Report of Committee to Evaluate Research and Academic Activities of the Division of Radio Astronomy of the National Astronomical Observatory of Japan

March 26, 2008

Summary

The committee to evaluate the radio astronomy research activities of the NAOJ has visited the Nobeyama and Mizusawa Observatories and considered presentations and material provided for the five radio astronomy projects: NRO, VERA, RISE, VSOP, and ALMA, as well as the radio astronomy division. Japan has a proud record of world class achievements in radio astronomy and the committee was impressed to see this record maintained with a number of truly exceptional achievements. There is an impressive new CO image of M51 using a combination of NRO and CARMA observations, ASTE results on high redshift sub-millimeter galaxies, parallax measurements with the innovative dual beam VERA telescope array, and an astounding gravity map of the far side of the moon. Planning and engineering developments include the approval of the VSOP-2 mission and the on-schedule delivery of the first three ALMA-J antennas.

The committee makes a number of general recommendations in relation to the research of the radio astronomy groups in NAOJ. We see greater opportunities to take advantage of technology transfer to industry and a need to increase the international take-up of Japanese technology. A recurring theme is the lack of funding for sufficient researchers to realise the full scientific potential of its investments and in these cases there may be an advantage in more collaborative research. Finally, we applaud NAOJ for its management of projects through research and development to construction and then operational phases but we note that a new long term project plan is now needed.

1 Introduction

Radio Astronomy is a very significant part of the NAOJ research activities. It is also an area in which Japan has a long history and had established a high international profile. Japan is well known for its leading role in: solar radio astronomy; millimetre radio astronomy and, in particular, millimetre interferometry; and for its involvement in VLBI, culminating in the first major VLBI space mission (VSOP) in 1997.

Radio waves are generated by a very diverse range of astrophysical processes ranging from high energy particles to thermal emission from cold clouds in the interstellar medium. Radio waves can be seen from even heavily obscured regions of dense star formation or from deep inside the nuclei of galaxies. Interferometric techniques at radio wavelengths provide the highest angular resolution astronomical observations currently possible.

Radio astronomy uses a common technique but covers a very broad range of science. Research at NAOJ goes from the moon to the large scale structure of the universe. This makes it difficult for a small committee such as ours to provide useful feedback on all the different areas of research. Instead of the detailed feedback requested on each self evaluation we prefer to give more general comments. This will still include specific comments on some of the exceptional achievements. Although the committee didn't disagree with any specific self evaluation, we did see some "calibration" differences between the different groups and we avoid this by treating all groups in the same general way in our report.

We suggest that this form of the report may be of more value to NAOJ than the detailed comments on self evaluation requested.

The Review Committee members were:
Ron Ekers (chair) (Federation Fellow, Australia Telescope National Facility, CSIRO)
Philip Diamond (Director, Jodrell Bank Centre for Astrophysics, University of Manchester)
Karl M. Menten (Executive Director, Max-Planck-Institut fur Radioastronomie)
Nobuyoshi Fugono (Advanced Telecommunications Research Institute International)
Masaru Kono (Global Edge Institute, Tokyo Institute of Technology)

On Feb 18 & 19 Ron Ekers visited Nobeyama Radio Observatory. On Feb 20 Karl Menten visited Nobeyama and Ron Ekers and Nobuyoshi Fugano visited Mizusawa. Committee members who visited Nobeyama and Mizusawa had adequate time to talk informally to staff and students. On Feb 21 at Mitaka we had a day of well prepared formal presentations with adequate time for discussion. During the morning of Feb 22 we requested an additional presentation on technical developments. Unfortunately, there was no time to talk informally to the staff or students at Mitaka. The committee met in closed session for the remainder of the second day and agreed on the report structure and general conclusions. The final report has been prepared with e-mail exchanges and contributions from the committee members.

The committee expresses its appreciation for the high quality material provided and for the organization of the visit which included the logistically demanding visits to the key observatory sites.

2 Evaluation

2.1 Nobeyama Radio Observatory

Serious radio astronomy in Japan started in Nobeyama. Since its establishment Nobeyama has performed pioneering roles in many areas of radio astronomy by producing excellent results and creating advanced key technologies, many of which have contributed to new research and projects such as VERA, ASTE and ALMA. We expect that Nobeyama can continue to be the nursery of radio astronomy into the future. As the Mecca of radio astronomy in Japan, it is fully agreeable and appropriate that Open Use and Education & Public Outreach are included in the major activities to give further importance in the future role of Nobeyama.

