VLBI Astronomy : A global overview of the current status

著者	Yoshiaki Hagiwara
journal or publication title	International Culture and Communication Studies
volume	4
page range	89-100
year	2021-03
URL	http://doi.org/10.34428/00012673

論文

VLBI Astronomy : A global overview of the current status

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Abstract

In astronomy, Very Long Baseline Interferometry (VLBI) is a powerful technique for exploring details of stars and galaxies at radio wavelength with unprecedented angular resolution. In order to realize VLBI using radio telescopes distributed in different regions and countries across oceans, the world-wide global collaboration is essential. Since 1967, when the first VLBI experiment was conducted in Canada, the progress of VLBI development has not been straightforward. VLBI is sometimes politics dependent since each radio telescope used for VLBI spans many countries based on different political systems. Recently, VLBI astronomers have come to the idea of creating an alliance for a ”global array” and have begun organizing meetings to carry out. Thus, the international VLBI community seems to converge to the global array alliance to make only one largest radio telescope array in the world. In this short article, the current status of VLBI astronomy with some history and future prospects is briefly reviewed from my view points.

keywords: radio astronomy, interferometry, VLBI, galaxies, stars

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1 Brief history

Very Long Baseline Interferometry (VLBI) is a radio interferometry that constitutes of more than two telescopes whose positions are geographically very separated to collect signals from astronomical objects, like quasars, masers, pulsars in greater detail [13]. VLBI is also capable of measuring precise positions of compact objects like pulsars and distant galaxies. The concept of VLBI was originally presented by Russian scientists: they are Leonid Matveenko, Nikolai Kardashev, and Gennady Sholomitskii [2]. The first VLBI astronomy experiments that include radio telescopes at the Algonquin Radio Observatory, Ottawa and the Dominion Radio Astrophysical Observatory, Penticton with a baseline of 3074 km, were successfully made in early 1967 by the Canadian scientists group and they detected quasars [1].

Shortly after the Canadian scientists' achievement, intercontinental VLBI experiments were conducted between the Unites States and Russia in 1969 [3]. The U.S.-Russia (USSR) VLBI experiments were conducted between the Greenbank 140-foot telescope in West Virginia and the Simeiz 22m telescope in Crimea, giving, for the first time, an angular resolution of better than 1 milliarcsecond (mas). It is interesting to note that those experiments were organized in the midst of the Cold War time, showing that scientists can sometimes find a way to collaborate even though there are different political principles among their nations.

When VLBI is used for geodesy and geophysics, it is often called geodetic VLBI or geo-VLBI. Geo-VLBI is used for measuring Earth's rotation, gravity, shape of earth, and tectonic plate movement from observing a point source in space such a quasar using pairs of radio telescopes whose locations are geographically very separated. Thus VLBI is used in geodesy since 1960s.

In Japan, VLBI was first introduced to the members of Communication

Research Laboratory (CRL) at Kashima in 1971 upon a contact from NASA to participate the VLBI experiments with a baseline of several thousands kilometers across the Pacific, which improves the position accuracy of VLBI stations and hence measurements of continental drift to an accuracy of centimeters [8].

Later in 1980s, first space-VLBI experiments, led by Jet Propulsion Laboratory (JPL), between a space-craft with a radio telescope orbiting around the Earth and ground-based telescopes were successfully conducted, producing radio images of distant quasars. That motivated to realize the first dedicated space-VLBI mission, VSOP (VLBI Space Observatory Programme) led by scientists in Japan, in collaboration with many international partners. VSOP is followed by the Russian space-VLBI project, RadioAstron later from 2011–2019 [12], which was originally planned to launch in 1980s, providing an expected angular resolution of 7 microarcsecond at 22 GHz that is two orders of magnitude better than that of VSOP at 5 GHz. Some more details on space-VLBI projects are described in Paper I [4]. Finally, some historical discoveries or events relevant to VLBI and radio astronomy are summarized in table 1.

In this short article, with an emphasis on the situation of Japan and east Asia, current status and future prospects of VLBI astronomy are presented from my personal view points.

2 Current VLBI situations

Currently, several VLBI facilities are being operated, some of them are regionally organized such as east-Asia VLBI Network (EAVN), Very Long Baseline Array (VLBA) in USA, and Long Baseline Array (LBA) in Australia with a baseline of several thousands kilometers, while some are extensively organized with a baseline of a near earth-size diameter. The existing VLBI networks are presented in Figure 1. Some details of EAVN have been described in Paper II [5]. Comparison of current major VLBI facilities is listed in Table 2 that is updated from Table 1 in Paper II, in which the EHT (Event Horizon Telescope) is the new sub-millimeter (sub-mm) VLBI aiming at imaging a black hole in galaxy. In 2017, EHT succeeded in detection of a black hole shadow at 1mm wavelength, the shortest wavelength ever observed effectively with VLBI, toward the active galaxy Messier 87 (M 87) [7].

