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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 ALMA, NRO 45m, and VLBI are shown. Then, research activities of Universities in Japan are described by the order of north to south.

J2. Atacama Large Millimeter/submillimeter Array (ALMA)

One of most important activities in Japanese radio astronomy is ALMA project. ALMA, an international partnership of Europe, North America and East Asia in cooperation with the Republic of Chile, is the largest astronomical project in existence. ALMA will be a single telescope of revolutionary design, composed initially of 66 high precision antennas located on the Chajnantor plateau, 5000 meters altitude in northern Chile. Japan has constructed ACA (Atacama Compact Array), which consists of four 12-m telescopes and twelve 7-m telescopes, and 3 band receiver cartridges for whole ALMA telescopes. The construction of ALMA is succeeding and scientific observations have been started. The common-use observation has been started in 2011. Call for Proposal for "Cycle 2" observation was announced and 1381 proposals were submitted in December 2013.

ALMA will have the following capabilities for the Cycle 2 phase (cited from the executive summary of the Proposer's Guide): thirty-four 12-m antennas for interferometric observations, the Atacama Compact Array (ACA, aka Morita Array) composed of nine 7-m antennas for interferometric observations (7-m Array) and two 12-m antennas for single-dish observations (Total Power Array), receiver bands 3, 4, 6, 7, 8 and 9 (wavelengths of about 3.1, 2.1, 1.3, 0.87, 0.74 and 0.44 mm), array configurations with maximum baselines ranging from ~160 m to ~1.5 km (~1 km for Bands 8 and 9), single-field imaging and mosaics of up to 150 pointings, polarization capabilities, and a set of correlator modes that will allow both continuum and spectral line observations simultaneously. Solar observations will not be available in Cycle 2. Projects requiring detection of extended emission should consider requesting ACA observations.

J3. Nobeyama 45m radio telescope and Atacama Submillimeter Telescope Experiment (ASTE)

The key roles of the Nobeyama Radio Observatory has been the further promotion of millimeter and submillimeter astronomy toward ALMA-era. For that purpose, the open use of NRO 45-m telescope and ASTE have been continued as well as performing legacy (see below) /key science projects with the best use of synergy by the complementary telescopes, the 45-m telescope and ASTE. In addition, the upgrade of existing instruments and the developments of new instruments have been done for performing cutting edge science as much as possible towards the ALMA era; e.g., the development of new receiver and spectrometer for the 45-m telescope.

Four “Legacy” projects with NRO 45m are running:

1. CO Galactic Plane Survey (PI: N. Kuno (NRO))
2. Star Formation Project (PI: F. Nakamura (NAOJ))
3. CO Multi-line Imaging of Nearby Galaxies (COMING) (PI: SORAI, Kazuo (Hokkaido University))
4. High-z Legacy Survey (PI: D. Iono, B. Hatsukade (NAOJ))

J4. Very Long Baseline Interferometry (VLBI)

Mizusawa VLBI observatory is carrying out VLBI Exploration of Radio Astrometry (VERA) project and the Japanese VLBI network project. VERA project aims to make the 3-D map of the galaxy and reveal the kinematic field of the Galaxy by precise astrometric observation. Scientific result including the estimation of the new Galactic parameters have been reported. A new VLBI correlator has been developed under the collaboration with NAOJ and Korean Astronomy and Space Science Institute (KASI), which will be used for the East Asian VLBI network observations. Some test observations were performed so far.

Mizusawa VERA observatory also organizes the Japanese VLBI network, which has 11 VLBI stations including VERA operated at 6, 8 and 22 GHz. The collaborating universities are; Hokkaido University, Tsukuba University, Ibaraki University, Gifu University, Osaka Prefecture University, Yamaguchi University and Kagoshima University. Also Institute of Space and Astronautical Science, Geographical Survey Institute, and National Institute of information and Communication Technology have joined to Japanese VLBI network.

A Space VLBI project (VSOP-2), in which a space radio telescope is used as a VLBI station, led by ISAS/JAXA was terminated due to some difficulties of development of the 9-m deployable radio telescope.

J5. 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. One of the results of this group is Sorai et al. (2012, PASJ, 64, 51) entitled "Properties of Molecular Gas in the Bar of Maffei 2". The abstract is quoted below.

