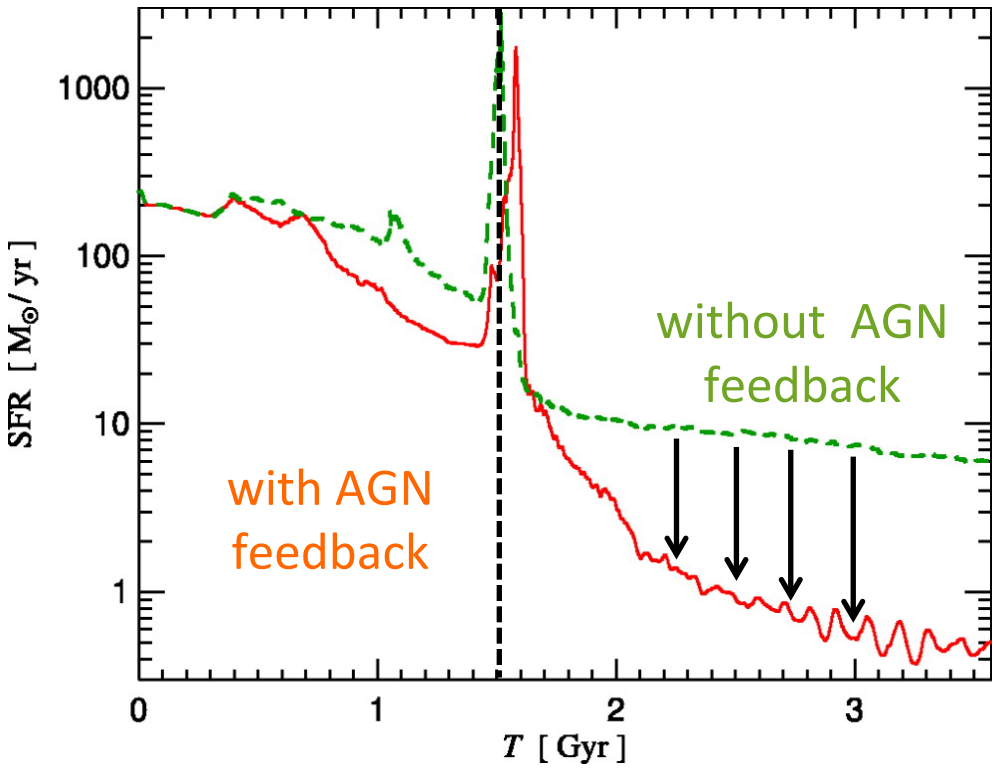
# Does AGN and stellar feedback affect the molecular gas in merger remnants?

Junko Ueda (SAO (SMA)/CfA)

