FY2023
NAOJ Project Review Report
Mizusawa VLBI Observatory

June 2024

External Evaluation Committee
for the Mizusawa VLBI Observatory

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External Evaluation Committee for the Mizusawa VLBI Observatory

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Executive Summary

The national research facilities are a valuable resource for a country and will continue to be so in the context/era of (huge) next-generation international projects coming online. Following the metaphor of the “iceberg model”, the high visibility new science appears on top of long term basic investment and expertise, where the know-how becomes knowledge. The roles of the national facilities include acting as pathfinders and developers of next generation technologies and to develop Japanese scientific teams and expertise in the building up towards leadership of bigger projects with the next-generation instruments, and finally, to support VLBI operations in joint observations with next-generation radio instruments coming online at the end of the decade. In particular, VLBI with SKA (Square Kilometre Array) is an essential niche, it requires an upgraded network of antennas across the globe; the same applies to other instruments. Last but not least, the national facilities fulfill a mission of contributing to human resource development of young researchers, improving the research capabilities of universities and other institutions, and outreach activities to return to society. VERA is an internationally competitive instrument already contributing to the roles mentioned above and the panel strongly recommends that it will continue to do so in the future.

The VERA galactic-scale astrometry program has fulfilled its goals to map the Milky Way’s spiral arms in 3D for the first time and to measure fundamental Galactic constants. This program has officially concluded and the main results have been made available to the whole astronomical community, achieving a major milestone for the VLBI field and for the Japanese VLBI community in particular. The latest publication, VERA Collaboration, Hirota et al. (2020), in the third PASJ Special Issue includes: the (first) VERA astrometry catalog, a comprehensive VERA astrometry comparative analysis with the other main VLBI astrometry projects, and between VLBI and Gaia measurements, and the up-to-date fundamental galactic parameters for the Milky Way. A main science highlight from the project is that SgrA* is at the dynamical center of the Milky Way. We recommend the Observatory take steps to enhance the visibility of the VERA Project outcomes and the Observatory in general, through their participation in other international high impact projects, e.g. EHT (Event Horizon Telescope). In the previous evaluation report from 2018 the VERA project was criticized for not publishing results and lacking plans for the future. Both have been addressed. The first with the major release of the VERA catalog and accompanying publications, the second one has been commenced, but there is space for further thinking on future plans. We encourage the Observatory to continue pursuing this goal.

The conclusion of the comparison study between VLBI and Gaia satellite is that VLBI astrometry continues to be a point of reference and presents benefits with respect to optical astrometry with Gaia in specific fields, such as imaging the spiral arm structure of the Milky Way and the measurement of the distance to Mira-type evolved stars, among others. The general consensus today is that VLBI and Gaia are complementary as they can observe different sources, and different regions, and that their combination provides important opportunities for astrometric cross-calibration and scientific cross-fertilization. Hence the panel concludes that VERA astrometry developments continue to be most relevant in the Gaia era.

State of the art broad-band technological developments in Mizusawa Observatory are currently leading the world scenario in a very competitive environment. This technology is internationally recognized as the path to enable the extremely large requirements on recording rates for next generation instruments (e.g. SKA-VLBI). VERA and East Asia VLBI Network (EAVN) are fantastic pathfinders to showcase these developments, making possible next-generation (instruments) science cases with today's instruments. The recording rates of the OCTAVE system, developed by the Observatory, amount up to a factor of ca. 6 times the current maximum from any other array; it enhances the VERA sensitivity and significantly broadens the discovery space that can be addressed. This achievement showcases the power of the accumulated technological and scientific know-how in the observatory. It should be noted that this technological development leads to a superior performance, surpassing the VLBA (Very Long Baseline Array). VERA is of direct interest for other next-generation instruments such as ngVLA (next-generation Very Large Array) at mm-wavelengths. Unfortunately the panel are seriously concerned that the long term operations under a critical tight budget[1] could hinder the worldwide/global lead position and recommends both the Observatory and NAOJ to explore possibilities for attracting additional funding; we provide several suggestions in Sect. 1.5 in the review.

The Observatory/VERA plays a major role in the EAVN open-use observations, a young but expanding network which is already producing international competitive science. The nature and outcomes of this collaboration are perfectly aligned with the Purpose, Missions and Primary Scientific Goals for the Mizusawa VLBI Observatory [AD02][2]. In addition, there are VERA stand-alone observations within the VERA Large-scale COllaborative

[1] The budget in this report does not include the permanent staff cost.

[2] [AD02] Scientific Goals and Missions - Mizusawa VLBI Observatory, see: https://www.nao.ac.jp/en/recommend/mission/mizusawa.html

Program (VLCOP[3]), started in September 2022, which offers machine time in exchange for an in-kind contribution. EAVN provides high dynamic range, resolution and astrometry; these rest on the longest baselines provided by VERA. Thus the panel recommends keeping operational the four VERA antennas and the unique dual-beam system, to enable high fidelity imaging and the "hybrid-mode" capability of the EAVN. We note the unique projects carried out by stand-alone VERA observations under the VLCOP program, and recommend efforts to support and expand this program. Both programs have room to improve their oversubscription rate. We recommend that improved international visibility, of both opportunities and previous outcomes, should address this issue.

A plan to reduce the operational budget has been successfully implemented. The in-house maintenance and automated operation has led to an impressive budget reduction since 2020 (approx. 50% over five years). We have made a comparative analysis of VLBI arrays to the best of our capacity and find that VERA is internationally competitive and at a very low relative cost. All the details are included in the review. Nevertheless we are concerned about the sustainability under the current stringent budget limitations, and other consequences such as the decrease in the number of publications due to reduced staff (postdocs) and increased antenna downtime. We applaud the proactive initiatives of the Observatory to attract non standard funding (eg JSPS, donations, crowdfunding, etc). We recommend NAOJ to consider maintaining the budget for the Observatory and we make a number of suggestions on how the Observatory could attract additional funding including the commercialization of their forefront developed technologies. Moreover, we note that the web presence of the Observatory is outdated and must be refreshed. Furthermore, to increase international impact, English versions are recommended. We recommend the Observatory to take action to address this.

The Mizusawa VLBI Observatory has hosted and provided research opportunities for a significant number of students, mainly from the University of Tokyo and SOKENDAI. The cooperation with Kagoshima University at IRIKI Station has also yielded remarkable results not only in operations but also in education. The unique educational programs at VERA have contributed to the development of not only astronomy researchers, but also diverse human resources. The panel hopes that these will be continued and expanded. The panel hopes that the VLCOP will continue to grow and that measures will be considered to expand VERA users and educational opportunities at the JVN

[3] VLCOP is a new common-use mode of VERA. Users are required to contribute, e.g. in AOC duties, in-kind contributions, and/or financial support for the observatory operation. VLCOP is open for research using VLBI and/or single-dish mode, including new instrumental developments, test experiments, and commissioning observations.

participating universities as well as other universities. The panel looks forward to the Observatory considering the actions necessary to develop users and expand VERA/JVN as a venue for human resource development, and to reaching out to non-JVN universities to expand training for graduate students from other fields in the future.

The discussions on the future plans of the Observatory include increasing the frequency range, for example to include higher frequencies (86 GHz). The panel looks forward to seeing this in place and integrated in the simultaneous multi-frequency observations mode with existing 22 and 43 GHz. Additionally, we think it is important to dedicate effort to further define the following fronts: Formalize the definition of Key Science Projects or Large Projects for the VLCOP program, define the role of EAVN post 2030, improve and create new global collaborations, and define a road map for the development of compatible instrumentation with other observatories, while exploiting complementarity. With respect to the next-generation radio instruments coming online, we urge the Observatory and NAOJ to define a realistic plan for the Observatory role in the SKA-VLBI era, and review the opportunities for VERA as a pathfinder for SKA. Equally, to assess the participation and collaboration with the centimeter-to-submillimeter wave next generation arrays, ngVLA and EHT, which share common grounds with technological and scientific expertise of the Observatory.

The panel has made recommendations to the Observatory and to NAOJ Executive which appear at the end of each section, indicated with “RCMD” and “N”, respectively, followed by a number in increasing order. We highlight the major recommendations to the Mizusawa Observatory adding an “M” at the end of the number.

Purpose and Evaluation Perspectives:

The purpose of the evaluation is to identify and summarize the activities of the project since the previous project review conducted in FY 2018 (January 7-8, 2019) from the following perspectives and make recommendations for improving future activities:

O1-Does the project produce internationally competitive science through its Open-Use programs?
O2-Does the project improve the research capabilities of universities and other institutions?
O3-Does the project contribute to human resource development of young researchers?

