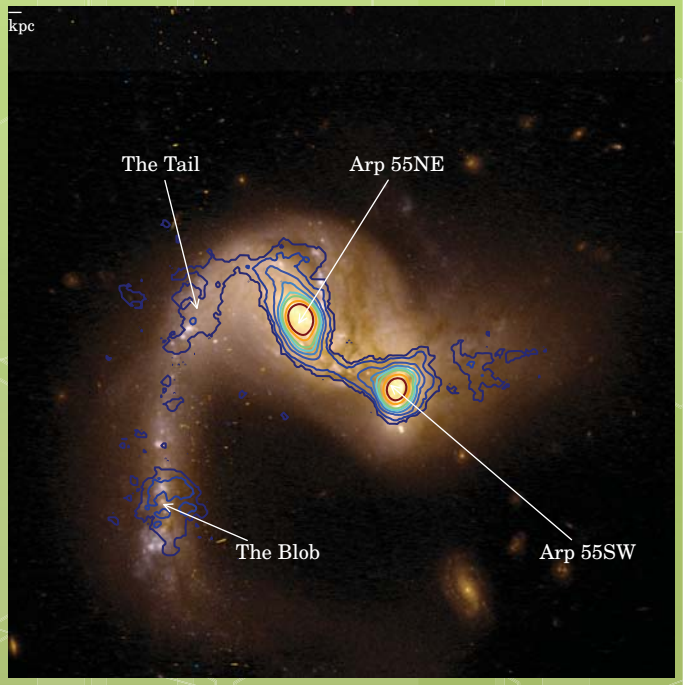


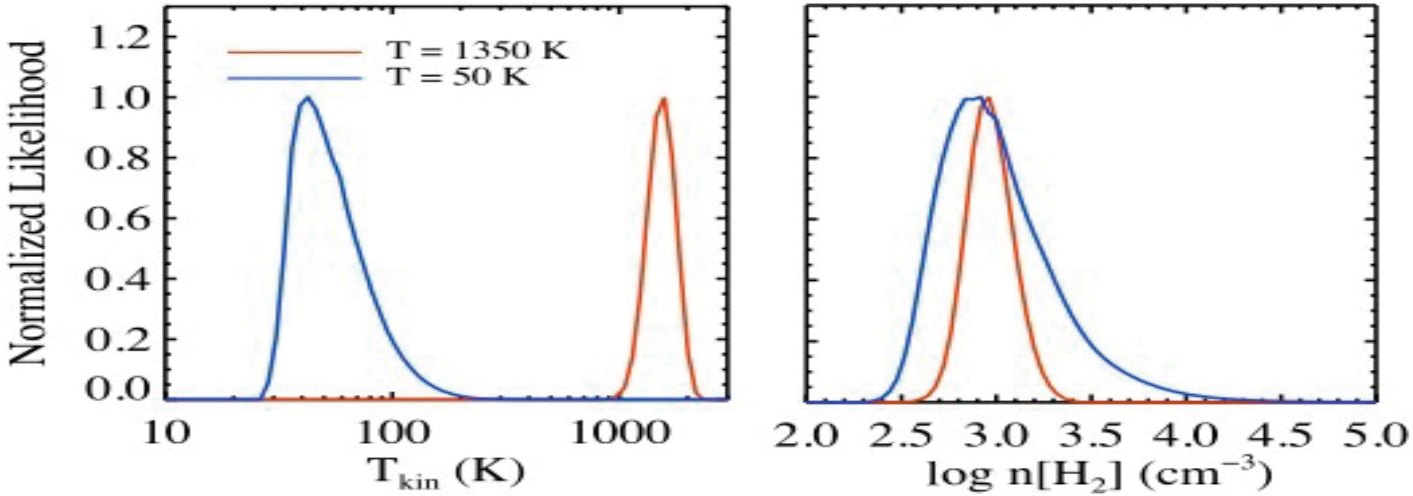
Extreme physical conditions in luminous infrared galaxies