# Feedback in mergers regulate star formation

*(Springel+05)*



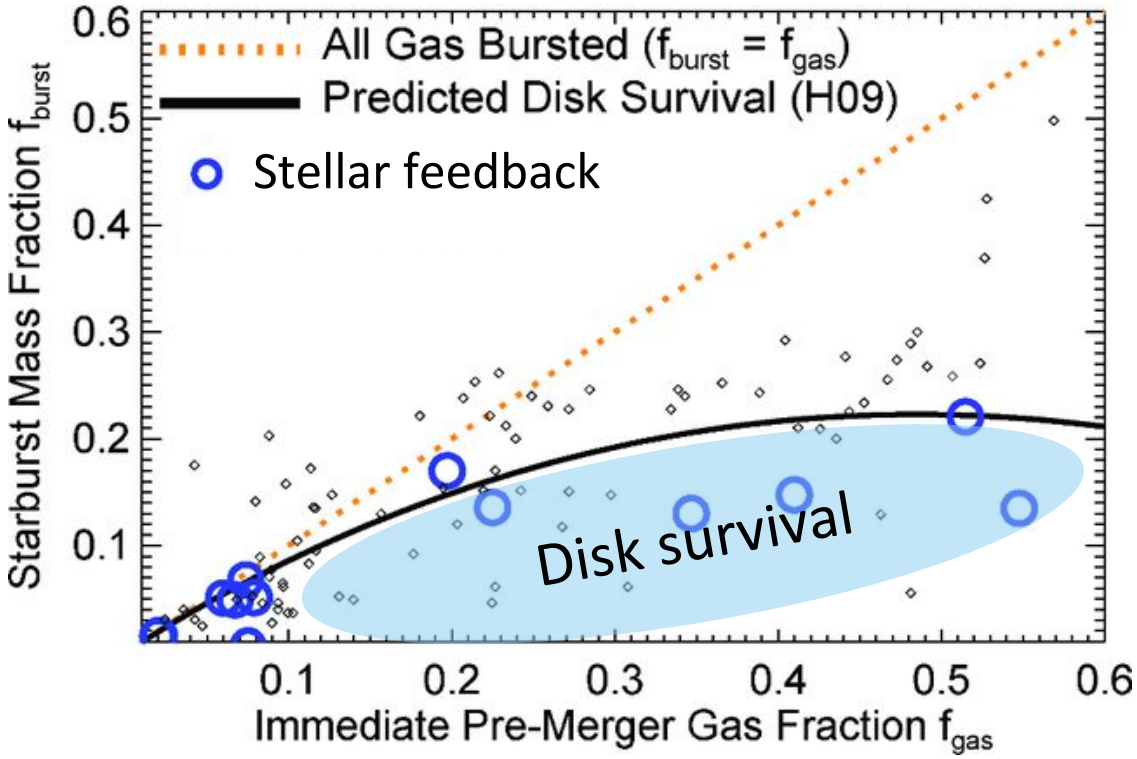

After the coalescence (~1.5 Gyr):

- A galaxy without AGN feedback keeps a high SFR for several Gyrs.
- The SFR declines on a short timescale due to AGN feedback.

(e.g., Powerful outflow/wind remove much of the gas from the central region)

