EAVN Status Report for 2019A

KaVA/EAVN User Support Team,
NAOJ, SHAO, XAO, and KASI

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Major revision since 2018B

- Nobeyama 45-m telescope joins in EAVN observations at 22 GHz (see Sections 2.2.1, 2.3.1, 3.1, 3.3, and 3.7).
- Nanshan 26-m telescope joins in EAVN open-use operation at 22 GHz (see Sections 2.2.3, 2.3.3, 3.1, 3.3, and 3.7).
- EAVN accepts a request of 'sub-array' configuration (see Section 3.1).

Contents

1 Introduction

This document describes the current observational capabilities and possible observing time of the East Asian VLBI Network (EAVN), and is a supplementary document to the KaVA Status Report [1]. EAVN is the international collaborative VLBI array operated by Korea Astronomy and Space Science Institute (KASI), National Astronomical Observatory of Japan (NAOJ), Shanghai Astronomical Observatory (SHAO; China), and Xinjiang Astronomical Observatory (XAO; China).

EAVN invites proposals for open-use observations to be carried out from January 15, 2019 to June 15, 2019 (2019A semester). The total observing time of 100 hours is provided for EAVN open-use operation to proposers, while the available machine time of each telescope is different between each other. Refer to Section 3 for more details.

In 2019A semester, EAVN is operated using 10 telescopes, 7 telescopes of the KVN and VERA Array (KaVA) in Korea and Japan, Nobeyama 45-m telescope in Japan, Tianma 65-m and Nanshan 26-m telescopes in China. Figure 1 shows location of EAVN telescopes which participate in open-use observations of EAVN in 2019A semester.

This status report mainly summarizes general information of EAVN, brief summary and the performance of Nobeyama 45-m, Tianma 65-m, and Nanshan 26-m telescopes, and how to prepare and submit proposals for EAVN. Refer to the KaVA Status Report [1], as well as the KaVA webpage (`http://kava.kasi.re.kr/`), for more details about KaVA.

Figure 1: Location of EAVN sites, including the Korea-Japan Correlation Center at KASI, Korea, overlaid on 'the Blue Marble' image (image credit: NASA's Earth Observatory).

2 System

2.1 Array

In 2019A semester, 10 radio telescopes (KVN 3 × 21 m, VERA 4 × 20 m, Nobeyama 45 m, Tianma 65 m, and Nanshan 26 m) are available for EAVN open use, as shown in Figure 1. Refer to the KaVA Status Report for more details about KaVA's array performance. Two observing frequencies, 22 (K-band) and 43 GHz (Q-band), are opened in 2019A semester. The maximum angular resolution is 0.55 mas at K-band for VERA-Ogasawara – Nanshan baseline and 0.63 mas at Q-band for VERA-Mizusawa – VERA-Ishigakijima baseline). The geographic locations and coordinates of Nobeyama, Tianma, and Nanshan, as well as KaVA, are summarized in Table 1. Figure 2 shows examples of (u, v) coverage.

