Recent Technical and Scientific Developments at the Arizona Radio Observatory

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Abstract

The Arizona Radio Observatory of Steward Observatory operates two facilities, the Sub-Millimeter Telescope on Mt. Graham (SMT), and the 12-Meter Telescope at Kitt Peak. SIS receivers at these two facilities currently cover the atmospheric windows between 65-380 GHz and 650-750 GHz. Several of these radiometers now employ broad-band, high sensitivity dual channel sideband-separating mixers. These new developments and current scientific results will be described.

1. Introduction

Since the discovery of CO in the Orion nebula in 1970, high resolution millimeter spectroscopy continues to be a very important scientific tool. The Arizona Radio Observatory (ARO) operates two facilities; the 12-Meter radio telescope on Kitt Peak, formally operated by the National Radio Astronomy Observatory (NRAO), and the 10-meter Sub-Millimeter Telescope (SMT) on Mount Graham. Observations at both facilities emphasize high resolution spectroscopy using near quantum limited coherent receivers and flexible resolution spectrometers. With a large collecting area, a 75 µm RMS surface and its location. the 12-Meter telescope, shown in Figure 1, is well suited for observations in the two atmospheric windows below 1.3 mm. The high surface accuracy achieved with a 15 µm RMS surface, a thermally stable back structure and panels composed of carbon-fiber reinforced plastic (CFRP) elements and an exceptional location at over 3100 meters combine to make the SMT, shown in Figure 2, an excellent instrument for observations at the shorter wavelengths. In fact, observations have been performed in excess of 1 THz. The instrumentation at both observatories has been chosen to provide high sensitivity and unambiguous signal discrimination essential for spectroscopy in spectrally confused sources such as Sagitarius B2. We shall discuss the recent developments at both telescopes.

Figure 1. The ARO 12-Meter telescope located on Kitt Peak, Arizona

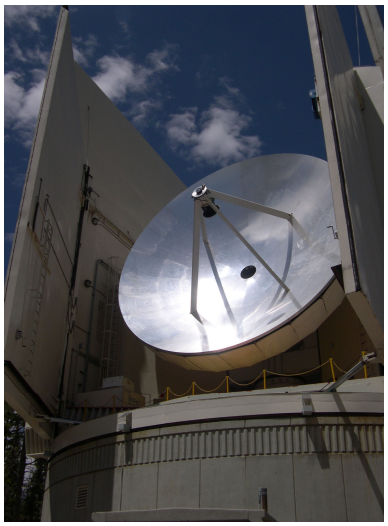

Figure 2. The ARO SMT located on Mount Graham, Arizona

2. Coherent Receivers

High sensitivity stable single sideband receivers are essential now, more so than ever, for investigations of more exotic interstellar molecular sources. The first such receiver in a series to be installed at an ARO facility uses dual polarization 1.3 mm sideband-separating mixers. The receiver provides both RF sideband signals simultaneously at two separate IF ports. The mixer assembly was developed by the Central Development Laboratory (CDL) of the NRAO for use in the Atacama Large Millimeter Array (ALMA) project.

To evaluate the new technology, a single mixer element was mounted along with a low noise temperature NRAO HEMT cooled pre-amplifier in an ARO insert. It was installed in an ARO Dewar as shown in Figure 3. The other two inserts shown in the figure contain double-sideband 1.3 mm mixers. Single polarization observations were first conducted at the SMT in February of 2006 followed by full operation of the dual-polarization sideband-separating receiver that fall.