Review Items, divided into five main categories

1. Summary of the VERA astrometry project
2. Achievement status of observatory's Purpose
3. Response to the recommendations in the FY2018 Project Review
4. Comparison with similar projects
5. Future Plan (beyond the period covered by the review)

Criteria for evaluation

(1.1) Review science outcome of VERA astrometry project
(1.2) Has the observatory developed new technology for post-VERA periods?
(1.3) Has the observatory made operation/maintenance of VERA efficiently?
(1.4) Has the public outreach been at reasonable level on VERA outcome and the observatory?
(1.5) Is the budget and staffing adequate to move to post-VERA science goals?

(2.1) Are the operational status, Japan's contribution, scientific results and impact (including cost-effectiveness) of the EAVN (East Asia VLBI Network) appropriate?
(2.2) Is the coordination with JVN (Japanese VLBI Network), and contribution to university research and education appropriate?
(2.3) Does the observatory expand EAVN well, and contribute to mm VLBI, and global VLBI and produce research outcome through collaboration?
(2.4) Has the observatory's study on SKA (Square Kilometre Array) made good progress? (eg SKA-VLBI white paper)

(3) Does the observatory respond well to recommendations in the 2018 review?

(4) Is the Mizusawa VLBI observatory competitive among similar research institutions overseas in terms of (1.1), (2.1), and (2.2), excluding the JVN results ?

(5.1) Advise how does NAOJ operate the NRO (Nobeyama Radio Observatory), Mizusawa, and ASTE (Atacama Submillimeter Telescope Experiment) projects more efficiently: these projects are currently managed separately by NAOJ.
(5.2) Evaluate the future plan of the Mizusawa VLBI Observatory. (eg. as an stand alone observatory, in regional collaborations and in the era of next generation radio instruments, for astronomy and geodesy)

Review results according to the items in the Review Perspectives

(1.1) Review science outcome of VERA astrometry project

The Observatory reported on the VERA Scientific highlights. Below, a summary of the discussions between the EEC members:

- The VERA galactic-scale astrometry program has officially concluded and fulfilled its goals to Map the Milky Way's spiral arms in 3D for the first time and to measure fundamental Galactic constants. This is a major milestone for the VLBI field and for the Japanese VLBI community in particular. The main results have been published, VERA Collaboration, Hirota et al. (2020), including the (first) VERA astrometry catalog. A main science highlight from the project is that SgrA* is at the dynamical center of the Milky Way; this follows from the agreement between the measured values for the location of the center of rotation with the distances to SgrA* measured with independent programs and bands in the spectrum, e.g. Gravity Collaboration. It is noteworthy that this project has been carried out in a healthy competitive atmosphere with observations with other arrays, mostly VLBA (Very Long Baseline Array), in an overall constructive collaborative fashion whilst maintaining separate leadership. The panel appreciates that this difficult equilibrium has worked out extremely well and in the best interest of the scientific outcomes.

- The importance of VLBI/VERA maser astrometry in the Gaia era:

Comparisons of Gaia results with external astrometric data is important to detect misbehaviours in Gaia data, as it was the case with the preceding astrometric mission, Hipparcos, and the Pleiades distance controversy, solved by VLBI. There is a wealth of comparative studies between astrometric results obtained by VLBI (eg VERA) and Gaia measurements. These started from the first Gaia data release and continues to be an active field of research. The general consensus today is that VLBI and Gaia are complementary as they can observe different sources, and different regions. Gaia has a much more limited study region (~4 kpc) compared to VLBI and cannot trace the spiral arms using young stars (SFR) observations, nor OH/IR evolved stars that have thick dust shells; only VLBI can do this. Gaia has shown the power of large astrometric surveys, and it is an inspiration for larger VLBI surveys with next-generation radio instruments. Also we note that Gaia results include corrections for the Galactic rotation from the VLBI datasets. Hence, VLBI continues to be a point of reference and present benefits with respect to optical astrometry from Gaia.

- Recent VERA Highlights:

A recent milestone is the 1st measurement of trigonometric-annual-parallax of SgrA*, led by Mizusawa Observatory (Oyama et al. 2024). The direct measurement of the distance to SgrA* is very significant scientifically yet very challenging, hence it has been considered a “dream project”. This measurement showcases the impact of the increased VERA sensitivity from the new digital broad-band back-end OCTAVE-DAS, developed at Mizusawa Observatory, and the power of the accumulated technological and scientific know-how in the observatory.

- Paper statistics and impact:

VERA astrometry maser publications up to 2019 amount to more than 60 papers, as listed in VERA Collaboration, Hirota et al. (2020); publications in 2020 continue a healthy trend. There is a significant decrease in VERA-only publications from 2021 onwards. There are several reasons contributing to this trend: on one hand, it takes a significant temporal baseline to generate astrometry results for new projects, particularly now that the galactic scale astrometric program has finished; also very important is the impact from decrease in funding, which propagate to no postdocs; conditional open time under the VLCOP program and increased array downtime due to antenna failures. On the other hand the committed time for EAVN observations was maintained at a stable level during this period of evaluation. EHT-related publications are at a historical maximum level during this period, as expected from a more mature array and, probably most important, joint observations with ALMA.

We commend the Observatory for producing internationally competitive science and the development of young researchers.

The EEC identifies the following areas of improvement:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 1M	Improve VERA visibility for enhanced Output and better Statistics: - 1a) Some exciting results such as in EHT are made possible because of existing Research Infrastructures, which must be made more visible when presenting the headline results. - 1b) We would encourage the presentation of VERA results at international conferences to make them more visible to researchers outside the VLBI community. At these VLBI conferences, to improve international visibility, stress the

	new opportunities with the new era of VERA, that is, the promotion of the VLCOP model and EAVN. Make a common practice to include a couple of slides with highlights and capabilities with the aim to attract non-local users. - 1c) User friendliness: Address issues with insufficient guidelines for VERA data analysis. We understand the lack of such guidelines was a flag raised by many students in the last VLBI-Consortium meeting held in Dec 2023. Then it was decided to create a new working group to generate such documentation and maintain it. We suggest the formation and support of a Working Group explicitly for this issue. - 1d) Investigate the option of pre-processing, with some of the basic steps, prior to downloading the observed data. - 1e) Help students to grow a smooth relationship with VERA data reduction and keep new experienced VLBI users happy. Consider using or adapting the existing user support in place for EAVN, which provides data analysis scripts for “AIPS”, sample key file and helpdesk. - 1f) Produce English documentation to encourage widespread use in the global community. Google translate plus a read through by an expert should be sufficient. Investigate including a version in English of the VLBI Consortium report (including the info on KSPs). - 1g) The link between VERA and universities is well established, providing education to many students in high-education institutions; we recommend that this good work should continue alongside advertising of the science capabilities of VLBI.

RCMD 2	On Publications and Citations: - 2a) Consider requesting inclusion of authors from a “Builders List” for publications that use the highest recording rate capability provided by OCTAVE-DAS (to increase publications from the observatory staff) - 2b) Citation of VERA Collaboration, Hirota+2020 paper “VERA Catalog” is low for such a significant work (69). We recommend that the online archive (and other earlier data products) is made more accessible, to increase utilization and thus recognition. Vizier would be a suitable resource.

RECOMMENDATIONS TO NAOJ Executive:

N1	The Observatory has the infrastructure and human resources capacity to carry out the recommendations above. - 1a) We recommend that NAOJ continues supporting the Observatory, maintaining the current funding levels to enable robust operations of the VERA network as part of EAVN and VLCOP programs.

(1.2) Has the observatory developed new technology for post-VERA periods?

Mizusawa Observatory has continued to develop their very impressive new digital broad-band back-end system, OCTAVE-DAS, and the correlator system for VERA (and EAVN). This is next-generation technology and upgrades the VERA array to the international forefront. It enables broad-band recording and playing up to a maximum rate of 32 Gbps, superior correlator performance using GPU technology, a wide band dual-polarization receiving system, among others. The parallax measurement of SgrA* is an outstanding scientific highlight and a beautiful demonstration (at 16Gbps, using OCTAVE-DAS) of the impact of broad-band sensitivity for astrometry in the SKA-VLBI era. Note that the SKA project requires VLBI recording data rates of, initially, ~80 Gbps and extending to ~800Gbps in Phase 2.

Also there are advances towards higher frequencies eg 86 GHz, W-band (with antenna efficiency 30%); VERA was designed as a single-frequency instrument, but now has been retrofitted for dual-band observing (at K+Q) and maybe for triple-band in the future (at K+Q+W). The simultaneous multi-frequency capability and the unique dual-beam feature enables new observing modes beyond today's frontier of VLBI capabilities.

