East Asian VLBI Network – The Evolution and Future of EAVN

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Abstract

Presently, the activity of astronomical VLBI in east Asia is rapidly growing up, which resulted in the formation of east Asian VLBI Network (EAVN) to which more than 15 telescopes in Japan, South-Korea, and China participate. By organizing these telescopes in east Asia, higher angular resolution resulted from the maximum baseline length of about 5,500 km between Ulmuqi and Ogasawara stations and better sensitivity by adding telescopes with large apertures will be provided. The performance of EAVN can be compared with Very Long Baseline Array (VLBA) in the US and European VLBI Network (EVN). From 2018, EAVN commenced international open use observation after enormous efforts of preparation for years, supported by VLBI community in east Asia. Despite of the current limited capabilities, EAVN has a lot of possibilities for playing a key role in global VLBI Network in near future. In this short article, the evolution, current status, and future prospects of EAVN are presented.

keywords：Radio astronomy, VLBI

1 Introduction

In the last two decades, VLBI (Very Long Baseline Interferometry) collaboration of radio astronomy in east Asia has been greatly developed mainly due to the construction of new telescopes or new VLBI networks: These are VERA (VLBI Exploration of Radio Astrometry), KVN (Korean VLBI Network), and Tian-ma 65 m and Nanshan 26 m telescopes in CVN (Chinese VLBI Network). As a result of that, the idea of coordination of a united VLBI network in east Asia has been matured among people involved in operating local VLBI networks in Japan, Korea, and China. On the other hand, VLBI observations in east Asia coordinated around 2010-2013 were temporally performed upon a request from an observer or group, while KaVA (KVN and VERA Array) is an open use facility constituting of seven telescopes of VERA and KVN and it is formally

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operated from 2014 based on the agreement between NAOJ (National Astronomical Observatory of Japan) and KASI (Korea Astronomy and Space Science Institute). For example, VLBI experiments between the Shanghai observatory and Japanese VLBI network (JVN) were successfully performed in 2010-2011, resulting to a number of 6.7 GHz methanol maser detections in our Galaxy and obtaining monitoring spectra of the masers [2].

In those days, it was often that in each experiment observers themselves must organize VLBI observations by contacting colleagues and telescope operators at each VLBI station, finding available observing slots and an available correlator that can deal with a favored recording format. All of these and other relevant preparations were used to be vital part of researches using VLBI. To avoid these efforts and focus on scientific outputs, many radio astronomers were apt to propose their observations to open use VLBI facilities such as VLBA in the United States or EVN in Europe, as these VLBI facilities are free to use for any scientists or students as far as their proposals are approved via peer-reviewing process. The reality was that many of VLBI astronomers in east Asia or even in Europe were using VLBA, since VLBA made many aspects necessary for VLBI observations much easier and realized what we call a "user-friendly" system.

Meanwhile, people involved with VLBI experiments in east Asia were wondering if they could organize their own VLBI facility based on regional international collaboration, like the case of the KaVA collaboration. Given the (u,v) coverage of VLBI network in east Asia (Fig.1), it would be easier to imagine the advantage in organizing a tied array in east Asia, as well as those in the US and Europe.

2 The early days of EAVN

The summer of 2013 was a time of small but a big progress in east Asian VLBI Network (EAVN) [1]. As the KaVA observations progressed, it became clear that there was an increasing demand for imaging capability, especially given some images of jets from active galactic nuclei (AGN) such as 3 C 84 or M 87 whose radio structures remain unresolved at 1 milliarcsecond resolution of KaVA.

An actual activity to realize the idea of extending the KaVA collaboration to north-west including China and other regions in Asia was initiated during the EAVN Workshop held at Jeju in 2013 June, where people who were involved with VLBI at NAOJ, JVN, KASI, and CVN gathered at a time to discuss on VLBI collaboration in Asia, probably, formally for the first time. In this memorial meeting, people agreed in making the VLBI collaboration forward as soon as possible. To proceed that, the formation of an intense working team, what we call "Tiger team" was suggested and agreed at the meeting.

The Tiger team members, which started with several people, were nominated from NAOJ, JVN, KVN, CVN, and ASIAA. They decided to have a tele-conference meeting nearly once in a month and a yearly face-to-face meeting at the EAVN symposium or some other meetings relevant to VLBI in Asia.
The primary aims of the Tiger Team are broken down as followings, 1) to operate EAVN by organizing a number of radio telescopes distributed primarily in east Asia, 2) to find out and sort out technical problems in order to operate EAVN telescopes as efficient as possible, 3) to invent original science cases using EAVN. The last one was not discussed in Tiger team, but it is being actively discussed separately in EAVN science working group members. To carry out the items 1) and 2), the Tiger team planned test experiments with intervals of 2-3 months using available telescopes of JVN, KVN, and CVN, some outcomes of which will be described at a later section.