# Feedback affects the gas distribution

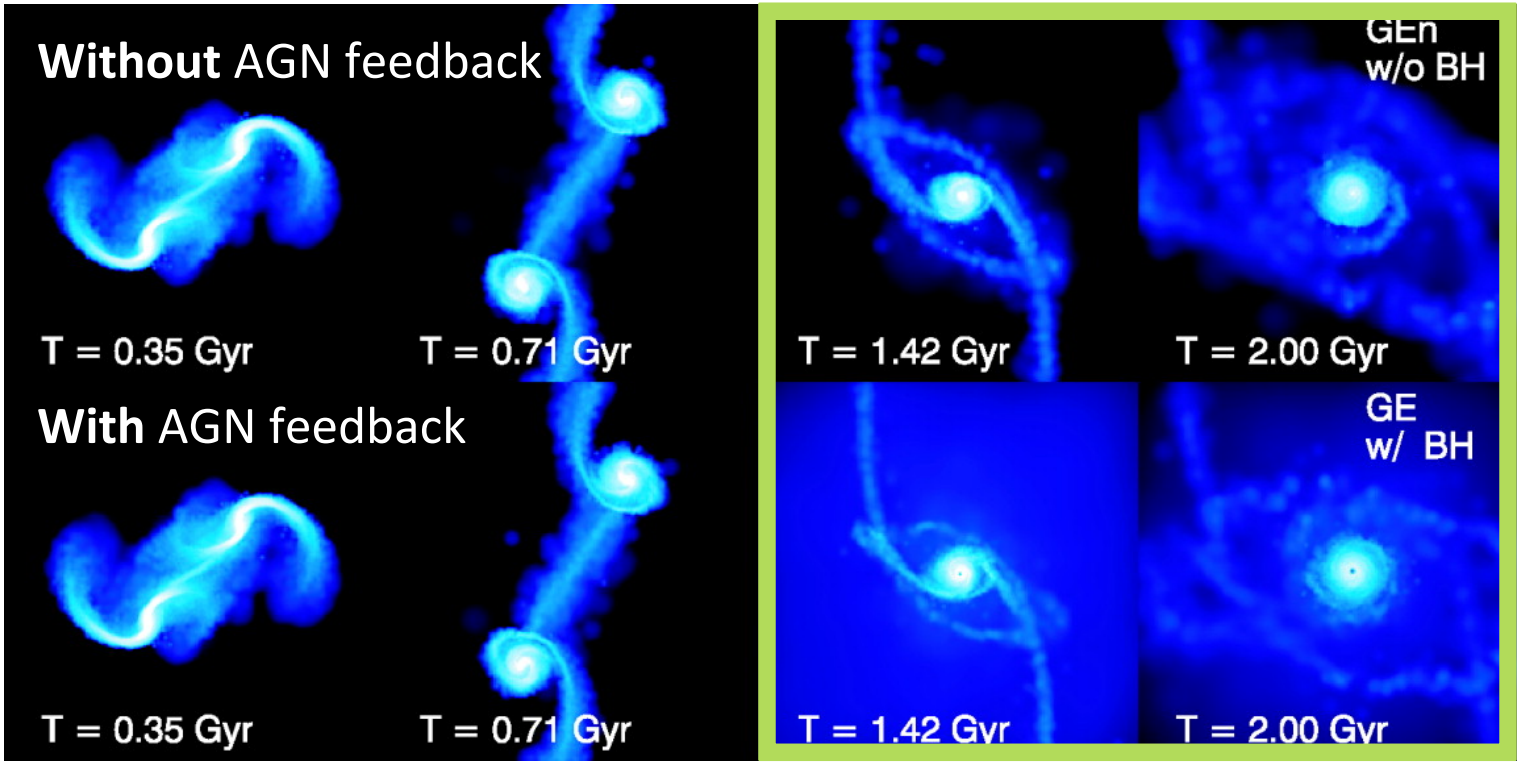
*(Hopkins+13, partially modified)*




- "$f_{burst} = f_{gas}$" indicates that all the gas were used in starburst.
- "$f_{burst} < f_{gas}$" indicates disk survival and reformation.
