Report of the FY2021 External Evaluation Committee for the Japanese VLBI Network (JVN) Project

Submitted to the NAOJ on 29 June 2022

EXECUTIVE SUMMARY

The Japanese VLBI Network (JVN), established in 2005, has evolved quickly to become fully operational thanks to the great effort from NAOJ and universities. The acceptance of the JVN as one of the inter-university collaborative projects of NAOJ for three years from April 2019 offered a great opportunity to enhance the science capability of the JVN, which consists of 9 telescopes covering baselines 50-2500 km operated at 6, 8 and 22 GHz.

The JVN comprises a healthy mix of technological development, telescope maintenance, and scientific expertise. The contribution from participating universities (Ibaraki University, Gifu University, Osaka Prefecture University, Yamaguchi University, and Kagoshima University) and the leadership of Prof. Fujisawa are highly valued in the success of the project. The JVN people have done their best to promote VLBI activities in Japan by carrying out ~90 observations (~600 hours) in the last three years and supporting more than 100 students (71 undergraduates, 35 Master, and 3 Doctoral students). The scientific outcomes are published in 14 JVN papers and 30 JVN-related papers.

There are two review items defined by the NAOJ on the scientific value and the educational activities of universities. The committee agreed on the self-evaluated achievement level of 80% for the proposed three primary science goals, i.e. Methanol Maser Monitoring, Extremely Compact HII Regions, and Gamma-ray Sources. The JVN has an outstanding role in fostering young students by training them in technology, exposing them to science, training them to write scientific proposals, and encouraging them to take a role as PIs of projects, research exchange/mobility programs, and contributing to the formation of professional researchers in a nurtured environment.

The committee realized the critical role of the VERA in maintaining the imaging capability of the JVN and of the wide-band and cooled receiving system on the telescope for improving the sensitivity of JVN observations.

1. Review process

The external evaluation committee (EEC) was officially appointed on 24 February 2022 (online) kick-off meeting with the following three members:

Shen, Zhiqiang: Chair of the committee
Director and Professor, Shanghai Astronomical Observatory

Onishi, Toshikazu: Vice Chair of the committee
Professor, Astrophysics Laboratory, Osaka Prefecture University

Rioja, Maria:
Senior Research Fellow, International Centre for Radio Astronomy Research (ICRAR)/CSIRO

The preparatory (online) meeting was held on 8 March 2022. This external evaluation of the Japanese VLBI Network (JVN) project was held online (zoom) on 22, 23, and 29 March 2022, as part of the process of the National Astronomical Observatory in Japan (NAOJ) to review various individual projects.

The EEC was pleased to receive well-prepared and valuable reports from the JVN Project Manager Prof. Kenta Fujisawa and from leaders/PIs of the 3 Primary Scientific Goals (1. Methanol Maser Monitoring; 2. Extremely Compact HII Regions; 3. Gamma-ray Sources). The EEC also had very fruitful interviews with young scientists, post-doctors, and graduate students regarding research, instrumentation, operation, and education activities with the JVN.

At the review meeting, in addition to a project report ([DD09]) by the PM, Prof. Fujisawa, there were progress reports on the science goals of the JVN ([S04] – [S07]) and reports from universities participating in the JVN (Yamaguchi University, Gifu University, Ibaraki University, Kagoshima University, and Osaka Prefecture University: [S08]-[S12]). In addition, interviews were conducted with six young researchers, which are reflected in this review document.

The other details of the review plan are described in [AD03] “JVN Review Plan”.

2. Evaluation of the given missions and primary scientific goals

There are two review items defined by the NAOJ. The following is the evaluation of the items. For reference, 14 JVN papers and 30 JVN-related papers have been published in the last three years ([S03]).

2.1 Review Item 1 (RI. 1): To build and operate the Japanese VLBI Network (JVN), a VLBI network consisting mainly of large radio telescopes operated by universities in Japan, and to achieve scientific research results (focusing on the three goals listed in "Scientific Goals and Missions" of the JVN) with the review perspective and criterion "Has JVN become a project

that generates research with high scientific value?"

The committee agreed on the self-evaluated achievement level of 80% for the proposed three primary science goals. Specifically, goal 1, "Methanol Maser Monitoring", was quite successful, goal 2, "Extremely Compact HII Regions", met the minimum success, and goal 3, "Gamma-ray Sources", was half done. More details are described below.

