

J1. Introduction

This report presents a summary of Japanese contributions, including those of international collaborations, in the field related to URSI Commission J during the last three years. It is not intended to be an exhaustive survey of all relevant works. If important contributions in some field are missing, it is due to the limited knowledge and effort of the editor. The most important progress of this field is found in ALMA project which is now operational and some scientific results have been obtained. In the following sections, projects led by National Astronomical Observatory of Japan (NAOJ) including NRO 45m, and VLBI (Mizusawa VLBI Observatory), ALMA (Chile Observatory) are shown. Most of this part is cited from “Annual Report of the National Astronomical Observatory of Japan, Volume 18.”

J2. Nobeyama Radio Observatory

(1) Scientific Studies

Nobeyama Radio Observatory are carrying out the (a) Star Formation Project, (b) Galactic Plane Survey, and (c) Nearby Galaxy Project as legacy projects with the 45-m telescope. The star formation project and the Galactic plane survey project obtained scientific data and their results are described below. Research results from open-use observations are given separately.

(a) Star Formation Legacy Project

In the Star Formation Legacy Project, we conducted largescale mapping observations toward three nearby star-forming regions, Orion A, Aquila Rift, and M17 in ^{12}CO (1-0), ^{13}CO (1-0), C^{18}O (1-0), and N_2H^+ (1-0). Many cores and clumps have been identified from structure analysis of these data. We succeeded in finding a protostellar molecular outflow in the Orion Molecular Cloud data by using existing data taken by BEARS.

(b) Galactic Plane Survey Project (FUGIN: FOREST Ultra-wide Galactic plane survey In Nobeyama)

We are conducting the highest resolution simultaneous survey to date of the ^{12}CO (1-0), ^{13}CO (1-0), and C^{18}O (1-0) emission lines in the Galactic Plane using FOREST aboard the 45-m telescope. We plan to make maps of the inner Galaxy and the outer Galaxy including the spiral arms and bar structure. In 2015, we covered areas with 46 and 28 square degrees for a total of 74 square degrees. In the last two years, 115 square

degrees have been mapped. As a result, we have revealed a wide range of molecular clouds and their fine structures and also found a new cloud-cloud collision system and an interacting region with a supernova.

(c) Nearby Galaxy Project (COMING: CO Multi-line Imaging of Nearby Galaxies)

We started COMING (CO Multi-line Imaging of Nearby Galaxies) in April 2015 to map more than 200 nearby galaxies in ^{12}CO , ^{13}CO , and C^{18}O J=1-0 emission lines using FOREST. As of now, mapping observations of more than 40 galaxies are complete. Among our samples, the precise $^{13}\text{CO}/^{12}\text{CO}$ line ratio has been obtained for a barred galaxy NGC 2903. Excitation analysis revealed that star formation efficiency is determined by molecular gas density. In addition, through comparison with archived data of CO (J=3-2), it became clear that gas content depends on the surface gas density in dwarf galaxy NGC 2976.

(2) Improvements and Developments

Maintenance of the 45-m telescope, the receiver systems, the cryogenics, etc. were performed as follows:

- The replacement of the sub-reflector servo system was completed. A plan was developed for the millimeter wave calibration drive system repairs to be conducted next year.
- Surface measurements with the holography system and surface adjustment were performed. Consequently the surface accuracy of the 45-m telescope was improved.
- Gold foil was put on the 2nd and 3rd mirrors to reduce the loss of the beam transmission system and decreasing the antenna noise temperature by about 10 K at 3 mm.
- Some parts of the new multi-pixel receiver FOREST were replaced and the gain stability and linearity were improved.
- New AD converters were installed in all the intermediate frequency lines and were used in open use observations.
- NRO supported user instruments including the Z45 receiver in the 45 GHz band, the digital spectrometer ROACH, and a 90/150 GHz continuum camera.

