New Achievements of ASTE: The Atacama Submillimeter Telescope Experiment

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New Achievements of ASTE: The Atacama Submillimeter Telescope Experiment

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ABSTRACT

ASTE is a 10-m submillimeter telescope operating in Atacama desert in northern Chile since 2002 by NAOJ and collaborators. Thanks to the excellent observing condition at the telescope site, ASTE has been producing numerous astronomical results from star forming regions, Galactic center, Magellanic clouds, nearby galaxies, and galaxy clusters. There has been three major improvements during the years 2007-2008: continuum camera "AzTEC", new SIS receiver "CATS345", and a wide-band spectrometer "WHSF". AzTEC is a 144 element bolometer array at 270 GHz, developed by University of Massachusetts and collaborators. The mapping speed reaches 10-30 arcmin^2/hr/mJy^2. CATS345 is a side-band separation (2SB) SIS receiver developed by University of Tokyo and NAOJ. The IF bandwidth is 4 GHz with side-band rejection ratio better than 10 dB. We have achieved the typical system noise temperature of 200-400 K (SSB) within 330-360 GHz, the best value being 150 K (SSB) at the frequency of ^{12}CO(J=3-2) at 345 GHz under a typical weather condition. The new spectrometer WHSF employs of an FX type auto-correlator, ultra-high speed sampler, and digital signal transmitter. It can be operated in two modes; 4096 MHz band-width x 2 IFs or 2048 MHz band-width x 4 IFs, both with 4096 channels in spectral resolution.

Keywords: Submillimeter Astronomy, ASTE, Atacama desert, Continuum imaging, Spectroscopy

1. THE ASTE PROJECT

1.1 The ASTE project

ASTE (The Atacama Submillimeter Telescope Experiment)[1] is a project to operate a 10-m sumbillimeter telescope in one of the best observing site which is located at Pampa la Bola (altitude 4,800 m) in the Atacama desert, northern Chile. The project is aimed for three main purposes: 1) explore the southern sky with submillimeter-waves, 2) on-site evaluation of methods and techniques for submillimeter observations, and, 3) provide students and young scientists the opportunity to study observational astronomy and its instrumentations. The project is being driven by the ASTE team, which is an inter-institute organization with National Astronomical Observatory of Japan, Universidad de Chile, University of Tokyo, Nagoya University, Osaka-prefecture University, Ibaraki University, and Hokkaido University. The telescope has been in operation in Pampa la Bola since early 2002.

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The telescope was initially assembled in year 2000 at Nobeyama Radio Observatory (NRO) located in Nagano prefecture, central Japan. Following the performance verifications and initial tests at NRO, the telescope was disassembled and shipped to Chile, and was deployed in Pampa la Bola at its altitude of 4,800 m.

Fig. 1. The ASTE telescope located at Pampa la Bola in northern Chile, at 4,800 m above sea level. The telescope is surrounded by several containers, such as operation room and lab containers.

1.2 The ASTE site

Based on the extensive site survey among various sites for submillimeter astronomy, we have chosen “Pampa la Bola” in the Atacama desert as the telescope site for ASTE. Pampa la Bola is located at an altitude of 4,800 m which provides us excellent observing condition for submillimeter astronomy. The ASTE telescope is located at (–22°58’18”, –67°42’11”)[2] which is approximately 70 km to the east of San Pedro de Atacama at an altitude of 2,400 m, where we situate our operation base. The atmospheric transmission measured at Pampa la Bola utilizing a FTS (Fourier Transform Spectrometer) is shown in Figure 2. This plot indicates that the atmospheric transmission among several windows for submillimeter-waves up to 900 GHz are as high as 60%. Numbers of radio telescopes have been operating in the vicinity, and future large radio telescopes are coming in.

