Initial Observations with an ALMA Band 6 Mixer-Preamp: Exciting Prospects for the Future

During the past spring, spectral-line observations were conducted using a new receiver containing an ALMA Band 6 (215-275 GHz) mixer/preamp with the Sub-millimeter Telescope (SMT) of the Arizona Radio Observatory (ARO) at the University of Arizona. This project was a joint collaboration between the Central Development Lab of NRAO, Art Lichtenberger of the University of Virginia and the ARO. The motivation behind these measurements was to evaluate ALMA technology and characterize mixer performance with real astronomical observations. The results of these tests were quite impressive, with record-breaking, single-sideband system temperatures and exceptional baseline stability over wide IF bandwidths.

In order to conduct these measurements, an ALMA Band 6 mixer- preamp was integrated into an insert at the ARO receiver lab and installed in the current 1.3 mm receiver Dewar at the SMT, as shown in Figure 1. The Dewar design at the SMT is similar to that used in the NRAO 12 m receivers, with insert positions arranged in a radial pattern. The insert with the ALMA components can be seen at the 12 o'clock position; two older 1.3 mm inserts are also visible in the Dewar. Although only a single polarization can be obtained from the one insert, the sideband-separating design of the ALMA mixer provides two IF signals: one from the upper and one from the lower sideband. The SMT spectrometer backends were configured to accommodate both sidebands simultaneously, each with an instantaneous bandwidth of about 2 GHz. The IF center frequency could also be steered in the range 5 – 7 GHz such that selected spectral transitions could be placed in the upper and lower sidebands. This flexibility was found to be useful for a variety of scientific programs.

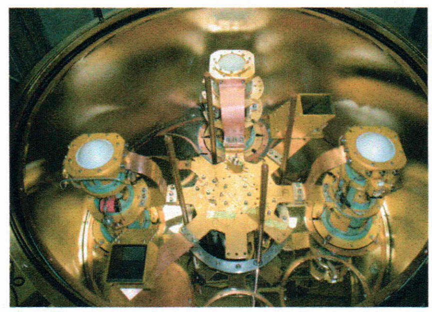

Figure 1: The ALMA mixer preamp mounted in an insert in the SMT 1.2 mm Dewar . The insert is at the 12 o'clock position.

The observations took place at the SMT (see Figure 2) in a series of 3-4 day sessions beginning in February and concluding in June. During the 21 total days of observations, various scientific studies were pursued: investigations of isotopic ratios in in planetary nebulae, on-the-fly mapping of giant molecular clouds, and spectroscopy of circumstellar envelopes of supergiant stars, molecular clouds and extra-galactic objects. Record-breaking system temperatures were found at numerous frequencies across the band. At 230 GHz, for example, a total calibrated system temperature on the sky of 107 K, single sideband, at an elevation of 50°, was recorded in the LSB; at 53° elevation, measurements at 245 GHz yielded T_{sys} = 105 K, single sideband, for the LSB. Typical system temperatures around 45° elevation were around 120 – 140 K, SSB. Performance was consistent across the entire 211 -

Figure 2: The SMT facility, located on Mt. Graham, AZ, was used for the ALMA tests: elevation 10,543 ft.

273 GHz range. The high sensitivity of the receiver resulted in the detection of molecular lines in our own atmosphere. The unexpected observation of ozone occurred during the standard total power calibration process. A representative calibration scan is shown in Figure 3; ozone lines appear at 247.762 GHz and 248.283 GHz. The combination of receiver sensitivity and atmospheric attenuation due to these transitions locally increased the system noise.

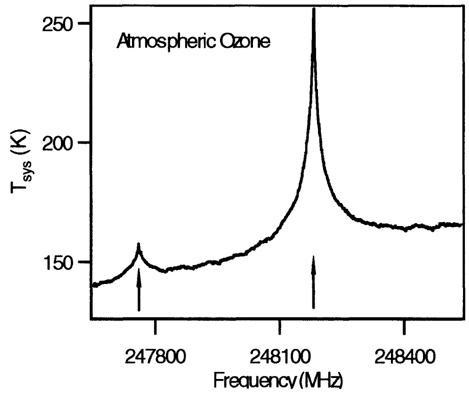

Figure 3: A calibration scan showing two atmospheric ozone lines near 248 GHz.

Image rejection was also excellent. Although the ALMA image rejection specification only required 10 dB, the actual values were typically greater than 20 dB in the LSB and greater than 15 dB in the USB. Simultaneous measurements of ^{12}CO and ^{13}CO in opposite sidebands showed that the image rejection in the LSB was greater than 22 dB at 230 GHz.