> We investigated the physical properties of molecular gas in one of the nearest barred spiral galaxies, Maffei 2, using the 12CO (J = 1-0) emission line taken for the Nobeyama CO Atlas of Nearby Spiral Galaxies. Position-velocity diagrams perpendicular to the apparent major axis of the bar show an abrupt velocity change across the bar, which is caused by molecular gas motion of ~100 km s^{-1} along the leading edges of the bar. The distribution of the peak temperature (Tpeak), velocity width (DeltaV), and integrated intensity of the 12CO spectra (ICO) in the ridges of the bar is quite different from that in the spiral arms in Tpeak-DeltaV-ICO space, suggesting that molecular-gas properties are different in these regions. Simple model calculations assuming an ensemble of uniform and spherical molecular clouds in a large velocity-gradient approximation indicate that molecular gas in the bar ridge regions may be gravitationally unbound, which suggests that molecular gas is hard to become dense, and to form stars. Moreover, the gravitationally unbound condition makes the CO-to-H2 conversion factor in the bar ridges smaller than in the arms. A lower star-formation efficiency in bars indicated by previous studies is caused by such a condition that molecular gas is gravitationally unbound, as well as by an overestimation of molecular gas mass in the bar regions relative to spiral arms using a constant CO-to-H2 conversion factor.

J6. Ibaraki University

The radio astronomy research group of Hokkaido University is led by Professor Munetake Momose. 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. One of the results of this group is Akiyama (2013, PASJ, 65, 123) entitled “An Observational Study of the Temperature and Surface Density Structures of a Typical Full Disk around MWC 480”. The abstract is quoted below.

> This paper presents observations of a protoplanetary disk around a Herbig Ae star, MWC 480, in 12CO (J = 1-0), 12CO (J = 3-2), 13CO (J = 1-0), and C18O (J = 1-0) emission lines. Double-peaked emission profiles originating from the rotating circumstellar disk were detected in all of the lines. The vertical temperature and radial surface density structures of the outer region of the disk were derived by applying the similarity solution in the standard accretion disk model. Taking advantage of differences in the height of the photosphere among the CO lines, the temperature in the uppermost 12CO (J = 3-2) emitting layer was shown to be about 3-times higher than that of any other CO emitting region, suggesting that there are at least two distinct temperature regions. Our modeling succeeds in describing all of the observational results obtained in the four CO lines, particularly different emission extents at different frequencies, by a single set of the parameters for a disk model. Since the similarity solution model could be the most suitable for the radial surface density structure, it is likely that the disk around MWC 480 evolves by transferring angular momentum outward via viscous diffusion. Although further quantitative studies are required for identifying what disk model is the best for describing physical disk structures, our results suggest the potential advantage of the similarity solution model, indicating that disks around Herbig Ae/Be stars likely have diffused gas in the outer regions, and that the disk surface density exponentially decreases with increasing radial distance.

J7. 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. One of the results of this group is Salak et al. (2013, PASJ, 65, 66) entitled "Large-Field CO(J = 1-->0) Observations of the Starburst Galaxy M 82". The abstract is quoted below.

> We present large-field (15.7 × 16.9 arcmin2) CO(J = 1-->0) observations of the starburst galaxy M 82, at an angular resolution of 22" with the NRO 45-m telescope. The CO emission was detected in the galactic disk, outflow (driven by the galactic wind) up to ~2 kpc above the galactic plane in the halo, and in tidal streams. The kinematics of the outflow (including CO line splitting) suggests that it has the shape of a cylinder that is diverging outwards. The mass and kinetic energy of the molecular gas outflow are estimated to be (0.26-1.0) × 109 Msun; and (1-4) × 10^{56} erg. A clump of CO gas was discovered 3.5 kpc above the galactic plane; it coincides with a dark lane previously found in X-ray observations, and a peak in H I emission. A comparison with H I, hot molecular hydrogen and dust suggests that the molecular gas shows signatures of warm and cool components in the outflow and tidal streams, respectively.

J8. 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. One of the results of this group is Hatsukade et al. (2011, MNRAS, 411, 102) entitled "AzTEC/ASTE 1.1-mm survey of the AKARI Deep Field South: source catalogue and number counts". The abstract is quoted below.

> We present results of a 1.1-mm deep survey of the AKARI Deep Field South (ADF-S) with AzTEC mounted on the Atacama Submillimetre Telescope Experiment (ASTE).We obtained a map of 0.25-deg^2 area with an rms noise level of 0.32 - 0.71 mJy. This is one of the deepest and widest maps thus far at millimetre and submillimetre wavelengths. We uncovered 198 sources with a significance of 3.5σ - 15.6σ, providing the largest catalogue of 1.1-mm sources in a contiguous region. Most of the sources are not detected in the far-infrared bands of the AKARI satellite, suggesting that they are mostly at z = 1.5 given the detection limits. We constructed differential and cumulative number counts in the ADF-S, the Subaru/XMM Newton Deep Field and the SSA 22 field surveyed by AzTEC/ASTE, which provide currently the tightest constraints on the faint end. The integration of the best-fitting number counts in the ADF-S