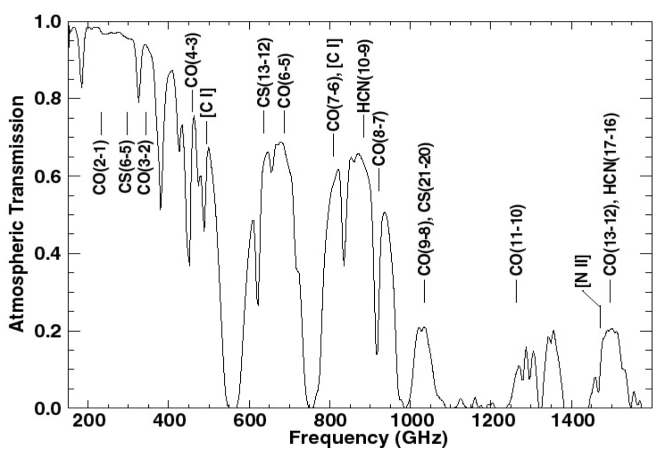

Fig. 2. Atmospheric transmission at the ASTE site (Pampa la Bola) measured by a Fourier-Transform Spectrometer[3]. The figure shows that our site has 60% or more transmission within major atmospheric windows.

Figure 3 shows the current view of the infrastructure for ASTE at Pampa la Bola at an altitude of 4,800 m. Several key facilities are surrounding the telescope, including the diesel driven electrical power facility, containers for telescope control, small lab to prepare the receivers, or a place to take a rest, weather station, and a satellite communication system. Some of the containers are oxygenated by the oxygen compressor for safety and comfort. The satellite communication system connects the ASTE site, our base facility in San Pedro de Atacama, and to the outside world through the internet. The telescope control system N-COSMOS3[4] and the satellite connection enable us to operate the telescope not only from the telescope site in the high altitude, but also remotely from the base facility in San Pedro de Atacama, and also from Japan at Mitaka, Tokyo or Nobeyama, Nagano of NAOJ. A big advantage to observe from Japan is that we are daytime in summer while Chile is winter night when they have the best observing condition.

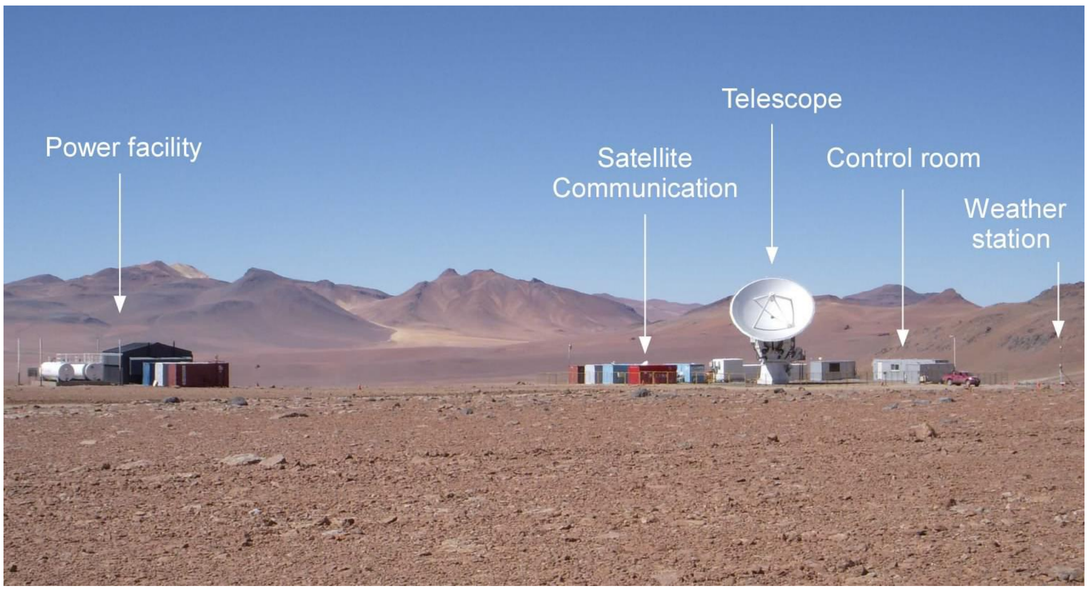

Fig. 3 The current view of the ASTE infrastructure at Pampa la Bola. Several key facilities are surrounding the telescope, including the electrical power facility, containers for telescope control, small lab to prepare the receivers, weather station, and a satellite communication system.