J3. Mizusawa VLBI Observatory

NAOJ Mizusawa VLBI Observatory operates VLBI (Very Long Baseline Interferometry) facilities such as VERA (VLBI Exploration of Radio Astrometry) and KaVA (KVN and VERA Array), and provides these unique facilities to the international user community to support the research activities at universities and research

institutes. In the meantime, astronomical research using these VLBI arrays is conducted mainly on the Galactic structure, celestial masers, AGNs and so on. Using the unique dual-beam system which is capable of phase referencing by observing two sources simultaneously, VERA conducts high accuracy astrometry of maser sources and determines the detailed structure of the Milky Way. In addition to the operation of VERA, maintenance and operation support were provided to the Yamaguchi 32-m Radio Telescope and two Ibaraki 32-m radio telescopes in collaboration with the local universities. International collaboration has been promoted particularly in the East Asia region through the joint operation of KaVA and the East Asian VLBI Network, the latter of which is a joint VLBI array between the People's Republic of China, Japan, and the Republic of Korea.

1. VERA

In FY 2015, the second part of the PASJ VERA special issue has been published as a continuation from the one in FY 2014. The FY 2015 part included 6 papers, and in total there have been 13 papers in the VERA special issues in 2014-2015. This has been the third PASJ VERA special issue after the ones in FY 2008 and FY 2011. As the results of the project observations of VERA, the parallaxes and proper motions have been reported for five galactic star-forming regions, namely, G48.99-0.30, G49.19-0.34, IRAS 20126+4104, IRAS 21379+5106, and IRAS 07427-2400. The last source is located in the Perseus spiral-arm, and together with the previously published sources associated with the arm, non-circular motion associated with the Perseus spiral-arm was successfully detected, showing systematic inward motion toward the Galactic center and lagging behind the Galactic rotation. It has been shown that the motions can be described well by a density-wave-type spiral model. This is the first result on the Galactic non-circular motion based on VERA astrometry, and thus it is one of the milestones of the Galactic structure study with VERA. Simulation studies have been performed to evaluate the expected accuracy with which future VLBI astrometry will be able to constrain the Galactic parameters. It is demonstrated that astrometric measurements for ~ 300 sources will provide accuracies of a few % for the Galactic fundamental parameters and accuracies of about 10 % for the parameters associated with the non-circular motion and asymmetric structure, such as spiral arms and/or bar. Astrometric results are also published for a late-type star U Lyn, and the data are used to calibrate the Period-Luminosity relation of Mira-type variables based on U Lyn and 8 other sources for which accurate distances have been measured so far. Other than the Galactic astrometry, astrometric observations of the core position of TeV blazar Mrk 501 have

been used to constrain the Lorentz factor of the jet, demonstrating that accurate VLBI astrometry has a wide range of possible applications other than Galactic structure studies.

2. JVN (Japanese VLBI Network)

The Japanese VLBI Network (JVN) is operated as a joint research project of NAOJ and seven universities. JVN consists of VERA and radio telescopes operated by universities and research institutes such as ISAS/JAXA, NICT, and GSI. VLBI observations by JVN were done for 250 hours at 3 bands of 6.7, 8, and 22 GHz in FY 2015. Single Dish Observations related to JVN were also done about 2000 hours at each telescope. The major research topics are AGNs, masers, and star forming regions. The main subjects of research are active galactic nuclei and masers in star-forming regions. Scientific results obtained with JVN were published as four papers, while ten more papers reported JVN related scientific studies. Fujinaga et al. (2016) reported the results of a gamma-ray-emitting-AGN survey through high-sensitivity VLBI observations. Sugiyama et al. (2016) reported the first results of internal motion in a 6.7 GHz methanol maser source obtained by EAVN (East-Asian VLBI Network) including JVN. Yonekura et al. (2016) reported on the telescope and observing system of Ibaraki station. Nine papers including the above four will be published as a special issue of PASJ in FY 2016. Education is also one of the main aims of university collaboration in VLBI. Twenty-nine students conducted undergraduate studies using JVN and related research activities. Sixteen master-course students completed their master's theses using JVN, and two Ph.D. students finished their theses using JVN. Many university students made presentations and talks in research meetings related to JVN.

