Report of the Review Committee for the Joint Institute for VLBI ERIC (JIV-ERIC)

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Executive Summary

JIV-ERIC has successfully consolidated and expanded its activities during the reporting period. It does an excellent job in supporting the European VLBI community and is central to the operations of the European VLBI Network (EVN). JIV-ERIC is enabling new and exciting science results and thanks to the JIV-ERIC support the EVN is performing front-line radio astronomy research. Adding new stations into EVN has been supported through several JIV-ERIC actions and resulted in an improved coverage of the UV plane. The ability to react quickly to transient phenomena has to be seen as a major expansion of the EVN capabilities and should include the development of the EVN-light sub-array for the future.

The JIV-ERIC staff are also producing interesting and relevant scientific results. They have been involved in many of the exciting new EVN discoveries and continue to be an extremely valuable asset of JIV-ERIC.

The transition to a European Research Infrastructure Consortium (ERIC) has been achieved without loss of service to the community. The expanded membership and partnership schemes prove to be effective. All EVN members should contribute to JIV-ERIC.

The review panel considers that JIV-ERIC has done an excellent job designing and operating the new SFXC correlator, providing support to the EVN operations, to the participating observatories and to the EVN users, as well as building a strong R&D division, which works on the continuous enhancement of the VLBI technique. New capabilities include real-time correlation of e-EVN and several extensions of the SFXC capabilities. Software developments also include the implementation of VLBI software in CASA. Near-field VLBI is now a mature technology and will be part of the PRIDE programme for the ESA Jupiter Icy Satellites Explorer (JUICE) mission.

Networking activities by JIV-ERIC were focussed through RadioNet and JUMPING JIVE, both funded through the European Commission. The new EVN science case and roadmap document will be an important basis for the future development of JIV-ERIC. JUMPING JIVE is charting the VLBI science into the SKA era under the JIV-ERIC leadership.

JIV-ERIC has proven extremely efficient in EVN user support and in implementing critical components of European VLBI. The expansion plans for new EVN stations, e.g. in Africa, are ambitious, but are critical steps towards a global VLBI. The review panel was highly impressed by the JIV-ERIC success in user support and the development of VLBI capabilities.

General Remarks

VLBI science has produced some fantastic results during the past years. The unique angular resolution provided by VLBI allowed the detection of the radio counterpart of the gravitational wave event GW170817 and the determination of the location of a Fast Radio Burst (FRB). These observations stand out as two discoveries, which provide interesting clues into astrophysical phenomena that are just emerging. Other noteworthy results include the first ever direct observations of radio jets regulating star formation (often referred to as ‘feedback’), the discovery of an excellent triple active supermassive black hole candidate, the influence of binarity in the mass ejection of a classical nova, an accurate distance measurement to an unusual compact binary system, which allowed the astronomers to learn about disk theory, observations of material close to black holes and the decomposition of the starburst galaxies into their individual constituents. JIV-ERIC staff were involved in the majority of these discoveries.

In 2015 JIVE has undergone a significant structural change from a foundation under Dutch law to a European Research Infrastructure Consortium (ERIC) regulated as a legal entity by the European Commission. Latvia joined JIV-ERIC as a member in 2016. JIV-ERIC is the first such consortium in astrophysics. Within the new structure JIV-ERIC obtained stable funding until 2020 through the members and partners. The services provided by JIV-ERIC to the European VLBI Network have not been affected by this transition. JIVE and JIV-ERIC represent a shining example of fruitful and efficient cooperation at the European level.

The JIV-ERIC legal status is in contrast with the EVN, which works under a Memorandum of Understanding, and leads to interesting incongruities between the two organisations. The relationship between EVN and JIV-ERIC appears suboptimal, mostly as a consequence of the loose collaboration under which the EVN operates. JIV-ERIC is a critical part of the EVN operations and data analysis. This situation requires that all EVN partners contribute in a structural way to JIV-ERIC. The financial planning of the next 5-year period offers an opportunity to place the current membership contributions on a clear and rational basis. This should ease new membership discussions in the future.

