SIS receivers for the Mt. Fuji submillimeter-wave telescope and Atacama Submillimeter Telescope Experiment

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Abstract— **We are developing submillimeter-wave receivers for the Mt. Fuji submillimeter-wave telescope and for the Atacama Submillimeter Telescope Experiment (ASTE). We have developed 492/345 GHz receiver for the Mt. Fuji submillimeter-wave telescope (Dia. 1.2 m), which was installed at the summit of Mt. Fuji (alt. 3725 m) in August 1998. The both 492 and 345 GHz bands are simultaneously received by separating 2 polarizations with a cooled free-standing grid. It employs Nb-base SIS mixers which are parallelly connected two or 10 junctions (Shi, Noguchi & Inatani 1997). The 492 GHz signal are received as lower side band by separating side bands with a new quasi-optical SSB method (Inatani et al. 1998). In the 1998 season, the receiver noise temperature at 492 GHz was 300 K in SSB and the system noise temperature including the atmospheric emission was typically 1200 K in SSB. We are developing an 809/492/345 GHz receiver for the winter season of 1999.**

A submillimeter receiver is designed for ASTE, which is a plan to operate a Large Millimeter and Submillimeter Array (LMSA) prototype antenna at Pampa la Bola (4800 m) in the northern Chile. The telescope with 10 m diameter will be delivered at Nobeyama (1350 m) in February 2000 and will be transported and installed at Pampa la Bola in August 2001. Millimeter and submillimeter receivers are mounted at the Cassegrain focus of the LMSA prototype antenna. The observing frequency covers the 80 - 350 GHz bands at Nobeyama in 1999 and 2000 and the 80 and 900 GHz bands at Chile from 2001.

Keywords— **Submillimeter-wave astronomy, SIS receiver**

I. Introduction

We are developing submillimeter receivers for astronomical observations between 300 and 850 GHz, using SIS mixers developed by T. Noguchi of Nobeyama Radio Observatory and S. C. Shi of Purple Mountain Observatory in China. One has been mounted on the Mt. Fuji submillimeter telescope which is recently developed for a large-scale survey of the Milky way in the CI 492 GHz line. The other is for a new 10 m telescope which will be installed at Pampa la Bola (el. 4800 m) in northern Chile in August 2001.

A group of University of Tokyo, Nobeyama Radio Observatory, and Institute for Molecular Science has jointly developed a submillimeter-wave telescope at the summit of Mt. Fuji to survey neutral atomic carbon (C_I) toward the Milky Way ([1], Figure 1, 2). The telescope has an 1.2 m main reflector with a surface accuracy of 10 μm in rms. A superconductor-insulator-superconductor (SIS) mixer receiver on the Nasmyth focus receives the 492 GHz band in SSB and the 345 GHz band in DSB simultaneously. An acousto-optical spectrometer (AOS) which has the total bandwidth of 0.9 GHz and 1024 channel outputs has been also developed. The telescope was installed at the summit of Mt. Fuji (alt. 3725 m) in August 1998. It has been remotely operated by using a satellite communication system from Tokyo or Nobeyama since November 1998. Atmospheric opacity at Mt. Fuji was 0.4 - 1.0 at 492 GHz during 30 % of time and 0.07 - 0.5 at 345 GHz during 60 % of time from November 1998 to February 1999.

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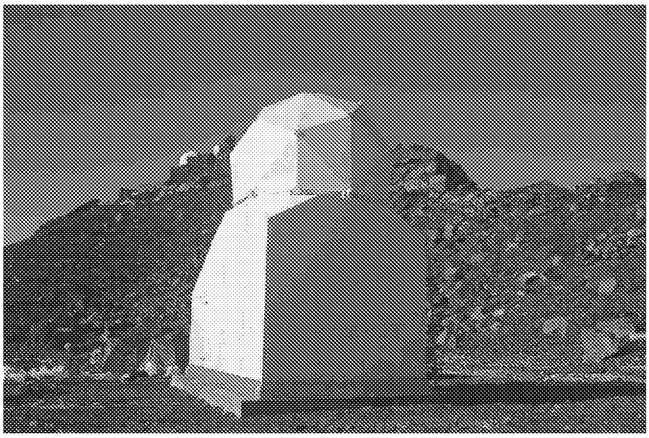