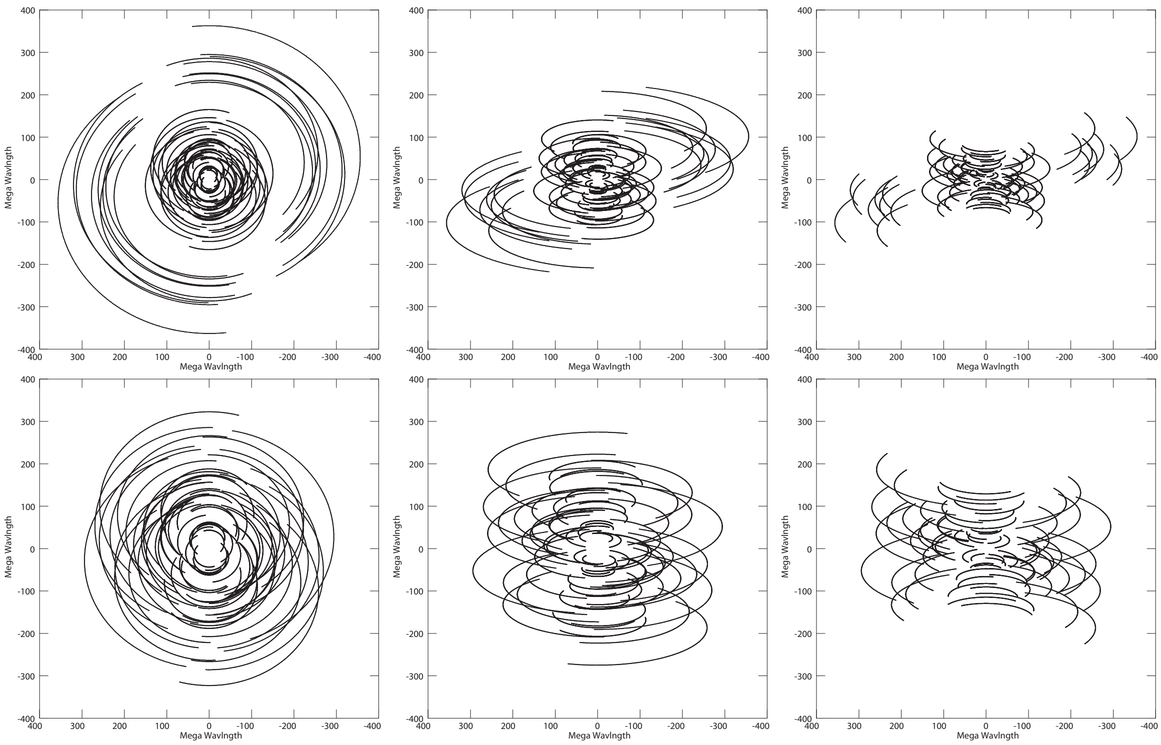

Figure 2: Examples of (u, v) coverage for an EAVN observation with full array configuration at 22 GHz (upper panels) and 43 GHz (lower panels) with the source's declination of +60° (left panels), +20° (middle panels), and −20° (right panels). Total observation duration of 10 hours and the antenna elevation limit of 15° are assumed for all cases.

2.2 Telescopes

2.2.1 Nobeyama 45-m Telescope

The Nobeyama 45-m Telescope (hereafter NRO45) is one of the largest millimeter radio telescope in the world. It has a Cassegrain-Coudé optics. The paraboloidal main reflector consists of about 600 pieces of panels, each of which has a surface accuracy of about 60 microns, and the deviation of the whole antenna from an ideal paraboloid is about 90 microns. The sub-reflector has a diameter of 4 m with a convex hyperboloid

Table 1: Geographic locations of each EAVN telescope.

Site	East Longitude [° ′ ″]	North Latitude [° ′ ″]	Ellipsoidal Height [m]	X [m]	Y [m]	Z [m]
Nobeyama[a]	138 28 21.2	35 56 40.9	1350	–3871025.4987	3428107.3984	3724038.7361
Tianma[b]	121 08 09.4	30 55 19.8	49.2	–2826708.6380	4679237.0440	3274667.5330
Nanshan	87 10 40.4	43 28 15.6	2029.4	228310.1700	4631922.7550	4367064.0740
Mizusawa[c]	141 07 57.3	39 08 00.7	116.4	–3857244.6475	3108782.9982	4003899.2132
Iriki[c]	130 26 23.6	31 44 52.4	573.6	–3521719.8292	4132174.6212	3336994.1399
Ogasawara[c]	142 12 59.8	27 05 30.5	273.1	–4491068.5584	3481545.0777	2887399.7419
Ishigakijima[c]	124 10 15.6	24 24 43.8	65.1	–3263995.1630	4808056.3180	2619948.7989
Yonsei[d]	126 56 27.4	37 33 54.9	139	–3042280.9137	4045902.7164	3867374.3544
Ulsan[d]	129 14 59.3	35 32 44.2	170	–3287268.6186	4023450.1799	3687380.0198
Tamna[d]	126 27 34.4	33 17 20.9	452	–3171731.5580	4292678.4878	3481038.7252

[a]The position was measured in late 2016.
[b]The epoch of the coordinate is January 01, 2014.
[c]The epoch of the coordinates is January, 01, 2015.
[d]The positions are obtained by the KaVA K-band geodesy program on January 24, 2014.

surface, the position of which is computer-controlled to follow the moving focal point because the main reflector deforms as the elevation angle changes. The slewing speed of the telescope is 20°/min (i.e., 0.3°/sec). The (EL, AZ) driving ranges are also summarized in Table 2. More details on the NRO45 can be found in the Nobeyama Radio Observatory official website [2].

