

Science Goal: *Measure the distribution and kinematics of molecular gas in a nearby starburst galaxy.*

The starbursts in luminous and ultraluminous infrared galaxies tend to be small (~ 1 kpc in size) and even the nearest of these galaxies are still quite distant in absolute terms (10s of Mpc away). Exploring the distribution, kinematics, and physical conditions of the gas and dust in these systems is a natural application for sub-mm interferometers. ALMA’s Early Science capabilities are well suited to study the nearest such galaxies. In this example, we replicate an SMA study of NGC 3256, one of the nearest luminous infrared galaxies by Sakamoto et al. (2006). Surveys by Downes & Solomon (1998) and Wilson et al. (2008) target larger samples of more distant samples and could be used to refine the sensitivity calculations.

We plan observations that will target the $J = 2 \rightarrow 1$ transitions of ^{12}CO and ^{13}CO and the 1mm continuum.

Receiver Band: Resolution is important here so Band 3, which contains the CO $J = 1 \rightarrow 0$ line, is not ideal. The gas tends to be fairly excited, making either the $J = 3 \rightarrow 2$ (Band 7) or the $J = 2 \rightarrow 1$ (Band 6) transition a reasonable target. The source is compact so high angular resolution is desirable and field of view is not a huge concern. The full extent of emission in NGC 3256 is ~ 5 kpc, or $\sim 30''$ at 35 Mpc. This makes either Band 6 or 7 good choices: Band 6 has the advantage an almost perfectly matched field of view while Band 7 includes brighter dust continuum. In either case, a small pointed mosaic would be useful if this mode is available.

Angular Resolution: We want to resolve the disk of molecular gas hosting the starburst. Such disks are often ~ 1 kpc in size, and this is the case in NGC 3256. In the present-day universe bright starbursts are relatively rare; even the comparatively nearby NGC 3256 is still ~ 35 Mpc away. This makes the central disk $\sim 5''$ in size. We want to clearly resolve the starburst and so target a resolution of ~ 0.5 – $1.0''$. The large velocity gradient in the galaxy minimizes concerns about spatial filtering in the CO line (at a given frequency, the structure is relatively confined), but we may expect that the continuum image will miss some flux.

Spectral Resolution: We want to resolve bulk motions in the galaxy and measure the dispersion along individual lines of sight to get an idea of the dynamics of the merger driving the starburst. Sakamoto et al. measure velocity dispersions (1σ) of 10–60 km s $^{-1}$ in NGC3256 and a total line width of ~ 200 km s $^{-1}$ for the galaxy. a spectral resolution of 5 km s $^{-1}$ will ensure that we can place at least 5 resolution elements across the line.

Channel Sensitivity: Sakamoto et al. (2006) report peak $^{12}\text{CO } J = 2 \rightarrow 1$ of 2-10 K in 10 km s^{-1} channels at $\approx 1.5''$ resolution in NGC 3256. The high brightness regions are still fairly compact compared to the beam, so these intensities may be somewhat diluted, meaning that the intensity peaks might be even higher at better resolution. If we cared only about this line we might target a 1σ sensitivity of 0.2 K per channel in order to get good SNR across the galaxy.

We would also like to observe the $J = 2 \rightarrow 1$ transition of the less optically thick ^{13}CO and C^{18}O lines. These are all fainter than ^{12}CO . For ^{13}CO the line intensity ratio with ^{12}CO is often in the range 5–10 but in NGC 3256. We will design our observations assuming a line ratio of 10, if ^{13}CO is much weaker (as Sakamoto et al. actually found in NGC 3256), one can somewhat improve the SNR by smoothing the data. For a line ratio of ~ 10 , we would need to target a sensitivity more like 0.02 K per channel, which is difficult at the original 5 km s^{-1} spectral resolution. However, we could use the ^{12}CO observations can meet the kinematic science goals, and target a lower spectral resolution of $\sim 20 \text{ km s}^{-1}$. This will still allow us to measure ratios of ^{12}CO to ^{13}CO . This target, $\sim 0.02 \text{ K}$ at 20 km s^{-1} resolution will drive our time request.

Continuum Sensitivity: Any correlator resources not allocated to the line observations can be productively assigned to image the 1mm dust continuum. If continuum were our main goal, we might prefer to use Band 7 to take advantage of the rapid increase in the dust continuum intensity with increasing frequency. The observations by Sakamoto et al. imply a peak intensity of $\sim 1 \text{ mJy/beam}$ for our proposed beam size, which we would expect to detect at reasonable significance in less than an hour of on source total integration with 2 GHz bandwidth.

AKL: This gets a bit complicated ... either a fairly complex dust equation involving assuming an emissivity or scaling from their beam to estimate a 1 mJy/beam .

Observing Time: To reach our target sensitivity on the ^{13}CO ($\sim 0.02 \text{ K}$ per $1''$ beam in a 20 km s^{-1} channel at 230 GHz) the sensitivity calculator suggests that we need ~ 3 hours on source. Making conservative estimates for efficiencies and overheads (always a good idea in the early days of a telescope), we might request 8 hours. The fainter, extended emission around the main starburst shows complex structure. To accurately reconstruct this with a limited number of antennas (as in Early Science), we want to ensure good coverage of the $u - v$ plane, which means that we wouldn't really want to try this experiment in less time anyways.

Pictures: go pick two of the panels from Sakamoto et al. (2006). Certainly the first panel of Figure 4, I would probably then pick either the T_{max} or the position-velocity diagram.