The panel appreciates that the new technologies developed by the Observatory improve the research capabilities of VERA and Japanese researchers and enable internationally competitive science. Likewise, that this capacity builds up from their accumulated experience in radio interferometry developments, and that it is a very valuable asset. In addition, the panel as well identifies this asset as a possible path to extract additional funding.

We commend the Observatory for developing world-class next generation technology for the post-VERA period and raising funding from the JSPS program.

The EEC identifies the following areas of improvement:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 3M	The Mizusawa VLBI Observatory develops next-generation technology internationally recognized. The Observatory should develop a more specific technology roadmap to take advantage of these opportunities.

RCMD 4	The panel is concerned that the long term operations under a critical tight budget could hinder the worldwide lead position in broad-band next-generation technological developments of the Observatory. The panel suggests the Observatory explore ways to attract additional funding, e.g. via commercialization of technologies (see section 1.5 for further discussions).

(1.3) Has the observatory made operation/maintenance of VERA efficiently?

The Observatory has put effective measures in place to continue operations in the midst of significant budget reduction, which have led to a staggering ~50% cost reduction of the running and maintenance costs over five years. These include: The promotion of in-house maintenance, plus the automation of the systems which has reduced the operational costs by reducing the number of staff required to run the antennas, and the VLCOP program which offers machine time under certain conditions that support the array operations.

The panel concludes that the Mizusawa Observatory has demonstrated excellent performance in these circumstances, and not just survived but thrived, delivering new scientific and technological highlights, which arise from the accumulated know-how acquired during the previous years of running VERA.

Effective teamwork and leadership have been key to continue running VERA through a difficult and challenging period. We applaud the team effort for managing to maintain and operate in such a tight cost-effective mode.

Nevertheless, while VERA has continued operations, the impact of budget reduction shows concerning signs: The transformation of the Observatory

management structure (i.e. staff extending/replacing their work roles) and reduced staffing levels (including post-docs) has led to a reduced number of refereed papers in the last couple of years and the array performance has been affected by antenna downtime.

We commend the Observatory for managing the maintenance/operations efficiently in a cost-effective way.

The EEC identifies the following areas of improvement:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 5	The observatory should continue to keep the safety and the health of staff members as the first priority. Beware that workplace stress can have a big health impact.

RCMD 6	On “good practise”: Anticipating delays in sourcing spare parts, that would increase downtime, we recommend investigating sourcing parts in advance from other similar decommissioned systems elsewhere if possible.

RCMD 7	On “share of acquired skill”: Make contact with other divisions about how the know-how developed by VERA in efficient maintenance can be shared with other projects and observatories in NAOJ, or conversely, the operational know-how from other projects be incorporated. These can contribute to the overall efficiency of the observatories in NAOJ.

RECOMMENDATIONS TO NAOJ Executive:

N2	We recommend not to decrease the budget, but to maintain it and explore paths in which it can be increased to alleviate some of the concerning signs and safeguard the valuable investment in infrastructure and human resources, accumulated during the last couple of decades. For further optimization of existing resources, e.g. regarding maintenance, a careful discussion with the NAOJ top management, including the institute observatory's directors is needed. “Tiger teams” of experts could help in specific cases.

(1.4) Has the public outreach been at reasonable level on VERA outcome and the observatory?

The observatory runs a suite of public outreach activities, comprising press releases, open-house days, regular public visits and cooperation with local communities. EHT-related news has had an outstanding impact in Japan, as it has world-wide. It is worth highlighting the elevated quantity of the donations received by the Mizusawa Observatory. These donations are significant in the context of the whole donations to NAOJ and also in the (NAOJ) budget for the Mizusawa Observatory. The panel is particularly impressed by this effort, as well as for the crowdfunding initiative to hire a young researcher in Black Holes (BH) studies. We agree that the elevated amount of the donations is a successful metric of the positive impact of the public outreach activities.

The panel believes it is worth highlighting this forward-looking and proactive strategy and attitude of the staff at Mizusawa Observatory in the midst of the tight budget-related challenges; this follows the same team spirit seen in the measures put in place for the efficient operation and maintenance of VERA. At the same time, having to resort to this source of income for covering the highly optimized running expenses of the observatory raises a red flag. If it is absolutely necessary to keep this situation in place, we invite NAOJ to consider "matching funding" schemes as a further incentive for public donations.

We commend the Observatory for the public engagement generated with their Outreach activities.

The EEC identifies the following areas of improvement:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 8	Mizusawa Observatory should update the public communication strategy, to ensure it delivers the desired objectives, including technical and engineering developments.

RCMD 9M	We note the VERA webpage is obsolete. We recommend working on the webpage showing the scientific and technological highlights to make it useful for researchers and attractive for the general public. It should have a section in English for international impact. Furthermore, it is vital to keep tools (e.g. web pages) updated or removed. The communication strategy should include plans for keeping resources current.

RECOMMENDATIONS TO NAOJ Executive:

N3	We invite NAOJ to consider “matching funding” schemes as a further incentive for public donations while the Observatory is relying so heavily on these, as this would stimulate and encourage such donations.

(1.5) Is the budget and staffing adequate to move to post-VERA science goals?

VERA and Mizusawa Observatory are essential players when national facilities are required, both as stand-alone infrastructure, and as a main component of EAVN and JVN. Projects with high visibility as EHT can only be performed when there are national facilities involved, which provide the essential background and instrumentation but also expert staff in all necessary aspects. That is, input on the instrument front end, back end and the data analysis.

The VERA project improves the research capabilities of universities and other institutions, and contributes to the education of young researchers. It is important to build up a capacity to lead projects in the era of next generation radio instruments. This takes time and should be initiated well in advance of the new instruments coming online. VERA is a perfect pathfinder to do so with the Japanese community, particularly when equipped with next-generation technology developed by Mizusawa Observatory.

VERA is a pathfinder for SKA (and ngVLA) now, and will be part of the network of global telescopes for VLBI observations jointly with SKA. As such it will require to be equipped to match its advanced features and robust operations. In the near future, telescope networks need to be maintained and further upgraded for robust operations. VERA has the technology developed in-house, and should use this strategic position for preparations towards gaining Japanese leadership in the scientific exploitation in the next generation era, by taking steps towards SKA-VLBI science cases using VERA.

It is worrying to see that the budget and staffing are in a critical state. Further reduction of the budget and staffing are not acceptable nor sustainable. Below are some suggestions for attracting extra funding from external projects and from the Observatory technological developments which may be of interest to other observatories, therefore are potential sources for generating additional funding. The panel recommend to explore them:

- Developing instrumentation of interest that may be sold to others (backends etc). Evaluate how to file Patents and protect Intellectual Property rights.
- Acquire external competitive projects, from JSPS Development program, SETI (Search for ExtraTerrestrial Intelligence), geodesy, etc.

For staffing:

- Establish Joint contracts (Example of Sakai-san, 50% paid by newspapers company. Newspapers are always looking for an expert in news items.)
- Foster Secondments of staff, for example people hired by universities or other third parties that work in VERA/Mz.

Given the cost-optimized situation of the Observatory the implementation of some of those probably requires NAOJ seed funding to start generating revenues. Some small extra financing may tip the difference between an upward or downward spiral of performance and capabilities.

Better efficiency could also be achieved by combining or collaborating with groups of other NAOJ facilities, some specific maintenance actions could be better done by “Tiger teams” of specialized workers that go where needed, avoiding duplication.

We commend the Observatory for moving forwards towards the post-VERA science goals.

The EEC identifies the following recommendation and area of concern:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 10M	The panel recommends that the Observatory investigates the suggested possibilities mentioned in Section 1.5 for acquiring extra funding, and any others that arise. We recommend conversations with colleagues from KASI (S. Korea) and/or Yebes (Spain) Observatories to learn about their experiences. These extraordinary measures should be in place for a limited period of time as they are not aligned with the purpose of the observatory.

RCMD 11	On "Staffing": We recommend the Observatory investigate the option of Joint contracts to alleviate the lack of personnel, as post-docs are a driving force for scientific projects, data analysis and increase publications. Consider also secondments of staff from collaborating entities (other projects/observatories inside NAOJ, Japanese universities, etc).

RECOMMENDATIONS TO NAOJ Executive:

N4	The focus of Mizusawa Observatory has been to maintain VERA operations (and observatory activity) at a reduced budget, in a cost effective way and it seems there is no room left for further optimization. Running costs are at the minimum for 4 antenna array, based on international comparisons. Four antennas is the minimum required for calibration using amplitude closure. We recommend keeping at least the same level of funding. It would be dangerous to reduce the budget, as both budget and staffing are fully optimized. We have suggested several possibilities for acquiring extra funding.