Fig. 1. Photograph of the Mt. Fuji submillimeter telescope

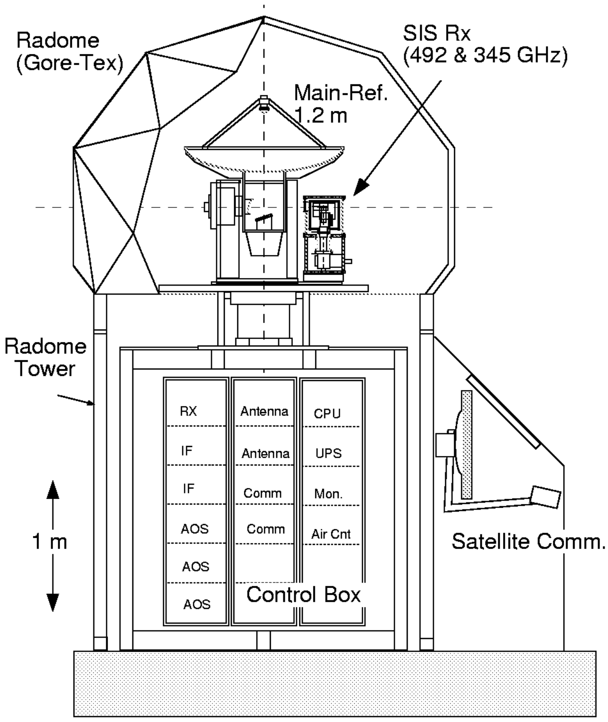

Fig. 2. Schematic drawing of the Mt. Fuji submillimeter telescope

The Atacama submillimeter telescope experiment (ASTE) is one of R&D activities for the Large millimeter submillimeter array (LMSA). We are planning to operate a new 10 m telescope at Pampa la Bola (4800 m) in northern Chile as a single-dish submillimeter telescope and the first element antenna for future interferometer. Technical and scientific purposes in this experiment are

1) to develop and evaluate a high precision 10 m antenna under exposed conditions at the site,
2) to develop and test low-noise submillimeter receivers and new SIS photon detectors,
3) to test various techniques for submillimeter observations, and
4) to explore the southern hemisphere in the submillimeter band: Galactic Center, Magellanic Clouds, and so on.

The telescope will be delivered at Nobeyama in February 2000. After a test operation up to 350 GHz at Nobeyama for one and a half years, the telescope will be transported and installed at Pampa la Bola in August 2001. The schematic drawing of the

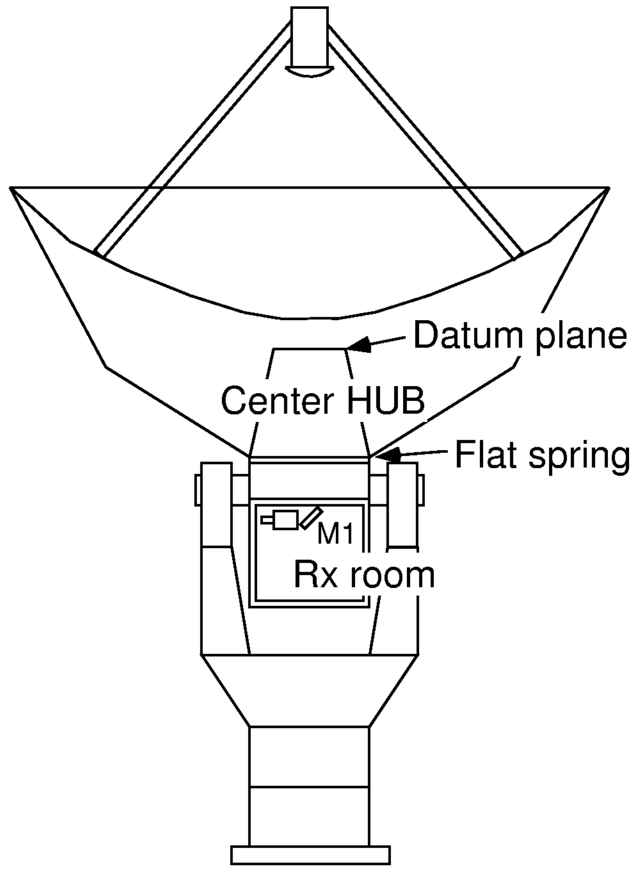

Fig. 3. Schematic drawing of the 10 m telescope for ASTE.

