Science Justification for ALMA Band 4

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1 Summary

The ALMA Band 4 covers the frequency range 125–163 GHz. At these frequencies the atmosphere is very transparent ($\geq$ 93%) providing an advantage over the 1.2 and 0.8 mm bands which are more affected by poor weather conditions. It will offer many scientific opportunities ranging from cosmology to astrochemistry. Significant contributions can be expected to the following research areas:

- Sensitive search of high redshift galaxies in the thermal dust continuum emission
- Probing cold molecular medium in normal field galaxies during their rapid evolution out to $z \sim 1$.
- Astrochemistry in star forming regions, dark clouds and evolved stars, including observations of deuterated species, observations of key density and temperature tracers for cold cloud environments.

2 Thermal continuum emission of high redshift galaxies

In the frequency range of the ALMA Band 4 (163 to 125 GHz or 2.4 to 1.84 mm) the flux densities of high redshift galaxies of a given luminosity do not vary strongly with redshift. For $T_{sys} = 80$ K (SSB) and a conversion of 30 Jy/K, the expected sensitivity is about 5 μJy (1σ) in 1 hour. Hence, a $4 \times 10^{12} L_\odot$ galaxy located at $z = 1$ to 10 will be detected with S/N of 10 in about one hour. Combined with the excellent atmospheric transparency at

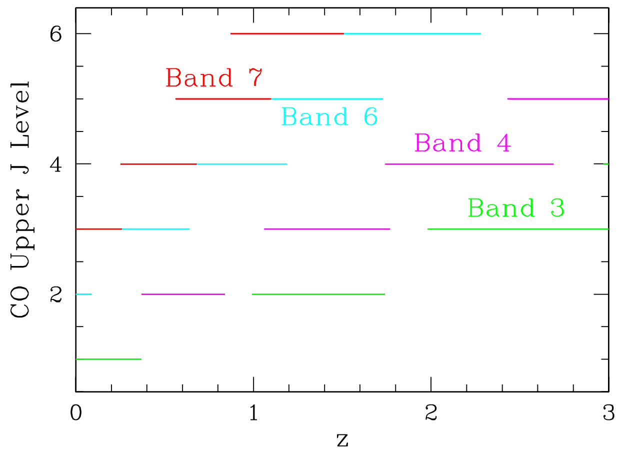

Figure 1: Redshift Coverage for CO transitions for the ALMA Bands 7, 6, 3 and 4.

these frequencies, Band 4 is thus a prime band to search for high z sources in the thermal dust continuum.

The ALMA Band 4 also offers a critical spectral energy distribution (SED) information for the highest redshift systems. At $z \sim 10$, the adjacent higher frequency bands probe only the peak of the dust spectrum. Determining dust mass and temperature requires measuring the submm drop-off, and the ALMA Band 4 is best suited to make this measurement.

3 Redshifted Lines

Band 4 also offers a unique opportunity to probe the mass, distribution, and kinematics of cold ($T \sim 10 - 20$ K) molecular gas in galaxies at redshift between 0.4 and 0.8, during which a strong evolution in star formation is known to have occurred from the optical and UV observations. As shown in Figure 1, ALMA allow us to investigate molecular gas in objects at all redshifts. Because the CO upper J levels of 3 and above require density and temperature well in excess of what is normally found in average giant molecular clouds, they preferentially trace the gas associated with actively star forming regions. For example, the expected CO (3–2)/(1–0) line ratio for a molecular cloud with average density of 10^2 cm^{-3} and $T = 20$ K is about 0.2 (see Fig. 4 of Mauersberger et al. 1999). This excitation requirement means that high J transitions of CO probe only the gas in the direct vicinity of OB stars (see Fig. 2) and are insensitive to the bulk of the molecular