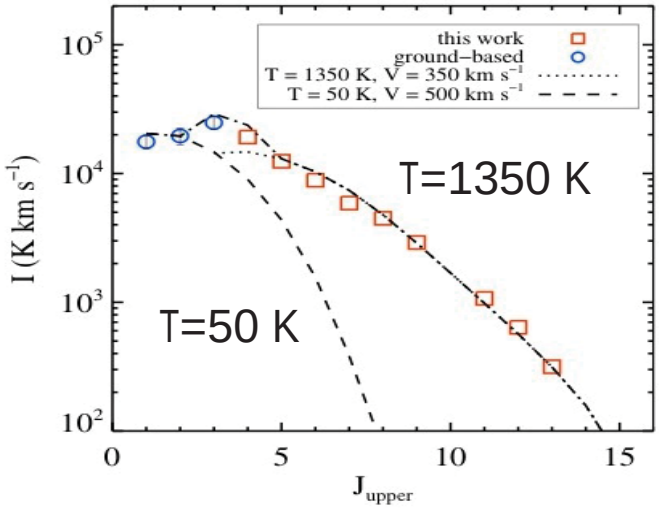
Chris Wilson
McMaster University

Outline

- Arp 220: dense gas and complex kinematics
- Dense gas tracers in galaxies
- Trends along the merger sequence:
  - $[^{12}CO]/[^{13}CO]$ abundance ratio
  - α_{CO}
- See also Saito et al. 2015 (VV114), Johnson et al. 2015 (proto-SSC in Antennae), Xu et al. 2014, 2015 (CO J=6-5 in NGC 34 and NGC 1614)

Global properties of Arp 220

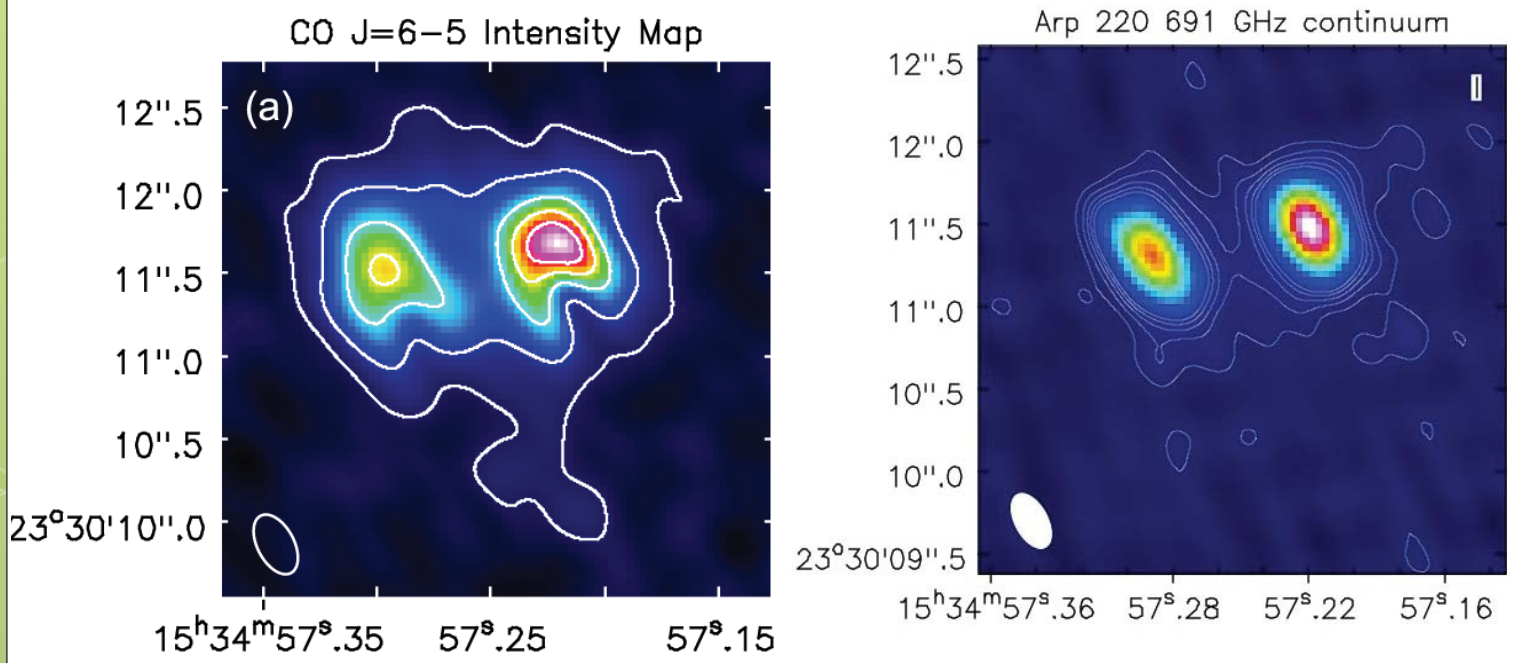




Hot molecular gas is 10% of the mass!