JIV-ERIC has developed several new capabilities, which are critical for a successful scientific operation of the EVN, while maintaining previous functions, like user support, development and operations of the data correlator, operating the EVN archive, and R&D coordination across the EVN. The real-time capabilities that have become available through e-EVN are enabling new science, in particular the observation and analysis of transient events, and represent a clear operational improvement with a direct feedback and calibration of the EVN array as it operates. The development of the software correlator has been continued during the reporting period and several important features have been added, again resulting in science results which were previously not achievable. JIV-ERIC supports new telescopes interested to join EVN through advice and training, both technical and scientific. It has undertaken several initiatives to expand the network and increase the UV coverage with the addition of eMERLIN, the Sardinia Radio Telescope, the Korean VLBI network, and Chinese stations. The addition of more African stations to bridge the gap from SKA-mid to the European VLBI is very important. Finally, JIV-ERIC has become very active as a coordinating function for the EVN and in running and contributing to several EC-funded networks to engage the community and plan the future.

The many successful activities of JIV-ERIC have been achieved with limited staff. The staff complement has decreased from about 29 FTEs in 2012 to 21 FTEs in 2018. Parts of the user support are financed through ephemeral funding, in particular the EC-funded RadioNet3 trans-national access scheme. The funding situation is currently satisfactory but relies too strongly on soft money which makes up ~45% of the 2018 budget. A more balanced budget with the core functions financed through the base funding should be the goal. This also means that all EVN partners should contribute their share to JIV-ERIC for these core functions, which are the basis for the scientific success of the network. The upcoming discussions of the renewal of the JIV-ERIC funding should be taken as an opportunity to clarify the JIV-ERIC core activities and request the appropriate funding from the JIV-ERIC partners and the EVN members who currently do not contribute to JIV-ERIC.

One of the main development activities of JIV-ERIC is the continuous improvements of the correlators, which are at the heart of the immense added value brought by VLBI to individual radio telescopes. The review panel was impressed by the significant efforts extending the capabilities of the software correlator (SFXC) which have led to extraordinary scientific results. All operational correlations have been done with SFXC since 2014 replacing the previous hardware correlator. New attributes resulted in exciting science results (de-dispersion was critical for the detection of the FRB) and/or improved operations. The versatility of SFXC is a clear plus and should be explored further. In parallel, the Uniboard

hardware correlator was developed as part of RadioNet. The follow-on study of the UniBoard[2] (also part of RadioNet) will be discontinued due to the versatility of SFXC and the improvement in computing speed over the years.

JIV-ERIC plays a very active role in the development of VLBI and in particular the EVN. It has assumed several critical functions for the EVN. The correlator, user support and EVN archive are the most visible contributions. Through various network activities, JIV-ERIC also acts as a catalyst for EVN developments and other important activities for radio astronomy. Discussions to possibly host some of the EVN functions (scheduler and secretariat) and other European radio activities at JIV-ERIC are envisaged.

JUMPING JIVE has proven to be a very effective way to chart VLBI capabilities into the SKA era. The various aspects (work packages) of JUMPING JIVE have set the foundation for a successful VLBI exploration including SKA. Several JIV-ERIC scientists are deeply involved in the definition of future EVN science cases. The new EVN White Book will be presented in 2019 and a draft version has already been discussed with the users at the recent EVN Scientific workshop in Granada. The roadmap should provide the basis for JIV-ERIC to define its future development activities and priorities. Unfortunately, the report was not yet available at the time of the review, so any impact of these developments are not taken into account here. The report by ASTRONET's European Radio Telescope Review Committee from June 2015 stated (p. 107) that 'EVN/JIVE delivers a wide range of excellent science and recommends extending the EVN sessions, use available telescopes at a higher fraction within the EVN and the evolution to a global VLBI network.' We fully support these recommendations. A sub-array of EVN telescopes of medium size (EVN-light) that would be able to observe a much higher fraction of the time is recommended. This sub-array would be very relevant for monitoring of variable objects, rapid-response observations and multi-wavelength campaigns.
Despite the efforts undertaken by JIV-ERIC to broaden the EVN user base, it still remains fairly small. JIV-ERIC has publicised VLBI, and in particular the new EVN capabilities, at conferences and through schools over the past years. The number of proposers has increased slightly, but a larger community should be reached in the future. The call for proposals of EVN time should be distributed more widely through new and different channels.