- Almost all of the models with stellar feedback show $f_{burst} < f_{gas}$.
  (disk survival)

# Feedback affects the gas distribution

*(Robertson+06)*



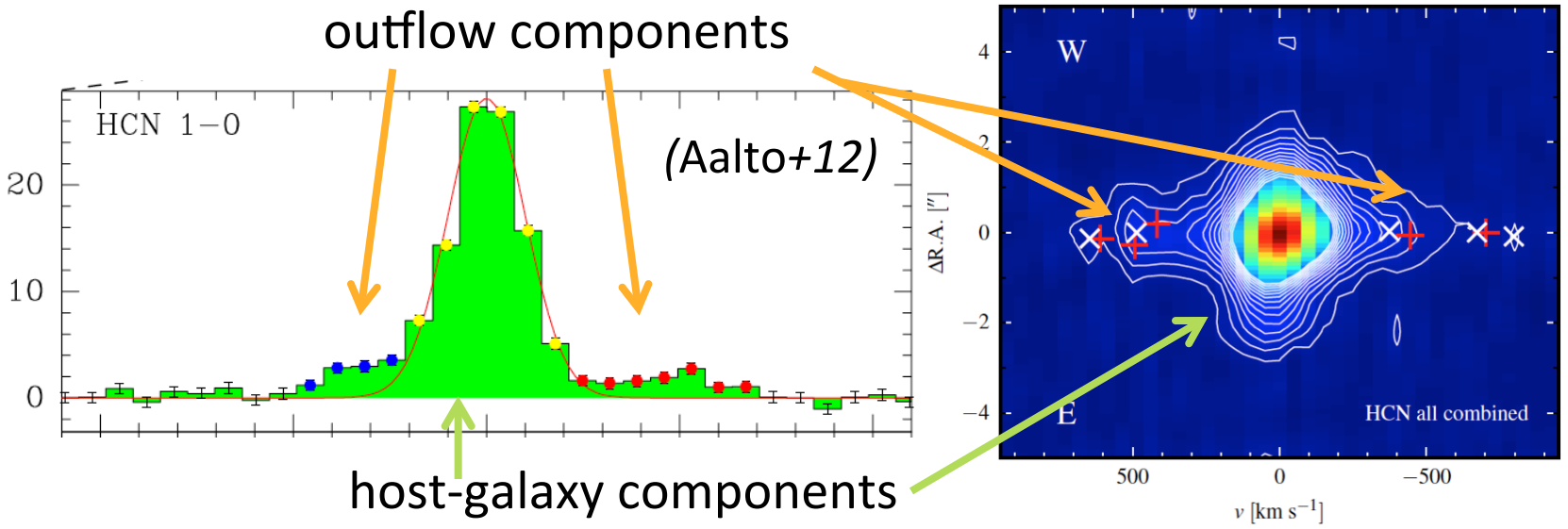

After two colliding galaxies merge:

- The model without AGN feedback shows the central high gas density.
- With AGN feedback, the gas is expelled by galactic outflows and winds, reducing the central gas density and producing an extended envelop.

# Galactic winds and outflows

- Galactic winds/outflows have been observed in cold molecular lines.
- The molecular winds and outflows may consist of dense (>$10^4$ $cm^{-3}$) gas. (e.g., Aalto et al. (2012) found high HCN/CO ratios in molecular outflow.)
- Large-scale molecular outflows have often been discovered using the dense gas tracers (e.g., HCN and HCO+).

*(*Lindberg*+15)*



# Aims of this study

- It is expected from simulations that AGN and stellar feedback could affect the gas distribution in post-merger galaxies.
- Galactic winds and outflows can be observed using the cold molecular lines, especially dense gas tracers.

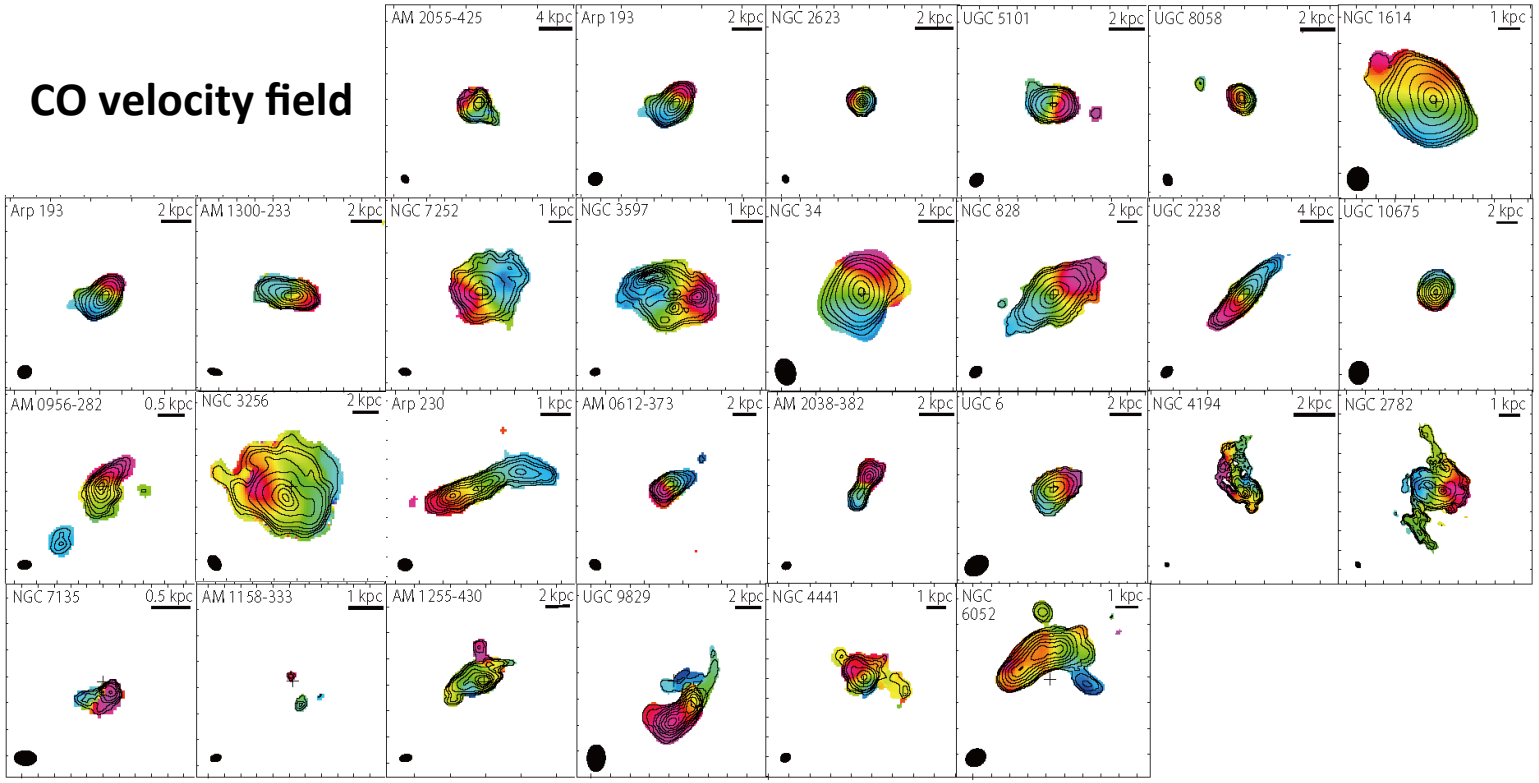
1. Looking for a signature of galactic winds and outflows in post-merger galaxies using the HCN emission.