2. RECENT STATUS

2.1 Observations

During the years 2004-2006, we have been concentrating on spectroscopic observations of various astronomical objects in the southern sky at 345 GHz. The observation was scheduled to concentrate on several key science projects, while allowing small observing projects to be accommodated as well. Supported by the excellent observing condition and instruments, numerous astronomical results have been published, including Star-forming regions[5,6,7,8,9,10,11,12,13,14], the Galactic center[16,17,18,19], and nearby galaxies[20,21,22,23,24,25,26]. These observations were mainly performed by utilizing the SC345 receiver and the XF-type digital spectrometer as described in the following section.

2.2 The Antenna

The ASTE 10-m antenna employs a Cassegrain optics with a receiver cabin under the elevation axis. The main reflector is supported by CFRP tubes and boards connected to a central hub made by invar. The surface consists of 205 machined aluminum panels, each of which being supported by motor driven actuators for automated surface adjustment. This allows us to set the entire 10-m surface to be adjusted within 10-20 minutes. The surface accuracy of the main reflector is

19 μm r.m.s., which was determined by the holography measurement. The subreflector is 62 cm in diameter which is supported by a hexapod parallel manipulator to allow it to move in all six-degrees of freedom. The pointing accuracy of the telescope was measured to be approximately 2 arcseconds r.m.s. during the winter night. Detailed description of the antenna is also discussed in Ezawa et al[1,27]. and Ukita et al.[28]

2.3 Instruments

Recently ASTE has been mainly performing spectroscopic observations at 345 GHz utilizing an SIS receiver SC345[25] and a digital spectrometer[29]. SC345 has been developed by the University of Tokyo and National Astronomical Observatory of Japan. The receiver employs a DSB mixer at 345 GHz integrated on a receiver cartridge, which plugs into the cryogenic system with thermal link, which is identical to the CATS 345 receiver described in section 4.

The 4.5-7 GHz IF is fed to the digital spectrometer[29]. This spectrometer consists of 4 banks of "XF-type" spectrometers, which first takes the autocorrelation of the signals and then calculate the power spectra. The basic design of the system is similar to the digital spectrometer for the Nobeyama 45-m telescope. The bandwidth and spectral resolution can be selected from either 512 MHz/1024 ch or 128 MHz/1024 ch.

The overall system shows a system noise temperature of 200-400 K (DSB) under a typical condition during the winter observing season at the ASTE site.

2.4 Control system

The control system of ASTE is designed to provide easy-to-use user interface even for remote operation through the internet. The framework of the ASTE control system is N-COSMOS3 [4], which was developed based on COSMOS-3 [30], the control framework of the Nobeyama 45-m telescope or the Nobeyama Millimeter Array. COSMOS-3 is capable both for continuum and spectroscopy observations with position switching and on-the-fly mapping[31]. The major enhancement of N-COSMOS3 is the capability for remote observation, which provides the observers the same look-and-feel interface as COSMOS-3. In order to accommodate the control within a very limited connection speed of the satellite link between the telescope and each remote site (56-64 bps), extreme care was taken for the data-rates between sites, as well as realizing a semaphore like system to avoid confictions amount multiple observing sites.