Research and methodologic developments for further EVN applications are actively conducted in four additional domains: near-field VLBI[1] applied to the positioning of interplanetary spacecraft, space VLBI, fundamental physics and ultra-long-wavelength astronomy. The official involvement in ESA's JUICE mission to the Jupiter system as official principle investigator of the PRIDE experiment is remarkable and adds to the more informal support to other ESA missions (Mars Express and Bepi-Colombo) and is testimony to the interest of the planetary exploration community for VLBI support. The JIV-ERIC management should take the necessary measures to secure the continuation of these activities in the future.

Evaluation of the JIV-ERIC organisation and achievements

1. *Effectiveness of JIVE operations, in particular EVN support, specifically correlation, user services, support of the network*

The review panel considers the JIV-ERIC operations very effective. JIV-ERIC provides outstanding support to both users and network. We highlight what we consider the most relevant achievements: 1) the development and operation of the SFXC, including new features; 2) the incorporation of the eMERLIN stations to the EVN network, increasing sensitivity to both extended and compact structures; 3) the replacements of disk packs by

[1] whose theoretical formalism also applies to cosmological studies

semi-automated FlexBuffs; 4) the development of user-oriented software pipelines and data tools required for the data analysis. Thanks to the global support of JIVE and the professional work of the different partners, the EVN provides front-line radio astronomy instrumentation including multi-frequency capability, large bandwidth/high sensitivity, polarization sensitivity, wide-field capability, good spectroscopic capabilities and real-time VLBI.

a) User Support (Correlation)

The new SFXC is the essential element of JIV-ERIC operations. It does not have hard limits (in the basic integration time, number of frequency points per sub-band/polarization, channel bandwidth, global bit-rate, number of stations) and incorporates new features (multi-phase centre; wide field mapping; polarization products; phasing-up the EVN; pulsar gating and binning; near-field VLBI). The big improvement in operations associated with the replacement of the old hard disks by the high capacity recorders FlexBuffs (up to 10 TB) at the stations, that store the data and send them later to the JIV-ERIC correlator FlexBuffs via internet connections is especially noted. In the case of the e-EVN observations, data are sent to the correlator in real time.

b) User Services

JIV-ERIC provides valuable user support from experiment design to data analysis. Updates of existing scheduling and proposal handling software and improved interfaces for data archive access allows a broader community to successfully utilize EVN. Visits to JIV-ERIC are promoted to help VLBI users with data reduction and analysis. A centralized approach, with JIV-ERIC now checking directly the observing schedules and conferring with PIs to create improved versions, especially for real-time e-EVN observations, presents an optimization of the use of the observing time.

The review panel regards the JIV-ERIC support operations as extremely successful.

2. The science output of JIVE + EVN

JIV-ERIC staff have been involved in many publications and have contributed to several important scientific results. Recent examples are the localisation of an FRB allowing for the first time a detailed assessment of the origin and environment of such an enigmatic phenomenon, and the observations of the only known neutron star-neutron star merger to date, with important implications for the interpretation as an off-axis version of the class of short gamma-ray bursts. The number of papers published continues to be high in view of the considerable service provided by the scientific staff. The impact of VLBI science is increasing and starts to match other astrophysical domains. Due to its high angular resolution, high sensitivity and superb astrometric precision, the EVN covers a vast range of astrophysical phenomena, establishing itself as a general-purpose observatory.