2.1.1 45m millimetre Telescope

When the Nobeyama 45m telescope came into operation in the early 1980s, it was the first "large" millimetre wavelength telescope. Its then innovative instrumentation (wideband HEMT receivers and wideband acousto-optical spectrometers) put it also ahead of large centimetre telescopes. Because of this powerful combination impressive results could be obtained, two of which may be singled out. The comprehensive spectral line survey of the 8–50 GHz frequency range toward the Taurus Molecular Cloud-1 resulted in the discoveries of a total of 11 new interstellar molecules. These were published from the late 1980s on, while the complete survey was published in 2004 (Kaifu et al. 2004). Second, the discovery of maser emission with extremely high velocities in the nucleus of the active galaxy NGC4258 by Nakai et al (1993), which was later shown to arise from the accretion disk around the central black hole. This was the first unequivocal evidence for a super-massive black hole in the nucleus of a galaxy and this observation opened a whole new era of AGN studies and will lead to high accuracy measurements of the Hubble constant.

The 45m telescope continues to produce important results: employing the 25-BEam Array Receiver System (BEARS) multi-beam receiver with the new on-the-fly mapping method a large number of nearby galaxies as well as galactic star-forming regions have been imaged. In particular, the imaging of the whole of the large spiral galaxy M51 in the 1-0 line of CO is most impressive and was greatly enhanced by the combination with data from the CARMA array, made possible by a strategically placed postdoc, J. Koda, at Caltech (Koda et al 2008).

The three legacy projects which have been developed as part of the strategy for the transition to the ALMA era promise a fruitful scientific return and are well tailored to the expertise of the scientists heading them and to the available instruments. A large-scale survey of M33 seems to be well underway.

The committee also wants to point out the fundamental data on 43 GHz SiO maser emission obtained by S. Deguchi and collaborators over the past 15 years. These NRO observations resulted in the detection of well over a thousand sources, representing a most important database that can be utilized for kinematical studies of the Milky Way (e.g. Deguchi et al, 2000, Deguchi et al, 2004, and many more). There is a tremendous potential of synergy between Dr. Deguchi and the VERA team that seems to be waiting to be exploited, for example in identifying the most interesting targets for VERA.

2.1.2 Future of the NRO 45m telescope

The NRO 45m telescope will continue to play an important role in millimetre astronomy. Its powerful array receivers will provide zero-spacing information for ALMA projects which observe large-scale structure in the 3 (and maybe the 2) mm window(s) and it will be a most important ground-based element of VLBI arrays involving VSOP-2. The 45m telescope also serves as an excellent resource for the training of students in mm-wave and radio astronomy; this is an essential activity that must continue for Japan to obtain the scientific return on its substantial investment in ALMA. To guarantee efficient future operation, however, major investments must be made: foremost here is refurbishment of the 45m telescope. Failing to do so will cause irreversible damage to its structure. Furthermore, given the importance of array receivers, the old AOS back ends should be replaced by digital spectrometers in due course and the upgrades to a new generation of 2SB SIS mixer front-ends should be continued. The committee noted and endorses the ongoing interaction with the ALMA technology development group as future instrumentation is developed for the 45m.

2.1.3 Nobeyama Millimetre Array (NMA)

The NMA has been in the forefront of mm array development for many decades and has been the key for training generations of Japanese astronomers with mm interferometry expertise. When ALMA comes into operation it will far exceed the capability of the NMA so the difficult decision which has been taken to close the NMA for general use and divert the operating budget and staff to ALMA is endorsed by the committee. The gap between the closing of NMA and the start of ALMA operations is unfortunate but is outside the control of NAOJ. The committee is satisfied that these issues have been carefully considered and that NAOJ is well aware that it will be important to evolve new ways of training young scientists who will be the future users of ALMA.

2.1.4 ASTE

The Atacama Submillimetre Telescope Experiment (ASTE) is a 10m dish operating with good efficiency at 270/345 GHz on the superb ALMA site in Chile. has had a successful start demonstrating is capabilities in eight articles of a special issue of the Publications of the Astronomical Society of Japan (2007). The importance of international collaboration is demonstrated by the deployment of the AzTEC bolometer array. The University of Massachusetts' 270 GHz continuum imaging camera (a 144 element bolometer) was successfully used on the ATSE telescope for 5 months in 2007. A number of highly successful programmes have been conducted, including a high red shift sub mm galaxy (SMG) survey of the fields where Subaru had detected a large scale structure with an over-density of Lyman α galaxies. This collaboration, bringing together two first class instruments, will produce exceptional results in this area with a high level of activity and strong international competition.

