WARM GAS AND TEMPERATURE GRADIENTS IN THE GIANT MOLECULAR ASSOCIATIONS OF THE ANTENNAE (NGC 4038/9). G. Petitpas, *(gpetitpas@cfa.harvard.edu)*, D. Iono, A. Peck, *Harvard-Smithsonian Center for Astrophysics, Hilo, HI, 96720*, C. Wilson, *McMaster University, Hamilton, ON, L8R 1W9*, S. Matsushita, *ASIAA, Taipei 106, Taiwan*, K. Sakamoto, *NAOJ, Mitaka, Tokyo, Japan*, J. Wang, P. Ho, Q. Zhang, A. Rots, Z. Wang, *Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, 02138*, M. Yun, *University of Massachusetts, Amherst, MA 01002*, J. Surace, *SIRTF Science Center, Pasadena, CA 91125*.

CO J=1$-$0 emission is often used as a tracer of molecular hydrogen. However, it identifies only the ambient gas in the ISM (*i.e.*, $n_{crit} \sim 10^{2.5}$ cm^{-3}, T$_{ex}$ = 5 K), and it is not the best tracer of the warmer and denser molecular gas that is the direct fuel for star formation activity. High resolution CO J=3$-$2 (*i.e.*, T_{ex} = 33 K, n$_{crit}$ $\sim$ 10^4 cm^{-3}) observations are now possible with the advent of the Submillimeter Array (SMA; Ho *et al.* 2004), revealing higher density gas in nearby galaxies that is spatially and kinematically distinct from low J transition CO emission (Iono *et al.* 2004; Sakamoto *et al.* 2004; Matsushita *et al.* 2004). Here we present a CO J=3$-$2 image of the nearby colliding galaxy system the Antennae (NGC 4038/9) obtained using the SMA.

The Antennae (NGC 4038/9) is one of the most well-studied colliding galaxy systems in the universe. Its proximity (19 Mpc) and unique morphology prompted detailed investigation at different wavelengths across the spectrum including radio (Hummel & van der Hulst 1986), sub-mm (Haas *et al.* 2000), MIR/FIR (Bushouse, Telesco & Werner 1998), optical (using HST) (Whitmore & Schweizer 1995), and X-ray (Fabbiano *et al.* 2003). The physical properties of young massive star clusters formed during the collision were investigated more recently by Wilson *et al.* (2003) where it was found that the masses (5×10^6 to $9 \times 10^8 M_\odot$) and mass profiles (slope ~ -1.4) of the gas in clusters are very similar to those detected in the Milky Way.

High J transition molecular gas has also been detected in abundance. Using the JCMT, Zhu, Seaquist & Kuno (2003) found that much of the CO J=3$-$2 emission from molecular gas dominates the overlap region, but the low angular resolution (FWHM $\sim 14''$) prohibits detailed investigation of the exact spatial distribution of the warmer and higher density molecular gas that is presumably associated with the clusters of young stars. Recently, Fabbiano *et al.* (2003) compared the X-ray emission, CO J=1$-$0 HI, Hα and radio continuum of the Antennae, and found that the pressures in different components of the gas in the ISM are comparable in the nuclear regions, but a notable lack of X-ray emission from the dusty overlapping region (where abundant CO was detected) was evident. Wang *et al.* (2004) imaged the Antennae with the Spitzer observatory at 3.6, 4.5, 5.8, and 8.0 μm, and found that the off-nuclear starbursts contribute a significant fraction of the star formation activity in this galaxy system.

In this poster we present high resolution images of ^{12}CO J=3$-$2 emission from the Antennae system taken with the Submillimeter Array. The data were obtained using a 5 point mosaic whose centers were chosen to cover the majority of the CO J=3$-$2 emission seen in the low resolution maps of Zhu *et al.* (2003). The final integrated intensity maps are shown in the left panel of Figure 1 as the red contours. For comparison, we also show the CO J=1$-$0 data from Wilson *et al.* 2000 in blue. The underlying greyscale image is the HST V band image from Whitmore & Schweizer (1995).

In our high resolution CO J=3$-$2 maps we see evidence of inflow along the spiral arms of both galaxies, resulting in strong shocks at the locations of the dust lanes of the HST image. These strong shocks also manifest themselves as an increase in the CO J=3$-$2 line dispersion at the intersection of the inflow along the arms and the gas in the nuclear disks.

The CO J=3$-$2 and J=1$-$0 maps show interesting differences in morphology. Of particular note is the nucleus of NGC 4039, where the CO J=1$-$0 emission is not seen, but the CO J=3$-$2 emission is strong. Another notable difference is seen in the southern bright knot of the overlap region. Here the CO J=3$-$2 peaks further south than the CO J=1$-$0 emission. These variations in morphology at different J-transitions are indicative of strong temperature gradients in these giant molecular associations (GMAs).

In order to investigate this behavior in more detail we have created CO J=3$-$2/J=1$-$0 line ratios from our SMA data and the OVRO data from Wilson *et al.* (2000). In order to directly compare these two very different data sets, we clipped both data sets to the same UV coverage (10 - 79 kλ) and convolved both data sets to the same beam size (4.8$\times$3.2$''$). Both data sets were binned to the same velocity resolution (20 km/s) and the resulting data cubes were divided channel by channel and scaled by 9.2 to convert the ratio data from Janskys to Kelvins. Ratios were only calculated for channels where the signal to noise was greater than 4. The channel by channel maps are too large to show here, so in Figure 1 (right panel) we present the average ratio per pixel over all velocity bins. The contours represent CO J=3-2/J=1-0 ratio values ranging from 0.6 to 1.6.