Goal 1: "to monitor more than 400 methanol maser sources with the JVN and to make the world's largest monitoring catalog that reveals the structure and intensity variability "

This study aims to determine the source showing periodic variability of the 6.7 GHz methanol maser and investigate the formation process of massive stars using the flux variability as a probe. The results of the single-dish observations of the ~450 targets with a total observation time of 12,368 hours have been compiled into the world's largest catalog of methanol maser variability, with 56 objects found periodic variability. These data are available worldwide on the website iMet (URL http://vlbi.sci.ibaraki.ac.jp/iMet/). As a bonus, an "accretion burst" phenomenon, in which a maser brightens rapidly, has been discovered. Many students participated in these studies, and it is fair to say that it was a great success. The VLBI observations did not reach their goal, but this was mainly due to the failure of the hydrogen maser at the Yamaguchi observatory, which halted imaging observations with the JVN for a year. When the hydrogen maser should fail again, we expect NAOJ and other VLBI observatories around the world to cooperate to find a quicker way to recover the maser [R1.3].

Goal 2: "to observe 390 extreme-compact HII regions with the JVN and identify the youngest HII regions out of them"

This study aims to detect thermal emission in the Extremely-compact HII (ECHII) region formed by massive stars with VLBI immediately after their formation. Taking advantage of the characteristics of the JVN, which is a short-baseline VLBI, the JVN detected massive stars and their thermal emission while they are forming. Observations were made for the target of 390 objects, but the number of valid observations was reduced to 255 objects due to observational problems. Fringes were detected in 122 of these sources, 22 of which had brightness temperatures below 10^5K. These are candidates for the ECHII region. In this sense, the committee judged that the minimal goal of this objective has been achieved. The results have not yet been published, but it was reported that the paper would be submitted soon.

Goal 3: "to make a catalog of radio sources for the possibly emitting gamma-ray by observing more than 1000 sources with the JVN"

Previous studies have shown that most gamma-ray emitting sources are dominated by blazars emitting high brightness radio emissions. Therefore, they aimed to identify radio sources corresponding to gamma-ray emitting sources by conducting VLBI observations of radio sources close to the gamma-ray sources and selecting radio sources with high luminosity. The goal, VLBI observations of 1000 sources, was not achieved. One of the reasons for this was the failure of the hydrogen maser at the Yamaguchi observatory, which interrupted observations for a year. Instead, observations were made with the Yamaguchi interferometer, which consists of 32m and 34m at the Yamaguchi station. As a result, 496 objects were successfully observed. Initial analysis indicates that 40 radio sources correspond to 35 unidentified gamma-ray sources (UGSs). The committee judged that the minimum goal was about 50% achieved based on these results.

The other scientific results:

In addition to the three science goals presented, reports were made on three other studies. The accretion burst found in the methanol maser monitoring observations was confirmed to be caused by accretion bursts by detecting the central protostar's brightening by tracking infrared and millimeter/submillimeter-wave continuum emission. A "pre-high mass protostar" search in the direction of infrared dark clouds using the Yamaguchi interferometer detected 30 protostar candidates embedded deeply in molecular clouds. Kagoshima University and Gifu University will collaborate to capture the structure and motion of orbiting masers with an angular resolution of milliarcseconds (mas), mainly using VLBI networks such as VERA/JVN and EAVN. These science expansions show the excellent potential of the JVN.

2.2 Review Item 2 (RI. 2): To contribute to the educational activities of university students through research with the review perspective and criterion "Does JVN contribute to the development of observational astronomy research conducted at universities and to the educational activities of universities?"

It is remarkable that many of the above-mentioned observations, science, and technology development results have been achieved through student-led initiatives: 71 undergraduate students, 35 master's students, and three doctoral students have participated in JVN-related research over the three years beginning in 2019. Clearly, the presence of telescopes and a development environment at the university has contributed greatly to attracting many students to its laboratories. In addition, having a telescope close at hand and ample opportunities to actually operate and develop it has played a

significant role in deepening students' understanding of telescope and radio reception. Inter-university exchange in science, telescope operation, and development is also expanding. The JVN has also been training some very active young researchers among many of these students. It has become an excellent educational venue, especially for undergraduate and master course graduate students, and therefore, the evaluation criterion for this review item is judged to be more than adequately met.

3. Other items

This section describes the views of the committee members on the items not listed in the Review Items.