VLBA operated by USA-NRAO (National Radio Astronomical Observatory) has been leading VLBI science for nearly two decades since around 1995, as it constituted of all ten homogeneous telescopes distributed over the country, which enables telescope calibration much easier than that by heterogeneous arrays like EAVN and European VLBI Network (EVN). EVN, which consists of a large group of different telescopes, has introduced a data pipeline calibration service to apply nominal calibration on all observing data, making complicated VLBI data calibration more accessible to end-users. Such services are spreading not only to EVN but also to VLBA and other VLBI facilities, which broadens the user community and creates a new user community in other fields of astronomy.

Regarding Japan, the future of VLBI is uncertain. The VERA project led by National Astronomical Observatory of Japan (NAOJ), which is the Galactic astrometry project, is scheduled to break the operations in 2022, while the VSOP-2, the Space VLBI project followed by VSOP-1 was cancelled due to technical problems. The possible future plan of Japanese VLBI, one of the possibilities at this point, is Japan’s initiative to promote EAVN based on VLBI research experiences and unique technology since 1970s and the expansion of EAVN into southeast Asia.

2.1 Global array

The concept of what we call, the ”global array”, seems to have been in the minds of VLBI researchers for a long time, but has never been realized to date. Although Space-VLBI (S-VLBI) comprising an orbiting telescope and ground telescope arrays can be considered the ” global array ”, which is not a facility that can be used for any target objects, the observing targets of S-VLBI are extremely limited, and there are major restrictions such as the adjustment of observing schedule between one or two orbiting telescopes and ground-based telescopes. The idea of an international global array by co-operating radio telescopes over the world was, probably first time, formally proposed by NRAO in January 2011. Since then, as far as known there has been no progress on the global array.

However, very recently, in May 2018 the idea of the global array has been re-proposed in international VLBI community at the EVN Directors Board Meeting, perhaps, with the initiative of JIVE (Joint Institute for VLBI ERIC), which was followed by a meeting held in September 2018 during EVN Symposium meeting, where VLBI representatives from Asia, Europe, USA, and Australia discussed together and the two other meetings took place in 2019 at the EAVN symposium and SKA-VLBI meetings in Manchester. In November 2019, the concept of the ”global array” or global array alliance was approved at the EVN board meeting. It is being expected that the global alliance will be further developed and establish a ”true” global array in near future.

The array concept includes the members of VLBI, which are listed in Table 2, showing interests in participation with many common frequency bands. The aim of the global alliance is to re-organize currently operating extensive arrays such as High Sensitivity Array (HSA) that VLBA, EVN, EAVN, and Bonn 100m telescope participate, EVN-global, and GMVA. Fraction of a total observing time for the extensive arrays is currently about only 4-5 percents, which the alliance can increase under close collaboration with the existing VLBI arrays. The problem seems to be that the collaboration of the arrays is based on bilateral or a local agreements rather than those among international VLBI members. By establishing the new alliance, it is expected to improve the conventional VLBI joint operation and build a wider VLBI array.

Below listed some technical issues to be sorted out to efficiently operate and improve the array performance.

1. Common frequency bands (1.4-1.6 GHz, 5-6.7 GHz, 8.4 GHz, 22 GHz, 43 GHz)
2. Higher frequency observations at millimeter wave (>86 GHz)
3. Polarimetric observation capability (LHCP, RHCP)
4. Frequency agility (frequent switching of observing frequencies among different frequency bands (e.g., between 22 GHz and 43 GHz band)
5. Recording modes compatibility - to establish common recording modes for global observations
6. Data correlation center - location of (software) correlators
7. User support - to provide data calibration (pipeline) service and assistance in interferometry data analysis for users unfamiliar to VLBI

Apparently, the last item of the user support is very important for attracting users outside the VLBI community, as VLBI calibration is very complicated that non-experts are apt to avoid using VLBI data, which contributed to keeping astronomers away from VLBI. It is thus being felt that data calibration service particularly for non-VLBI experts would be crucial to expand new users and expect support from wider astronomy community. Adding to the items above, coordination scheme and logistic matters such as scheduling of telescopes would be necessary. Maybe GVWG, global VLBI Working Group that was organized for VSOP-1 project can be reorganized to discuss these issues.

2.2 Square Kilometre Array and VLBI

Square Kilometre Array (SKA) is ”a next-generation radio telescope that will ultimately have a square kilometer of collecting area, making it the most sensitive radio telescope in the world. The project to design and build the SKA is an international collaboration, involving 15 countries” [9]. SKA is a potential partner of the global array as the 1 km^2 collecting area will be an advantage in increasing telescope sensitivity and it dramatically boosts up source detection thresholds and imaging sensitivity. SKA organization should be aware of merits of collaboration with the global VLBI alliance because higher angular resolution, which seems to be an only weakness of SKA, can be achieved only by combining with the global array.