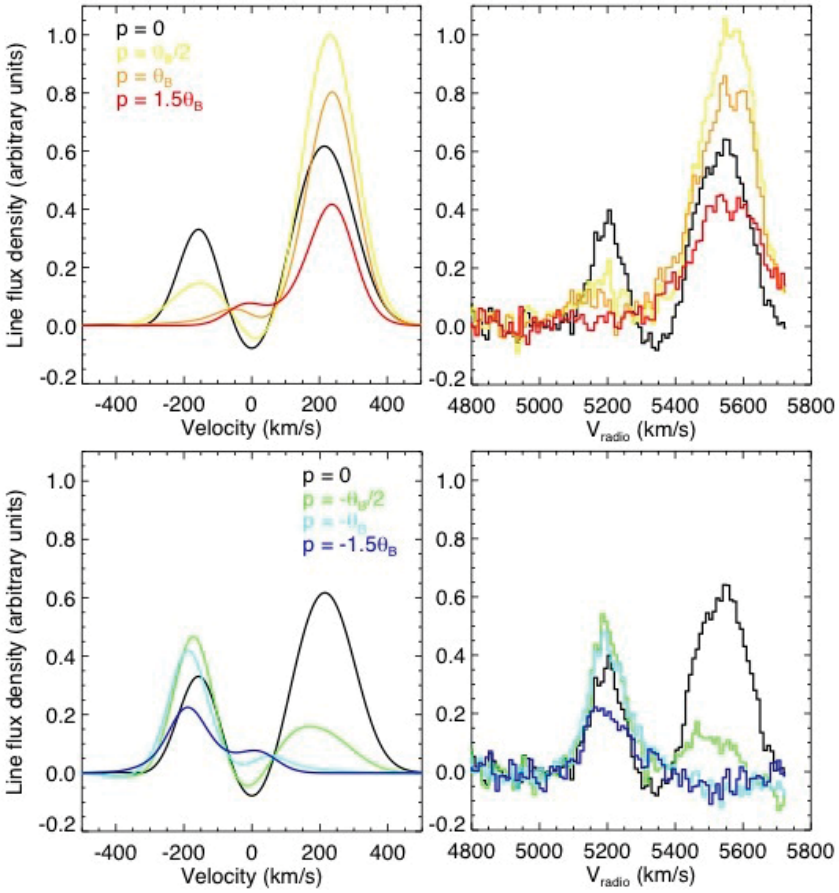
Rangwala et al. 2011, ApJ

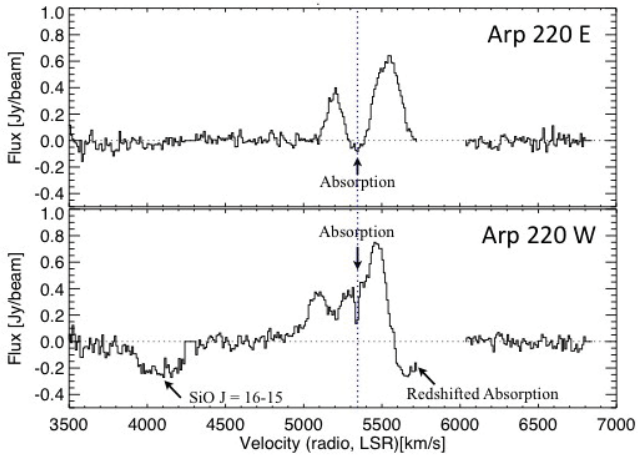
Arp 220 in ^{12}CO J=6-5 and continuum with ALMA