2. Checking whether the gas distribution is different between post-merger galaxies with and without a signature of galactic winds and outflows.

# Sample: Merger remnants

- Targets: 28 merger remnants (post-merger galaxies)
  - They are a sub-sample of our previous CO study (Ueda et al. 2014)
  - All galaxies were detected in the CO
  - 22/28 sources have molecular gas disks (1.1 kpc $\leqq R_{CO} \leqq$ 9.3 kpc)

**CO velocity field**



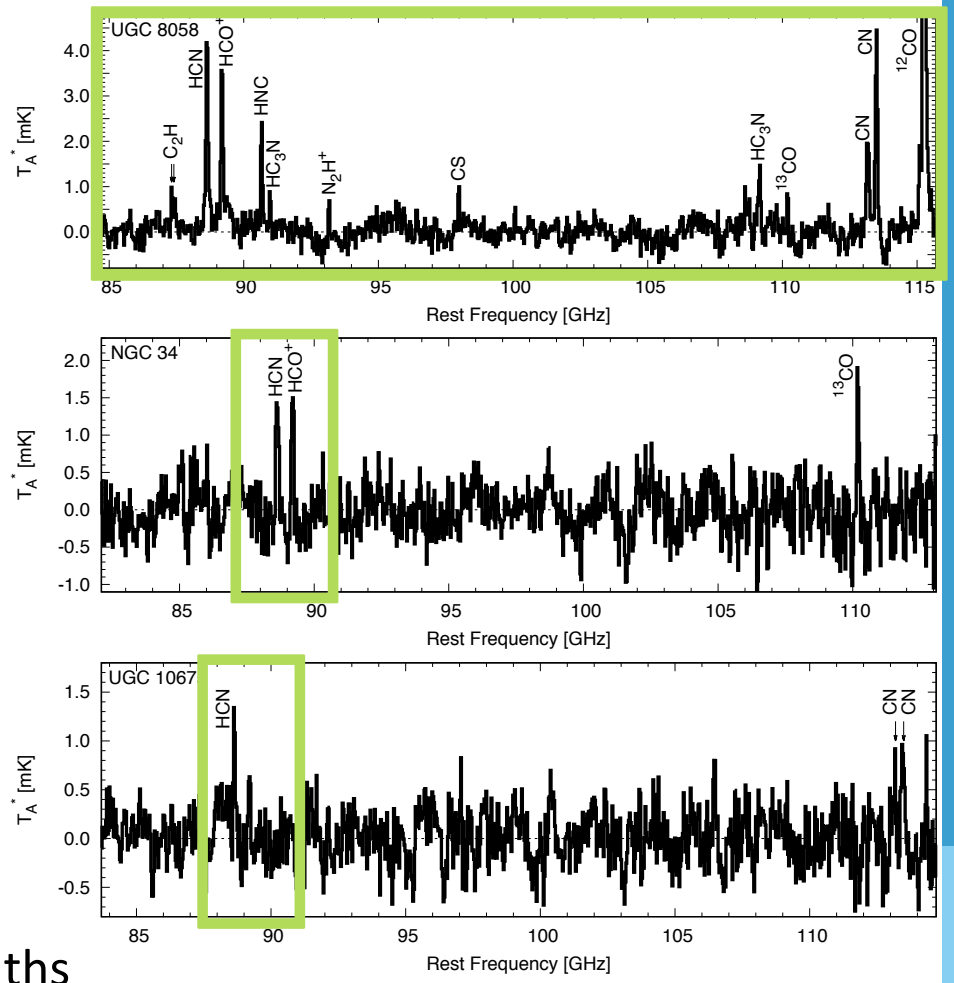
# Multi-line Observations with LMT

- Multi-line observations (λ = 3mm) towards 28 merger remnants using the **Large Millimeter Telescope (LMT)**
- We used the Redshift Search Receiver (RSR), producing a flat baseline over the entire **38 GHz (73–111 GHz) bandwidth** with **31 MHz (100 km/s at 93 GHz) spectral resolution**.
- **The primary beam sizes are 20" - 28", which cover the maximum extent of the CO emission** for almost all of the sample sources.
- The rms noise levels in ~100 km/s are $S$ = 1- 3 mJy.

($T_A^*$ = 0.14 - 0.40 mK, $S/T_A^*$ = 7 Jy/K)

# Results

- 21/28 sources were detected in at least one molecular line emission.
- Mrk 231 is the most prolific galaxy of our sample in terms of molecular complexity. 11 species were identified.
- The main target line, **HCN (1-0) is identified in 16 sources.** These galaxies except for UGC 10675 are also detected in the $HCO^+$.




→ Investigating the HCN line widths of the 16 sources with robust HCN detections

# Signature of galactic winds and outflows

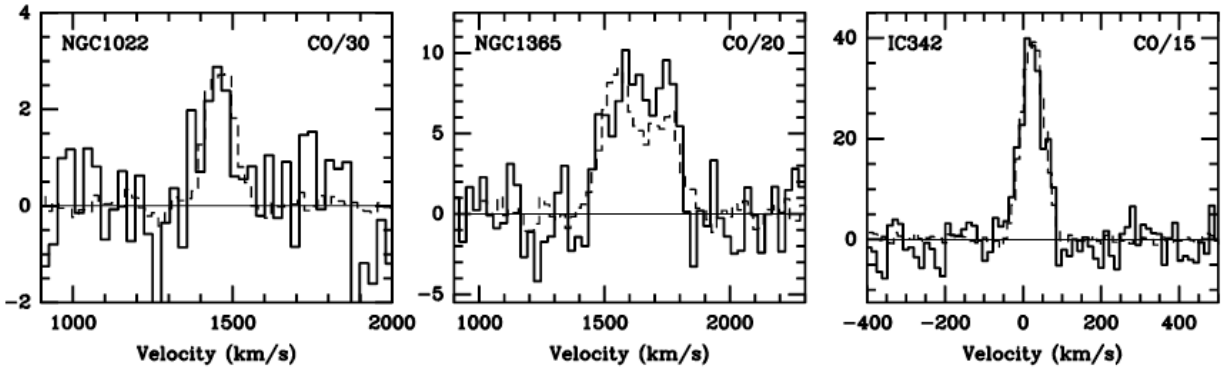
***Method:*** Comparing the line width of the HCN with the CO

Galaxies with AGN and/or starburst activities have large line widths of the HCN compared to the CO, but not all.