TABLE I
Specification of the ASTE telescope

Main reflector	10 m diameter, f/D = 0.35
surface accuracy	$< 25\ \mu$m
surface panels	205 pieces, Al
BUS	CFRP and Invar joints
Subreflector	0.6 m with wobbling
Pointing	< 1 arcsecond
Fast switch	$3°$/s, $3°/s^2$
Receiver cabin	$3.2 \times 2.2 \times 1.8$ m^3
Total weight	50 ton

telescope is shown in Figure 3 and the specification is tabulated in Table I. For the Nobeyama operation, a shaped Cassegrain optics is designed to achieve higher main-beam efficiency at millimeter-wave bands. A Gaussian optics will be replaced for the Chile operation to optimize submillimeter-wave observations up to 850 GHz. A subreflector will be changed from 0.45 m diameter for the Nobeyama operation to 0.6 m diameter for the Chile operation.

II. Receiver of Mt. Fuji telescope

We have developed an SIS (Superconductor-Insulator-Superconductor) receiver of the 809 (CI $^3P_2 -^3 P_1$), 492 (CI $^3P_1 -^3 P_0$)and 345 (CO $J = 3-2$) GHz bands for the Mt. Fuji submillimeter telescope ([1], Figure 4, 5). We employed Nb-based parallel connected twin junction (PCTJ[2]) for the 345 and 809 GHz mixers and Nb-based distributed junction (DJ) for the 492 GHz mixer. The 492 GHz signal is received in lower side-band (LSB) with a new qausi-optical SSB mixing method ([3]). As shown in Figure 6, RF and LO signals are divided and coupled by means of a single wire grid. The RF signal is fed to two mixer horns with a phase difference of 180 degree, but the LO signal is with that of 270 degree. The latter phase difference is generated by a reflective circular polarizer. After the IF signals are diplexed with 90 degree phase difference, the USB and LSB signals are obtained. We used only the LSB signals. The Y factors of two SIS mixers were independently measured o n the various I-V points at an experimental room. The two mixers have broad tunable range. The LO power for two mixers is controlled simultaneously. On the other hand, mixer bias for two mixers is applied independently. Each mixer had noise temperature of 120 K in DSB. The receiver had noise temperature of 300 K in LSB at 492 GHz. We estimated the image rejection ratio using higher-order frequency emission from the 345 GHz LO. In the IF band between 1.8 and 2.5 GHz, the ratio was roughly 0.9. The 345 GHz signals are received as upper side-band with lower side-band. The receiver noise temperature was 200 K in DSB at 345 GHz.

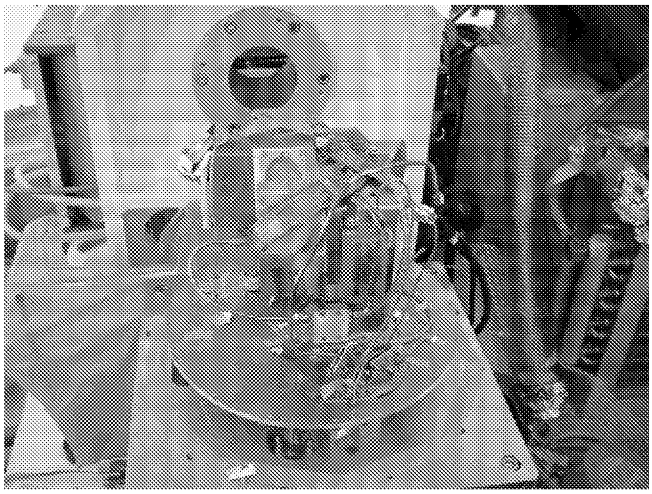

Fig. 4. Photograph of an SIS receiver for the Mt. Fuji submillimeter-wave telescope