3. Japan-Korea Joint VLBI (KaVA)

Following the successful opening of KaVA common-use observations and the first publications of KaVA papers in FY 2014, the science productivity of KaVA is growing satisfactorily with the stable array operation throughout FY 2015. As for AGN science, the detailed motions of relativistic jets are now regularly monitored for a number of sources; three refereed papers were published on several bright blazars including 3C345 during FY 2015. Moreover, our KaVA monitoring of the M87 jet made the first discovery of a superluminal motion near the black hole. The talk on this result was selected for a press release at the ASJ meeting in March 2016 and was picked up by many media outlets, returning scientific results from KaVA to the broad general public. Another refereed paper reporting a detailed imaging of SiO masers around the late-type star WX

Psc was also accepted. The KaVA Large Program has finally started from late FY 2015, which aims at performing ambitious, high-scientific impact studies with KaVA by spending a large amount (typically more than 100 hours per year) of the machine time. Currently three large programs are ongoing, each of which is led by one of the three KaVA science working groups (AGN, star-forming regions, and late-type stars). Not only researchers in NAOJ/KASI but also many external researchers (universities in Japan/Korea, Australia, Italy, etc.) are joining these projects. Scientific outcomes based on these programs will be expected to emerge from the next year.

4. East-Asian VLBI Network (EAVN)

Aiming at expanding the capability of international VLBI over East Asia, the development of the East-Asian VLBI Network (EAVN) is currently underway as a collaboration between Japan, South Korea, and China. Technical assessment of the array and test observations are promoted by the Japan-Korea-China joint task force (the so-called Tiger Team), and in FY 2015 a report summarizing the successful detections of fringes over the last few years was published in the proceedings of an international conference (Wajima et al. 2015). Following this success, in FY 2015 further test observations were conducted to evaluate the imaging performance of the EAVN array at 8, 22, and 43 GHz. Detailed reports of these data will appear next year. Meanwhile, recently there is a growing discussion toward the future construction of a new VLBI facility in Thailand (Thailand VLBI Network; TVN). In these circumstances, in FY 2015 a KaVA science workshop was held in Thailand in collaboration with local astronomers, and discussed the possibility and potential impact of the future extension of TVN by joining the EAVN. In FY 2015 the annual EAVN workshop was held at Hokkaido University, and the next meeting in FY 2016 will take place in China.

5. System Development

In 2015, the magnetic tape recorders were replaced with new hard disk drive recorders, and the Mitaka FX correlator was also replaced with a newly developed software correlator. The software correlator is located at Mizusawa Campus and is now in regular operation. The modifications to the KJCC (Korea Japan Correlation Center) system were done based on the feedback from scientific evaluation of the KaVA observations. Discussions on future development have been done in particular toward high frequency VLBI and SKA as future extensions of VLBI activities. Basic design and development were done including a low power consumption optical transmitter, ultrawideband A/D convertors, high accuracy surface reflectors, and balloon-borne radio

interferometry.

J4. Chile Observatory

The ALMA Project is a global partnership of East Asia (led by Japan), Europe, and North America (led by the United States) in cooperation with other nations to construct and operate a gigantic millimeter/submillimeter radio telescope deploying 66 high-precision parabolic antennas in the 5000-m altitude Atacama highlands in northern Chile. ALMA aims to achieve a spatial resolution nearly ten times higher than that of the Subaru Telescope or the Hubble Space Telescope. Early scientific observations with ALMA began in FY 2011 with a limited number of antennas and full operation commenced in FY 2012. This report describes the progress of the ALMA project, which includes the results of the open-use scientific observations and public outreach activities. The ASTE telescope is a single-dish 10-m submillimeter telescope located in the Atacama highlands. It has been operated to make headway into submillimeter observations toward the ALMA Era. This report also describes the progress of the ASTE telescope.

1. ALMA Project Progress

Along with scientific observations, ALMA commissioning observations have been underway, including polarization tests and solar observation tests. NAOJ staff members played leading roles in the polarization tests and solar observation tests. As demonstrated by Koichiro Nakanishi and Hiroshi Nagai for polarization, and Masumi Shimojo for solar observation tests, East Asian researchers have been taking the initiative in the international teams. Also Band 10 receivers, the highest observing frequency band, became available for scientific operations starting from the fourth round of open-use observations of ALMA (Cycle 3) which started in FY 2015. The sub-components developed by Japan, such as the antennas, correlators, and receivers (Bands 4, 8, and 10), are working properly for the operations.