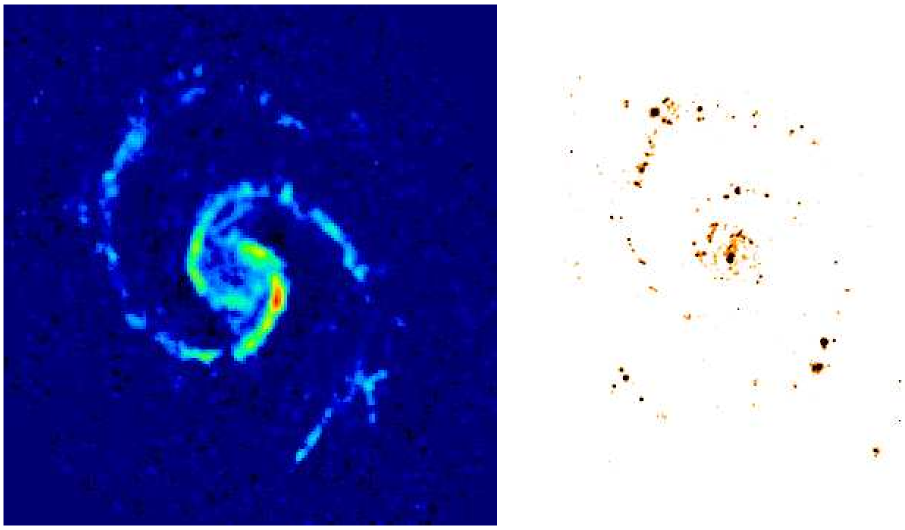

Figure 2: CO (1–0) emission (left panel) in the face-on spiral M51 is distributed smoothly along the spiral arms. The higher J CO transitions require the density and temperatures found only in the immediate vicinity of bright HII regions (as traced by Hα on the right panel).

gas associated with colder clouds. Thus probing the nature of the bulk of the molecular gas, which may be quiescent and cold in normal disk galaxies, would require observations of $J = 1$ or $J = 2$ lines. Cold molecular clouds at $z = 0.0 - 0.4$ and $z = 1.0 - 1.8$ can be accomplished by observing the CO (1–0) and (2–1) transitions occurring in the bands 3 & 6, but the ability to trace the evolution of molecular gas content in normal field galaxies between the critical redshift range of $z = 0.4 - 0.8$ will be lost unless the Band 4 is also available.

Another potential use of Band 4 is to search for the [CII] 158 μm emission line, the major cooling line of galaxies, in sources which would have been detected at redshifts in the range 10 and 14.

4 Astrochemistry and Galactic Studies

The 2 mm atmospheric window is know to be very rich in spectral lines both in star forming regions (Zyuris et al. 1993) and in circumstellar envelopes (Cernicharo et al. 2000). It contains the J=2-1 transition of many simple linear molecules composed of 3 to 4 atoms of cosmically abundant elements, the fundamental transitions of H_2S and NO, SiC_2, many linear carbon chain molecules C_nH as well as large organic molecules. It is expected that spectral surveys in the ALMA Band 4 will provide a wealth of new chemical species and new constraints on the chemistry in the interstellar medium.

Deuterated species should also be mentioned since the first priority ALMA Bands 3, 5, 7 and 9 will not trace them in cold regions. The lines of deuterated molecules are mostly expected in the 70-90 GHz Band and the 2-1 transition lines will fall in the 140-155 GHz region. Whereas the 3-2 transition lines will also be accessible in the 210-270 GHz band, those lines may not be the best probes because deuterium is enhanced in cold regions and may not be much enhanced in warm regions.

Band 4 opens up the possibility to trace clouds in low lying transitions of abundant molecules such as H_2CO. Observations of dense cores have shown that roughly half of the H_2CO column density lies in low excitation regions and is probed by the 2-1 line at 150 GHz or by the 1-0 line at 72 GHz, neither of which are in the planned receivers for first light. Therefore the formaldehyde line covered by Band 4 will offer a valuable tool for tracing the cold gas in dense clouds.