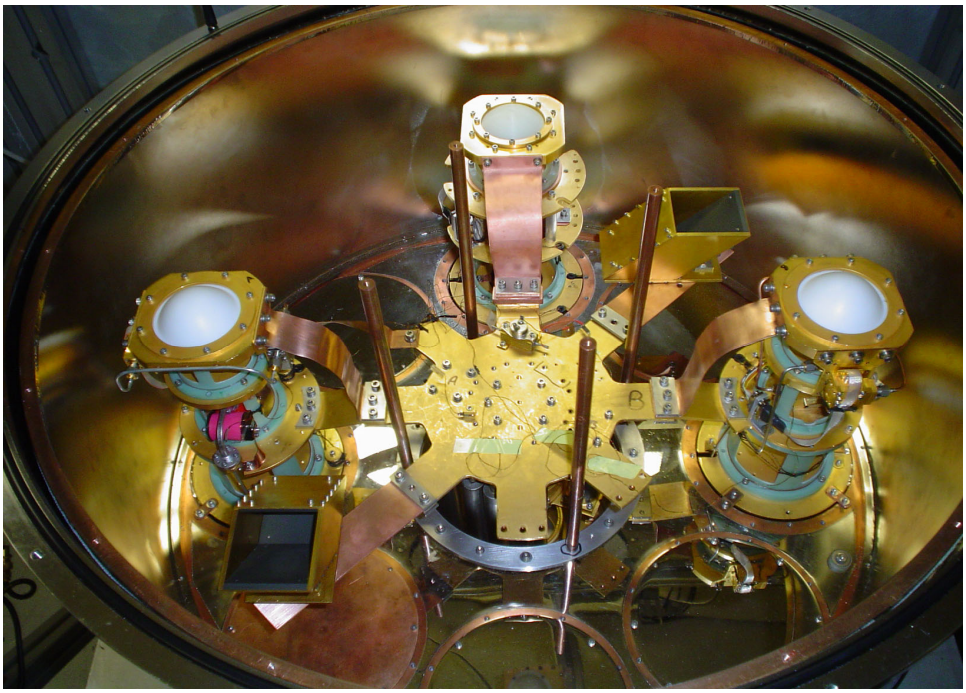

Figure 3. Evaluation 1.3 mm Sideband Separating Receiver

The mixer assembly integrates two native double sideband mixers, a quadrature RF splitter, an IF quadrature combiner, and an in-phase LO splitter to form a sideband-separating mixing assembly. A block diagram of the mixer is shown in Figure 4. These mixers provide a single sideband calibrated system temperature on the sky of 107K at 230 GHz and at an elevation of 50º. Higher in the band, at 245 GHz, the system temperature was measured at 105K at an elevation of 53º. The initial single mixer observational results are described in more detail in the October 1996 issue of the NRAO Newsletter [1]. In the dual polarization receiver, a wire grid is used to separate the orthogonal linear polarizations, but will soon be replaced with a waveguide orthomode polarizer.

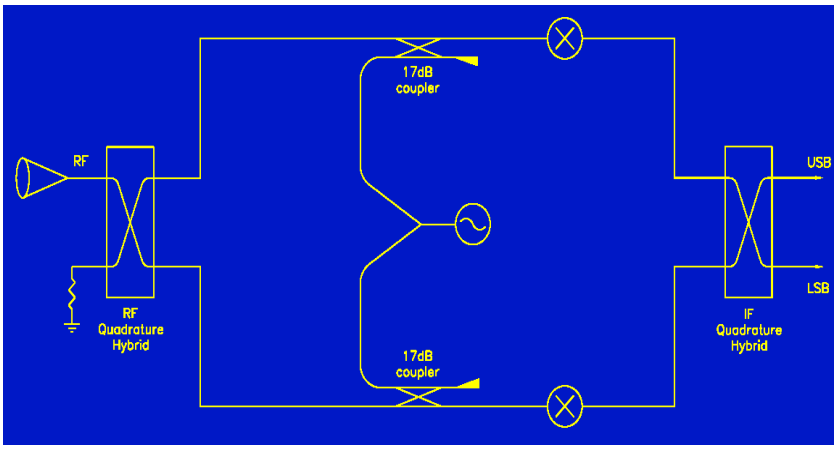

Figure 4. Sideband Separating Mixer Schematic

The newest SMT receiver covers the full 460 µm atmospheric window from 600 to 720 GHz. It underwent its final development during this winter. The receiver with only a single mixer installed is shown in Figure 5. Astronomical evaluations are planned for early March. The final receiver configuration contains two double sideband (DSB) mixers supplied by the Space Research Organization of the Netherlands and a cooled wire grid to provide dual linear polarization reception. In fact, all of the receiver's optics are cooled to achieve low noise temperature. The local oscillator utilizes a Gunn diode driving a Virginia Diodes nontupler and is injected by a quasi-optical beam splitter. The DSB receiver noise temperature is expected to be around 250K.

