

Observatory Report from Japan

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Abstract

Recent three major activities of radio astronomy in National Astronomical Observatory of Japan (NAOJ) are presented. One is the construction of Atacama Large Millimeter/submillimeter Array (ALMA); NAOJ is constructing Atacama Compact Array (ACA) for ALMA, and ALMA band-4, -8, and -10 receiver cartridges for all of ALMA antennas. The others are activities for running Nobeyama Radio Observatory (NRO) and Mizusawa VLBI observatory. Toward science with ALMA, NRO is operating the 45 m telescope, and ASTE (Atacama Submillimeter Telescope Experiment) 10 m telescope in Chile in collaboration with Japanese universities and the University of Chile. Mizusawa is operating VERA (VLBI Exploration of Radio Astronomy) dedicated to phase referencing VLBI for Galactic astronomy, consisting of four 20 m telescopes across Japan and performing astrometry observations of H₂O or SiO maser sources. Other activities led by Japanese universities are also reported.

1. Introduction

NAOJ runs two observatories, NRO and Mizusawa VLBI observatory, for cosmic radio astronomy, and runs NSRO (Nobeyama Solar Radio Observatory). NAOJ also runs ALMA with international partners at ESO and NRAO, and the Joint ALMA Observatory (JAO). The East-Asian ALMA Regional Center (EA-ARC) operated at NAOJ is the observer interface for Japanese and Taiwanese user community. Japanese university groups also runs telescopes for millimeter and submillimeter astronomy and for VLBI observations. The recent activities of cosmic radio astronomy in Japan are briefly introduced in this report.

2. Telescopes for mm and sub-mm astronomy

2.1 ALMA

NAOJ is constructing the Atacama Compact Array (ACA) [1], which consists of four 12-m antennas and 12 7-m antennas. One of the four 12-m antennas delivered to JAO from NAOJ was used for the first successful interferometric test at the Array Operation Site (AOS at an altitude of 5000 m) in 2009. The other three 12-m antenna and 12 7-m antennas are under the evaluation test at the Operation Support Facility (OSF).

There are ten ALMA receiver cartridges at millimeter and sub-mm wavelengths (31.3 to 950 GHz); Band 1 through Band 10. NAOJ is in charge of the delivery of three bands out of ten: Band 4 (125 to 163 GHz), Band 8 (385 to 500 GHz), and Band 10 (787 to 950 GHz). The Band 4 and 8 receiver cartridges passed the final design review in 2009. The Band 4 and 8 receivers were shipped out to Chile and installed on the ALMA antenna at OSF. Astronomical sources were successfully received with both receivers during the evaluation test in 2010. The world's highest performance low-noise Band 10 receiver was also successfully developed [2]. A compound superconductive material NbTiN is used for the Band 10 SIS (Superconductor-Insulator- Superconductor) tunneling junctions.

2.2 NRO 45m telescope

Wide field spectral line mapping has been performed with the 25 BEam Array Receiver System (BEARS) at 3 mm on the 45m telescope and the On-The-Fly (OTF) mapping technique. The whole disk region of a nearby galaxy M33 was mapped in carbon mono-oxide CO(1-0) line, and the breakdown of Kennicutt-Schmidt star formation law at giant molecular cloud (GMC) scales was revealed with comparison between the surface density of molecular gas and star formation rate [3]. The northern part of Ori-A GMC and the ρ Ophiuchi main cloud were also mapped in CO(1-0) [4, 5]. High quality images with the combination of BEARS and OTF are widely used for the single dish and

interferometer data combine. A very impressive and beautiful CO(1-0) image covering a whole area of a nearby galaxy M51 has been obtained with combining data from NRO 45 m telescope and the Combined Array for Research in Millimeter Astronomy (CARMA) [6].

New sensitive receivers at $\lambda = 3$ mm have been developed and installed. One is a single beam, two polarization 2SB-type (sideband separating type) SIS receiver (T100), and another is a similar but twin beam receiver (TZ100) for high-z CO search. The combination with a newly installed wide-band spectrometer (SAM45; covering 32 GHz in total with 65 k spectral channels) is very powerful for line surveys as well as the blind search of the CO ladder toward high-z galaxies. The initial results of line surveys with T100 are recently published [7, 8].

2.3 ASTE 10m telescope

ASTE is a 10 m submillimeter telescope located at Pampa la Bola in the Atacama desert in Chile. AzTEC 144 pix Bolometer camera at 1.1 mm was mounted on ASTE during 2007 to 2008. Several key science projects had been done with AzTEC on ASTE. One of the key science projects is the extensive surveys of blank fields for detecting millimeter/submillimeter galaxies (SMGs). The surveys provided us with one of deepest and widest surveys and uncovered more than 1000 SMGs so far [e.g., 9-11]. Other is the surveys of nearby star forming regions. The surveys covered 20 deg^2 in total with a depth of 10 mJy, and discovered many 1.1 mm sources in Lupus, Ophiuchi, Chamaeleon, and Orion regions [4, 12]. Nearby galaxies such as LMC, SMC, and M33 were also observed with AzTEC/ASTE.