- Dust traces two high density (10^4-10^5 cm^{-3}) nuclei (Wilson et al. 2014, ApJ)

Arp 220 in ^{12}CO J=6-5 with ALMA



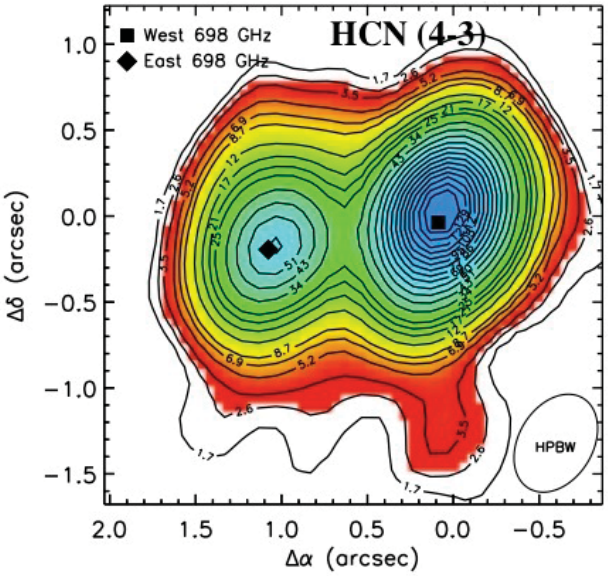


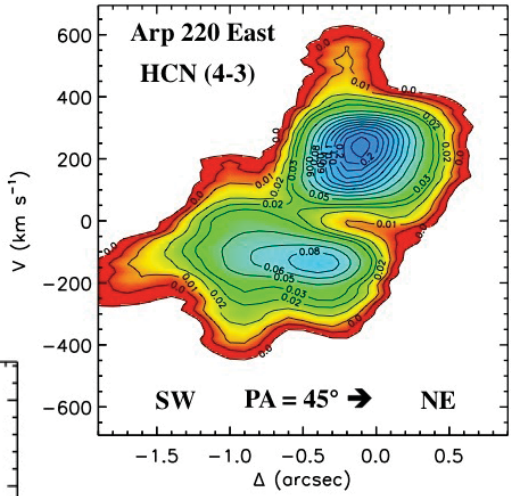
- Asymmetric line profiles modeled as rotating disk
  - $\tau_{line} \sim 4$, $\tau_{dust} \sim 1$
- foreground absorption needed to reproduce line asymmetry

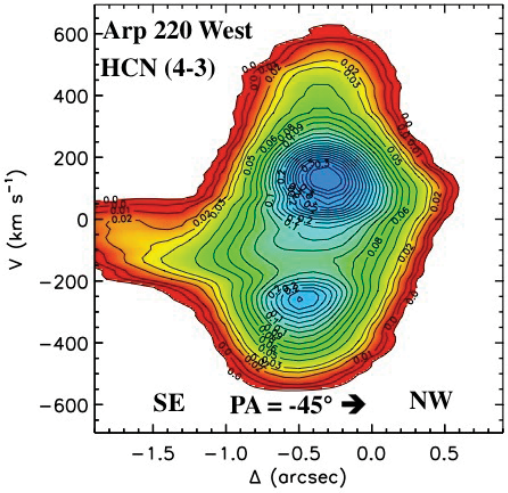
(Rangwala et al. 2015, ApJ)