2.2 VERA and the VLBI Networks

The committee was really impressed that the key technologies such as low noise amplifiers, high speed correlator, dual beam antenna systems and real time VLBI system with long distance optical fibres have been developed, installed and facilitated with NAOJ’s own research efforts and in-house development. This is a good approach to research in any research institution but, unfortunately, it is a research style that is being lost in recent times both in Japan and the rest of the world.

We hope that the advanced VLBI developments demonstrated with VERA will be extended outside of Japan to access longer baselines by international cooperation.

2.2.1 VERA Science

VERA is a unique instrument in the world; with its dual-beam receiving system it is the only VLBI array designed specifically for astrometry. The specifications of the 4 antenna array require the delivery of 10 microarcsecond accuracy astrometry to achieve VERA's two major scientific goals: the measurement of the dynamics of the

Galaxy and the determination of the 3D velocity structure of molecular gas around evolved stars and star-forming regions.

After a five year construction period VERA started scientific observations in 2004/5. However, it is clear from published data and from the presentation by the VERA Director that the team has not yet fully achieved the required astrometric accuracy. The current best measurements achieve ~40 microarcsec; the limiting factors being the current measurements of the baseline error (which will improve with time) and the excess path length arising in the troposphere. The VERA team are working hard to improve on these limitations but it must be realised that there is a possibility that they will not be able to achieve the original specification.

That said, the early results from VERA are impressive. Two results in particular stand out:

1) The trigonometric parallax measurements of the H_2O maser Sharpless 269 (Honma et al., 2007). VERA measured a parallax of 189 ± 8 microarcseconds, which corresponds to a distance of 5.28 ± 0.24 kpc. S269 is in the outer part of the Galaxy; the difference of its rotation velocity and that of the Sun is less than 3%. This gives a strong constraint on the flatness of the outer rotation curve, and provides a direct confirmation of the existence of a large amount of dark matter in the Galaxy's outer disk. Clearly, more such measurements are required but this is a major early result from VERA.

2) The measurement of the distance to the Orion-KL region. Hirota et al. (2007) observed the H_2O maser in Orion and determined a distance of 437 ± 19pc. More recently, Kim et al (2008, in prep) measured the parallax of the powerful SiO maser and calculated its distance to be 419 ± 6 pc. These results compare well with the recent VLBA measurements of Menten et al (2007), who measured the parallax of non-thermal stars to estimate the distance of 414 ± 7pc. This is an excellent confirmation of the capabilities of VERA, and especially impressive for an interferometer with much shorter baselines.

An issue of concern to the committee is the current restricted manpower available to work on the flood of data that is emerging from VERA, this is illustrated by the limited number of refereed VERA publications that have appeared to date. In order to achieve the ambitious goal of determining the overall dynamics of the Galaxy, additional skilled manpower is required to analyse the data from the several hundred maser sources which will be observed. Unless a reliable pipeline can be constructed then the work will have to be done by graduate students and post-docs. This may mean that moves should be made to open up the VERA archive to international groups, possibly in collaboration with Japanese astronomers. This will ensure that the science that should be achieved by the investment made in VERA is delivered in a timely fashion.

2.2.2 Japanese VLBI Networks

The National Network provides valuable collaboration between a number of Japanese University Groups, and is also an excellent base for developing the e-VLBI technology, which will be a key development for future VLBI systems world wide. Although it is a good way to foster NAOJ/University collaboration in Japan it may suffer scientifically from the lack of international participation.

2.2.3 East Asian VLBI Networks

The East Asian VLBI Network, once established, will extend the Japanese VLBI Network to include stations in Korea and China. The EAVN will be unique in the world having, at the same time, a high-frequency capability as provided by VERA, the KVN and the JVN and a centimetric capability with large dishes. Such a network will be an essential component of the ground network for VSOP-2 as well as having significant impact as a stand-alone array, or as part of a global network.

Through this effort Japan is having a big impact in the region but resources, especially key scientific staff are spread extremely thinly. The committee reinforces one of the themes of this report and suggests that the best way to ensure full scientific exploitation of the expensive facilities is to open them up to the world's astronomical community, i.e. to ensure that an 'open skies' policy is fully implemented.

2.2.4 Geodetic Observations at Mizusawa

Mizusawa VERA Observatory used to be one of the six International Latitude Observatories in the world. Established in 1899, this observatory carried out various geodetic and geophysical observations before it merged with the NAOJ in 1988. Because of this history, measurements with tiltmeter and extensometer, as well as superconducting gravimeter are still carried out at Esashi earth tide station of Mizusawa VERA Observatory. Recent addition of VLBI and GPS capabilities augment the ability to observe geodetic parameters (Earth tides, polar motion, etc.) more precisely. Because the changes are slow as well as very small, it is necessary to continue the measurements for a long interval. The Committee feels that there is a good potential in exploring the geodetic problems, if various observational data can be integrated in the researches.