3. NEW INSTRUMENTS – CONTINUUM CAMERA

3.1 AzTEC camera

AzTEC[32] is a 144 element bolometer camera at 270 GHz (λ = 1.1 mm) developed by University of Massachusetts and collaborators. The detector consists of silicon nitride spider-web bolometers with neutron transmutation doped Ge thermistors. The detector is cooled down to 0.3 K by a closed cycle three-stage ^{3}He refrigerator mounted on a 4 K cryostat. The operation of the 0.3 K refrigerator is automated by computer controlled which can be done remotely, while the 4 K cryostat is cooled down by liquid helium and liquid nitrogen.

The camera was designed for the Large Millimeter Telescope (LMT), and it was deployed on to the James Clerk Maxwell Telescope (JCMT) during years 2005-2006. The JCMT run was a great success leading to numbers of results (eg. COSMOS survey [33]).

3.2 AzTEC on ASTE

Following the success of the JCMT run, both the AzTEC team and the ASTE team discussed to have this AzTEC camera on board ASTE telescope for the subsequent years 2007-2008. AzTEC was shipped to Chile in March 2007, and installed into the ASTE receiver cabin in April 2007. The optics were designed newly to match the ASTE telescope, while the original electronics including the data acquisition system has been utilized on ASTE, by interfacing and synchronizing them to the ASTE telescope control system (N-COSMOS3[4]). After the extensive effort to establish the system, we achieved our first light from Jupiter on May 8, 2007.

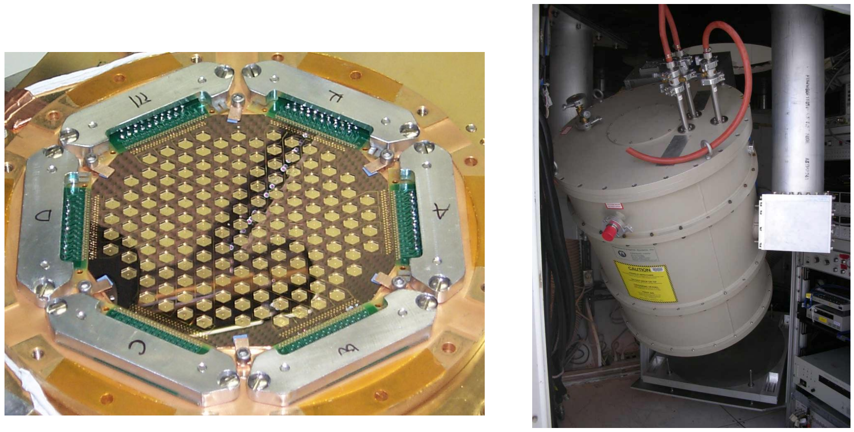

Fig. 4. (left) The AzTEC bolometer array, (right) The AzTEC cryostat mounted in the receiver cabin of ASTE

The observation with AzTEC on ASTE is done remotely either from the base camp in San Pedro de Atacama, or either of the remote sites: Mitaka or Nobeyama campus of NAOJ, and University of Massachusetts/Amherst in U.S.A. The ^{3}He refrigerator can be operated remotely as well, while the people on duty for operation in Chile refills AzTEC cryostat with cryogens (liquid helium and liquid nitrogen) every 2 or 3 days.

3.3 First year observation with AzTEC on ASTE

The first year observing run of AzTEC on ASTE has been done during June-October 2007. Major portion of the observing time were allocated to the three key science projects, which are extensive survey of submillimeter galaxies (SMGs), as well as Sunyaev-Zel'dovich effects through clusters of galaxies, and wide-field imaging of star forming regions. The actual mapping speed of 10-30 arcmin^2/hr/mJy^2 has been achieved for point-like source surveys.

Figure 5 shows one of the results from the SMG survey[34]. Approximately 700 hrs of observing time was spent for the SMG survey during the 2007 run. We have so far mapped out over 1 deg^2 as deep as 0.5-1 mJy/beam, to detect 300-400 sources.