In general, the scientific output from EVN still appears to be extendable. There are no direct statistics available on the overall impact of EVN observations. It remains a goal for the EVN to further contribute to exciting science results like the ones of the past few years.

The JIV-ERIC staff is doing a good job in publishing their results comparable to the level of other international astrophysics institutes. The review panel regards the quality of the JIV-ERIC science output as very good.

3. *The research and development activities, specifically on digital technology, connectivity, space science applications and astronomical software*

The review panel was very impressed with the technical developments. JIV-ERIC clearly has a strong team with expertise across a broad range of skills and with the capability not only to support regular operations but to develop state-of-the-art hardware and software to enhance the EVN capabilities. Of key importance has been the upgrade and continued development of the software correlator SFXC which has now taken over correlation of all e-VLBI. EVN is currently the only VLBI network that can operate in real time. As such, these developments have enabled new modes of operation that have the potential to make VLBI observations attractive and feasible to a wider section of the astronomy community. We note the importance of improved software for automatically triggered observations which will improve the ability to follow-up astronomical transients.

The panel was also impressed to see that JIV-ERIC takes a leading role in R&D activities with strong connections to other current and future facilities. In particular we recognize the importance of the JIV-ERIC team's close involvement in the SKA SaDT consortium, building on their own expertise in data transport and the distribution of time and frequency signals using the White Rabbit protocol. This should put the JIV-ERIC team in a good position for a continued role in SKA as the project develops. The work that the JIV-ERIC team has undertaken in collaboration with NRAO to fully implement VLBI capability into the CASA software package is also important. Not only does this reinforce a central role for the JIV-ERIC team within the worldwide VLBI effort, but implementation of this capability in a common-user software package has the potential to open up VLBI to the wider community. We also note the significant role that JIV-ERIC will likely play in the up-coming JUICE mission as a result of their work on developing a near-field VLBI technique.

Finally, it is clear that the JIV-ERIC team is well-placed to take advantage of future developments in both digital backend technology and wide-bandwidth communication. During the period covered by this review the team has developed the infrastructure and support such that real-time correlation of 8 stations at 2 Gbps is now possible, and with much increased reliability owing to improved remote monitoring of the stations. The team is to be commended for achieving this, particularly with the number of new antennas that have been (or are in the process of being) integrated into EVN and the increase in complexity and heterogeneity of the stations.

We rate the achievements in this area as outstanding.

4. *JIVE's activities as a research infrastructure and its ability to implement EC programmes in the interest of the EVN and its user community*

The coordinating activities of JIV-ERIC are extremely important for the progress of EVN and the establishment of global VLBI as a new observing tool. The panel was particularly impressed by the very successful JUMPING JIVE initiative, which is leading the way of EVN into the SKA era. JIV-ERIC is central to this activity and coordinates some of the most important work packages. JIV-ERIC also assumed a central role for the development of the EVN and its connections to a future global VLBI. The new EVN science cases and roadmap will set the development of EVN and JIV-ERIC.

The efforts to bring more telescopes into the EVN (and the global network) are commendable and will expand the scientific potential of VLBI further. The efforts by JIV-ERIC to increase its service to the EVN are also noted. Plans for an EVN-light to use smaller antennas with lower pressure factors for more frequent VLBI use is an attractive option to follow interesting transient events at short notice. The JIV-ERIC initiative to expand the African network for an optimal use of VLBI with SKA-mid is an important investment into the future.

JIV-ERIC is providing the critical user support for EVN users, including consultation for proposal preparations, scheduling and data reduction. Through the collaboration in ASTERICS and in ESCAPE, JIV-ERIC is providing various additional services to EVN (e.g. transient alerts, data streaming, archives, scheduling and pipelines).

The panel finds that JIV-ERIC is doing an excellent job in serving the EVN community.