HCN J=4-3: Dense gas in Arp 220

Integrated HCN intensity





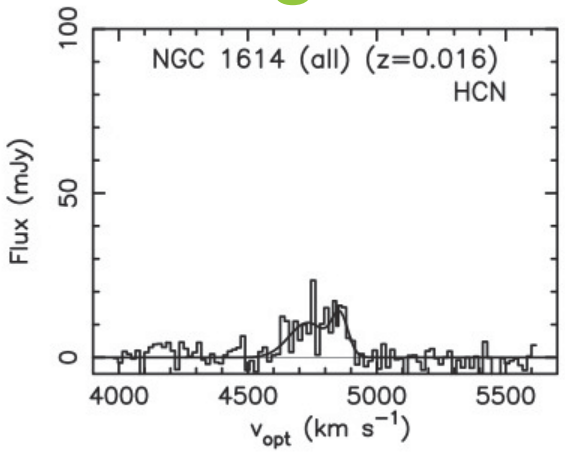


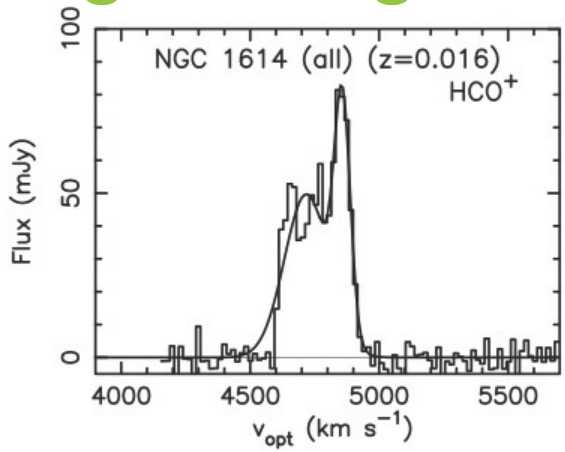
Position-velocity plots

Gas densities few x 10^5 cm^{-3}
Dynamical masses few x 10^9 M_o

Scoville et al. 2015 ApJ

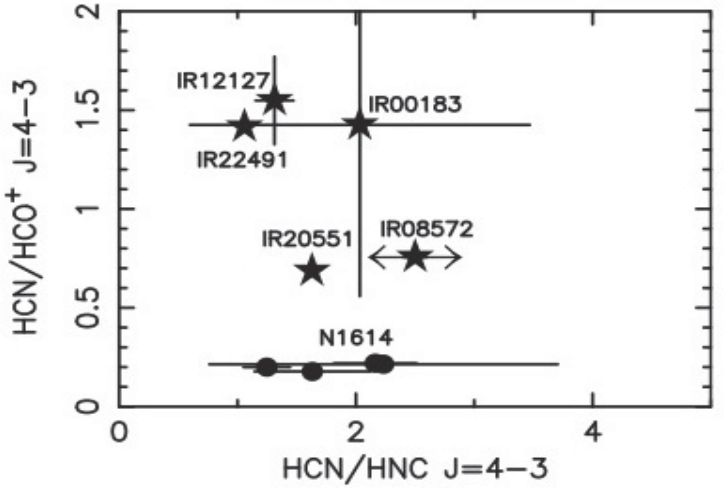
HCN, HCO+, HNC: Tracing dense gas in galaxies