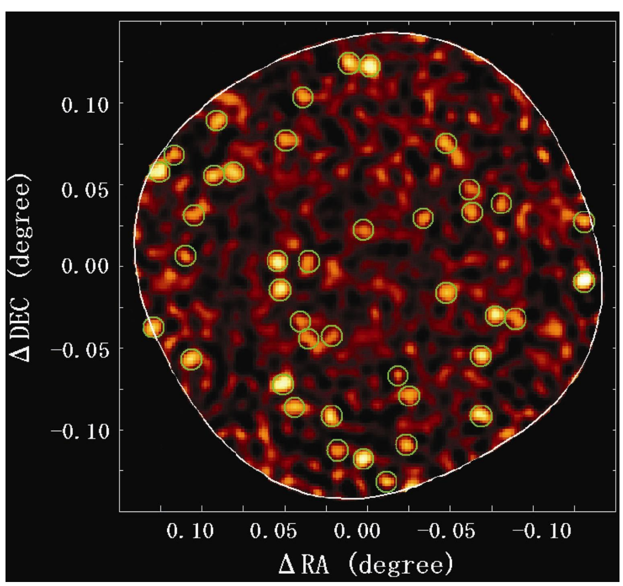

Fig.5 Image taken with AzTEC on ASTE from one of the deep fields (Hatsukade et al.[34]). Circles in the image indicate the 3.5 σ detections.

4. NEW INSTRUMENTS – SPECTROSCOPY

4.1 New Receiver – CATS345

In October 2007 we have started to operate a new receiver CATS345 (CArtridge-Type Sideband-separating receiver for ASTE 345 GHz band)[35]. CATS345 has been developed by the University of Tokyo, National Astronomical Observatory of Japan, and Osaka-prefecture University. The receiver employs a cartridge type plug-in cryogenics, where a common cryostat powered by 4-K GM refrigerator can be shared among multiple units of receiver cartridges. The mechanical and thermal specification of the cartridge is designed to be compatible to those of ALMA (the Atacama Large Millimeter/submillimeter Array). CATS345 is equipped with a sideband separating (2SB) SIS mixer at 345 GHz (or λ = 870 µm), with its IF frequency of 4-8 GHz for each sidebands. The typical system noise temperature measured on ASTE was among 200-400 K (SSB) for its sensitive bands at 330-360 GHz, while achieving the best value of T_{sys}=150 K (SSB) for ^{12}CO(J=3-2) at 345 GHz. The measured image rejection ratios were around 10 dB within the whole LO frequency range.

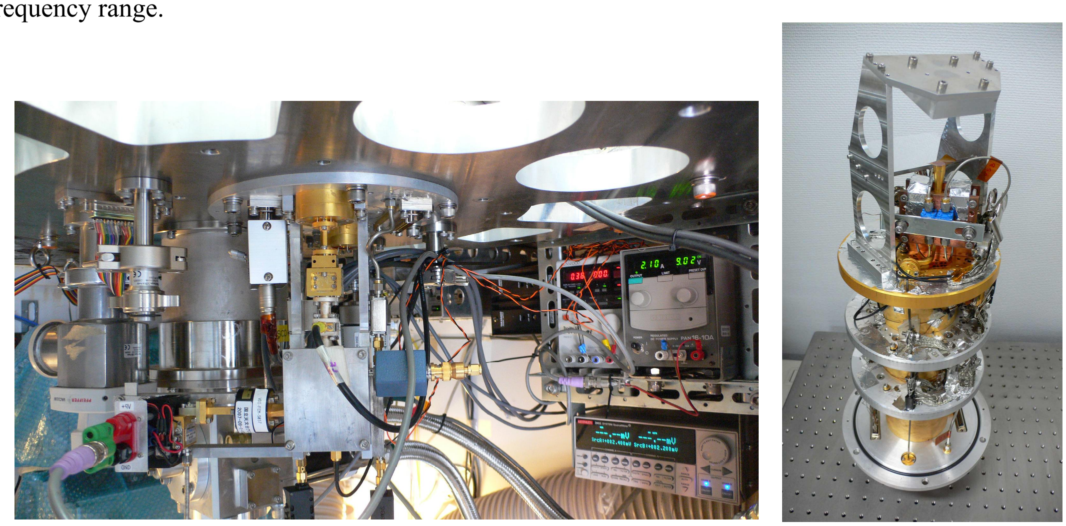

Fig. 6. (left) The CATS345 receiver system mounted on the ceiling of the ASTE receiver cabin. The cryostat employs a plug-in cryogenic system for receiver cartridges. (right) The receiver cartridge of CATS345 in the lab.