3 Space-VLBI and EAVN

Thus, before the time of 2013, the EAVN was a concept but not an actual facility. One might ask why EAVN had become more concrete activity at the time of 2013. To my personal opinion, one of the motivations for initiating EAVN was failure of the Japan-led Space-VLBI (hereafter, S-VLBI) project of VSOP-2 in 2010, the more details of which are described in Paper I [4]. The VSOP (VLBI Space Observatory Programme) mission led by Japanese VLBI community was being carried out from 1997-2005, collaborating with international partners of 11 institutions over the world [6, 7]. People involved with the VSOP were truly impressed with the importance of international collaboration to conduct VLBI successfully at that time. Following the success of VSOP, VSOP-2 was being planned with an expected launch in early 2011. It was being expected that VSOP-2 would continue and further develop the international VLBI collaboration by formulating a new international collaboration scheme. For instance, since the Shanghai observatory participated to VSOP, Chinese VLBI community might have expected similar collaboration for VSOP-2. However, the expected S-VLBI collaboration had been gone with the termination of VSOP-2 decided at the Japanese space agency in 2010 due to some technical problems. After 2010, the idea of a new S-VLBI mission was proposed in China, although which has not yet been realized at this time of early 2019. The success of the international collaboration through the VSOP had demonstrated to people in east Asia the scientific merits of longer baseline and advantages of having their own local VLBI network. Considering these, one might think that it would be very natural for radio astronomers to reiterate thoughts on a new VLBI collaboration scheme instead of S-VLBI in east Asia.

4 Technical challenges

In September 2013, the EAVN tiger team conducted the first EAVN experiments at 8.4 and 22 GHz bands, having eleven telescopes shown in Fig.2 together. The bright radio continuum source, a quasar 3 C 273 was observed both at 8.4 and 22 GHz. Data were recorded at 1 Gbps recording rate and processed on the Korea-Japan Joint VLBI Correlator (KJJVC) at the Korea-Japan Correlation Center (KJCC) in Daejeon. Interferometer "fringes" from most of the telescopes were detected at 8.4 GHz but not at 22 GHz because of misoperation in frequency setup at each station (Fig.3).
In January 2014, the third fringe experiments were performed to revenge the failure in the former experiment at 22 GHz. A quasar 3 C 345 as a radio continuum source and stellar maser W49N as a line source were observed for 1 – 2 hours both at 8.4 and 22 GHz, resulting in the fringe detection at 22 GHz [5]. Data from different stations were successfully recorded in different formats: Japanese telescope stations of VERA and JVN record in two different formats, while those in CVN and KVN use compatible recoding formats. (This sort of problem was also seen in production of scheduling files to be used for telescope operation at each station: CVN and KVN stations use the common VLBI scheduling formats developed originally for VLBA or EVN, while none of the stations in Japan adopts that but they use their original scheduling format.)

5 EAVN performance

Table 1 lists the performances of existing VLBI facilities. One of the biggest advantages of EAVN is that we will obtain higher angular resolution that is provided by 5,500 km baseline length made up from the Ulmuqi – Ogasawara baseline (Fig.2) and better sensitivity by adding up large telescopes such as Tian-ma 65m telescope. Clearly, the performance of EAVN is no better than VLBA or EVN, however EAVN is much more powerful than VERA, CVN, and KVN.
Very recently, the dual circular polarization receivers at 22 and 43 GHz have been installed to the two telescopes of VERA and installation of the dual polarization receiver is being planned at the other two telescopes of VERA. This will expand millimeter wave VLBI polarimetry network in east Asia, including Tian-ma 65 m at Shanghai. (Fig.4)

6 Future prospects

While some technical developments of EAVN are undergoing, there are plans to build new telescopes or extend the existing array in Asia. These plans are broken down as followings. There might be some other plans.

- •Thailand VLBI Network (TVN)
- •Extended Korean VLBI Network (Extended KVN or EKVN)
- •Qitai 110m Radio Telescope (QTT) in China