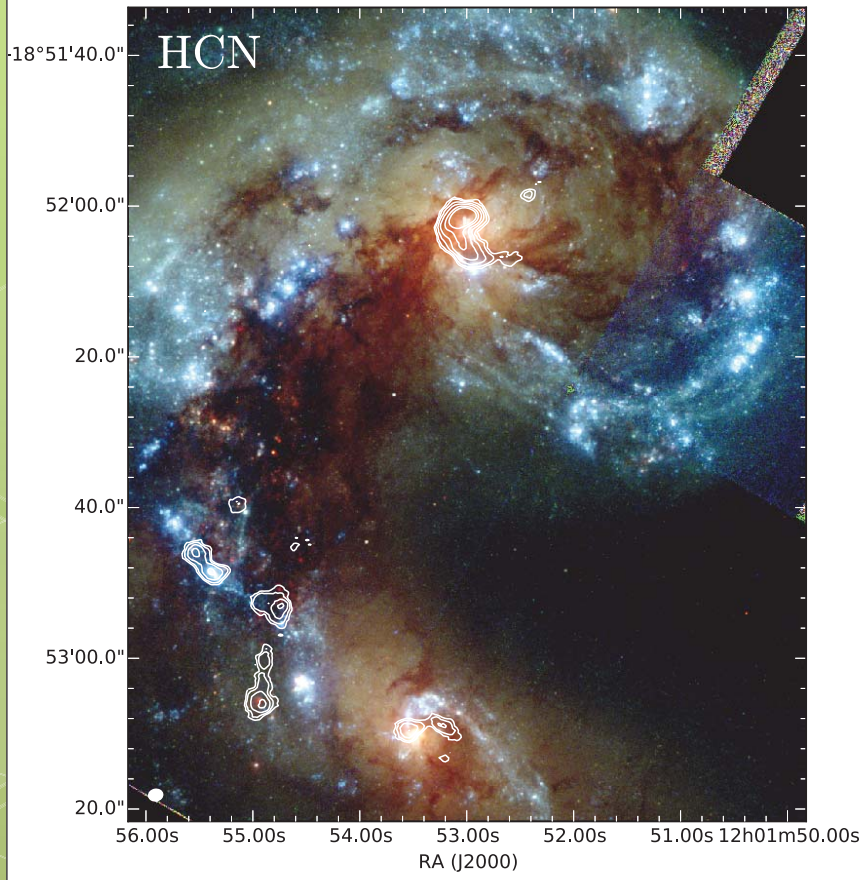
Imanishi & Nakanishi 2013, 2014, AJ

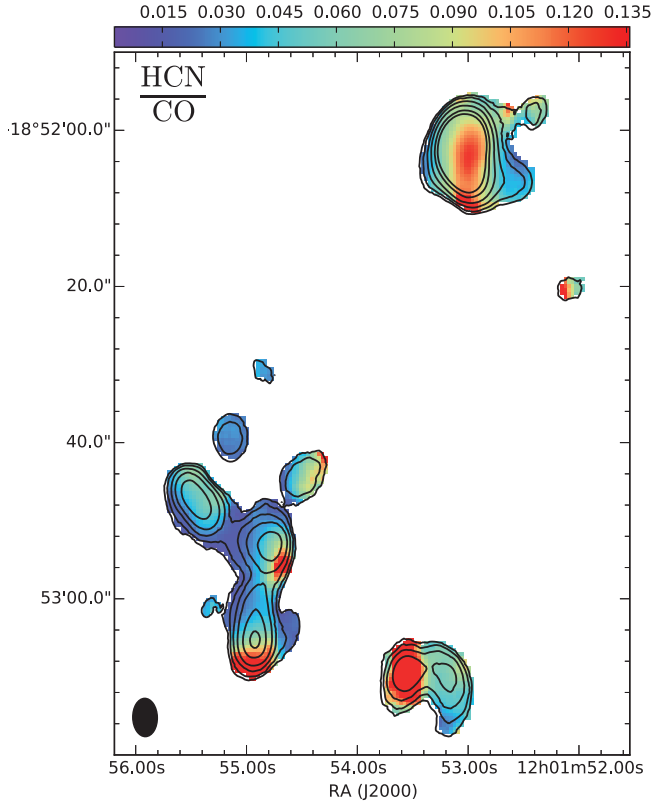
- J=4-3 transitions: critical densities 10^6-10^7 cm^{-3}
- HCN/HCO+ ratio tends to be larger in AGN-dominated systems