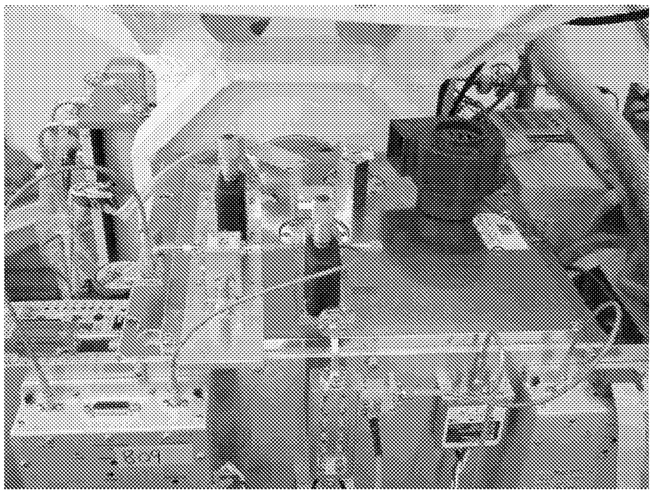

Fig. 5. Photograph of the LOs for the Mt. Fuji submillimeter-wave telescope.

The LO signals for 492 and 345 GHz are generated by multiplying an output of the W-band ($\sim$ 80 GHz) Gunn diode with

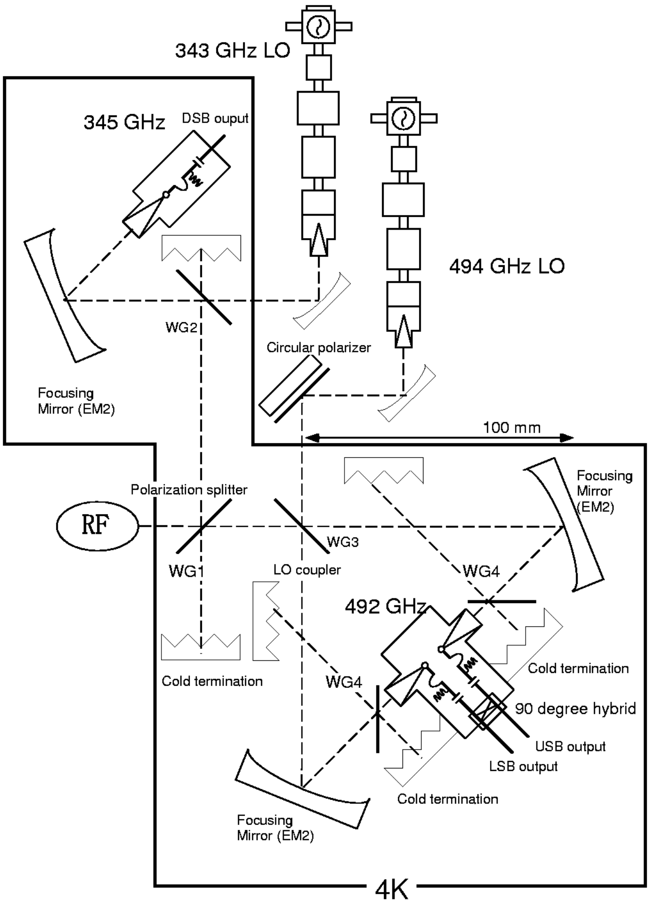

Fig. 6. Schematic drawing of the 4K optics in the dewar.

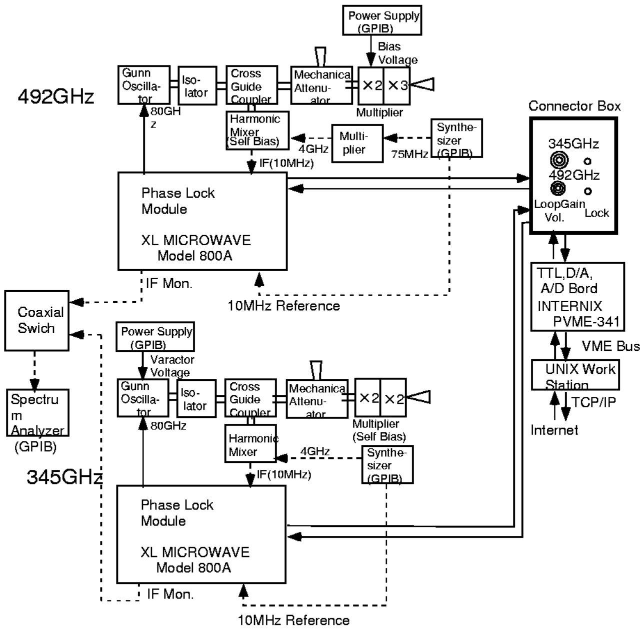

Fig. 7. Schematic drawing of the local oscillators and the phase lock-loop system.