The receiver sensitivity at the 12-Meter telescope in the 85 to 115 GHz portion of the 3 mm window will be improved with the installation of a sideband-separating mixer receiver in the spring. The SIS mixer element was designed by the CDL of the NRAO for ALMA Band 3. The mixer assemblies are being produced by the Herzberg Institute for Astrophysics and operated by the National Research Council of Canada. Other receivers using this mixer design achieve receiver noise temperatures less then 50K.

A fundamental Gunn oscillator provides the local oscillator signal. It is injected into the signal input through a 17 dB coupler that is integrated into the mixer block as in the 1.3 mm design. The final IF generation occurs in the quadrature power combiner that is before the low noise IF amplifiers.

6. SMT IF Infrastructure

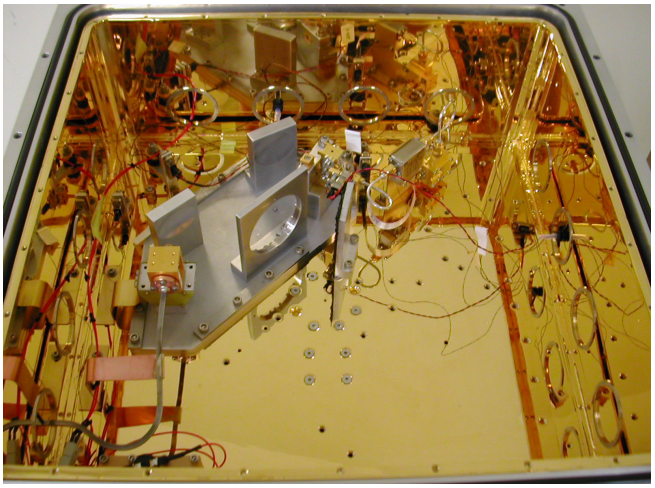

Figure 5. Single mixer version of the 640 µm Receiver

An octave bandwidth IF system provides the interconnection between 4 signal channels from a receiver to the current spectrometers. The recently installed 4 to 8 GHz wide IF system is the unifying signal routing backbone of the SMT. Four channels of high stability continuum backend are also available to any selected receiver. In addition, a 4-port cross-point switch provides interconnection flexibility between the channels of any selected receiver and the multiple inputs of the spectrometers.

With receivers and the IF backbone capable of supporting signals covering 16 GHz of bandwidth, the IF system provides an additional mechanism to interface with the narrower spectrometers. Each of the 4 signal channels has its own narrow band selector that effectively tunes its spectrometer input to any desired frequency within the IF band.

7. SMT High Resolution Spectrometers

To obtain the ultimate performance from a high sensitivity, high resolution broadband spectral-radiometer system demands a high stability spectrometer. The ARO recently installed a 2048 channel spectrometer based on tried technology. This spectrometer provides 1 MHz resolution elements that can be partitioned to support up to 4 independent IF input signals. This design easily supports the dual-polarization sideband-separating receivers. A smaller spectrometer based on the same analog technology supports resolution elements of 250 KHz. Again, the input signals can be partitioned amongst four IF channels.

8. Observing Trends

A major expense for any observer granted telescope time is the cost of traveling to the observatory and being away from their home base during the observing program. In order to reduce these costs, the ARO recently upgraded its SMT control and user systems to permit remote observing. This enables anybody with Internet access to conduct an observing session at either of the two ARO facilities as if they were sitting in the control room alongside the telescope operator. A "chat" window provides easy bi-directional communication between the observer and the operator. A suite of standard Internet tools and specifically designed programs enable the remote observer complete access to all the information available on site. This system has become very popular with both observers and observatory staff.