2. ALMA Open-Use and Scientific Observations

The fourth round of open-use observations of ALMA commenced in October 2015 as Cycle 3. The Cycle 3 main capabilities include: interferometric observations using thirtysix 12-m parabolic antennas; Atacama Compact Array (ACA) observations (interferometric observation with ten 7-m antennas and single-dish observations with two 12-m antennas); seven frequency bands (Bands 3, 4, 6, 7, 8, 9, and newly-added Band 10); maximum baselines greatly extended from 1.5 km to 10 km (for Bands 3 to 6),

5 km (for Band 7) and 2 km (for Band 8 to 10); and polarization for continuum observations. In response to the Cycle 3 call for proposals, 1578 observation proposals were submitted from all over the world. This figure exceeded the world's highest number of proposals ever recorded, which was submitted to the Hubble Space Telescope. Such a high submission rate to ALMA shows high expectations for “the global telescope ALMA” with the potential to contribute to a wide-range of fields such as galaxy formation, star and planet formation, the Solar System, astrobiology, and interstellar chemistry. An open call for the fifth round of open-use observations was issued as Cycle 4. The anticipated capabilities of Cycle 4 include: interferometric observations using forty 12-m antennas; ACA observations (interferometric observation with ten 7-m antennas and single-dish observations with three 12-m antennas); seven frequency bands (Bands 3, 4, 6, 7, 8, 9, and 10), maximum baselines of 12.6 km (for Bands 3 to 6), 6.8 km (for Band 7), and 3.7 km (for Bands 8 to 10). Cycle 4 also provides new opportunities for large programs that require long observations exceeding 50 hours; millimeter-wavelength VLBI observations; ACA stand-alone mode; solar observations; and polarization for spectral line and continuum observations. The public call for Cycle 4 proposals is set to close at 00:00 JST on April 22, 2016. Cycle 4 is scheduled to start in October 2016. Open use of ALMA has already produced a number of scientific achievements. This section describes some of them, focusing mainly on East Asian projects. A research group led by Yoichi Tamura at the University of Tokyo found several dust clouds with a size of 500 light-years distributed inside SDP.81 through detailed analyses of the image of the gravitationally lensed galaxy SDP.81 captured by high-resolution observations with ALMA and comparison of this image to its gravitational lens model. The results of their study also indicate the existence of a supermassive black hole over 300 million times more massive than the Sun at the center of the foreground galaxy. A research group led by Kyoko Onishi at SOKENDAI (The Graduate University for Advanced Studies) observed the barred spiral galaxy NGC 1097 with ALMA and through a detailed study on the kinematics of molecular gas at the center of the galaxy found that this galaxy harbors a supermassive black hole 140 million times more massive than the Sun. This research result is based on the ALMA observation data obtained within a two-hour observation, which demonstrates the outstanding capability of ALMA in the mass measurement of supermassive black holes. A research team led by Hideki Umehata successfully captured a cluster of nine starburst galaxies in a cluster of young galaxies 11.5 billion light years away from the Earth (at the center of a “proto-Great Wall” known as the largest structure in the Universe). This result supports the idea that the proto-Great Wall is the matrix that

supports the formation of galaxies. This could lead to unveiling the formation process of starburst galaxies and their subsequent evolutionary process. A research team led by Yusuke Aso at the University of Tokyo and Nagayoshi Ohashi at NAOJ observed a proto-star called TMC-1A and revealed the movements of the inner rotating gas disk around the proto-star and the outer gas envelope with the highest accuracy ever achieved. The high-sensitivity observations with ALMA made it possible to directly observe the boundary between the disk surrounding the proto-star and the outer infalling gas envelope. These results are very important in finding out when the proto-planetary disk appears in the process of star formation and how it evolves.