3.1 Project Operation

JVN is operated by a total of 23 staff members from five universities and the National Astronomical Observatory of Japan, Mizusawa VLBI Observatory, as well as their graduate students. The total budget for FY2021 was 58 million yen. Maintenance costs for each telescope in Ibaraki and Yamaguchi are about 10 million yen or less per year, while the 11-m telescope in Gifu costs less than 1 million yen per year. The Iriki station in Kagoshima is maintained by VERA's budget. Other budgets are used to hire researchers, etc. Considering that the telescopes in Ibaraki and Yamaguchi are large and old, maintenance efforts are being made with meager budgets. It is reasonable to say that the telescope maintenance and instrument development are supported by the dedicated efforts of a very small number of employed researchers. [R2.1]

The regular meetings play an essential role in the smooth operation of the JVN. On the other hand, students are often involved in actual telescope operation, maintenance, and instrument development, and it would be good to have meetings for a regular exchange of information on the operation and technical development, including students. Prompt sharing of this information and support needs among universities would lead to more efficient operations. [R1.2]

3.2 Receiver development and telescope maintenance

Improving the performance of telescope receivers is very important in expanding the range of science that can be achieved. The JVN has led university-led efforts to improve telescope performance in a variety of areas: directly related to the JVN is the development of broadband receivers in the 6.5-12.5 GHz and 6.5-23 GHz bands, and related to VLBI are the 22/43/86 GHz simultaneous observation system for the HINOTORI project, the VERA, an 86 GHz receiver for the NRO 45m telescope. The committee was impressed by the development of VLBI instrumentation, such as what the OPU group has achieved, which is a high-level standard and will significantly improve the JVN performance.

As for telescope maintenance, the telescope has managed to survive on a small budget due to the extremely dedicated efforts of a few people, and this does not appear to be sustainable. While it is

important to consider further budget and personnel support, it will also be important to sustain the transfer of maintenance skills, including those of the technicians at the Mizusawa VLBI Observatory and the NRO. The same applies to the technical development mentioned above. Rather than relying on only a few groups and people, it is important to form a broad group that can discuss these issues and improves the efficiency of the telescope and receiver development system in Japan as a whole. [R1.2, R1.3, R2.1, R2.2, R2.3]

3.3 Role of VERA in terms of the JVN project

Although the VERA group (Mizusawa VLBI Observatory) is explicitly listed in the JVN Organizational Structure [DD01, S01], there was little explanation of VERA's role in the JVN in the review documents and presentations except for the technical support, so we requested an additional explanation on this matter [S16]. The JVN observations can be roughly divided into two parts: one baseline observation between Ibaraki and Yamaguchi and imaging observations including VERA. "Review Item 1" focuses primarily on observations with a single baseline between Ibaraki and Yamaguchi.

We would like to note that the JVN and VERA-coupled imaging observations have produced scientific results of disk and outflow around massive protostars using the 6.7 GHz CH3OH masers and high-resolution images of AGN jets. The observation time of JVN including VERA is currently short, less than 100 hours per year; we hope that the effective use of VERA in the JVN will be seriously considered in the future, as it will greatly expand the scope of science, especially for imaging observations. [R1.1, R2.1, R2.2, R2.3]

4. A list of recommendations

4.1 Recommendations to the JVN

R1.1 The long-term success of the JVN will benefit from increasing its emphasis on excellence of scientific research and requiring significant scientific goals and outcomes

R1.2 Create an "Operations working group": Telescope maintenance is essential. Professional and more efficient support needs to be improved for operation.

i. Provide training courses to staff and students (e.g. inter-university VLBI summer school) in a systematic fashion: Member holding expertise in telescope maintenance (Mizusawa VLBI Observatory of NAOJ) could help. This provides a useful, effective way of maintaining good network operations and provides a good experience for students as well.

ii. Create a dedicated "technical discussions" communication channel: Consider creating and opening a group communication channel dedicated to regular (or when needed) technical consultations.

R1.3 Keep the JVN competitive by maintaining and upgrading the telescope infrastructure, including but not limited to, observation system, VLBI digital system (e.g., VLBI terminal), increasing bandwidths, sensitive receivers, agile replacement of broken elements (H-maser), using the technological development and maintenance expertise in the JVN when available and/or from external sources otherwise.

4.2 Recommendations to the NAOJ

R2.1 Continuation in support of the JVN to make the best use of existing Japanese radio telescopes in terms of future budget and manpower spending

i. Keep and preferably increase the budget to allow the JVN to hire dedicated persons in charge of telescope maintenance and operations.

ii. Keep the 2-beam system on the VERA telescopes. This provides a unique capability on the JVN, opening up many fields of high-impact astrophysical investigations through precise astrometry. Such a capacity makes the network more internationally competitive and continues to apply to joint observations with EAVN providing astrometric registration of images from the entire array, as in for example ESTEMA.

R2.2 Foster stronger interaction and collaboration between NAOJ and universities

R2.3 A longer-term strategic plan (including technical developments, human capacity building, etc.) is needed for the healthy development of the JVN in the context of existing and planned VLBI networks.

Acknowledgments

We express thanks to the Director and all the members, post-doctors and students of the JVN and NAOJ administration for preparing this evaluation in a very efficient way.

Appendix 1: Schedule of the review meeting

Appendix 2: Evaluation documents provided