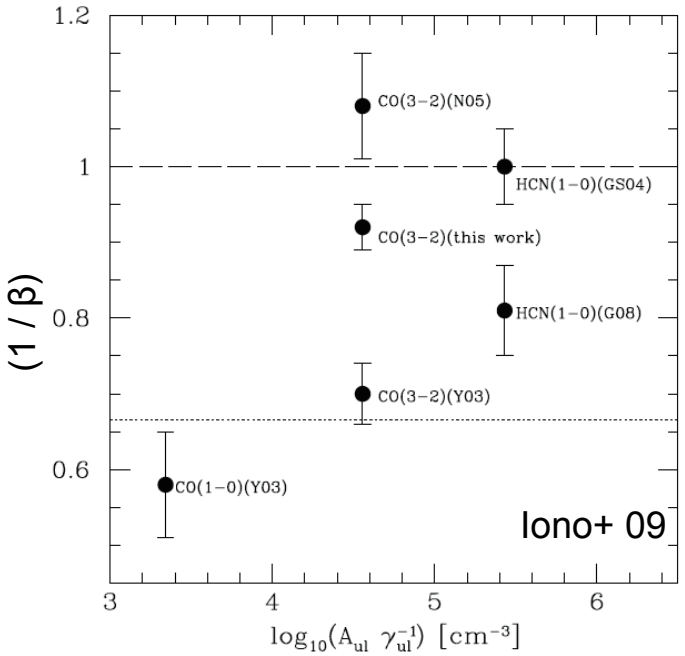
- 34 nearby galaxies with $10^{10} < L_{IR} < 10^{12.5}\ L_{\odot}$
- Molecular line observations:
  CO(1-0), HCO+(1-0), HCN(1-0), HCO+(3-2) & HCN(3-2) [Gao & Solomon '04, Gracia-Carpio+08, Bussmann+08]
  - Range in $n_{crit}=10^{3.3} - 10^{7.7}\ cm^{-3}$
- Homogeneous AGN identification
  (*BPT* optical emission-line diagnostic)

# $L_{IR} - L'_{mol}$ relations



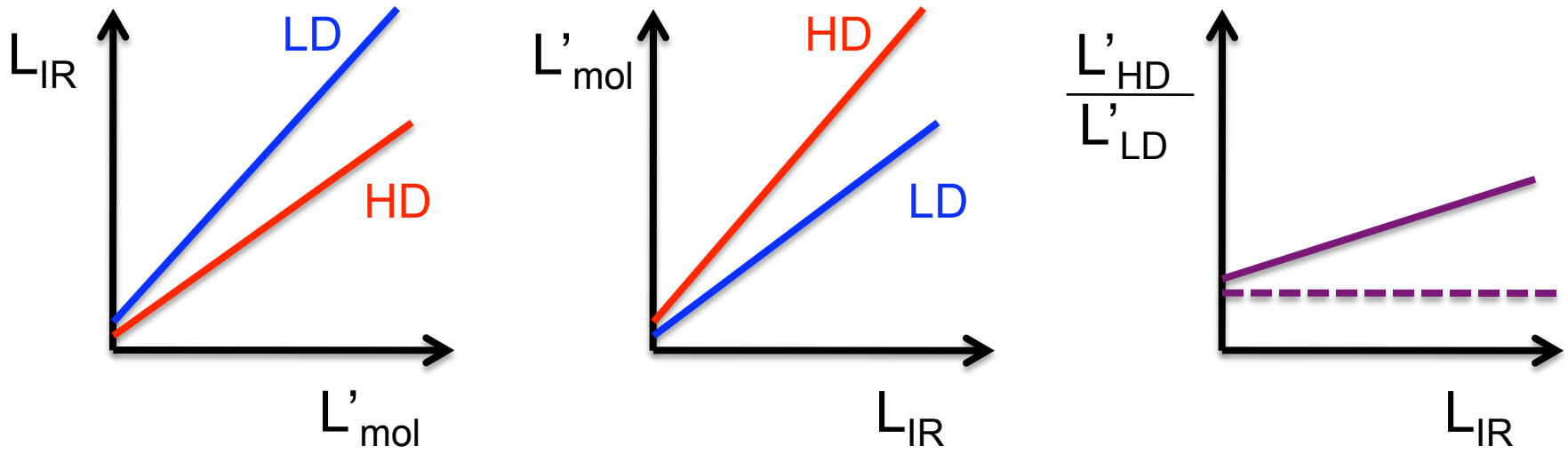
# $L_{IR} - L'_{mol}$ index as a function of $n_{crit}$