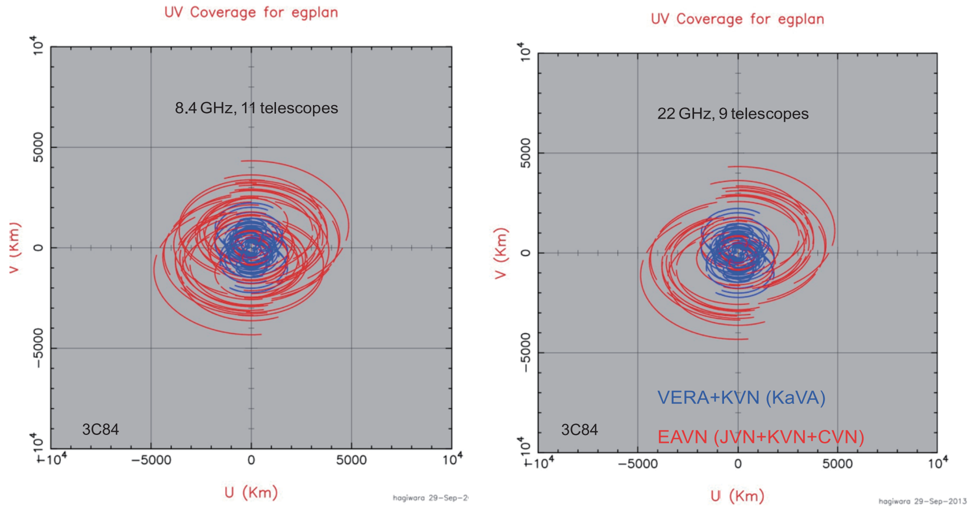

Fig. 1: Comparison of (u,v) coverages for a quasar 3C 84 of KaVA (inner part) and EAVN (outer part), obtained at 8.4 GHz (*left*) and 22 GHz (*right*).

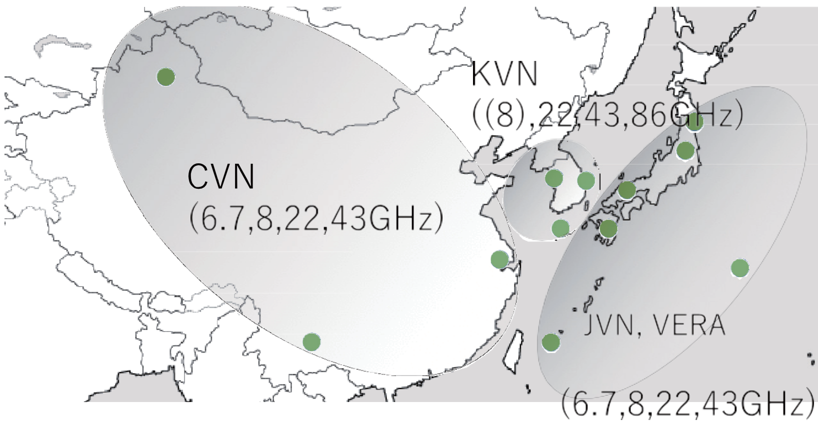

Fig. 2: A sketch of geographic locations of east Asian VLBI Network (EAVN). JVN stands for Japanese VLBI Network, and CVN does for Chinese VLBI Network.

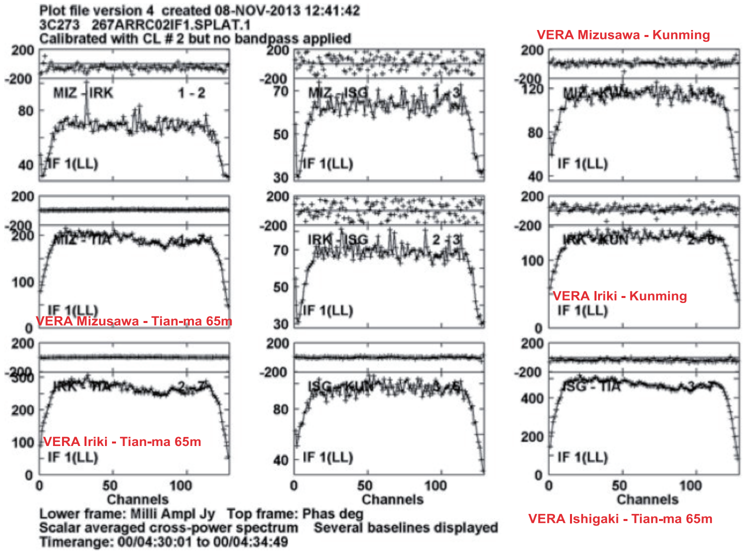

Fig. 3：Interferometer fringes of first fringe tests at 8.4 GHz in September 2013 are displayed. The continuum source 3C 273 was observed and data were averaged over 4 minutes (Data courtesy of EAVN Tiger team and CVN, NAOJ, and KVN). Fringes are seen over the all baselines.

