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Site testing at Dome Fuji for submillimeter and terahertz astronomy: 220 GHz atmospheric-transparency

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Abstract

We measured the 220 GHz atmospheric-transparency at the Dome Fuji station in Antarctica from 18 December 2006 to 14 January 2007 using a tipping radiometer. The mean optical depth at zenith was 0.045 ± 0.007, and during 98% of this period we measured an optical depth of less than 0.06. These data indicate that the atmospheric-transparency in summer at Dome Fuji is comparable to that of well-known submillimeter astronomical sites such as the Atacama desert in Chile in their best seasons.

Keywords: Submillimeter and terahertz astronomy; Site testing; Atmospheric opacity

1. Introduction

There are many astronomically important spectral lines of atoms, molecules, and ions in the submillimeter and terahertz frequency ranges, some of which are listed in Table 1. Recently, radio-receiver technology has been developed to take advantage of higher-frequency bands and it is now possible to construct submillimeter and terahertz radio telescopes. However, submillimeter observations can be obtained only at dry and high-altitude sites such as Mauna Kea in Hawaii, the Atacama desert in northern Chile, Gornergrat in Switzerland, Mt. Graham in Arizona, and the South Pole, because of improved atmospheric-transparency in the presence of reduced quantities of water vapor and oxygen. The atmospheric attenuation is mainly determined by the amount of water vapor and oxygen, and is expressed by the atmospheric optical depth. The atmospheric-transparency at these sites is not sufficiently low for terahertz astronomy; drier and higher-altitude sites are preferable. The Antarctic Plateau may be the best location on earth for astronomical observations in the terahertz band. Site testing has been performed or is currently taking place on the Antarctic Plateau at the South Pole, Dome C, and Dome A (e.g., Lane, 1998; Lawrence, 2004).

The Japanese Antarctic station, Dome Fuji (77°19′S, 39°42′E) is located at an altitude of 3810 m

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Table 1
Astronomically important spectral lines in the THz frequency range.

Frequency	Line	Target
461.0 GHz	CO($J=4-3$)	Warm and dense molecular clouds
492.2 GHz	[CI] $^3P_1-{}^3P_0$	Diffuse gas around molecular clouds
806.7 GHz	CO ($J=7-6$)	Hot and dense cores in molecular clouds
809.3 GHz	[CI] ($^3P_1-{}^3P_0$)	Diffuse gas around molecular clouds
921.8 GHz	CO ($J=8-7$)	Hot and dense cores in molecular clouds
1037 GHz	CO ($J=9-8$)	Hot and dense cores in molecular clouds
1267 GHz	CO ($J=11-10$)	Hot and dense cores in molecular clouds
1382 GHz	CO ($J=12-11$)	Hot and dense cores in molecular clouds
1463 GHz	[NII] ($^3P_1-{}^3P_0$)	Ionized diffuse gas
1497 GHz	CO ($J=13-12$)	Hot and dense cores in molecular clouds
1902 GHz	[CII] ($^3P_{3/2}-{}^3P_{1/2}$)	Strong line in galaxies
1956 GHz	CO ($J=18-17$)	Hot and dense cores in molecular clouds

on a plateau halfway between the South Pole and the ocean (Fig. 1; Watanabe et al., 1999). The annual average temperature at the station is −54.4 °C, and the lowest ever temperature was −79.7 °C (Yamanouchi et al., 2003). Because of the combination of low temperature and high altitude, a very small optical depth is expected at Dome Fuji. In addition, the average fraction of the sky obscured by clouds over the period 1995–1997 was just 30% (Yamanouchi et al., 2003). The mean wind speed is 5.8 m s^{-1} (Yamanouchi et al., 2003), rarely exceeding 10 m s^{-1}. These stable weather conditions are advantageous for the accurate pointing of telescopes and practical observing time.

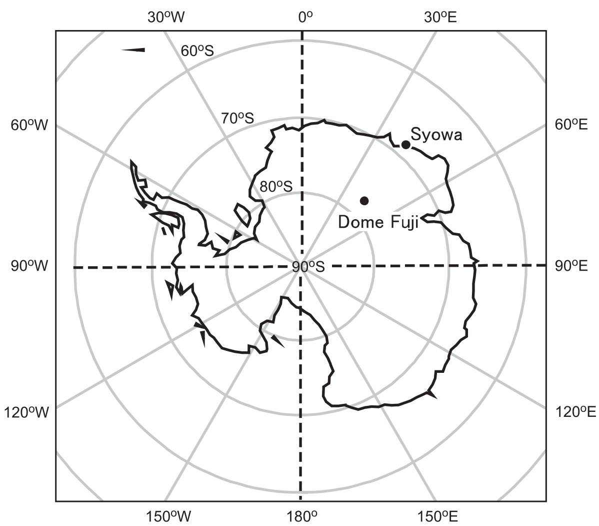

Fig. 1. Location of Dome Fuji in Antarctica.

We plan to construct astronomical telescopes at Dome Fuji. Measurement of the atmospheric-transparency is a first step toward developing submillimeter and terahertz astronomy at the station. Optical-depth measurements at 220 GHz are useful for comparison with other observatory sites, because many optical-depth records are available (e.g., Chamberlin and Bally, 1994; Otárola et al., 2005; Radford, 2002). In this paper, we report on atmospheric-transparency measurements at 220 GHz obtained at Dome Fuji.

2. Instruments

The atmospheric-transparency at zenith was measured with a 220 GHz tipping radiometer. The radiometer is an instrument capable of observing the brightness temperature of the sky using a narrow beam pointing toward a certain elevation angle. Figs. 2 and 3 show a block diagram of the radiometer system and its appearance, respectively. The radiometer was designed to operate at the low temperatures prevalent at Dome Fuji. It was developed by modifying the 220 GHz radiometer used for site testing at the Atacama Large Millimeter/submillimeter Array (ALMA) site (Kohno et al., 1995). An offset 83 mm (diameter) parabolic mirror with a corrugated feed horn at its focus produced a narrow beam of 63 arc minutes diameter. A stepping motor controlled the mirror's rotation around the elevation axis.

We employed heterodyne detection, which generates down-conversion of higher-frequency to intermediate-frequency (IF) signals, because direct detection of the 220 GHz signal was difficult. A GaAs Schottky-barrier diode harmonic mixer produced an IF signal at 1.2–1.6 GHz by mixing the signal from the sky with a second harmonics of local signal. The local signal at 109.13 GHz was generated by a Gunn oscillator. The mixer operated in double-sideband (DSB) mode so that the IF signal at 1.2–1.6 GHz contained the sky signal in both sidebands at 219.28–219.68 and 216.84–217.24 GHz. The IF signal was detected by a power meter and subsequently recorded using a personal computer. Receiver sensitivity is expressed by the equivalent noise temperature. The receiver noise temperature was evaluated based on the Y-factor method, which measures the difference in response of the receiver when its input port is terminated by hot