During the ALMA test time, a survey of carbon isotope ratios in planetary nebulae was initiated by Xilouris and collaborators. Most of the 29 objects studied lie well in the Galactic Plane, and therefore large offsets were required in position-switching mode in order to reduce the contamination from Galactic CO. Even with an off position as far away as 4° in Galactic latitude, baseline stability was excellent, as shown in Figure 4. Here a raw spectrum of the CO, J= 2-1 transition observed towards PN K3-55 is displayed, covering over 400 MHz with no baseline removed from the data. This survey, although at its initial stage, has more than doubled the number of PNe where a carbon isotope ratio has been measured. Preliminary results indicate severe ^{13}C depletion, supporting the idea that at the end of stellar evolution, standard nucleosynthesis fails to match the observations. In particular, for low mass stars, non-standard mixing mechanisms need to be invoked.

Equally remarkable were data obtained in a spectral survey of SgrB2(N), a dense cloud core, by Apponi, Ziurys, and students. Spectra were taken with almost 2 GHz of total bandwidth per IF channel. Figure 5 shows one of the single-sideband spectrum at 246 GHz obtained in position-switching mode with a 30 arcminute offset in azimuth. Despite the relatively short integration time of 30 minutes, the spectral density is extremely high. Rejection of the image sideband was greater than 99% at this frequency, and therefore virtually every feature present in these data is in the signal sideband. A more detailed

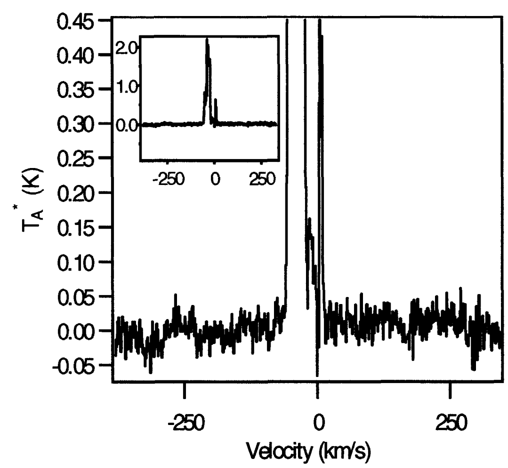

Figure 4: Baseline of a ^{12}CO, J=2-1 spectrum obtained towards the PN K3-55 in position-switching mode with a 4 ° OFF position. The integration time is 12 minutes. The full spectrum is shown as an inset in the upper left-hand corner.

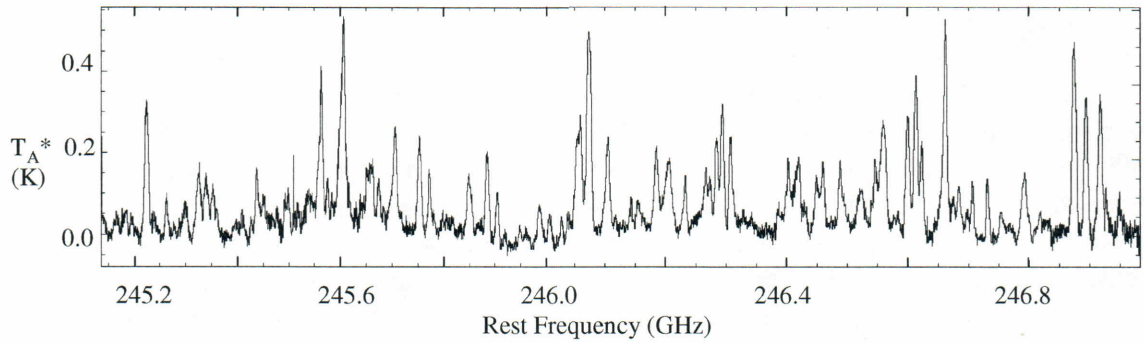

Figure 5: Spectrum of SgrB2 (N) near 246 GHz, taken in position-switching mode, with a total integration time of 30 minutes with almost 2 GHz instantaneous bandwidth. The rich chemistry of this region is striking, with the weakest lines detectable at a 3 sigma level of 15 mK.

spectrum is shown in Figure 6. Here a sample of the survey is shown at 231.5 GHz, covering 1 GHz in frequency. The spectral-line confusion limit has been reached in these data after 2 hours of integration, and the noise level can be seen only in a small section of the spectrum at the right hand corner. The spectrum in fact is so confused that only about 50% of the features have been indicated on the plot. About 72 individual lines are present, half which are unidentified. Once again, the image rejection is better than 20 dB. These data are about a factor of 10 more sensitive than any other current 1 mm spectral-line surveys. Obtaining confusion-limited spectra with high image rejection is the absolute best that can be achieved in this source. Analysis of this survey will prove definitively which complex species are actually present in this object.