N5	The panel recommends that NAOJ explore other funding revenue paths in conversations with Mizusawa Observatory staff. We have suggested in Sect. 1.5 several possibilities for acquiring extra funding and staff. Given the cost-optimized situation of the Observatory these probably require NAOJ to provide initial seed funding, if needed, to start the process.

(2.1) Are the operational status, Japan's contribution, scientific results and impact (including cost-effectiveness) of the EAVN appropriate?

Mizusawa Observatory/VERA plays a major role in the EAVN, a young but expanding network. The nature and outcomes of this collaboration are perfectly aligned with the Purpose, Missions and Primary Scientific Goals for the Mizusawa VLBI Observatory [AD02]. A publication led by Miz Observatory contains a comprehensive overview of the EAVN observing system and early science (Akiyama+2022).

Below we summarize the conclusions from the panel discussions relevant to this review item:

The panel highlights some of the aspects where the contribution of Miz Observatory has a significant impact in EAVN scientific outcomes:

1) EAVN grew out of the Japan/Korea collaborative KaVA (Korean VLBI Network and VERA Array) instrument, and as such Japan/Miz Observatory has a foundational role. VERA is a main player in EAVN, with participation in nearly every EAVN experiment. The EAVN main correlator is a joint Japan-Korea facility and Japan funds ⅓ of operational costs for processing EAVN data (~1000 hours/year).

2) EAVN is a young and growing network that is delivering exciting internationally competitive early science, such as the high impact M87 studies recently published in Nature (Cui et al. 2023), where VERA played a critical role. The Ogasawara and Ishigaki-jima stations are located at the easternmost and southernmost ends of the EAVN, respectively, and are the critical stations for achieving high resolution and high imaging performance of the EAVN, as required cutting edge science in the study of black holes using AGN observations (Mizusawa Observatory's *Primary Scientific Goal 1*.).
3) The distinct dual-beam system in VERA stations enables a unique bona-fide precision astrometry EAVN capability in the so-called hybrid observing mode, where the combination of the dual-beam system from VERA antennas operating within the larger EAVN array results in improved astrometry outcomes, by removing source structure systematic effects which limit the precision. This is the basis to produce astrometric animations (i.e. movies) for dynamic studies of late-type stars within the ESTEMA EAVN Large Project (e.g. Xu et al. 2022) (Mizusawa Observatory's *Primary Scientific Goal 2*.).
4) Fast progress towards enabling broadband EAVN capacity, using the OCTAVE system developed by Mizusawa Observatory, which is currently enabling 4 times larger recording rate (16 Gbps) than the highest available in most other VLBI array (4 Gbps for VLBA & EVN; 1 Gbps for LBA), and with plans to increase it to 8 times larger (32 Gbps). The OCTAVE system is already installed in many EAVN antennas and discussions for open use of broadband EAVN observations are underway. The outstanding sensitivity is a sure path to turn EAVN into a very competitive array, attracting more proposals to carry out internationally competitive science, through its open use program.
5) Operational status of EAVN:
   The EAVN organization into science working groups with focus on different research fields is a good idea, as this contributes to building up collaborations in the region (and beyond) and promoting an effective use of the array. This approach guarantees the demand for the array arises from the science drivers across many areas of expertise. Moreover it contributes with a positive impact in the education of young researchers. Mizusawa Observatory leads the User support initiatives, with development of pipelines, Key/sched sample files to prepare observations, and a helpdesk service.

We, the panel, assess the cost-effectiveness of Japan’s contribution to the EAVN to be appropriate, based on details presented in Review Item 4.

We commend the Observatory for the major contributions to EAVN.

The EEC identifies the following areas of improvement:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 12	On Contribution to Improve EAVN visibility, Output and Statistics: The oversubscription rate for EAVN is ca. 1 and this needs to be improved; also it is dominated by East Asia researchers. We request that Mizusawa observatory uses its international standing and connections to work towards increasing the pool of users and number of proposals: - 12a) More global advertising. Eg. researchers presenting EAVN results in international meetings, could be encouraged to include one slide for this purpose prepared by the Observatory. This should include array characteristics, unique features, proposal details, scientific highlights. - 12b) To improve international visibility, the proposal referees could include international ("at large") members.

RECOMMENDATIONS TO NAOJ Executive:

N6	We recommend keeping operational all 4 VERA antennas and their unique dual-beam system to further expand the competitive science with EAVN (and VLCOP) programs.

(2.2) Is the coordination with JVN, and contribution to university research and education appropriate?

The Mizusawa VLBI Observatory has contributed to graduate education on several levels. First, students from the University of Tokyo and SOKENDAI are directly supervised by faculty members at Mizusawa. Second, educational activities, including observations and operations, are conducted at VERA IRIKI station in cooperation with Kagoshima University. In addition, the Mizusawa VLBI Observatory indirectly contributes to the education of local universities at the major JVN stations in Ibaraki, Yamaguchi, Gifu, and Tomakomai (which is no longer in operation).

Education for University of Tokyo, Sokendai, and Kagoshima University students using VERA

Despite the relatively limited number of staff, the Mizusawa VLBI Observatory has hosted and provided research opportunities for a significant number of

students, mainly from the University of Tokyo and SOKENDAI (a total of 28 students since 2010 and 7 since 2019, over the past 5 years). Some of these students are currently in leadership positions as faculty members at research institutes or universities. The student interviewed during the review worked on a topic related to complex observing technique, which is only possible under the guidance of supervisors who are deeply involved in the operation and development of the observatory site.

The cooperation with Kagoshima University at IRIKI Station has also yielded significant results not only in operations but also in education: since 2005, 17 students have received Ph.D. degrees and 67 have received master's degrees. This is an outstanding number for a university that is not a designated national university like the University of Tokyo. Students from Kagoshima University also visit Mizusawa Observatory to learn about telescope operation and data reduction, and to interact with Mizusawa staff and students.

The educational programs with hands-on telescopes at VERA sites were unique. The panel hopes that these will be continued and if possible, expanded. For example, we recommend starting discussion of exploring the possibility of inviting students not only from universities in the JVN, but also from other nearby research-oriented universities, such as Tohoku University. Although not a direct charge of this review, similar results have been achieved in the activities of the JVN, and the panel believes that such educational activities can be continued and developed in the future with the universities participating in the JVN.

Toward a future of improved cooperation between JVN, universities, and the Mizusawa VLBI Observatory

VERA is in the early stages of a new project with redefined goals, but it is good that it is focusing on more integrated operations with JVN and EAVN. According to the presentation materials at last year's VLBI symposium of the Japan VLBI Consortium[4], seven of the VLCOP programs to be implemented in 2022-2023 have been submitted by universities, all of which are JVN core members (4 from Kagoshima, 2 from Yamaguchi, and 1 from Ibaraki). This can be regarded as a good start, but there is room for further expansion in the future, and the panel hopes that the VLCOP program will be more widely used as a venue for observational research, development, and student training, as well as for further deepening the collaboration between JVN/EAVN and VERA.

[4] https://drive.google.com/file/d/1buHxmDyWrJHNqQ8XvXgJYdrw3aYb0eW0/view

Due to lack of time during this review, it was not possible to review in detail the collaboration with universities outside the JVN using VERA and to identify problems or barriers in its implementation, with the sole exception of insufficient documentation for data analysis. One of the reviewers found out after the review that there is a master student from the University of Electro-Communications (not included in JVN) who is conducting research activities with EATING VLBI at the Mizusawa VLBI Observatory as a special research student. Therefore, the review panel has no specific recommendations for improvement, but looks forward to the Observatory considering the actions necessary to develop users and expand VERA/JVN as a venue for human resource development, and to reaching out to non-JVN universities to expand training for graduate students from other fields in the future.

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 13	The educational programs with the University of Tokyo, Sokendai, and Kagoshima University are unique and diverse. The panel hopes that these will be continued and if possible, expanded. For example, we recommend starting discussions about inviting students not only from universities in the JVN, but also from other nearby research-oriented universities, such as Tohoku University.

RCMD 14M	We recommend that the VLCOP will continue to expand VERA users and educational opportunities at the JVN participating universities as well as other universities. The remarkable results in education have been achieved in both VERA and the JVN activities, and the panel looks forward to further developing these efforts under VLCOP.

(2.3) Does the observatory expand EAVN well, and contribute to mm VLBI, and global VLBI and produce research outcome through collaboration?

VERA is a main player in EAVN, providing machine time, a long term expertise to operate a network and advanced high data rate capacity technology. Mizusawa Observatory is at the core of the EHT collaboration, leading the japanese contribution, eg ALMA phase-up, development of imaging tools, multiwavelength (mm) follow up of EHT main targets M87/SgrA*. The latter, a collaboration led by Mizusawa Observatory researchers and young researchers educated in the Observatory, involves EAVN, and VERA VLCOP, and has produced the main scientific outcomes in both networks. Pursuing

this forefront science is a good driver for future expansion of EAVN towards higher frequencies (eg 3mm); we recognize the internationally competitive science from this program and recommend the ongoing developments to equip VERA for 86 GHz observations and integrate it for multi-frequency simultaneous observations with 22 and 43 GHz.