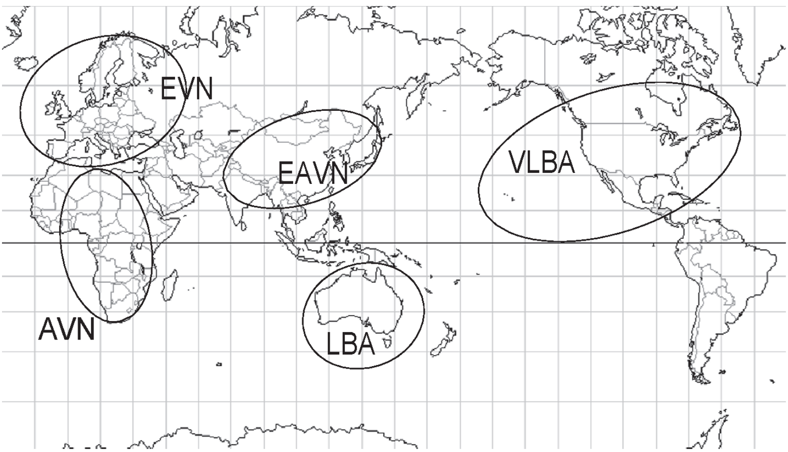

Fig. 1: An overview of current VLBI networks is presented. Two major VLBI networks of VLBA and EVN and the regional networks EAVN, LBA, and AVN(African VLBI Network) are shown. The concept of a global array is a collection of radio telescopes that makes up these VLBI networks to build the world’s only one largest array.

2.3 Global array and VLBI in Japan

There seems to be no choice for Japanese VLBI community but to participate to the global alliance as EAVN is being expected to be a part of the global array by Chinese and Korean VLBI community. Presently, EVN-global observations involve telescopes of CVN (Chinese VLBI Network) and KVN (Korean VLBI Network) are already involved. Considering that there is no new plan for VLBI project coming after VERA, Japanese VLBI researchers should be able to lead VLBI technically and scientifically in Asia, based on relatively longer VLBI experience and contribute more to a global VLBI on behalf of east and southeast Asia region. As mentioned above, given that the truly global VLBI observations and SKA-1 are upcoming in the next decade, Japanese VLBI community is expected to actively participate them.

3 The future

Thanks to the great success of discovering the black hole shadow in the active galaxy M 87 by EHT (Event Horizon Telescope) [7], the importance of VLBI or interferometry for research of black hole physics has been recognized again among astronomers. While writing this article, the team that predicted the presence of a black hole in our Galactic center by infrared observation has won the Nobel Prize in 2020. In this sense, the future of VLBI has become even brighter since the phenomenon near a super massive black hole can be imaged only by VLBI with microarcsec angular resolution.

As Figure 2 indicates, resolving a structure of a black hole shadow surrounding a super massive black hole (SMBH) is capable presently only by EHT equipped with unprecedented angular resolution at sub-mm. There are only a few galaxies whose black hole shadow can be imaged even with EHT. We have to bear in our mind that ALMA is a vital part of EHT for detecting the shadow image, and therefore ALMA-VLBI collaboration will be a key for success in the study of SMBH.

The future of VLBI in east Asian countries except Japan is brighter. In South Korea, it has been decided to expand KVN, and the total number of VLBI stations will increase to four stations from the current three stations. Since KVN telescopes can observe frequencies up to 129 GHz with dual frequency reception, KVN can participate global millimeter wave VLBI network such as GMVA. Japan has the Nobeyama 45 m telescope that is the most sensitive millimeter telescope in east Asia, however global VLBI participation of the 45m has been limited for technical and operational reasons that has been a longstanding issue. As written above, currently there has been no proposal of a new VLBI project in Japan and if this situation continues, the existence of VLBI astronomy itself in Japan might be jeopardized.

In China, the Tian-ma 65m telescope at Shanghai has just begun to participate to EAVN test experiments and other telescopes included to Chinese VLBI Network (CVN) participate regularly to EVN observations. In Thailand, the new 40m radio telescope is being developed at Chengmai and is being planned to participate to EAVN and LBA, as a result of which a baseline will be even longer within Asia. Thus, VLBI in Asia is healthy and full of bright future.

4 Summary

I have described a part of the current situation of VLBI in the world, especially focusing on the current situation in Japan. The severe conditions of the Japanese VLBI community motivated me to write this article.