5. *In-house scientific research, educational activities, outreach and society.*
The JIV-ERIC staff contribute to the scientific life of their host institution, ASTRON, and actively pursue their research within this environment. Many of the JIV-ERIC positions are at the postdoctoral level and it is important for these young researchers to develop their careers. JIV-ERIC provides a good platform for the scientific growth of these young scientists. JIV-ERIC is involved in supervising students in the Netherlands and beyond, and shares a summer student program with ASTRON. The staff play an important role in the training of new VLBI users by organising VLBI tutorials, participating in VLBI schools and radio conferences, and teaching at universities. Especially within JUMPING JIVE, efforts are made to support science in Africa and in making VLBI accessible to the general public. Beyond pure scientific research, JIV-ERIC's activities also contribute to economically relevant developments in connectivity, software and the European Open Science Cloud (EOSC).

JIV-ERIC is very active in spreading the information and excitement of VLBI to the community and into the wider society. The review panel was very pleased to see the many activities in this area and congratulates the JIV-ERIC staff to the success.

Overall, JIV-ERIC excels in all its activities and provides first-rate services to the EVN community.

Recommendations

1. Develop a strategy for the funding discussion with the JIV-ERIC members. The goal should be to have all EVN members also members of JIV-ERIC. Poland and Finland should become members of JIV-ERIC.
2. Actively approach new partners with interest in VLBI activities for JIV-ERIC membership or partnerships.
3. JIVE needs to be put on a more secure and stable funding base that covers the core programme with financial commitments to be secured on a multi-year basis. Define a strategy for extra funding.
4. JIV-ERIC should define its core programme and separate 'additional' projects.
5. Build upon already existing monitoring and transient VLBI research, EVN-light and 'real-time' VLBI.
6. Derive technical requirements for JIV-ERIC developments from the EVN science case, e.g. flexible backends, frequency agility and wide-band receivers. Use the EVN science case to prioritise the JIV-ERIC R&D developments.
7. Advertise the call for proposals more widely (e.g. EAS email distribution) to continue to broaden the user base. More strongly advertise high-angular resolution astrophysics (astrometry, monitoring) capabilities opening new science opportunities. The online public EVN archive, with pipeline processed data, should be maintained and advertised to maximize the use of these data by non-specialists. Explore joint programmes with X-ray or gamma-ray facilities.
8. Evolve SFXC to higher bit rates. Keep developing SFXC to maintain the state of the art.
9. Keep monitoring the array in real-time for quality control and improved performance
10. Encourage a clear vision of JIV-ERIC in the SKA era, specifically the importance of VLBI. Continue to seek ways to provide input into the SKA-VLBI science cases,

specifically identifying and defining SKA areas where JIV-ERIC can provide unique support.

11. JIV-ERIC currently has a strong involvement in near-field VLBI, which is a unique capability in Europe. JIV-ERIC needs to retain this expertise. PRIDE offers a great opportunity to enable unique science.
12. Keep promoting the Earth VLBI alliance for global collaboration.

Annex 1

Review Terms of Reference

Terms of Reference for the review of the Joint Institute for VLBI ERIC (JIVE) on behalf its partners under coordination of NWO

Version 1.0, 26 March 2018 - Francisco Colomer, JIVE

The review will consider and assess developments and operations at JIVE since the time of the last review of JIVE, published in March 2012. It will address the possible development of JIVE over the next funding period 2020-2024, as well as of its mission on a longer-term perspective, particularly in view of the development of the SKA. In making its reasoned judgment on the mission, strategy, and performance of JIVE, the review panel will consider both JIVE's mandated role to support the operations of the European VLBI Network (EVN) and its in-house programme, both for astronomy as well as technical research and development.

In making the review it will consider:

- - The satisfaction of the partners in JIVE and their wishes for the development of JIVE services,
- - The financial implications foreseen on the basis of these wishes,
- - Options for future technical and operational development at JIVE towards its mission,
- - The scientific achievements of JIVE staff obtained in the past years,
- - The science case for the future, in a worldwide context,
- - Governance issues for JIVE and European radio astronomy.