VERA was a founding member of East Asia to Italy: Nearly Global (EATING) VLBI international project with joint observations between VERA and the three VLBI Italian telescopes (INAF, Italy). This successful collaboration story is now expanded to include the EAVN and is a precursor towards the Global VLBI Alliance (GVA).

We commend the Observatory for the contributions to EAVN.

The EEC identifies the following areas of improvement:

RECOMMENDATIONS TO THE OBSERVATORY:

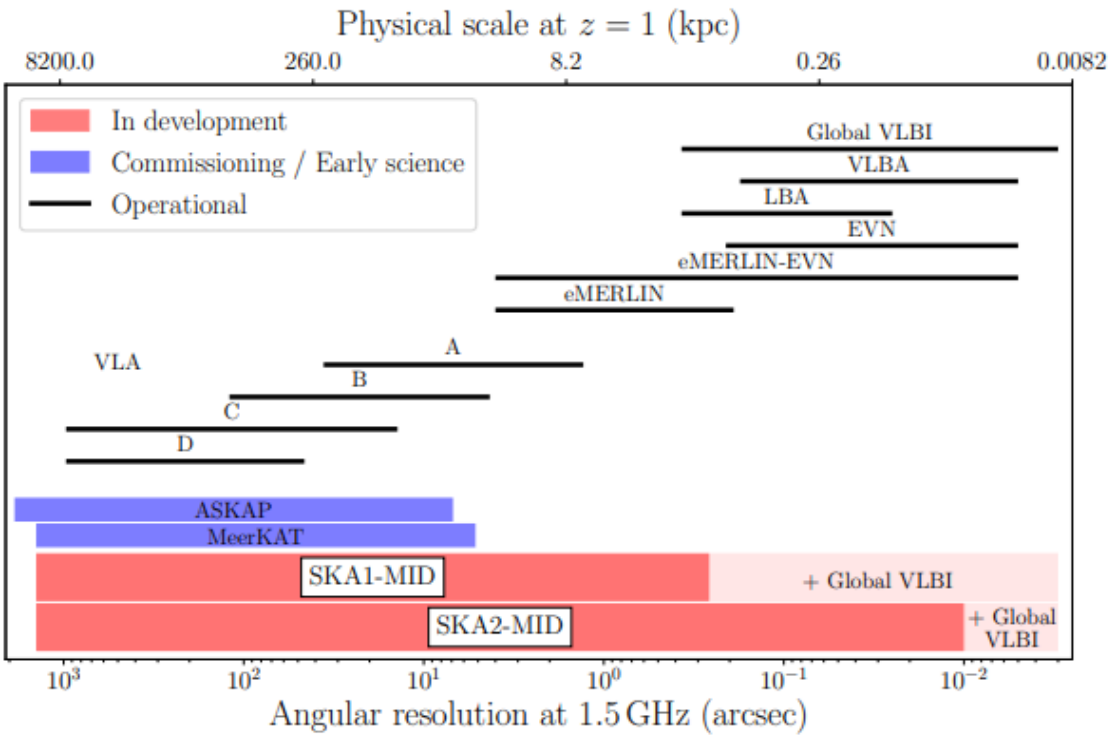
RCMD 15M	Increase Frequency Range -15a) We recommend to pursue ongoing developments aiming at equipping VERA, and suitable EAVN stations, for 86 GHz observations and integrate it for multi-frequency simultaneous observations with 22 and 43 GHz to continue the current high impact science. - 15b) There are important regional developments towards the lower frequencies, especially with FAST getting VLBI-ready. This is a very significant and unique opportunity in the building up towards SKA-VLBI. The VLBI exploitation is a great opportunity in the region. While we understand that the resources are limited, the Observatory should also consider to be part of this, based on their unique contribution and experience.

RCMD 16M	We recommend the following measures to improve and create global collaborations: - 16a) Japan has great potential to lead the SKA-VLBI and Global VLBI Alliance. The Observatory should discuss with NAOJ executives how to participate. - 16b) Discussions with other arrays to develop compatible instrumentation, while exploiting complementarity. - 16c) Explore new collaborations with international VLBI networks (e.g. an associate membership of EVN?). - 16d) Discuss the future of EAVN after 2030.

(2.4) Has the observatory's study on SKA made good progress?

Japan Science Council has developed a Master Plan for participation in SKA since 2010, which is reviewed every 3 years, and a SKA-JP symposium is held annually. Very important achievements are the two Science Books (2015, 2020) and the PASJ Special Issue (2023). The contribution of Mizusawa Observatory is outstanding, in particular the development of new instrumentation and the scientific output of the working groups. This committee will however not enter to evaluate its impact as contribution to SKA as a whole, since this is out of its competences.

There is on the other hand a very clear specific role for Mizusawa Observatory in the preparatory and current construction of the first phase of SKA (SKA-1), to mention the technology development for wideband recorders, and the contribution of VLBI science by astrometry with high sensitivity, or ultra-precise astrometric surveys with many sources (multi-beam VLBI, soon MultiView with multi-beam systems). It is to be noted that SKA-VLBI, which defines the inclusion of the SKA-1 into VLBI arrays, and/or the combination of SKA-1 with long VLBI baselines, provides capabilities to realize many of the SKA-2 science goals[5] indicated in the SKA Science Book.



[5] https://arxiv.org/pdf/1901.10361

Specifically, Mizusawa Observatory (and Japan, in general) could contribute greatly to the efforts on SKA-VLBI. This requires the completion of the Global VLBI Alliance[6] (GVA) to coordinate the VLBI networks to involve (EVN, VLBA, EAVN, LBA, maybe AVN (African VLBI Network) and IVIA (Initiative for VLBI in IberoAmerica) someday). This GVA will partner in a SKA-VLBI Consortium, who completes the developments in SKA and provides the instrumentation (VLBI terminal) and organizes the correlation. The EC project "JUMPING JIVE" site lists some major opportunities for fundamental contributions to development of SKA-VLBI. There are some major opportunities for contributions to development of SKA-VLBI that match the skills of the Mizusawa Observatory.

- D10.1: Details on VLBI interfaces to SKA consortia[7]
- D10.2: Operational model for inclusion of SKA in Global VLBI[8]
- D10.3: Portfolio of SKA-VLBI Science cases with details on science requirements[9]
- D10.4: Report on SKA-VLBI Key Science Projects[10]

In the short/mid term, tests with joint observations between the SKA-MID precursor MeerKAT (in South Africa) and existing VLBI networks, in particular the EVN and EAVN, could help prototype SKA-VLBI by realizing MeerKAT-VLBI.

The large project resembles an "Iceberg" in which SKA facility is the tip, while the rest of the iceberg are the national facilities that maintain locally the essential required expertise; in this respect, SKA requires local expertise in member countries, national facilities provide experience in operations of great value. Moreover, since SKA-VLBI does not require SKA-JP, these developments -and specifically the SKA-VLBI Consortium- could be led by Mizusawa Observatory. Thus this represents a great opportunity for Mizusawa, but needs to be supported by NAOJ; we recommend exploring the requirements with discussion documents, which require no (or very little) expenditure but place the Observatory in the prime position.

We commend the Observatory for hosting the SKA1 Promotion Group (SKAJ).

[6] http://www.gvlbi.org/
[7] https://jumping.jive.eu/exec/d10.1.pdf
[8] https://jumping.jive.eu/exec/d10.2.pdf
[9] https://jumping.jive.eu/exec/d10.3.pdf
[10] https://jumping.jive.eu/exec/d10.4.pdf

The EEC identifies the following opportunities:

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 17M	The Observatory should study the requirements for the global efforts in SKA-VLBI, specifically: - 17a) the development of an SKA-VLBI Consortium which would link the SKA to the VLBI networks by the completion of the Global VLBI Alliance (GVA) - 17b) the development of a VLBI terminal capable of meeting SKA data rate requirements.

RECOMMENDATIONS TO NAOJ Executive:

N7	NAOJ needs to plan for its involvement in SKA and support the observatory if it is going to contribute to SKA-VLBI and GVA.

(3) Does the observatory respond well to recommendations in the 2018 review?