3. ASTE Telescope

The ASTE telescope has been operated to promote fullfledged submillimeter astronomical research in the southern hemisphere and to develop/verify observational equipment and methods. With the ALMA telescope entering its operation phase in FY 2012, ASTE will be engaged mainly to provide observational evidence for strengthening ALMA observation proposals and to pursue development for enhancing ALMA's future performance. Other than ALMA, there are only two large-scale submillimeter telescopes with a 10-m-class antenna that can observe the southern sky in the world: one is ASTE and the other is APEX operated by ESO. Therefore, having ASTE operated by Japan will be a big advantage in strengthening ALMA proposals and in implementing our strategies for further extending the capabilities of observing equipment. Looking to the future, ASTE is also important since it provides opportunities for nurturing young researchers who will play key roles in the equipment development for the next generation. In the near future, ASTE will be incorporated into the open-use program to have organic collaboration with the Nobeyama 45-m Radio Telescope. Three public calls were made in FY 2015 for open-use observation proposals: the first call (2015a) for spectroscopic observations in 345 and 460 GHz bands was from June to September, the second call (2015b) and an additional call for spectroscopic observations only in the 345 GHz band (2015c) from October to December. To render support for researchers contributing to enhancing the observational performance of ASTE, the Guaranteed Time Observation (GTO) scheme has been offered since FY 2013. This allows them exclusively to make proposals for the GTO slots. A total of 53 proposals for open-use observations and GTO slots had been made including 25 for open use and one for GTO in the first call; 12 for open use in the second call; and 15 for open use in the additional call. These proposals were reviewed by the NAOJ Chile Observatory program subcommittee and 41 proposals were subsequently adopted, including 22 for open use

and one for GTO in the first call; 11 for open use in the second call; and seven in the additional call. Open-use observations were carried out from the ASTE Mitaka operation room, other universities or research institutes between June 8 and December 18, 2015.

J5. Division of Radio Astronomy

The Division of Radio Astronomy oversees Nobeyama Radio Observatory, Mizusawa VLBI Observatory, the RISE Lunar Exploration Project, and NAOJ Chile Observatory operating the Atacama Large Millimeter/submillimeter Array (ALMA) and Atacama Submillimeter Telescope Experiment (ASTE). The scientists and engineers of these projects are attached to the Division of Radio Astronomy, which promotes radio astronomy research to harmonize these radio astronomy projects. The research themes of the Division of Radio Astronomy are represented by keywords such as Big Bang, early Universe, galaxy formation, black holes, galactic dynamics, star formation, planetary system formation, planets and satellites, the Moon, the evolution of interstellar matter, and the origin of life in the context of the evolution of the Universe. Radio astronomy unravels mysteries and phenomena in the Universe through radio waves, which are invisible to human eyes. The detailed research results are reported in each project's section and in the research highlights. The Radio Astronomy Frequency Subcommittee has been established within the division, engaging in discussions on protection against artificial interference generated by electrical equipment, which causes major obstacles in radio astronomical observations.

The mission of the Radio Astronomy Frequency Subcommittee is to protect the environment for radio astronomy observations. In 1932, Karl Jansky of the U.S.A. first discovered radio waves emitted by astronomical objects, albeit accidentally. Since then, dramatic advances have been made in radio observation methods, showing us new perspectives of the Universe invisible at the optical spectrum. The fact is that four Nobel Prizes have been awarded to achievements made in the field of radio astronomy. Just as light pollution from artificial light sources is an obstacle in optical observation, artificial radio interference generated by the electronic devices which surround us is a major obstacle in radio observations. Breathtaking advancement has been achieved in wireless communication technologies in recent years, and wireless commercial products such as mobile phones, wireless LANs, and automotive radars are widely used. The areas of radio applications will further expand in the future owing to its ubiquitous nature. But because of its unique capabilities, compatibility among various radio services, including both active and passive ones, will become a serious issue. Frequency

is a finite resource and its sharing is an unavoidable issue. Therefore, further efforts will be necessary for maintaining the sky free from artificial interference for better radio astronomy observations.