Other surprising results were obtained with the new ALMA 1 mm system. A spectral survey of the oxygen-rich supergiant VY Canis Majoris was begun by Woolf, Milam, Apponi and Ziurys. In only a few days observing time, this study revealed that

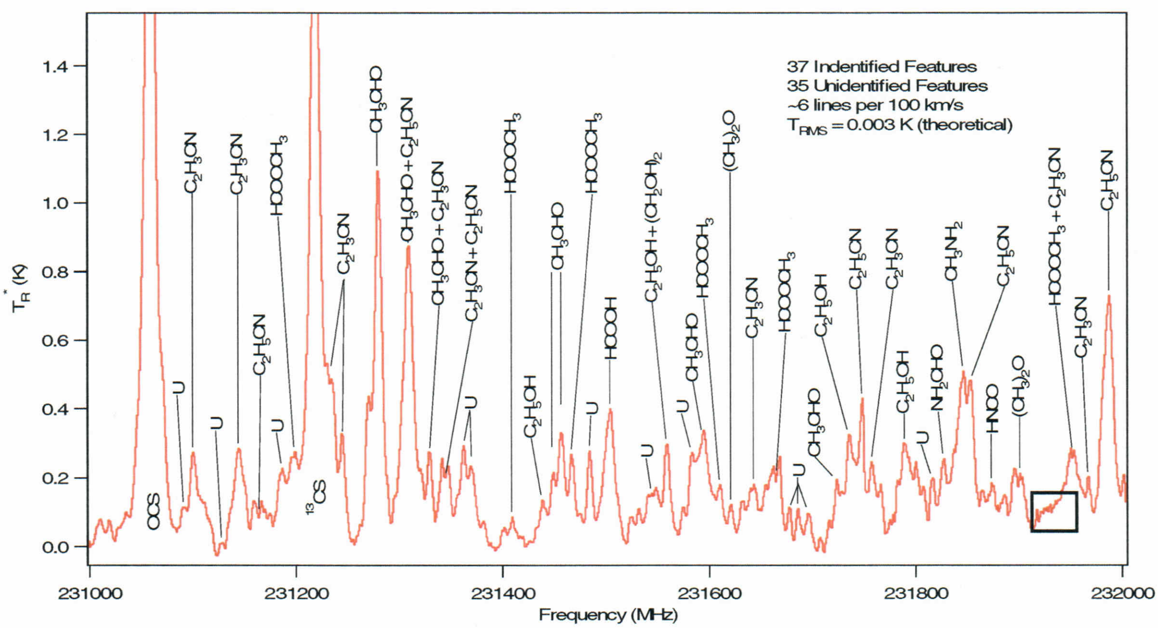

Figure 6: Confusion-limited spectrum obtained towards SgrB2(N) in 2 hours of total integration time. The image rejection is >20 dB and the large number of distinct features arise from the signal sideband – not all are marked. The actual noise level is indicated by the box on the lower right.

the envelope of this star has a chemistry far more complex than previously thought. An amazing array of interesting molecules were detected, including NaCl, PN and HCO^+. CN, HNC, HCN, and CS were also found – strong evidence that CO does not control the carbon chemistry in this source. On-the-fly (OTF) observations were made of the W3 and W51 giant molecular clouds, as well, by Peters and Bieging. The receiver was tuned to place the J = 2-1 transition of ^{12}CO in the upper sideband and that of the ^{13}CO in the lower sideband, with good image rejection in both sidebands. A region 0.42 square degrees was mapped in W3 and 0.33 in W51, with high quality spectra in both cases.

More observations will be conducted with this receiver in the fall. However, these preliminary results have already demonstrated the superior quality of the ALMA Band 6 mixer-preamp. (A more complete description of the technical aspects of the test receiver can be found in ALMA Memo #553.) The extremely good sensitivity of the Band 6 system, coupled with the high stability, bodes well for the future. The data obtained here are an exciting prelude to the wonderful science that will emerge from ALMA at 1 mm.

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