We, the panel, commend the Mizusawa Observatory for taking on board all the recommendations in the previous report. In particular, the Mizusawa Observatory has been working hard to improve efficiency in maintenance and operation, resulting in the 68% cost cut. The observatory adopts in-house mode for the maintenance of the telescope, such as painting and EL motor replace, to cut the cost to be paid to manufacturers. A new scientific operation mode of VERA, VLCOP Program, has enabled the observatory to continue scientific observations with VERA under the very tight budget condition. The Mizusawa observatory is also promoting open use of KaVA / EAVN, and the observing time is now ~1000 hours per year. With these telescopes, the Mizusawa Observatory has been producing cutting-edge science in various scientific fields. Those scientific highlights include the EHT and EAVN observations of M87, monitoring of the maser motions with KaVA, and parallax measurements of Sgr A*. The view of the panel is that the Mizusawa Observatory has responded well to all the recommendations from the review in 2018.

(4) Is the Mizusawa VLBI observatory competitive among similar research institutions overseas in terms of (1.1), (2.1), and (2.2), excluding the JVN results?

We present comparative discussions with respect to similar overseas institutions on, first, in terms of the outcomes and operations of VERA, in VLCOP and EAVN observations, and, second, in terms of contribution to university research and education.

Firstly, we propose to assess the competitiveness of Mizusawa Observatory by comparing VERA to the American, European and Australian VLBI arrays. The detailed comparison is in Appendix A, which should not be publicized.

We have sourced information on publications, observing times and budget to the best of our ability based on information provided by the Observatory, EVN Biennial Reports, ATNF Annual Reports for LBA, and personal communications for VLBA under the commitment to keep this confidential and solely for the purpose of this report (specially budget-wise).

We extract the following conclusions from the comparison of VERA performance with other arrays:
Cost-effectiveness:

1) VERA operational costs are extremely low in comparison with other facilities in Europe and USA, in total budget per hour and also on a per-antenna basis.
2) VERA has a similar operational cost to the Australian LBA, while providing nearly 2-3 times the observation time.

Publication/outcomes:

3) VERA number of publications per year is less than for the EVN and much less than for VLBA but better than LBA.
4) The VERA publication costs are extremely low compared to other arrays, which underlines the cost-effectiveness of the array.

This means that VERA is competitive in terms of number of publications per hour of observation and very competitive in terms of number of publications per dollar. We note also that VERA science is dominated by astrometry, which requires multiple observing sessions, whereas the other arrays can focus on science requiring a single observing epoch. Nevertheless the reduction of budget has had a noticeable negative impact in the number of publications in the second half of the period under evaluation since 2021. The panel strongly believes that early actions should be put in place so this trend can be reversed.

Other comparison metrics (not from table):

5) Statistics by proposal oversubscription: VLBA 2.0; EVN 1.8; LBA 1.5; VERA/EAVN ~ 1
6) Max. Recording Rate (currently): VERA 24 Gbps; EVN,VLBA 4 Gbps; EAVN 1 Gbps; LBA 1 Gbps

This means that VERA is very competitive in terms of recording rate and thus sensitivity, which scales with the square root of the recording rate and there is room for improvement in proposal submission.

The fundamental role of the Observatory and VERA in EAVN is described in detail in Section 2.

Secondly, on the question whether the Observatory is competitive in terms of contribution to university research and education: The Observatory plays a key role in university research and education. The Iriki station of VERA is the central place for students in Kagoshima university to learn and operate a radio telescope and radio interferometer. In the era of big telescopes such as ALMA, students have little chance to directly see and operate telescopes, and the VERA telescopes located in Japan are therefore precious for Japanese students. Many students working on radio astronomy, not just students working on the VERA data but also ALMA and the other data, participate in the operation of VERA for their own education. Present and forthcoming PhD (not master) students are working on the KaVA and EAVN data. The Kagoshima research group has been publishing VERA papers continuously.

RECOMMENDATIONS TO THE OBSERVATORY:

The recommendations [RCMD 13, 14M] in section 2.2 also apply here

RECOMMENDATIONS TO NAOJ Executive:

N8	The Observatory/VERA are performing extremely well compared to other international institutions. We are concerned that this might not be sustainable under the current plan for a budget drawdown. The panel strongly feels that expectations of running VERA on such a tight budget is not compatible with international standards, as shown in discussions in Sect. 4. The link between VERA and universities is well established, and provides education to many students in high education institutions. We strongly recommend that NAOJ continues to support the Observatory with the necessary budget, which should at least be maintained.

(5.1) Advise how does NAOJ operate the NRO, Mizusawa, and ASTE projects more efficiently: these projects are currently managed separately by NAOJ.

The idea of combining the operations for Mizusawa, Nobeyama, and ASTE is being considered as a way to manage Mizusawa Observatory and the other two observatory/project effectively. Commonality exists in maintenance, as all telescopes built by Mitsubishi Electric, which allows for potential collaboration in this area. However, the combining operations are not necessarily simple and/or easy because the three institutes are very different, with the only exception being the VLBI operations in Nobeyama. The in-house expertise in Mizusawa Observatory could be transferable, but there are barriers due to the organization structures. For example, Nobeyama pays Mitsubishi for maintenance, which is a different style of working. ASTE has less overlap.

RECOMMENDATIONS TO NAOJ Executive:

N9	We recommend that NAOJ formalizes the communication between the directors (and internal experts) of the three institutes to reach an agreement on how to maintain the three observatories, given the further decrease of the available budgets. The Tiger Team concept is one of cost-effective optimized operations of the three institutes. In any case, this decision should involve relevant expert people in the observatories in the decision making process, as they will be highly impacted. Support will be required to accommodate the required flexibility in work assignments within NAOJ policy, with special attention not to overload the staff with duties beyond their core responsibilities.

(5.2) Future Plans of Miz VLBI Observatory

Mizusawa Observatory has a bright future, both as a core institution of EAVN and other international projects, in particular those that are VLBI-related, and with VERA as a stand-alone facility. Furthermore it is recognized by the Square Kilometer Array Observatory (SKAO) as a pathfinder for SKA, and it can be for other coming next-generation radio instruments; we refer to discussions on the technological contributions (sect. 1.2) and the importance of building up the future Japanese SKA user community (sect. 1.5).

Regarding VERA (stand-alone), it is essential to continue identifying KSPs

which exploit its unique capabilities, given the current world-beating broadband and dual beam systems. Below are some on-going VLCOP projects that could be developed into KSPs:

1) Follow up of the SgrA* trigonometric parallax measurement project at 43 GHz with improved calibration (e.g. water vapor radiometers, MultiView observations, etc). In the near future, when available, expand to astrometry at 86 GHz.
2) Astrometry studies of evolved OH/IR stars is a VLBI-unique niche and can provide complementary results to Gaia's astrometry.
3) Dynamic picture of Galactic bulge region using astrometry measurements towards SiO masers.
4) Furthermore, observations of Maser-Quasar pairs within reach now because of VERA increased sensitivity.

The committee supports the on-going high frequency developments at 86 GHz, and its integration into the simultaneous Multi-frequency capability. VERA, NAOJ and KVN would then share this unique mode and benefit EAVN observations. This is a unique opportunity for VERA, since it would benefit from advanced technology developments before other arrays, particularly in Europe, catch up. Non-local users could be attracted by improving the international visibility of the post-galactic astrometry VERA, e.g. promoting the VERA catalog and web (including a version in English), attending conferences (also abroad and of other disciplines) etc.

EAVN involvement must of course continue, and the collaboration with other VLBI networks within the Global VLBI Alliance. We agree with the views of Mizusawa Director, that the future direction of VLBI is through collaboration rather than competition, in the context of Global VLBI. Mizusawa Observatory will keep contributing to EAVN through operation of VERA and the KJCC correlator, and conducting research.

The future of SKA in Japan is tightly linked to Mizusawa Observatory, the seed and core for developments but also training of skilled staff. VERA is already recognized as a pathfinder by the SKA Observatory. An appropriate budget is required; therefore it is expected that the current one is at least maintained, and not reduced. As for additional funding, new paths to generate external funding for Mizusawa Observatory should be explored, in addition to those in place (like JSPS grants and crowd funding). Some suggestions have already been mentioned in Section 1.5, for example, by exploring possible paths for revenue benefits from technological developments, to be in place for a limited period of time and with initial investment of NAOJ to make these happen.

A long-term array maintenance plan should build on the success of adaptation to the recent conditions. We recommend joint discussions to explore the pros and cons from a collaboration with other institutions (Nobeyama Observatory, universities) through the establishment of "Tiger teams" of experts, or secondment of staff to Mizusawa Observatory.