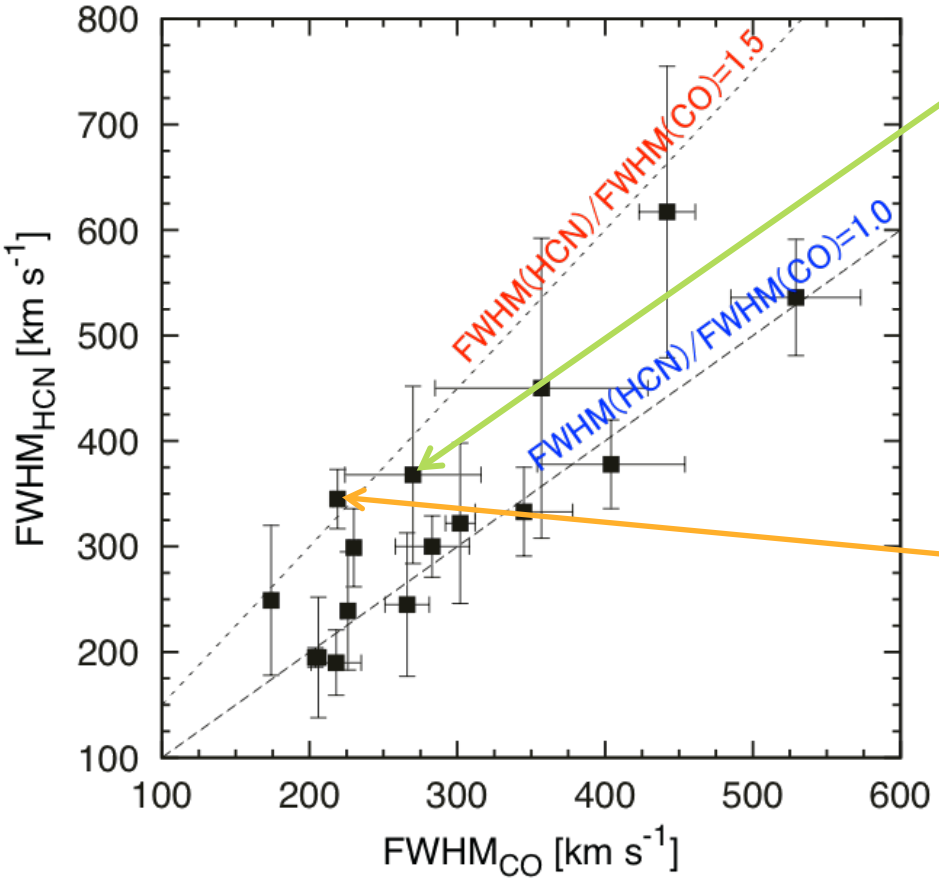
e.g.) NGC 1068 (composite): FWHM(HCN)/FWHM(CO) = 1.8±0.2
M82 (starburst): FWHM(HCN)/FWHM(CO) = 1.2±0.1

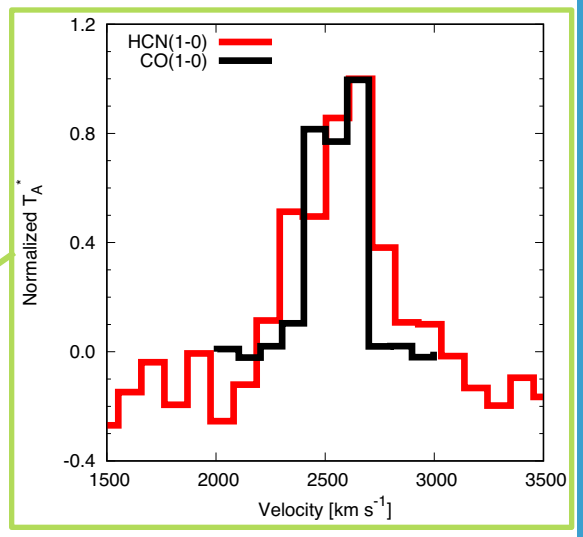
(data obtained with the IRAM 30m telescope (Aladro et al. 2015))