Moreover, bad news relevant to VLBI seems to be mostly limited in Japan. The CRL Kashima 34m telescope that was a vital telescope of early VLBI network in Japan was shut down in 2019, damaged by the typhoon. Recently, the drastic reduction of the VLBI project budget at NAOJ has been talked about. It can be said that the VLBI community in Japan is at a crossroads. If a right choice at this crossroads is done, we will have a bright future, but if not, we may be abandoned in the history of VLBI astronomy. I wonder if how many community members share this sense of crisis. To determine the future VLBI, choice is

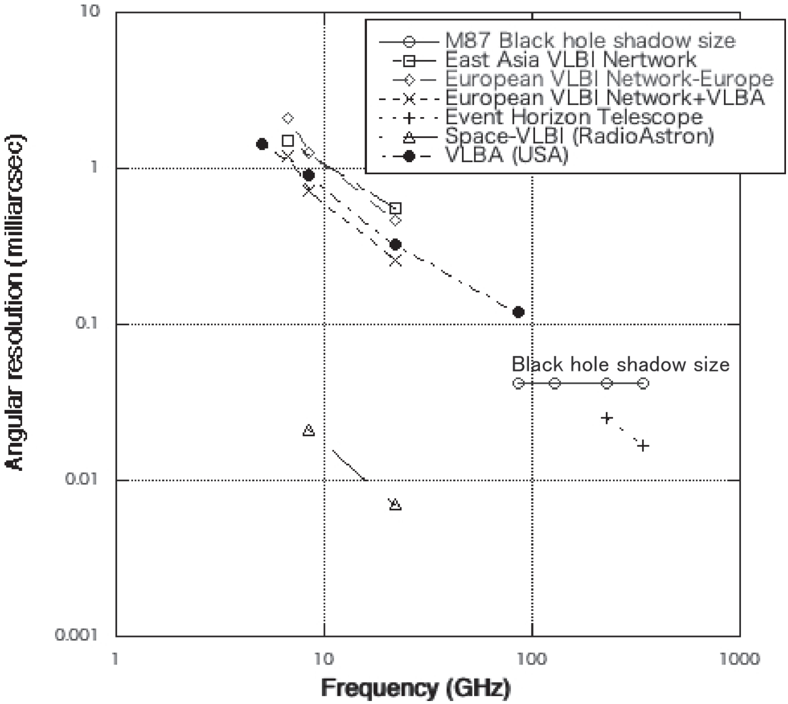

Fig. 2: Comparison of angular resolution of existing VLBI facilities with an angular size of the black hole shadow detected toward the well-known active galaxy Messier 87 [7].

definitely in our hands.

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Table 1: Historical events relevant to VLBI

Year	Events	Note
1963	Discovery of a quasar, 3C 273	
1964	Discovery of 3K cosmic microwave background radiation	[11]
1965	Idea of VLBI proposed in Russia (Soviet Union)	
1967	First VLBI experiments in Canada at 440 MHz between Penticton 26m and Algonquin 46m	3074 km baseline
	Discovery of pulsars	by Jocelyn Bell
1977	First VLBI experiments at 4 GHz in Japan	Kas34m-Yokosuka12.8m
1988	KNIFE (Kashima-Nobeyama Interferometer) operation	Kas34m-NRO45m
1995	Discovery of the H_2O maser disk in NGC 4258	[10]
1986	First space-VLBI imaging (TDRSS) at 2.3,15 GHz	JPL, U.S. (-1988)
1997	Space-VLBI, VSOP/HALCA operation (-2005)	ISAS/JAXA, Japan
2011	Space-VLBI, RadioAstron operation (-2019)	ASC, Russia
2019	Detection of the black hole shadow at 1mm in M 87	EHT (sub-mm-VLBI)
	Next space-VLBI mission discussion	sub-mm Space-VLBI

Table 2: Current VLBI facilities (2020-)

Array	Baseline (km)	Resolution (mas(max))	Area (m^2)	Antennas	Band (GHz)	Region
EAVN	5500	0.5	15000	15	6.7–43	east-Asia
EVN	11000	0.2		16	1.4–43	Europe/Asia/ Africa
VLBA	8600	0.2	4900	10	1.4–86	U.S.
EHT	10000	0.04		8	230	World wide
LBA	9800			7	1.4-22	Australia
GMVA	12000	0.05		15	86	Europe/US/ Korea
(Global Array)	11000	0.2	70000	<20	1.4–43	World wide)
SKA-1(2023-)	150		32600		0.35–26	Australia/Africa
SKA-2(2028-)	3000		440000		0.35–50	Australia/Africa

EAVN: East-Asia VLBI Network; EVN: European VLBI Network; VLBA: Very Long Baseline Array (U.S.); EHT: Event Horizon Telescope; LBA: Long Baseline Array; GMVA: Global mm VLBI Array; SKA: Square Kilometre Array