2.3 RISE Project

The RISE group at NAOJ is a part of the Japanese SELENE mission (Kaguya satellite) currently orbiting the moon. The RISE group is responsible for precise gravity determination with a combination of Doppler effect and VLBI measurement using two sub satellites, and height observation by laser altimeter. Since the launch on Sept. 14, 2007, the whole surface of the moon has already been covered by measurements. While the good quality topographic map of the polar region obtained from altimeter observation is a good achievement, the detailed gravity map of the moon is astounding and is tremendously important.

The whole moon gravity map was already produced based on the NASA Clementine and Lunar Prospector missions carried out in 1994 and 1998, respectively. Kaguya results for the near side of the moon are quite similar to the earlier results. However, for the far side, a gravity map with an accuracy comparable to the near side was only made possible with the brilliant combination of Doppler effect and VLBI measurement using radio telescopes carried out by the RISE group (Kikuchi et al., 2004). This unprecedented result will be a milestone event in the study of the origin, evolution, and present status of the moon. We highly commend their achievement which required a rare combination of space and radio astronomy techniques. We wait in anticipation for the publication of the full results in a scientific journal.

Only preliminary results were presented to the committee as the researchers had not yet obtained JAXA's permission to release results. We recommend that NAOJ establish reasonable policy with JAXA for the dissemination of results to the academic community and even to the public, without solicitation for permission in each and every case.

2.4 VSOP Project

VSOP (Halca) was not originally planned as a scientific mission but, in addition to the instrumental goals, important scientific results were obtained. VSOP also demonstrated to the world the feasibility of space VLBI and, most importantly, involved Japanese radio astronomers in a complex network of international collaborations. These collaborations included both operations and science activities. Operations involved space agencies, ground based astronomy facilities in many countries, and correlator centres. Strong international scientific collaborations emerged and the whole science program was coordinated by an international committee of astronomers. The collaborative programs set up for VSOP are regarded as highly successful by the international community.

2.4.1 VSOP-2

The Japanese VSOP group went on to plan a follow-up mission, VSOP-2, which has now been approved (ASTRO-G) by the Japanese Space Agency. This is certainly an outstanding achievement.

The VSOP-2 science case was recently discussed in detail at a very well attended international meeting at ISAS/JAXA in Sagamihara. VSOP-2 will combine the increased resolution possible in space with attributes that surpass those available to Halca. Its bandwidth, polarisation and phase referencing capability will make VSOP-2 a particularly powerful instrument and several key science goals were identified at the Sagamihara meeting, namely:

- probing the structure and magnetic field of the accretion disks round super massive black holes in the nuclei of galaxies;
- understanding of the physics of jet acceleration and collimation;
- the routine and rapid monitoring of the motion of H_2O masers in galactic star-forming regions;
- understanding the mechanisms driving the magnetospheres of proto-stellar objects.

In addition, VSOP-2 and its associated ground-array will provide a high-resolution capability for many different types of observation by individual research groups.

However, we note, and the VSOP-2 team realises, that some of the more ambitious objectives such as shadows cast by the black hole on the accretion disk (Takahashi et al 2007) will be very challenging. Another challenge, though potentially fruitful project is the imaging of radio emission from protostars on sub-AU scales. Note, however, that the emission from such sources is highly variable and is extremely weak (mJy or sub-mJy intensity for most of time; see, e.g. Forbrich et al. 2007) and so requires lots of collecting area. Many of these sources can increase their intensity more than tenfold within hours (see Forbrich et al. 2008) so if a rapid response triggering scheme can be implemented to dynamically reschedule telescopes when a flare commences the observation may be possible. Once VSOP-2 is successfully launched, this project will surely achieve a high level of performance.

One issue of concern is the organizational change of the space agencies in Japan. ISAS has become a part of JAXA which is a large and relatively bureaucratic organization. NAOJ needs to watch carefully to ensure that the same flexibility in operation as achieved in VSOP/Halca can be realised with VSOP-2.

2.5 Atacama Large Millimetre Array (ALMA)

In the 1980s Japan, along with the US and Sweden made proposals for a large mm array. The Japanese proposal was inspired by the successful operation of the millimetre interferometer at the Nobeyama Radio Observatory and became one of the three roots that eventually grew to become the ALMA project. Due to financial constraints Japan did not continue as a partner in the initial international agreement between the US and ESO but did maintain much of their research activity related to ALMA technology. Hence, when Japan re-joined the ALMA project in 2004 it was in a good position to contribute advanced technology and to add an important extension to ALMA called ALMA-J. This includes three additional frequency bands and a more compact array of smaller dishes which provides brightness sensitivity and short baselines that will be critical for ALMA imaging of larger structures and is now a key part of the enhanced ALMA project.