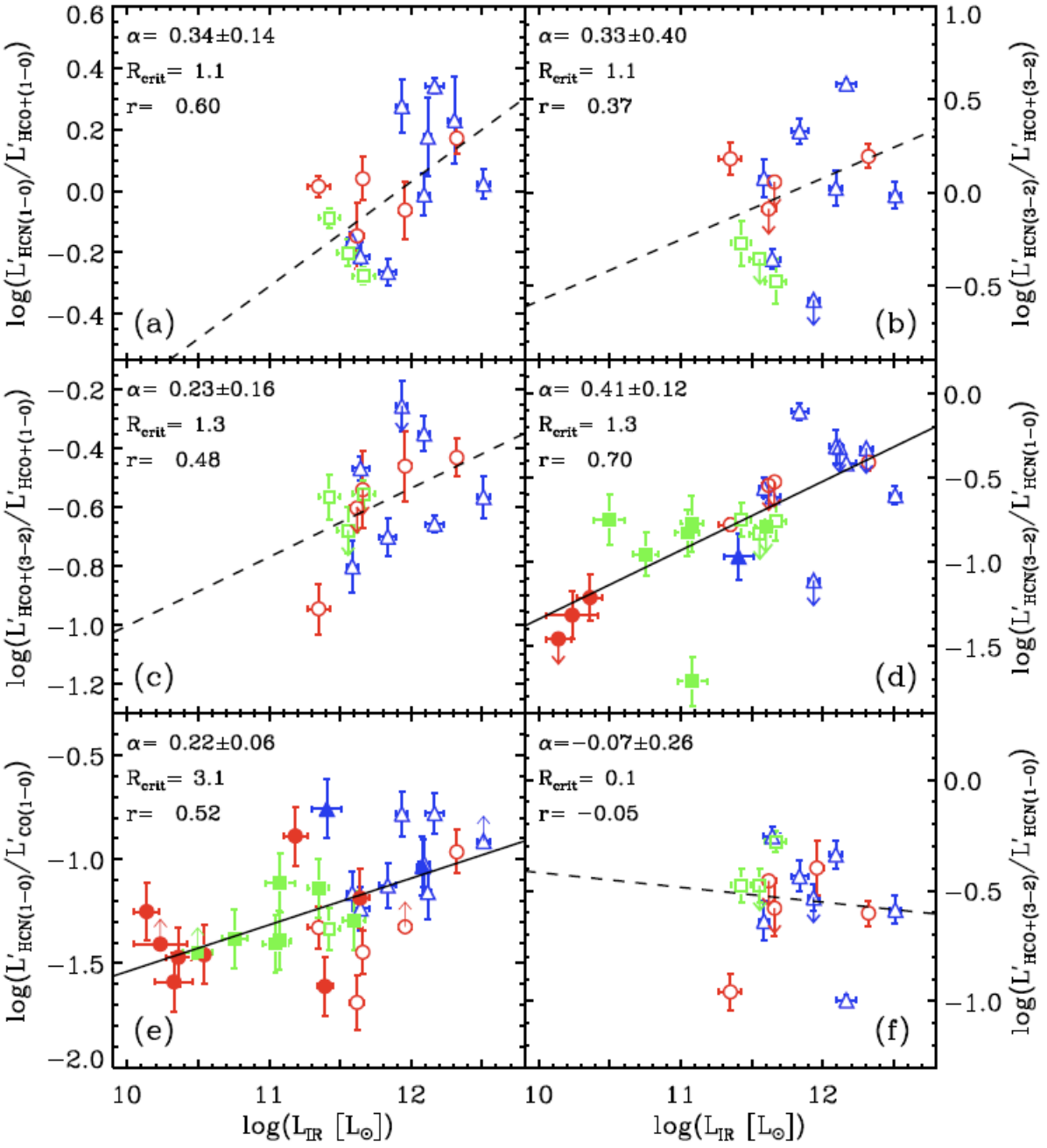

- Overall: relation between $L_{IR}$-$L'_{mol}$ becomes shallower as $n_{crit}$ ⇧ (Conversely, $L'_{mol}$-$L_{IR}$ becomes steeper)