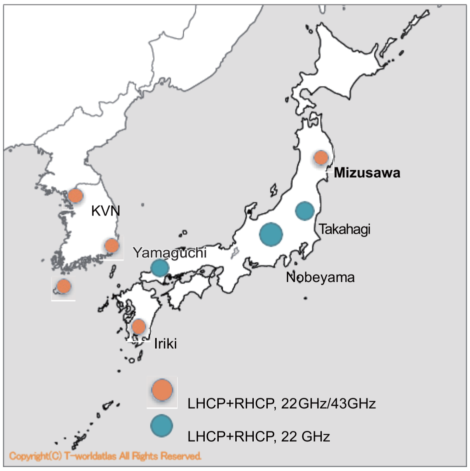

Fig. 4：Overview of radio telescopes with dual polarization receiving capability in Japan and South-Korea at the timing of 2017. LHCP/RHCP denotes left/right-hand circular polarization, respectively.

These plans will definitely and greatly improve the (u,v) coverage and sensitivity of EAVN (Fig.1). Thai National Radio Observatory plans to build three radio telescopes in Thailand. The construction of one of them, which will participate to EAVN, is underway. As the EAVN test observations of AGN jets progressed, there is an increasing demand for imaging at higher frequency, especially at higher than 43 GHz (7 mm). Presently, people are preparing 86 GHz observations, using KaVA and Nobeyama 45m telescope. Despite of such constructive activities, most unfortunately, closure of some telescopes in Japan used for VLBI seems to be taken up for discussion. One day, we might be asked by our funding agencies : "Which telescope do you need for VLBI?, or Which one do you need not? ". I hope the day would not come to us, at least, in the next decade. I believe that Japanese VLBI community should be able to lead science and instrumentation of EAVN with their own telescopes now and in the future.

7 Summary

In recent years, a lot of activities to promote VLBI collaboration in east Asia region have ben seen. The open-use observations of EAVN has just begun since the 2018 Semester. So it is expected that many of scientific results from EAVN and technical developments at the upcoming VLBI meetings shall be reported in the following years. Moreover, existing VLBI facilities should be able to form a true global VLBI to enhance their capabilities. In such a current circumstance, EAVN should be able to play a vital role in the global VLBI community, bringing contributions from Asia.

YH acknowledges all colleagues involved with EAVN in cooperation with organizations and radio telescopes in Japan, Korea, and China. YH also thanks EAVN Tiger team members for their tremendous efforts in preparation of EAVN in various aspects. EAVN is the international VLBI array operated by Korea Astronomy and Space Science Institute, National Astronomical Observatory of Japan, Shanghai Astronomical Observatory, and Xinjiang Astronomical Observatory. This work was supported by JSPS KAKENHI Grant Number JP15H03644.

Table 1：Comparison of existing VLBI networks

Array	Baseline[f] (km)	Telescopes	Band (GHz)	Region
EAVN	5500	15	6.7,8.4,22,43	east Asia
VLBA[a]	8600	10	1.6-86	USA
EVN[b]	11000	16	1.4-43	Europe, China[e], South Africa[g]
LBA[c]	9800	7	1.4-22	Australia, South Africa[g]
CVN[d]	4000	4	1.4-22	China
JVN	2300	8	6.7,8,22	Japan
VERA	2300	4	6.7,22,43	Japan
KVN	476	3	22,43,86,129	South Korea
GMVA[h]	12000	15[i]	86-95	Europe, USA, South Korea

a) Very Long Baseline Array, operated by NRAO
b) European VLBI Network, organized by JIVE
c) Long Baseline Array, organized by ATNF
d) Chinese VLBI Network
e) Shanghai and Urumqi station participating to EVN, f) Maximum baseline length
g) Hartebeesthoek Observatory in South-Africa participating to EVN and LBA
h) Global mm-VLBI Array
i) The number of participating telescopes, including EVN, VLBA, KVN, and ALMA, depends on a best effort basis [3]

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和文摘要

東アジアVLBIネットワーク(EAVN)
— EAVNの進化と将来

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要旨

近年の東アジア地域におけるVLBI(超長基線電波干渉計)天文学の発展は目覚ましいものがある。日本、中国、韓国に展開する15台以上の電波望遠鏡を結合する「東アジアVLBIネットワーク(EAVN)」の誕生は、その一つの成果である。EAVNにはおよそ5,500キロメートル(中国ウルムチ局と小笠原局間)に及ぶ最長基線がもたらす空間分解能と、大口径の望遠鏡が加わることによる感度の向上が期待され、その性能は米国内のVLBIネットワークVLBAや同じく欧州のEVNに迫るものである。東アジア地域のVLBIコミュニティの支持を基に様々な努力を経た結果、EAVNは2018年より国際共同利用観測を開始することに至った。現状の限られた観測性能にも関わらず、EAVNは潜在的には将来の「グローバルVLBIネットワーク」の実現において重要な役割を果たすことが期待されている。本論文では、EAVNの現在に至るまでの軌跡と現状、さらには将来の発展性に関して述べる。

keywords：電波天文学, VLBI