4.2 New Spectrometer – WHSF

In October 2007 we have installed a new spectrometer called WHSF (Wide-band High resolution Spectrometer with FFX correletor) which was developed by National Astronomical Observatory of Japan and The University of Tokyo. The system is consists of three main blocks, ultra-high speed sampler (8Gsps), a digital signal transmission system (DTS), and a FX type correlator.

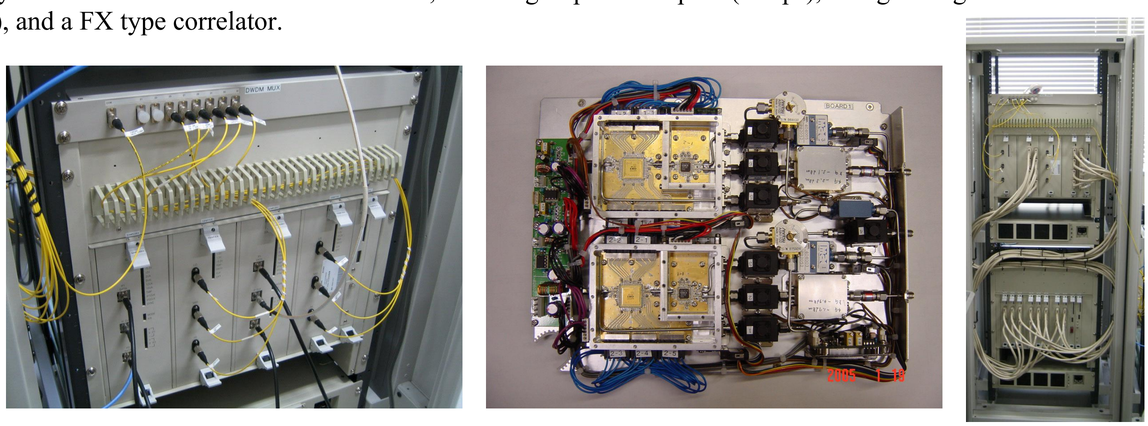

Fig. 7. (left) The “front-end” section of the WHSF system mounted in the receiver cabin, (middle) Close up view of the ADC board, (right) the digital correlator section of the WHSF system.

The “front-end” block of WHSF which consists of two high-speed sampler, is mounted in the receiver cabin of ASTE. The sampler employs a 8 Gs/s 1-bit ADC[14]. The digitized signal will then be multiplexed and transmitted through a DTS of 60 Gbps, which leads to the FX correlator installed in one of the containers on the ground on-site. The detailed configuration and its evaluation results are summarized in Okuda et al.[36]

The spectrometer as a system covers 8 GHz bandwidth in total: 4 GHz bandwidth with 2048 ch for 2 individual IFs, or 2 GHz bandwidth with 2048 ch for 4 individual Ifs. Hence this spectrometer can cover the entire 4 GHz bandwidth of both sidebands from the CATS345 receiver simultaneously.

4.3 Observation with CATS345+WHSF

Following the installation of CATS345 and WHSF, we have received the first wave with this system on November 2007. Figure 7 shows the first spectra from IRC+10216 taken by CATS345 and WHSF on ASTE. Multiple molecular lines are clearly seen in the wide-band spectra covering 8 GHz; 4 GHz each from upper/lower side-band with a flat base-line. The major advantage of this system is that each 4 GHz bandwidth spectra can be taken as a “one-shot”, which would be mostly powerful for line-surveys or to observe galaxies with broad spectral lines.