# Comparing HD & LD Tracers




Ratio of molecular lines with different densities should vary with $L_{IR}$

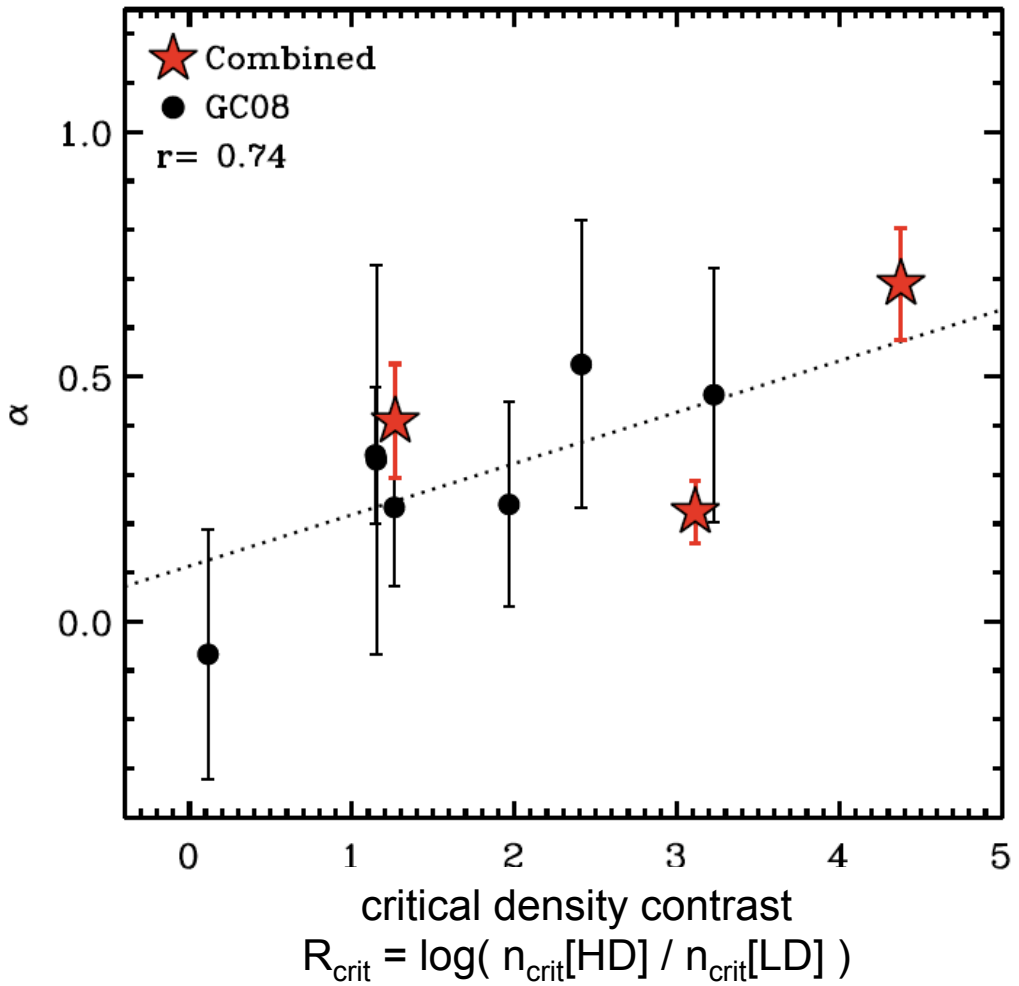
$(L'_{HD} / L'_{LD})$ ↑ with $L_{IR}$




critical density contrast:

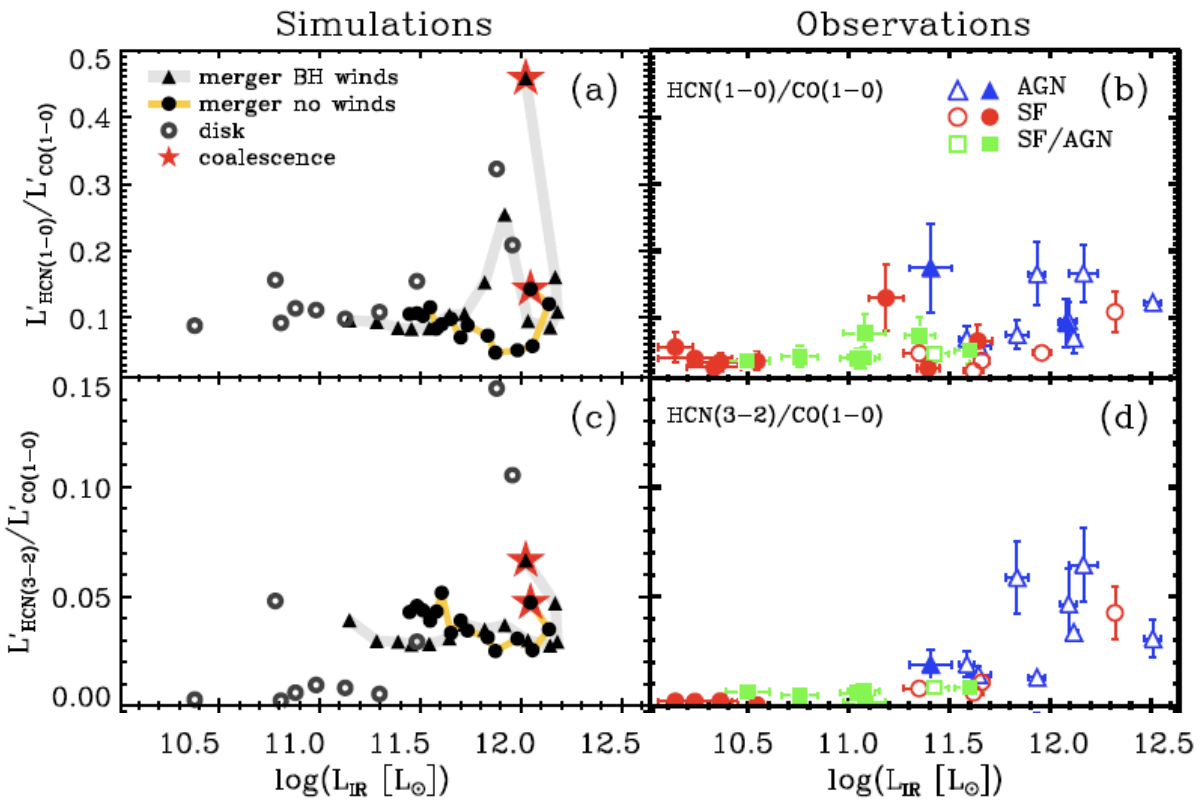
$R_{crit}$ = log( $n_{crit}$[HD] / $n_{crit}$[LD] )

# HD/LD line luminosity ratios




- HD/LD line luminosity ratios increase with $L_{IR}$ (index $\alpha$>o)
- This effect is more pronounced for higher density contrast
- Larger samples over a larger dynamical range would help confirm this trend