finds that the contribution of 1.1-mm sources with fluxes of ~1 mJy to the cosmic infrared background (CIB) at 1.1 mm is 12 - 16 per cent, suggesting that the large fraction of the CIB originates from faint sources of which the number counts are not yet constrained. We estimate the cosmic star formation rate density contributed by 1.1-mm sources with ~1 mJy using the best-fitting number counts in the ADF-S and find that it is lower by about a factor of 5 - 10 compared to those derived from UV/optically selected galaxies at z = 2 - 3. The fraction of stellar mass of the present-day universe produced by 1.1-mm sources with ~1 mJy at z = 1 is ~20 per cent, calculated by the time integration of the star formation rate density. If we consider the recycled fraction of >0.4, which is the fraction of materials forming stars returned to the interstellar medium, the fraction of stellar mass produced by 1.1-mm sources decreases to 10 per cent.

J9. 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. The introduction of their research cited from the web site is shown below.

Molecular clouds are birthplaces of new stars and planetary systems, which are being studied extensively as an important target of astronomy and astrophysics. Although the main constituent of molecular clouds is a hydrogen molecule, various atoms and molecules also exist as minor components. The chemical composition of these minor species reflects formation and evolution of molecular clouds as well as star formation processes. It therefore tells us how a particular star has been formed. We are studying star formation processes from such a unique viewpoint.

Since the temperature of molecular cloud is as low as 10 K, only way to observe its physical structure and chemical composition is to observe the radio wave emitted from atoms and molecules. In particular, there exist a number of atomic and molecular lines in the millimeter to terahertz region, and we are observing them with various radio telescopes such as Nobeyama 45 m telescope and IRAM 30 m telescope.

We have recently established a new chemistry occurring in the vicinity of a newly born star, which is called Warm Carbon Chain Chemistry (WCCC). We have found high abundances of various carbon-chain molecules in a lukewarm region near the protostar in

L1527. This is very surprising, because carbon-chain molecules are known to exist in the early stages of cold starless cores. In WCCC, carbon-chain molecules are produced by gas phase reactions of CH_4 which is evaporated from ice mantles. Existence of WCCC clearly indicates a chemical variety of low-mass star forming regions, which would probably reflect a variety of star formation.

In parallel to such observational studies, we are developing a hot electron bolometer mixer (HEB mixer) for the future terahertz astronomy. We are fabricating the diffusion cooled HEB mixer using Nb and the phonon cooling HEB mixer using NbTiN in our laboratory. Our NbTiN mixer shows the noise temperature of 500 K at 800 GHz, which is well comparable to the results reported by other groups. We are also studying bath-temperature dependence of the noise temperature in order to explore the mixing mechanism of the HEB mixer.

J10. 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. Recent significant results are such as "High-mass star formation induced by cloud-cloud collision" or "Gamma-ray emission from Super Nova remnant and the interstellar matter". One of the results of this group is Fukui et al. (2012, ApJ, 746, 82) entitled "A Detailed Study of the Molecular and Atomic Gas toward the gamma-Ray Supernova Remnant RX J1713.7-3946: Spatial TeV gamma-Ray and Interstellar Medium Gas Correspondence". The abstract is quoted below.

RX J1713.7-3946 is the most remarkable TeV gamma-ray supernova remnant (SNR) that emits gamma-rays in the highest energy range. We have made a new combined analysis of CO and H I in the SNR and derived the total protons in the interstellar medium (ISM). We have found that the inclusion of the H I gas provides a significantly better spatial match between the TeV gamma-rays and ISM protons than the H_2 gas alone. In particular, the southeastern rim of the gamma-ray shell has a counterpart only in the H I. The finding shows that the ISM proton distribution is consistent with the hadronic scenario that cosmic-ray (CR) protons react with ISM protons to produce the gamma-rays. This provides another step forward for the hadronic origin of the gamma-rays by offering one of the necessary conditions missing in the previous hadronic interpretations. We argue that the highly inhomogeneous distribution of the ISM protons is crucial in the origin of the gamma-rays. Most of the neutral gas was likely swept up by the stellar wind of an OB star prior to the supernova (SN) explosion to form a low-density cavity and a swept-up dense wall. The cavity explains the low-density site where the diffusive shock acceleration of charged particles takes place with suppressed thermal X-rays, whereas the CR protons can reach the target protons in the wall to produce the gamma-rays. The present finding allows us to estimate the total CR proton energy to be $\sim 10^{48}$ erg, 0.1% of the total energy of the SN explosion.

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