TABLE II
PRESENT STATUS OF THE RECEIVER NOISE TEMPERATURE FOR THE MT. FUJI SUBMILLIMETER-WAVE TELESCOPE

810 GHz DSB	600 K
490 GHz DSB	120 K
490 GHz SSB	300 K
350 GHz DSB	80 K

3×2 and 2×2 multipliers (Radiometer Physics GmbH.), respectively. The LO frequency is stabilized to a signal generator in the 4 GHz region by the phase-locked loop (PLL) as shown in Figure 7. The LO signals are quasi-optically coupled to the RF signals by cooled free-standing grids in the dewar.

The receiver employs a 2-stage Gifford-MacMahon cryocooler, which has a cooling capacity of 0.5 W on the 4 K cold stage and 10 W on the 40 K stage with 3 kW power consumption (Sumitomo RDK 204A). The compressor for this cryocooler is cooled by a water circulator. A vacuum pump composed of a rotary pump and a turbo molecule pump evacuates the receiver dewar to an order of 10^{-4} mbar before the cooling. The compressor, the water circulator, and the vacuum pump are put on the azimuth table.

Optical components on the antenna optics and optical components in the receiver dewar has been mechanically aligned to the axes and the 4 K stage of the cryocooler, respectively. To align the optical axis of the telescope and that of the receiver system we employed a simple method using a diode laser. Two pin-holes with 1 mm diameter separated by 50 mm are put on the position of the mixer horn with an accuracy of 10 μm and they are used to define the optical axis of the receiver. The laser beam passing through these two holes illuminates the sub-reflector with a spot size of 2 mm diameter. We adjusted the position of the receiver at the room temperature using a three-dimensional mechanical stage between the receiver and the azimuth table so that the laser beam coincides with the center of the subreflector within 1 mm at a distance of 1.5 m, even if the elevation angle of the main reflector changes from 90 degree to 20 degree. We considered that the length of the cryocooler becomes 1 mm short at the operating temperature. This method can align the receiver with respect to the antenna optics with an angular accuracy of $3'$.

A Nb-base 810 GHz mixer has been mounted in the dewar to observe the CI ($^3P_2 -^3 P_1$: 809 GHz) and CO (J=7-6: 807 GHz) lines for the 1999 winter season. The 809 GHz signal is separated from the 345 GHz optics by a dichromatic low-pass filter. The receiver noise temperature was measured to be 600 K in DSB in the laboratory as shown in Figure 8. The present status of the receiver noise temperature for the Mt. Fuji submillimeter-wave telescope is summarized in Table II.

III. A SUBMILLIMETER RECEIVER FOR ASTE

A submillimeter-wave receiver (345GHz) and a millimeter one (100 & 230 GHz) have been developed for the Nobeyama operation of the 10 m telescope (Figure 9). A suspension frame of two receivers are hung from a ceiling of a receiver cabin at the Cassegrain. Two frequencies out of three are simultaneously received as dual polarizations. All mixers in the receivers are parallel connected twin junction (PCTJ) or distributed junction (DJ) made at Nobeyama Radio Observatory. The optics involves two ellipsoidal mirrors. The millimeter receiver works as a holography receiver. For Nobeyama operation, the millimeter receiver hold a direct position from M1 to optimize the holography measurements.

Above 300 GHz, the local oscillator signal are coupled quasi-optically to the RF signal by a polarization grid in front of the horn. Two stages Gifford-Macmahon cryocooler with a capac-

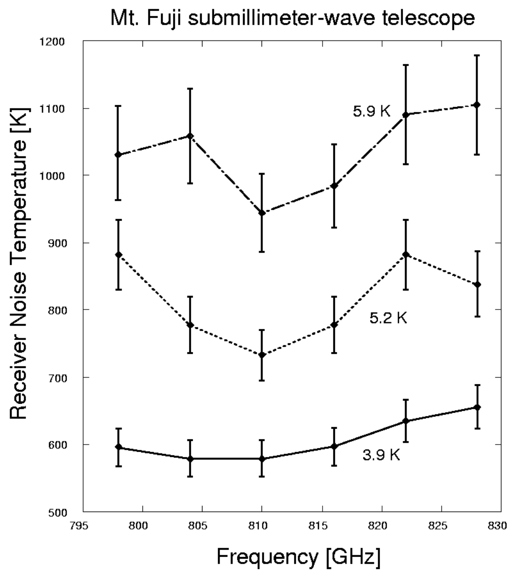

Fig. 8. Noise temperature of the 810 GHz receiver for the Mt. Fuji submillimeter telescope