# Comparison with models



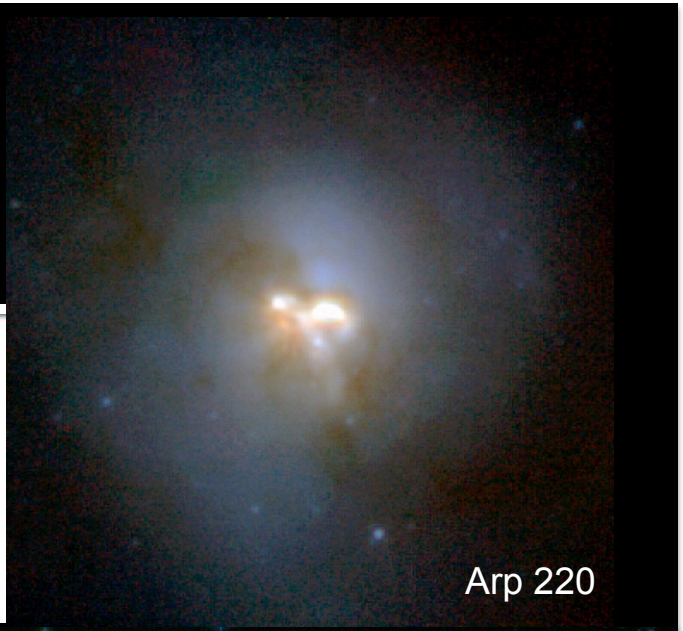

- Simulations: gas-rich disk galaxies and galaxy mergers with ***fixed*** Galactic abundance
- Higher spread of HCN/CO luminosity ratios in more IR-bright galaxies
- Evolutionary stage of the merger may play a role

# Conclusions

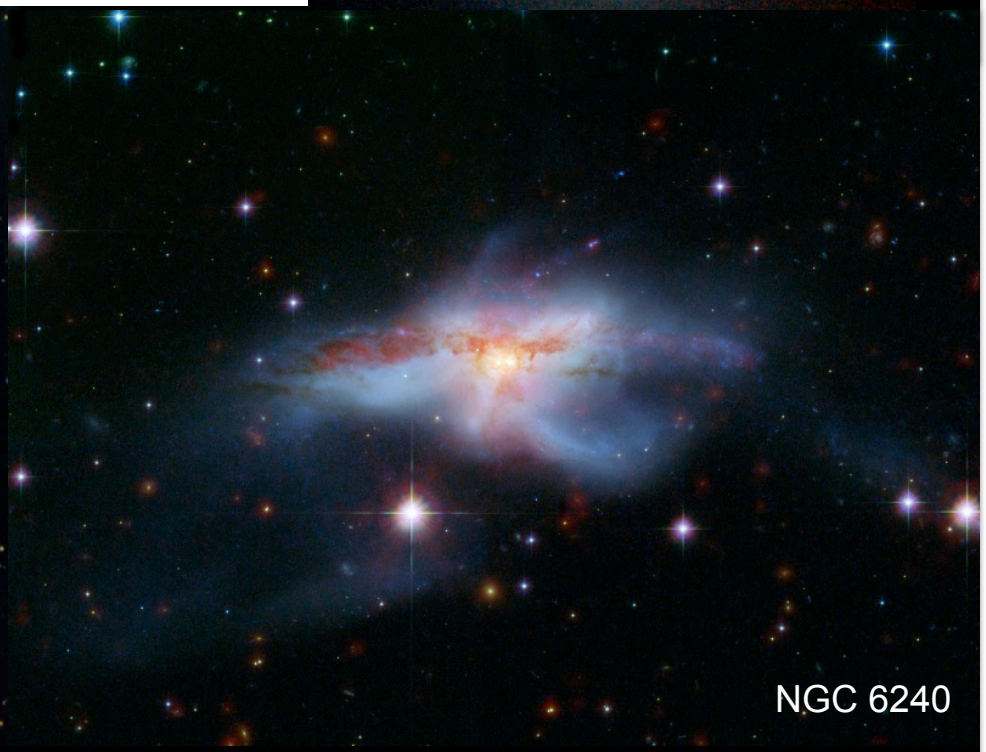
- Our results support a higher dense gas fraction (higher average density) in ULIRGs
- We reproduce the observed spread of HCN/CO without AGN-induced chemistry/abundance effect
- AGN reside in high-density gas-rich systems and are generally not the main driver of a higher HCN/CO luminosity ratio

# Conclusions II

- Increased density of molecular gas during galaxy merger may be the underlying cause of the higher $L_{HD}/L_{LD}$


Arp 220


NGC 520


NGC 6240