Science operation with 2SB-type 345 GHz receiver on ASTE and commissioning with ALMA band-8 qualification model were also conducted in 2008 and 2010. The wide field mapping of OMC-1 in the neutral carbon [CI] line at 492 GHz has been done successfully in the commissioning phase. New TES (Transition Edge Sensor) bolometer camera at 1.1, 0.85, 0.45 mm (169, 271, and 881 pix, respectively) is under development at NRO in collaboration with U. Tokyo, Hokkaido Univ., UC Berkley, McGill and Cardiff Univ., and the commissioning (for two wavelengths, 1.1 and 0.85 mm) on ASTE is planned this year.

ASTE telescope was also used for the 1.3 mm VLBI experiments in Apr., 2010. The VLBI observing system for ASTE was newly developed by NAOJ sub-mm VLBI group and Sgr-A* in the Galactic center and calibrators were observed together with other telescopes in Hawaii and Arizona. The data analysis is underway with a VLBI correlator at Mitaka/NAOJ.

2.4 Other telescopes

The survey telescopes listed below are operated by Japanese university groups for millimeter and submillimeter molecular line observations. NANTEN-II is located closely to ASTE 10 m telescope in Chile. Other two telescopes are located at NRO.

- NANTEN-II 4 m submillimeter telescope in Chile (see [13] for recent results)
- Osaka Prefecture Uni. 1.85 m survey telescope at NRO
- AMANOGAWA 60-cm telescope at NRO (see [14] for recent results)

3. Telescopes for VLBI

3.1 VERA

Intensive astrometric observations of Galactic maser sources have been performed with VERA, and trigonometric parallaxes (and distances to maser sources) and proper motions are successfully obtained; the distance is derived to be 178^{+18}_{-37} pc for the nearby star forming region, the ρ ophiuchi [15], and $11.6^{+5.3}_{-2.8}$ kpc (the farthest case) for the star forming region in the far outer Galaxy, IRAS 05137+3919 [16]. VERA has also been used for estimating the angular velocity of Galactic rotation at the Sun, the distance to the Galactic center, and the structures of spiral arms near the Sun [17, 18].

3.2 Japanese VLBI Network

The Japanese VLBI Network (JVN) is a collaborative project among Japanese universities and institutes, which is based on VERA antennas and other antennas in Japan. This project is jointly operated by Hokkaido Univ., NAOJ, Ibaraki Univ., Gifu Univ., Osaka Prefecture Univ., Yamaguchi Univ., Kagoshima Univ., and other institutes. Several astronomical observing programs are performed every year: NRO 45 m telescope is used for a few programs out of them [e.g., 19]. The main telescopes for JVN are listed below. These telescopes are also used for the single dish observations of astronomical sources.

- Tomakomai 11 m telescope operated by Hokkaido Univ. (see [20] for recent results)
- Takahagi 32 m telescope
- Gifu 11 m telescope
- Yamaguchi 32 m telescope (see [21] for recent results)

4. Activities for the future

4.1 Plan for Large Single Dish Telescope

NRO and Japanese university groups started planning of the post-NRO 45 m/ASTE large mm/sub-mm telescope, which could be complementary to and synergetic with ALMA, SPICA (SPace Infrared telescope for Cosmology and Astrophysics), and SKA (Square Kilometer Array). A working group was recently formed to collect major science cases focused on research areas such as e.g., cosmology, galaxy formation and evolution, physics and chemistry of interstellar matter, star and planet formation.

4.2 SKA

Japan SKA consortium of researchers was established in 2008 to promote science and technologies for SKA in Japan. The SKA-Japan Workshop was held at Mitaka/NAOJ in 2010 with inviting SKA-related colleagues from Australia, Korea, South Africa, and US. Science with SKA and the future collaboration were discussed.

4.3 Small Satellite for CMB measurements

KEK (High Energy Accelerator Research Organization in Japan) group started the design study for a small satellite for measuring the B-mode polarization of the cosmic microwave background (CMB), called "LiteBIRD." The group and collaborators have been developing superconducting detectors (TES, MKID etc.) at millimeter wavelengths for LiteBIRD and ground-based telescopes for the CMB measurements such as PolarBear let by UC Berkeley. The KEK group is joining ground-based CMB projects, QUIET and PolarBear.

4.4 Antarctic THz Telescope

Tsukuba University group is planning the Antarctic THz telescope and conducting site testing using a 220 GHz tipping radiometer at the Showa Station in Antarctic.

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