Radio Astronomy Frequency Subcommittee is to ensure that radio astronomical observations are free from artificial interference and to raise public awareness of the importance of the protection activities. Radio astronomical observation does not emit radio waves; thus, it does not interfere with other wireless communications. A proactive approach is needed to widely raise awareness of the efforts to protect the environment for radio observations. Regular explanatory sessions are provided at the Ministry of Internal Affairs and Communications (MIC) and regional Bureaus of Telecommunications to solicit appreciation of the importance of protecting the field. The coordination between the community of radio astronomy and commercial wireless operators is led by the MIC within Japan and internationally by the International Telecommunication Union (ITU) Radiocommunication Sector (ITU-R) of the United Nations. As part of the activities for FY 2015 the Subcommittee took an active role in formulating the opinion of the Japanese radio astronomical community (on behalf of the Japanese radio astronomers) in these coordination efforts. The Subcommittee is composed of members from NAOJ and representatives of universities and research institutes in Japan.

J6. Hokkaido University

The radio astronomy research group of Hokkaido University is led by Associate Professor Kazuo Sorai. They use their own Tomakomai 11m radio telescope and Nobeyama 45m radio telescope for the study of Galactic plane survey and the dynamics of the extra galaxies with molecular lines.

J7. Ibaraki University

The radio astronomy research group of Hokkaido University is led by Professor Munetake Momose and Associate Professor Yoshinori Yonekura. They use Nobeyama 45m radio telescope, ALMA for the study of star formation with molecular lines. Moreover, two 32-m radio telescope (Hitachi and Takahagi) are operated by the group under collaboration with NAOJ. These telescopes are used as elements of the Japanese VLBI Network, and single telescope for methanol and water maser observations.

J8. Tsukuba University

The radio astronomy research group of Tsukuba University is led by Professor

Naomasa Nakai. They use Nobeyama 45m radio telescope for the study of galaxies and active galactic nuclei (AGNs). Tsukuba 32-m antenna for geodetic VLBI owned by the Geospatial Information Authority of Japan (GSI) is used by Tsukuba group as a radio telescope.

J9. Institute for Astronomy of the University of Tokyo

The radio astronomy research group of Institute for Astronomy of the University of Tokyo is led by Professor Kotaro Kohno. They use ASTE 10m radio telescope and ALMA for the study of Highest redshift (sub)millimeter galaxies.

J10. Astro-Chemistry

Professor Satoshi Yamamoto leads the Astro-Chemistry Group in the University of Tokyo. Their research subjects are: Submillimeter-wave and Terahertz Astronomy, Chemical Evolution of Interstellar Molecular Clouds, Star and Planet Formation, Development of Terahertz Detectors.

J11. Nagoya University

The radio astronomy research group of Nagoya University is led by Professor Yasuo Fukui. They use their own NANTEN2 telescope located in the Atacama plateau in Northern Chile, Nobeyama 45m radio telescope, and ALMA for the study of interstellar matter and star formation.

J12. Osaka Prefecture University

The radio astronomy research group of Osaka Prefecture University is led by Professor Hideo Ogawa, Kazutoshi Ohnishi, and Hiroyuki Maezawa. They use their own 1.85m telescope and SPART 10m telescope at Nobeyama, and Small telescopes in the Campus of Osaka Prefecture. Their research has wide variety, such as development of radio astronomical observation system, molecular clouds and star formation, and planetary atmosphere.

J13. Yamaguchi University

The radio astronomy research group of Yamaguchi University is led by Professor Kenta Fujisawa. They use Yamaguchi 32-m radio telescope under collaboration with NAOJ. Their research focuses on star formation with masers, active galactic nuclei. Yamaguchi University leads the Japanese VLBI Network.

J14. Kagoshima University

The radio astronomy research group of Kagoshima University is led by Professor Toshihiro Omodaka and Toshihiro Handa. They use one telescope of the VERA network, Iriki 20-m, under collaboration with NAOJ. Their research focuses on the galactic dynamics, star formation, evolved stars. They lead the SKA Japan consortium. Square Kilometer Array (SKA) is the world largest radio telescope project planning to construct large interferometers in the decade of 2020.

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