Technology developed for ALMA-J is impressive and is having impact on the entire ALMA project with high and positive visibility for Japan. For example, the advanced correlator design used for ALMA-J influenced the other ALMA partners to adopt more advanced and more powerful technology. The construction and on-time delivery of the first three ALMA-J dishes to the ALMA site is a very impressive milestone and sets a benchmark for the project.

One of the very high technical risk items identified in the ALMA project (see § 2.5.1) has been the photonic local oscillator system. This has been under development at NRAO in the US but the NRAO design has not yet met the required specification. A photonic local oscillator system was independently developed at NOAJ's discretion as a backup. This involves a different and innovative design which has achieved very impressive performance. We understand that discussions between Japan and NRAO are underway and the Japanese design may be incorporated in the production version of the local oscillator system. This is not only a great technical achievement by the NAOJ group but an excellent example of how involvement in a large international project like ALMA can lead to ongoing technology collaboration and Japanese visibility.

2.5.1 ALMA External Review

The ALMA project itself has its own regular review process. Quoting from the ALMA Annual External review, 18 October 2007:

ALMA is a truly impressive project in scope as well as the capabilities it will bring to sub-millimetre astronomy. Not only will ALMA be one of the largest and most complex astronomical instruments, it will also be situated in one of the most remote and logistically challenging locations in the world. The payoff to its respective *scientific communities and the collective efforts in achieving this vision is something for all involved to take pride in.*

Development of potential back-up LO by Japan is solid future risk mitigation and we fully support the continued effort for this key subsystem.

A number of IPT's show strong examples of tri-lateral involvement in consideration of the longer-term integration of ALMA-J into a single operating observatory, we strongly encourage a more complete integration of ALMA-J efforts as early as possible.

3 Future Planning

The committee noted with interest the classification of different major projects within NAOJ as Category A, B and C. We were informed that on 1 April 2008 the RISE Project would be promoted from Category B to C, recognising that it is now in its established and operational phase. In addition, at the same time the Space VLBI Project Office would move from Category A to B, reflecting its funding status and its change to a development phase.

This categorisation demonstrates that there is a strong and active project management culture within NAOJ that recognises the maturity level of projects and moves them between categories as appropriate.

Of concern to the committee was the evident lack of a long-term plan in the NAOJ radio astronomy division. The committee, and senior NAOJ staff, recognise that it takes many years for a project to move from its conceptual phase, through Category A to B and then C. It is therefore of concern that there is no new Category A project to take the place of VSOP-2. There is a danger that the long-term future of radio astronomy in Japan will be threatened if this planning activity is neglected.

There is one aspect of this concern, which is shared by all the members of the committee, which seems to be a more general issue. It is observed that some of the research institutions and researchers in Japan tend to hesitate or refrain from discussing projects openly, especially internationally, until the project has been officially approved or the budget is allocated. Most advanced and challenging research projects today, especially in astronomy, require large budgets and long time scales. If Japan continues in this manner, it may lose the chance to propose ideas and influence directions for better research and may even lose the opportunity to join. These are serious lessons that could be learnt from the ALMA case. It is the responsibility of today's researchers, especially managers, to understand the issues and to make a break-through for future generations.

The committee notes that this planning gap could be very well filled if Japan became involved in the international collaboration to develop the Square Kilometre Array (SKA). Japan is involved in many key SKA technologies and could become involved in both planning and technology developments without the need to make any long term commitment ideas at this stage.

Appendix

List of materials provided to the committee.

1. Charge to committee.
2. "Documents and Materials for External Evaluation".
3. Meeting agenda.
4. Copies of oral presentation materials.
   a) International Review of NAOJ (Fukushima)
   b) Outline of the Division of radio Astronomy (Manabe)
   c) Activities of the Division of radio Astronomy
   d) Mizusawa VERA Observatory (Kobayashi)
   e) ALMA at NAOJ (Hasegawa)
   f) Space VLBI Project Office (Inoue)
   g) RISE Project (Sasaki)
   h) Recent Progress and Future Plans of NRO (Kawabe)
   i) InP technology development for radio astronomy (Kawaguchi) - at our request
5. VSOP-2 Science Goals
6. ALMA Annual External review (Sep 2007)
7. Recent progress and Future Plans of NRO
8. Lists of papers published.
9. List of Post Docs, Students and PhD staff.

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