Dense gas in the Antennae: into the heart of a merger

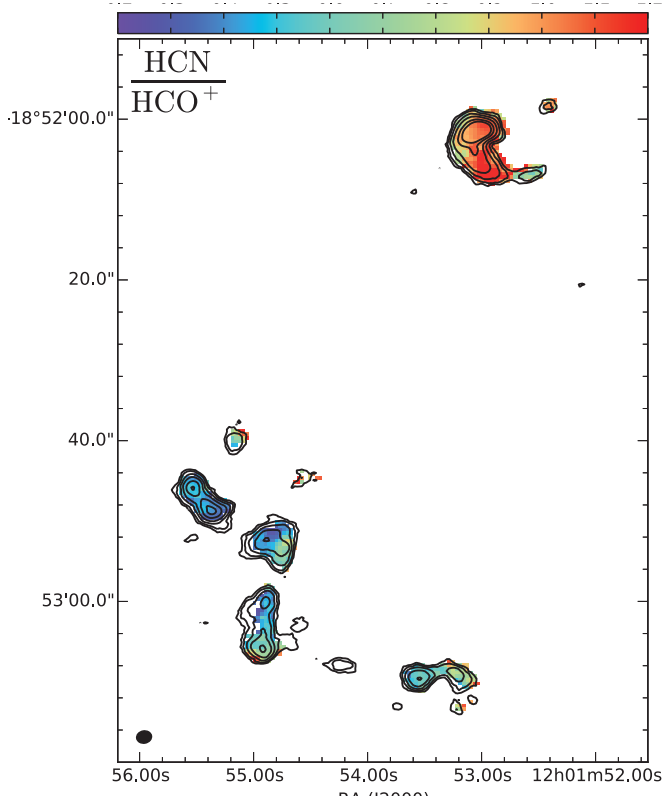
Schirm et al., 2015, ApJ, submitted





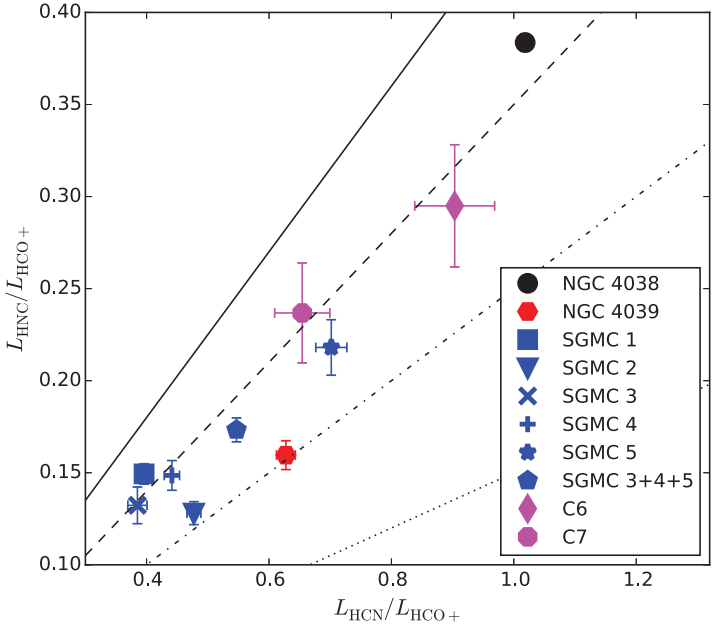
HCN/CO: higher dense gas fraction in two nuclei

Dense gas in the Antennae: into the heart of a merger



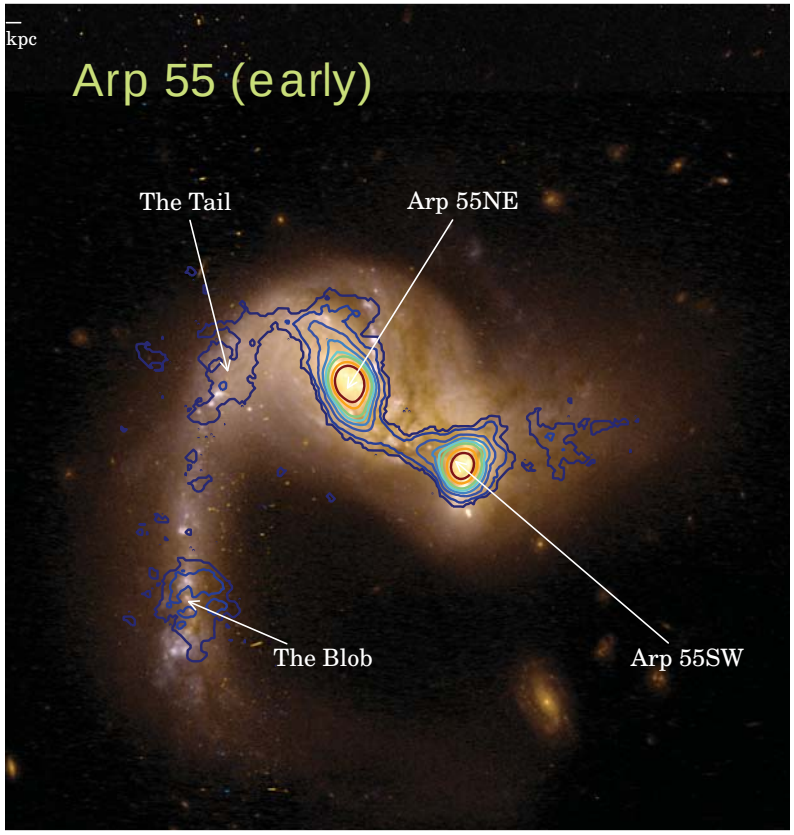
HCN/HCO+: changes in cosmic ray rate?