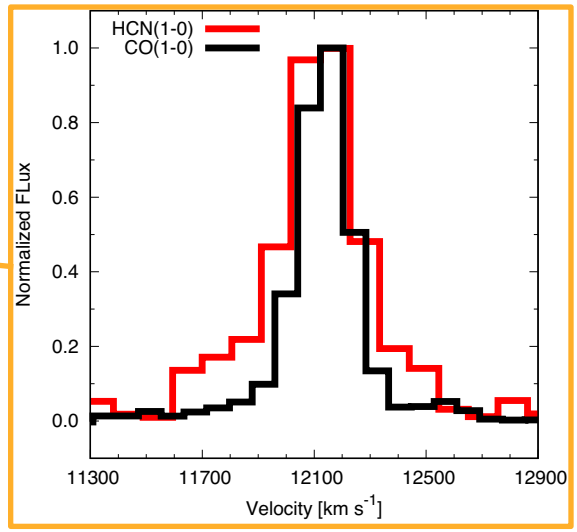
The HCN line profiles have the same line widths as the CO lines.
(e.g., Solomon et al. 1992, Helfer & Blitz 1993, Gao & Solomon 2004)



# Large line width of the HCN



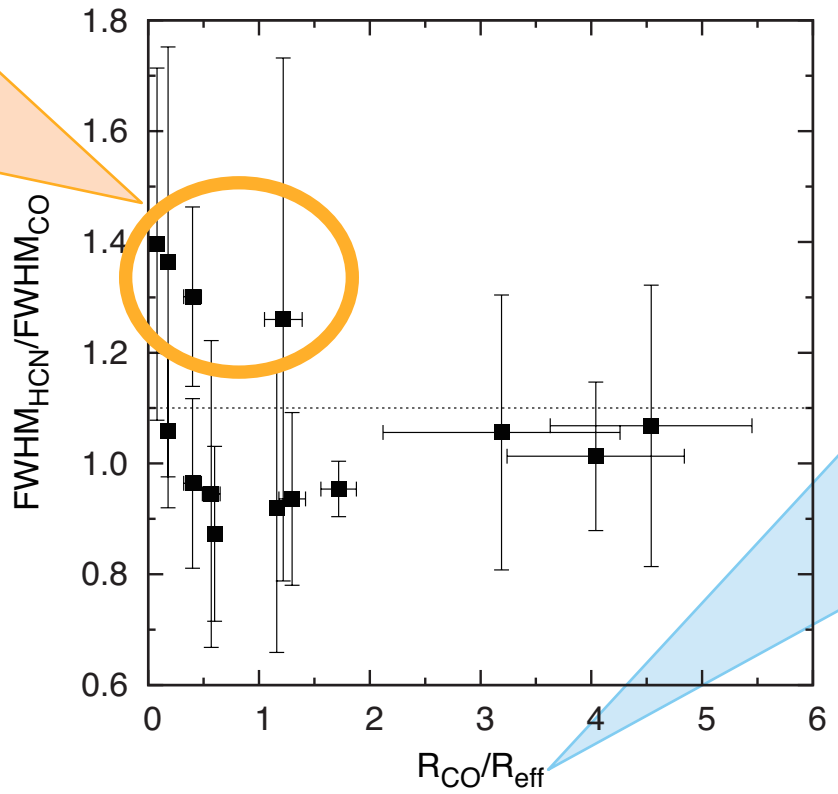




Half of 16 sources with robust HCN detections have large line widths of the HCN compared to the CO.

# Feedback affects the gas distribution?

- large HCN line width
- compact molecular gas disk




**$R_{co}/R_{eff}$**: the relative size of the molecular gas disk to the stellar component

**$R_{co}$**: the size of the molecular gas disk

**$R_{eff}$**: the *K*-band effective radius

- While the statistics are small, sources with large FWHM(HCN)/(CO) (>1.2) have compact molecular gas disks.
- If the large HCN line widths result from the feedback, this suggests that the feedback may destroy the extended molecular gas disks (?)

# Summary

- We have conducted multi-line observations of 28 local merger remnants using the LMT. 22/28 sources have molecular gas disks.
- The main target molecule, HCN (1-0) is identified in 16/28 sources.
- Half of 16 sources have large line widths of the HCN compared to the CO. These large line widths may result from galactic winds and outflows driven by AGN and starburst.
- We also find that sources with large FWHM(HCN)/(CO) have compact molecular gas disks.
- If the large line widths of the HCN result from AGN/stellar feedback, this suggests that the feedback may destroy the molecular gas disks.
- High-resolution observations will confirm the presence of galactic winds and outflows clearly.