  In the review, the panel will distinguish a number of aspects of JIVE. The panel is asked to provide a rating for all of these aspects separately, as well as an overall rating. The specific elements for consideration are:

1. Effectiveness of JIVE operations, in particular EVN support, specifically correlation, user services, support of the network,
2. The science output of JIVE + EVN,
3. The research and development activities, specifically on digital technology, connectivity, space science applications and astronomical software,
4. JIVE's activities as a research infrastructure and its ability to implement EC programmes in the interest of the EVN and its user community,
5. In-house scientific research, educational activities, and outreach.

The review panel is expected to base its review and evaluation on:

- - Documents provided by JIVE: annual reports and additional specific documentation,
- - A self-assessment document by the JIVE management,
- - Statements by the JIVE partners,
- - A site visit to JIVE and meetings with its staff.

The JIVE Council shall establish the review panel. Financial support for the panel is provided directly from JIVE's general funds. The report of the Review shall be issued as a public document by the JIVE Council.

Annex 2

Membership of the JIVE Review Board

Dr. Bruno Leibundgut (chair)	ESO, Garching, Germany
Prof. Antxon Alberdi	IAA-CSIC, Spain
Dr. Michel Blanc	IRAP-OMP, France
Prof. Andreas Eckart	Universität zu Köln, Germany
Prof. Gijs Nelemans	RU Nijmegen, the Netherlands
Dr. Helene Sol	Obs. Paris-Meudon, France
Dr. Angela Taylor	Oxford University, UK
Dr. Grazia Umana	INAF-Catania, Italy
Secretary:	
Dr. Saskia Matheussen	NWO, the Netherlands

Annex 3

Review Agenda

Monday 5 November 2018					
Oort Room, ASTRON/JIVE, Dwingeloo					
time	*end*	#	*item*	*speaker/responsible*	*slides*
12:30			Pickup at hotel (or direct transport to JIVE)		
13:00	14:00		Lunch		
14:00	15:30		Welcome and introduction	Simon Garrington	
				Bruno Leibundgut	
				SM / PC	
		1.0	Progress Report	Paco Colomer	PDF
15:30	16:00		Tea break		
16:00	16:30	2.0	User´s experience		
		2.1	Tracing AGN feedback with VLBI	Robert Schulz	
		2.2	VLBI observations of gravitational lensing systems	Cristiana Spingola	
16:30	17:00		Tour of Facility		
17:00	17:45	3.0	JIVE structure and partnership	Paco Colomer	PDF
17:45			Return to hotel		
18:30			Dinner (Panel only)		
Tuesday 6 November 2018					
Oort Room, ASTRON/JIVE, Dwingeloo					
9:00			Pickup at hotel		
		4.0	Current activities	JIVE MT	
9:30	9:55	4.1	Correlator Operations	Bob Campbell	PDF
9:55	10:20	4.2	Research & Development	Arpad Szomoru	PDF
10:20	10:50		Coffee break		
10:50	11:15	4.3	Space Science and Innovative Applications	Leonid Gurvits	PDF
11:15	12:00	4.4	JIVE Support and Science	Zsolt Paragi Huib van Langevelde	PDF PDF
12:00	13:00		Lunch		
13:00	14:00	5.0	Strategy and future	Paco Colomer	PDF
14:00	15:30		Panel Closed session	Bruno Leibundgut	
15:30	16:00	6.0	Interaction with JIVE staff & Tea break		
16:00	17:00		JIVE Director, JIVE MT, and JIVE Council chair available for questions	Paco Colomer, JIVE MT, HvL, STG	
17:00	18:00		Panel closed session	Bruno Leibundgut	
18:00			Return to hotel		
18:30			Dinner (Panel only)		
Wednesday 7 November					
Spiegelzaal, Hotel Wesseling, Dwingeloo					
9:00	10:00		Panel Closed session	Bruno Leibundgut	
10:00	11:00		Preliminary feedback to director	Bruno Leibundgut	
11:00			Coffee, Adjourn		