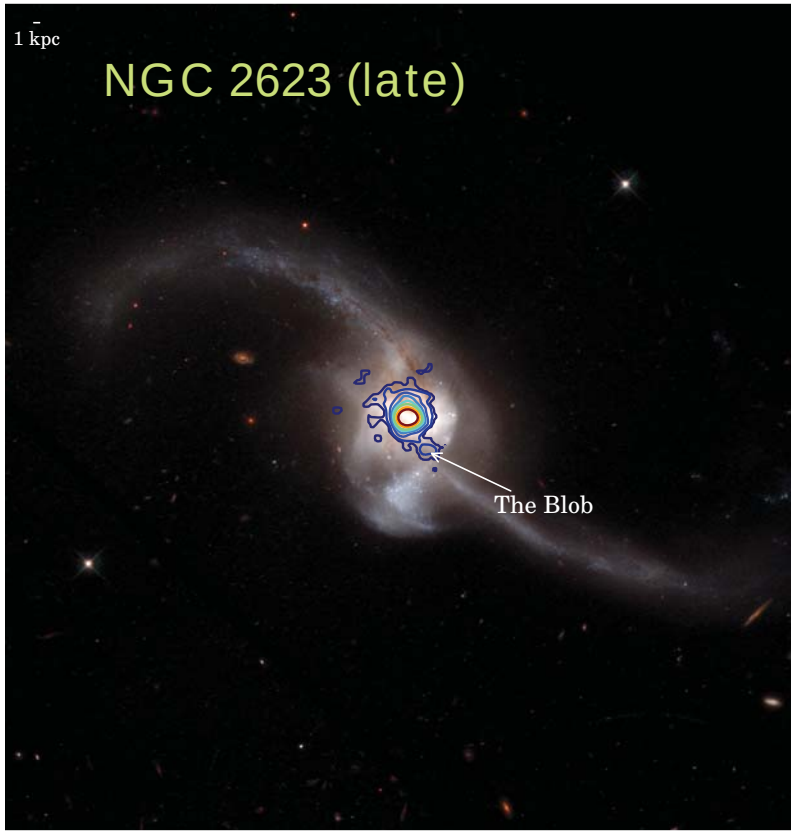
Schirm et al., 2015, ApJ, subm.



Uniform HNC/HCN ratio requires PDRs with mechanical heating

Molecular gas in LIRGs: trends along the merger sequence





^{12}CO J=1-0 data from CARMA on HST image

Kaz Sliwa, Ph.D. thesis and in prep

$^{12}CO/^{13}CO$ abundance ratio is high in LIRGs

- Four galaxies, range of merger properties
  - Arp 55, NGC 1614, VV114, NGC 2623
- RADEX + Bayesian likelihood modelling of low-J ^{12}CO and ^{13}CO lines
- Find high abundance ratios $[^{12}CO]/[^{13}CO]$ ~ 100-200
  - except Arp 55 (earliest) which has ~30
- How to drive up this ratio (Casoli et al. 1992)
  - Inflow of low ^{13}CO abundance gas from large galactic radii
  - massive stars produced in starburst enrich ISM in ^{12}CO

Sliwa et al. 2013, 2014, and in prep

The CO-to-H_2 conversion factor is mostly ULIRG-like

- Can constrain CO-to-H_2 conversion factor, α_{CO} by comparing N(CO) (from RADEX models) to I(CO) (measured)
  - Must assume $x_{CO}={}^{12}CO/H_2$ abundance ratio
- α_{CO} ~ 0.1 $(3x10^{-4}/x_{CO})$ $M_o/(K\ km/s\ pc^2)$ in NGC 2623 and Arp 55
  - 0.5 for VV114
  - 0.9-1.5 for NGC 1614
- For Arp 55 and NGC1614, also constrain $x_{CO} > 1\text{-}2 \times 10^{-5}$ using M_{dyn}

Sliwa et al. 2013, 2014, and in prep

Conclusions

- We see significant changes in the molecular gas in mergers compared to normal spirals
- Dense gas tracers are a powerful new tool to study the extreme ISM