The aperture efficiency and beam size of the NRO45 at K- and Q-bands are listed in Table 3. The values for NRO45 are based on the latest measurements in autumn 2017, where the Jupiter or the Mars was used as a reference source. The elevation dependence of the aperture efficiency is approximately constant over a range of El $\sim 25° - 50°$ at both K- and Q-bands.

2.2.2 Tianma 65-m Telescope

The Tianma 65-m Telescope (hereafter TMRT65) has a shaped Cassegrain-type design with a 65-m diameter main reflector and a 6.5-m sub-reflector on Az-El mount. The main reflector consists of 1008 aluminum panels deploying an active surface control system with 1104 actuators. The prime mirror achieves a surface accuracy of about 0.3 mm rms after compensating the gravitational deformation in real time by the active surface control system. The secondary mirror has a surface error of 0.1 mm rms. A rotatable receiver cabin with the feeds covering frequency range from S-band (2 GHz) to Q-band is mounted at the Cassegrain focus, while the L-band (1.6 GHz) feed is off focus mount separately. The slewing rates of the main reflector are 0.5°/sec in azimuth and 0.3°/sec in elevation, as shown in Table 2.

The aperture efficiency of TMRT65 is above 50% at both K- and Q-bands with the active surface control system (see Table 3). The main reflector panels were assembled to give the maximum surface accuracy at the elevation angle of 52°. The aperture efficiency goes down to less than 10% at low ($< 10°$) and high ($> 80°$) elevation angles, mainly due to the gravitational deformation. The active surface control system is used for compensating the gravitational effect at different elevation angles, making the gain curves as a constant over the elevation. Figure 3 shows the elevation dependence of the aperture efficiency at Q-band with or without the active surface control. The active surface control system is set ‘ON’ by default at K- and Q-band observations.

Dual-beam receivers are installed in TMRT65 at both K- and Q-bands. These two beams have a fixed separation angle of 140 arcsec at K-band and 100 arcsec at Q-band. One of the beams is placed at the antenna focus for VLBI observations. Typical sidelobe levels are 13 – 15dB at both K- and Q-bands. The measured beam sizes (HPBW) are listed in Table 3.

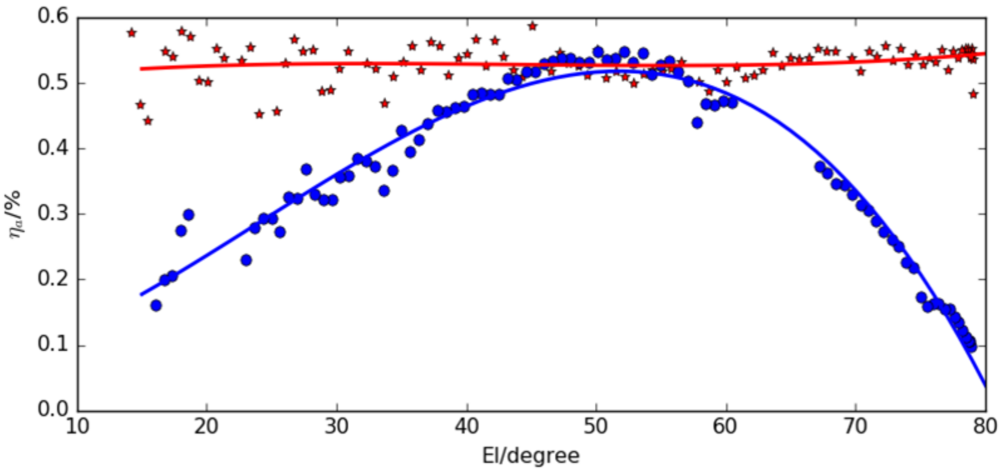

Figure 3: Elevation dependence of the aperture efficiency ($\eta_{\rm eff}$) for TMRT65 at Q-band. The red and blue colors represent $\eta_{\rm eff}$ with or without the active surface control, respectively.