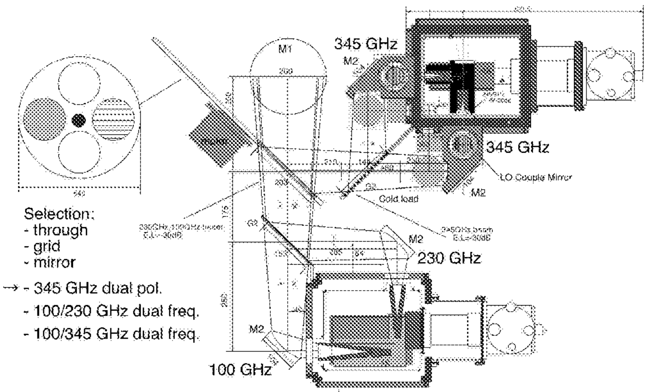

Fig. 9. Schematic drawing of receivers for the Nobeyama operation of a new 10 m telescope

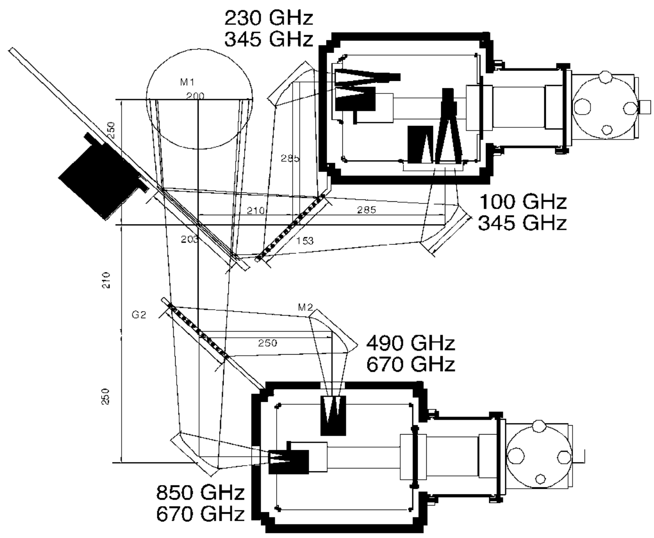

Fig. 10. Schematic drawing of receivers for the Chile operation of the 10 m telescope

ity of 1 W at the 4 K stage for power consumption of 7 kW (Sumitomo RDK408D) is employed with the both receivers. By using a He pot, the temperature variation of the 4 K stage is reduced from 0.5 K to 0.05 K. The submillimeter receiver is equipped with a cold calibrator at the 40 K stage for intensity calibrations. The standard chopping wheel method needs to know a weighted sky temperature with an atmospheric opacity at a submillimeter-band for intensity calibration. However, it is difficult to measure the temperature in the case of large opacity such as $\sim$ at 492 GHz.

All optical components in the receiver cabin are aligned at an accuracy of less than 0.4 mm. The beam efficiency is degraded by -0.1 dB in maximum with a 0.4 mm displacement of an optical component. We align them as follows: The M1 mirror is aligned to the optical axis defined by the main reflector. As it is served as a guide to alignment, a plate and the receiver suspension frame is put on the ceiling of the receiver room. Almost all optical components are mounted to the receiver suspension with an accuracy l of 0.2 mm. On the other hand, cooled optical components in the dewar are aligned to the M1 or the subreflector by a laser beam aligned by two pin-holes put in replace of the mixer horn. We confirm the alignment by using 3 dimensional measuring system (Spin-arm) with a positional accuracy of 0.1 mm made by Mitsutoyo.

Figure 10 shows an arrangement of the Chile operation. The submillimeter holds a direct position from the M1 to optimize submillimeter observations. Our developements are
1) multi-horn receivers to cover all frequencies from 80 to 850 GHz planed for the Atacama Large Millimeter/submillimeter Array (ALMA); 2) compact quasi-optical side-band separating receivers for submillimeter bands. The second item will be realized by improving a method by Inatani et al. (1998).

Acknowledgments

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