RECOMMENDATIONS TO THE OBSERVATORY:

RCMD 18M	Enhance stand-alone VERA and EAVN to continue to deliver internationally competitive science. - 18a) Formalize the definition of new KSP projects that will exploit the unique opportunity of VERA, given the current world-beating broadband system, based on some of the on-going VLCOP projects. Consider the benefits of using the EAVN for those KSPs when the array is equipped with matching broadband system. - 18b) Improve the international visibility of the post-galactic astrometry VERA era, promoting the VERA catalog and web (including a version in English), attending conferences (also abroad and of other disciplines) to attract new local & international users.

RCMD 19M	Explore and Exploit unique features: VERA as a Pathfinder for next generation radio instruments: -19a) Exploit the unique opportunities of the VERA dual-beam system, and 86 GHz, immediately, benefiting from advanced technology developments before other arrays catch up. -19b) Explore the impact of broadband and simultaneous multi-source observations capabilities for precise VLBI astrometry, paving the way towards ultra precise and large astrometric surveys. -19c) Explore the combination of dual-beam and multi-frequency VERA features for enhanced coherence time and mm-VLBI precise astrometry. -19d) Review the opportunities for Low-Frequency high-sensitivity astrometry with FAST, as this is relevant for a pathfinder instrument and potentially leads into SKA-VLBI. -19e) Ensure robust operations of the VERA Network, by appropriate maintenance of the systems.

RCMD 20M	Continue the involvement in EAVN, contributing through

	operation of VERA and the KJCC correlator, and conducting research.

RCMD 21	Develop a long-term maintenance plan for the Observatory. Consider the pros and cons of a collaboration with other institutions (e.g. Nobeyama Observatory, universities) through, for example, the establishment of “Tiger teams” of experts, or secondment of staff to Mizusawa Observatory.

RECOMMENDATIONS TO NAOJ Executive:

We note that N7 is also relevant to Section 5.2 on Future plans.

Appendix A: Comparative Table

(Not for public release)

Appendix B: Summary of Recommendations (grouped by Sections)

(nomenclature: RCMD/N *number[letter]*; RCMD *number[letter]*M if major)

	Recommendations to Mizusawa Observatory	
Section 1.1		
RCMD 1M	Improve VERA visibility for enhanced Output and better Statistics - 1a) Some exciting results such as in EHT are made possible because of existing Research Infrastructures, which must be made more visible when presenting the headline results. - 1b) We would encourage the presentation of VERA results at international conferences to make them more visible to researchers outside the VLBI community. At these VLBI conferences, to improve international visibility, stress the new opportunities with the new era of VERA (post-galactic KSP astrometry). That is the promotion of the VLCOP model and EAVN. Make a common practice to include a couple of slides with highlights and capabilities with the aim to attract non-local users. - 1c) User friendliness: Address issues with insufficient guidelines for VERA data analysis. We understand the lack of such guidelines was a flag raised by many students in the last VLBI-consortium meeting held in Dec 2023. Then it was decided to create a new working group to generate such documentation and maintain it. We suggest the formation and support of a Working Group explicitly for this issue. - 1d) Investigate the option of pre-processing of the data, with some of the basic steps, prior to downloading the data. - 1e) Help students to grow a smooth relationship with VERA data reduction and keep new experienced VLBI users happy. Consider using or adapting the existing user support in place for EAVN, which provides data analysis scripts for “AIPS”, sample key file and helpdesk. - 1f) Produce English documentation to encourage widespread use in the global community. Google translate plus a read through by an expert should be sufficient. Investigate including a version in English of the VLBI Consortium report (including the info on KSPs). - 1g) The link between VERA and universities is well established, providing education to many students in high-education institutions; we recommend that this good work should continue along side advertising of the science capabilities of VLBI.	Major
RCMD 2	On Publications and Citations: - 2a) Consider requesting inclusion of authors from a “Builders List” for publications that use the highest recording rate capability provided by OCTAVE-DAS (to increase publications from the observatory staff) - 2b) Citation of VERA Collaboration, Hirota+2020 paper “VERA Catalog” is low for such a significant work (69). We recommend that the online archive (and other earlier data products) is made more accessible, to increase utilization and thus recognition. Vizier would be a suitable resource.	
Section 1.2		
RCMD 3M	The Mizusawa VLBI Observatory develops next-generation technology internationally recognized. The Observatory should develop a more specific technology roadmap to take advantage of these opportunities.	Major

RCMD 4	The panel is concerned that the long term operations under a critical tight budget could hinder the worldwide lead position in broad-band next-generation technological developments of the Observatory. The panel suggests the Observatory explore ways to attract additional funding, e.g. via commercialization of technologies (see section 1.5 for further discussions).	
Section 1.3		
RCMD 5	The observatory should continue to keep the safety and the health of staff members as the first priority. Beware that workplace stress can have a big health impact.	
RCMD 6	On “good practise”: Anticipating delays in sourcing spare parts, that would increase downtime, we recommend investigating sourcing parts in advance from other similar decommissioned systems elsewhere if possible.	
RCMD 7	On “share of acquired skill”: Make contact with other divisions about how the know-how developed by VERA in efficient maintenance can be shared with other projects and observatories in NAOJ, or conversely, the operational know-how from other projects be incorporated. These can contribute to the overall efficiency of the observatories in NAOJ.	
Section 1.4		
RCMD 8	Mizusawa Observatory should update the public communication strategy, to ensure it delivers the desired objectives, including technical and engineering developments.	
RCMD 9M	We note the VERA webpage is obsolete. We recommend working on the webpage showing the scientific and technological highlights to make it useful for researchers and attractive for the general public. It should have a section in English for international impact. Furthermore, it is vital to keep tools (e.g. web pages) updated or removed. The communication strategy should include plans for keeping resources current.	Major
Section 1.5		
RCMD 10M	The panel recommends that the Observatory investigates the suggested possibilities mentioned in Section 1.5 for acquiring extra funding, and any others that arise. We recommend conversations with colleagues from KASI (S. Korea) and/or Yebes (Spain) Observatories to learn about their experiences. These extraordinary measures should be in place for a limited period of time as they are not aligned with the purpose of the observatory.	Major
RCMD 11	On "Staffing": We recommend the Observatory investigate the option of Joint contracts to alleviate the lack of personnel, as post-docs are a driving force for scientific projects, data analysis and increase publications. Consider also secondments of staff from collaborating entities (other projects/observatories inside NAOJ, Japanese universities, etc).	

Section 2.1		
RCMD 12	On Contribution to Improve EAVN visibility, Output and Statistics: The oversubscription rate for EAVN is ca. 1 and this needs to be improved; also it is dominated by East Asia researchers. We request that Mizusawa observatory uses its international standing and connections to work towards increasing the pool of users and number of proposals: - 12a) More global advertising. Eg. researchers presenting EAVN results in international meetings, could be encouraged to include one slide for this purpose prepared by the Observatory. This should include array characteristics, unique features, proposal details, scientific highlights. - 12b) To improve international visibility, the proposal referees could include international (“at large”) members.	
Section 2.2		
RCMD 13	The educational programs with the University of Tokyo, Sokendai, and Kagoshima University are unique and diverse. The panel hopes that these will be continued and if possible, expanded. For example, we recommend starting discussions about inviting students not only from universities in the JVN, but also from other nearby research-oriented universities, such as Tohoku University.	
RCMD 14M	We recommend that the VLCOP will continue to expand VERA users and educational opportunities at the JVN participating universities as well as other universities. The remarkable results in education have been achieved in both VERA and the JVN activities, and the panel looks forward to further developing these efforts under VLCOP.	Major
Section 2.3		
RCMD 15M	Increase Frequency Range -15a) We recommend to pursue ongoing developments aiming at equipping VERA, and suitable EAVN stations, for 86 GHz observations and integrate it for multi-frequency simultaneous observations with 22 and 43 GHz to continue the current high impact science. - 15b) There are important regional developments towards the lower frequencies, especially with FAST getting VLBI-ready. This is a very significant and unique opportunity in the building up towards SKA-VLBI. The VLBI exploitation is a great opportunity in the region. While we understand that the resources are limited, the Observatory should also consider to be part of this, based on their unique contribution and experience.	Major
RCMD 16M	We recommend the following measures to improve and create global collaborations: - 16a) Japan has great potential to lead the SKA-VLBI and Global VLBI Alliance. The Observatory should discuss with NAOJ executives how to participate. - 16b) Discussions with other arrays to develop compatible instrumentation, while exploiting complementarity.	Major