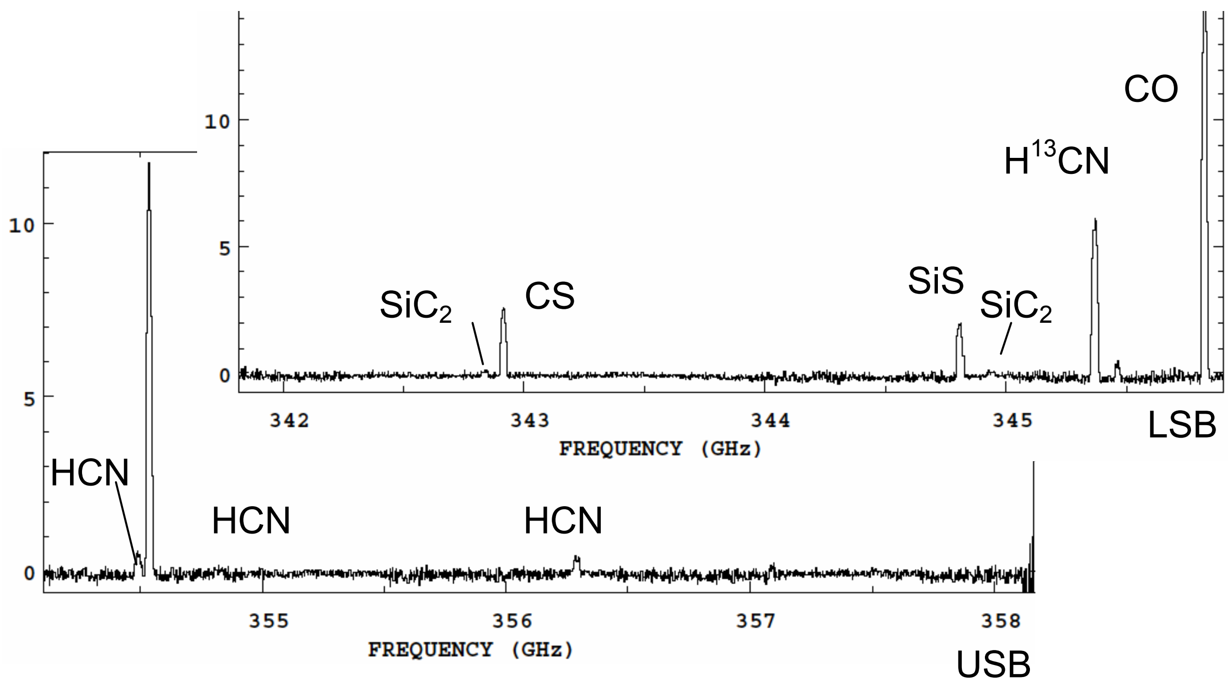

Fig. 8 The first spectra taken with CATS345 and WHSF on ASTE from IRC+10216. Total bandwidth of 8 GHz is observed with 4 GHz bandwidth from both upper and lower sidebands.

5. SUMMARY

There has been major improvements to the ASTE instrumentation during years 2007-2008. AzTEC, a 144 element bolometer camera at 270 GHz, was installed to ASTE in April 2007. The system achieved a mapping speed of 10-20 arcmin^2/hr/mJy^2 , which enables the extensive survey of various astronomical objects. A major fraction of observing time of AzTEC on ASTE was spend for submillimeter galaxy survey, which covers over 1 deg^2 as deep as 0.5-1 mJy/beam to detect 300-400 sources. CATS345, a side-band separating (2SB) SIS receiver together with WHSF, the F-FX type wide-band spectrometer, was installed to ASTE on October 2007. These two new instruments allow us wide-band spectroscopic observations covering 8 GHz in bandwidth.

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