The single dish CO J=3$-$2/J=1$-$0 line ratios measured by Zhu *et al.* (2003) showed values less than one for all regions detected. Since the 14$''$ beams of their data do not allow resolution of small scale features, they were unable to see the hot spots detected in our observations. If we convolve our line ratios to lower resolution, we also derive average line ratios $<$ 1. There are not enough hot spots in the map to result in an average J=3$-$2/J=2$-$1 ratio $>$ 1 when convolved to the JCMT resolution. The high resolution data presented here emphasize the importance of studying the ISM at high resolution when trying to determine the relation between the molecular gas properties and star formation activity.

Galaxy interactions and mergers are believed to be an important triggering mechanism of starburst activity. A substantial fraction of the FIR luminous galaxies (ULIRGS) are known to show sever morphological disturbance, suggesting merger

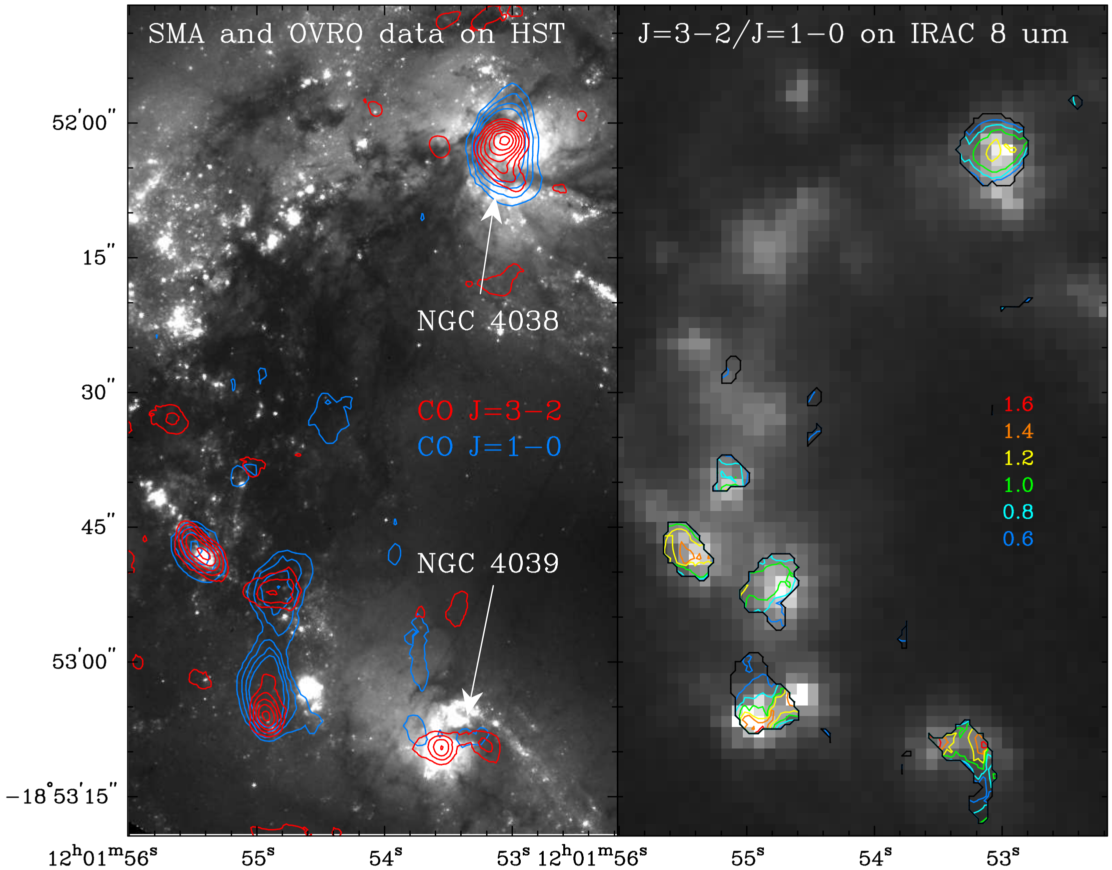

Figure 1: (Left): CO J=3−2 data taken with the Submillimeter Array (red) overlain on CO J=1−0 data taken with the Owens Valley Radio Observatory Millimeter Array (Wilson *et al.* 2000). The underlying greyscale image is an HST V-band image from Whitmore & Schweizer (1995). There are regions where the peak of the CO J=3−2 emission does not correspond with the peak in the CO J=1−0 emission. (Right): The CO J=3−2/J=1−0 line ratio compared to the Spitzer IRAC 8μm image from Wang *et al.* (2004). There is a clear correlation between the hot spots in the Spitzer image and the regions where the line ratio is elevated.

induced starburst and the reprocessed dust emission as the main source of the large FIR emission. From high resolution deep optical and submillimeter observations, it is becoming evident that many of the bright high-z sub-mm galaxies are also mergers (Chapman *et al.* 2003; Iono *et al.* 2005). Thus studies such as this one where we have determine the detailed gas properties and the associated star formation activity of mergers in the local universe will lead to a better understanding of the physical properties in early galaxies.

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