	- 16c) Explore new collaborations with international VLBI networks (e.g. an associate membership of EVN?). - 16d) Discuss the future of EAVN after 2030.	
Section 2.4		
RCMD 17M	The Observatory should study the requirements for the global efforts in SKA-VLBI, specifically: - 17a) the development of an SKA-VLBI Consortium which would link the SKA to the VLBI networks by the completion of the Global VLBI Alliance (GVA) - 17b) the development of a VLBI terminal capable of meeting SKA data rate requirements.	Major
Section 4		
RCMD 13	The educational programs with the University of Tokyo, Sokendai, and Kagoshima University are unique and diverse. The panel hopes that these will be continued and if possible, expanded. For example, we recommend starting discussions about inviting students not only from universities in the JVN, but also from other nearby research-oriented universities, such as Tohoku University.	
RCMD 14M	We recommend that the VLCOP will continue to expand VERA users and educational opportunities at the JVN participating universities as well as other universities. The remarkable results in education have been achieved in both VERA and the JVN activities, and the panel looks forward to further developing these efforts under VLCOP.	Major
Section 5.2		
RCMD 18M	Enhance *stand-alone* VERA and EAVN to continue to deliver internationally competitive science. - 18a) Formalize the definition of new KSP projects that will exploit the unique opportunity of VERA, given the current world-beating broadband system, based on some of the on-going VLCOP projects. Consider the benefits of using the EAVN for those KSPs when the array is equipped with matching broadband system. - 18b) Improve the international visibility of the post-galactic astrometry VERA era, promoting the VERA catalog and web (including a version in English), attending conferences (also abroad and of other disciplines) to attract new local & international users.	Major
RCMD 19M	Explore and Exploit unique features: VERA as a Pathfinder for next generation radio instruments: -19a) Exploit the unique opportunities of the VERA dual-beam system, and 86 GHz, immediately, benefiting from advanced technology developments before other arrays catch up. -19b) Explore the impact of broadband and simultaneous multi-source observations capabilities for precise VLBI astrometry, paving the way towards ultra precise and large astrometric surveys. -19c) Explore the combination of dual-beam and multi-frequency VERA features	Major

	for enhanced coherence time and mm-VLBI precise astrometry. -19d) Review the opportunities for Low-Frequency high-sensitivity astrometry with FAST, as this is relevant for a pathfinder instrument and potentially leads into SKA-VLBI. -19e) Ensure robust operations of the VERA Network, by appropriate maintenance of the systems.	
RCMD 20M	Continue the involvement in EAVN, contributing through operation of VERA and the KJCC correlator, and conducting research.	Major
RCMD 21	Develop a long-term maintenance plan for the Observatory. Consider the pros and cons of a collaboration with other institutions (e.g. Nobeyama Observatory, universities) through, for example, the establishment of “Tiger teams” of experts, or secondment of staff to Mizusawa Observatory.	

	Recommendations to NAOJ Executive
Section 1.1	
N1	The Observatory has the infrastructure and human resources capacity to carry out the recommendations above. - 1a) We recommend that NAOJ continues supporting the Observatory, maintaining the current funding levels to enable robust operations of the VERA network as part of EAVN and VLCOP programs
Section 1.3	
N2	We recommend not to decrease the budget, but to maintain it and explore paths in which it can be increased to alleviate some of the concerning signs and safeguard the valuable investment in infrastructure and human resources, accumulated during the last couple of decades. For further optimization of existing resources, e.g. regarding maintenance, a careful discussion with the NAOJ top management, including the institute observatory's directors is needed. “Tiger teams” of experts could help in specific cases.
Section 1.4	
N3	We invite NAOJ to consider “matching funding” schemes as a further incentive for public donations while the Observatory is relying so heavily on these, as this would stimulate and encourage such donations.
Section 1.5	
N4	The focus of Mizusawa Observatory has been to maintain VERA operations (and observatory activity) at a reduced budget, in a cost effective way and it seems there is no room left for further optimization. Running costs are at the minimum for 4 antenna array, based on international comparisons. Four antennas is the minimum required for calibration using amplitude closure. We recommend keeping at least the same level of funding. It would be dangerous to reduce the budget, as both budget and staffing are fully optimized. We have suggested several possibilities for acquiring extra funding.

N5	The panel recommends that NAOJ explore other funding revenue paths in conversations with Mizusawa Observatory staff. We have suggested in Sect. 1.5 several possibilities for acquiring extra funding and staff. Given the cost-optimized situation of the Observatory these probably require NAOJ to provide initial seed funding, if needed, to start the process.
Section 2.1	
N6	We recommend keeping operational all 4 VERA antennas and their unique dual-beam system to further expand the competitive science with EAVN (and VLCOP) programs.
Section 2.4	
N7	NAOJ needs to plan for its involvement in SKA and support the observatory if it is going to contribute to SKA-VLBI and GVA.
Section 4	
N8	The Observatory/VERA are performing extremely well compared to other international institutions. We are concerned that this might not be sustainable under the current plan for a budget drawdown. The panel strongly feels that expectations of running VERA on such a tight budget is not compatible with international standards, as shown in discussions in Sect. 4. The link between VERA and universities is well established, and provides education to many students in high education institutions. We strongly recommend that NAOJ continues to support the Observatory with the necessary budget, which should at least be maintained.
Section 5.1	
N9	We recommend that NAOJ formalizes the communication between the directors (and internal experts) of the three institutes to reach an agreement on how to maintain the three observatories, given the further decrease of the available budgets. The Tiger Team concept is one of cost-effective optimized operations of the three institutes. In any case, this decision should involve relevant expert people in the observatories in the decision making process, as they will be highly impacted. Support will be required to accommodate the required flexibility in work assignments within NAOJ policy, with special attention not to overload the staff with duties beyond their core responsibilities.
Section 5.2	
N7	NAOJ needs to plan for its involvement in SKA and support the observatory if it is going to contribute to SKA-VLBI and GVA.

Appendix C

Schedule of meetings of the EEC Review Panel:

Date yyyy.mm.dd; hh:mm (JST)	Location
2023.10.31; 16:00-17:00	@Remote/Zoom
2023.12.19; 17:00-18:00	@Remote/Zoom
2023.12.22; 17:00-18:00	@Remote/Zoom
2024.03.07; 09:00-18:15	@ Mizusawa VLBI Observatory
2024.03.08; 09:00-17:00	@ Mizusawa VLBI Observatory
2024.05.02;16:00-17:00	@Remote/Zoom
2024.05.10; 17:00-19:00	@Remote/Zoom
2024 5.31 16:00-17:15	@Remote/Zoom

Agenda of Review Meeting held in Mizusawa Observatory, March 7-8, 2024:

Day 1 Date: Thursday, March 7, 2024 9:00–18:15 Place: NAOJ Mizusawa Campus, Main Building, Conference Room 309 (3F)	
◆Advance Meeting (closed)	
09:00 – 09:35	EEC meeting (face-to-face intro & revise review plan)
◆Mutual Introductions (open)	
09:45 – 10:05	Introduction of the project members to the EEC; Introduction of the EEC members to the attendees and of the agenda of this Review meeting.
◆Presentation from MIZ (1) (open)	
10:05 – 12:13	Presentation from the project for Review Item **[1]** + Q&A
12:13 – 13:10	(Lunch Break)
◆Presentation from MIZ (2) (open)	
13:10 – 15:02	Presentation from the project for Review Item **[1]** + Q&A (continued)
15:02 – 15:12	(Break)
15:12 – 17:08	Presentation from the project for Review Item **[2]** + Q&A
◆Interview (1) (closed)	
17:08 – 17:38	Group Interview with project members
17:38 – 18:15	Group Interview with users, postdocs and PhD students

Day 2 Date: Friday, March 8, 2024 9:06–17:05 Place: NAOJ Mizusawa Campus, Main Building, Conference Room 309 (3F)	
◆Presentation from MIZ (3) (open)	
09:06 – 10:12	Presentation from the project for Review Item **[3]** + Q&A
10:12 – 10:44	Presentation from the project for Review Item **[4]** + Q&A
10:44 – 10:53	(Break)
10:53 – 12:00	Presentation on SKA
12:00 – 12:30	(Lunch Break)

◆Observatory Tour	
12:30 – 13:20	Observatory Tour (20-m Antenna and VERA System)
◆Presentation from MIZ (4) (open)	
13:20 – 14:24	Presentation from the project for Review Item **[5]** + Q&A
◆Interview (2) (closed)	
14:30 – 15:15	Interview with MIZ Director
◆Discussion (closed)	
15:15 – 16:30	EEC meeting
◆Closing (Open)	
16:30 – 17:05	Executive Summary (Briefing to the project members)

Note:

-"open" all members of the project are welcome; "closed" invitation-only (by EEC).

- MIZ is an abbreviation for the Mizusawa VLBI Observatory.

Review Items

[1] Summary of the VERA astrometry project

[2] Achievement status of observatory's Purpose

[3] Response to the recommendations in the FY2018 Project Review

[4] Comparison with similar projects

[5] Future Plan (beyond the period covered by the review)