In addition to the cost benefits to an observer, remote observing permits the ARO to implement Priority Observing. The atmospheric transparency at the very short wavelengths is dependent on water vapor content and is highly variable. By implementing a policy of Priority Observing, the shortest wavelength programs are ensured the best conditions. Remote observing makes this possible.

Using the upgraded ARO facilities, interesting new scientific results have been emerging. The very stable, high sensitivity receivers have enabled a closer look at the circumstellar envelopes of oxygen-rich stars, in particular VY Canis Majoris. An unusual chemical and morphological structure has been discovered in this super giant star, as illustrated in Figure 6. Several distinct outflows have been found that are chemically different [2]. A survey of $^{12}C/^{13}C$ ratios in circumstellar shells and protoplanetary nebulae have been conducted, which provide details on

stellar mixing processes as a function of stellar age [3]. Several new interesting molecules have been discovered as well, including PO [4] and CCP [5]. The SMT has also been used in critical VLBI experiments [6].

9. Future Prospects

The ARO has embarked on a program of full-band coverage with high sensitivity SIS receivers, a 4 GHz instantaneous IF passband, single sideband response, and simultaneous dual polarization capability. Programs are currently underway to produce receivers for the SMT in the 385 to 500 GHz band and the 785 to 950 GHz band. An improved receiver in the 275 to 370 GHz band is a future program.

With a goal of 16 GHz of IF bandwidth, a full bandwidth and flexible spectrometer is planned. Partitioned bandwidth hybrid spectrometers have been tried in the past with limited success, but with the expansion of high speed analog and digital devices, a high resolution digital FFT approach seems the most likely. Such a spectrometer would provide the wide bandwidths necessary with the flexibility to choose from a range of resolution bandwidths.

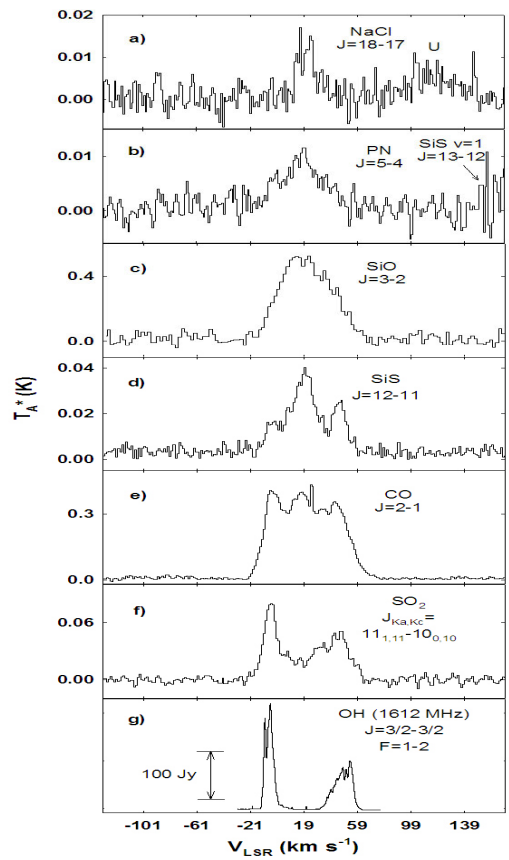

Figure 6. Molecule Profiles in VY Canis Majoris

10. Conclusions

The facilities of the ARO provide high sensitivity SIS receivers and flexibly high resolution spectrometers. By now, three new high sensitivity SIS radiometer systems will be operational and a 2048 channel spectrometer at the SMT. With the high sensitivity and stability offered with sideband-separating mixers and new spectrometers, millimeter and sub-millimeter heterodyne spectroscopy has a bright scientific future.

11. References

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