2.2.3 Nanshan 26-m Telescope

The Nanshan 26-m Telescope (hereafter NSRT26) has a Cassegrain-type design with a 26-m diameter main reflector and a 3-m sub-reflector on Az-El mount. The telescope was constructed in 1991 with 25-m-diameter main reflector, while refurbishment of the telescope was completed in 2015 resulting in enlargement of the main reflector of 26 m and improvement of the antenna surface accuracy. Receivers at five frequency bands, L, S/X, C, K, and Q, are equipped, while the new Q-band cooled receiver has been installed in 2018 and is under evaluation. The surface accuracy of main- and sub-reflectors are 0.18 mm rms and 0.1 mm rms, respectively. The slewing rates of the main reflector are 1.0°/sec in azimuth and 0.5°/sec in elevation, as shown in Table 2. The aperture efficiency of NSRT26 is 60% at K-band (see Table 3).

2.3 Receivers

2.3.1 Brief Summary of NRO45 Receiving System

The NRO45 covers an observing frequency range of 20 – 116 GHz with multiple receivers. The VLBI backend system of the NRO45 is currently equipped at K-band and Q-band. Figure 4 illustrates a flow diagram of the VLBI receiving system in the NRO45. The observable RF range and typical receiver noise temperature for the receivers at K- and Q-bands are also summarized in Table 4. The received RF signals

Table 2: Driving performance of EAVN telescopes.

Driving axis	Driving range	Max. driving speed	Max. driving acceleration
		Nobeyama	
AZ[a]	$-60° \sim 510°$	0.3°/sec	0.3°/sec^2
EL	$12° \sim 80°$	0.3°/sec	0.3°/sec^2
		Tianma	
AZ[a]	$-60° \sim 425°$	0.5°/sec	0.27°/sec^2
EL	$8° \sim 88°$	0.3°/sec	0.16°/sec^2
		Nanshan	
AZ[a]	$-270° \sim 270°$	1.0°/sec	0.5°/sec^2
EL	$5° \sim 88°$	0.5°/sec	0.5°/sec^2
		VERA	
AZ[a]	$-90° \sim 450°$	2.1°/sec	2.1°/sec^2
EL	$5° \sim 85°$	2.1°/sec	2.1°/sec^2
FR[b]	$-270° \sim 270°$	3.1°/sec	3.1°/sec^2
		KVN	
AZ[a]	$-90° \sim 450°$	3.0°/sec	3.0°/sec^2
EL	$5° \sim 85°$	3.0°/sec	3.0°/sec^2

[a]The north is 0° and the east is 90°.
[b]Field rotator. FR is 0° when Beam-1 is at the sky side and Beam-2 is at the ground side, and CW is positive when a telescope is seen from a target source.

Table 3: Aperture efficiency and beam size of EAVN telescopes.

	K-band (22 GHz)		Q-band (43 GHz)	
Telescope name	η_A (%)	HPBW (arcsec)	η_A (%)	HPBW (arcsec)
Nobeyama	61	72	53	39
Tianma	50	44	50	22
Nanshan	60	115	–	–
Mizusawa	47	141	51	71
Iriki	47	149	44	78
Ogasawara	50	143	45	78
Ishigakijima	49	144	48	79
Yonsei	55	127	63	63
Ulsan	63	124	61	63
Tamna	60	126	63	63

are down-converted into an IF range of 5 – 7 GHz, and the IF signals are then mixed down to the base band of 512 – 1024 MHz, which is the input to the A/D sampler.

Currently, one of the receivers can be selected by switching the mirrors in the optics in a few minutes manually. In the near future, K- and Q-band observations can be conducted simultaneously by inserting a perforated high-pass dichroic plate. When using the dichroic plate, the gain of the Q-band signals may be reduced by 0.3dB (in 2018 June), causing the rise of the system noise temperature by about 30 K.

2.3.2 Brief Summary of TMRT65 Receiving System

Figure 5 shows a flow diagram of the VLBI receiving system in TMRT65. TMRT65 has the receivers for 8 frequency bands, L (1.4 GHz), S/X (2.3/8.4 GHz), C (6.7 GHz), X/Ka (8.4/31.0 GHz), Ku (15 GHz), K (22 GHz), and Q (43 GHz). The K- and Q-band receivers are cooled HEMT receivers with dual circular polarizers. The observable frequency range and the typical receiver noise temperature are shown in Table 4. The

Table 4: Frequency range and T_{RX} of receivers at each EAVN telescope.

Band	Frequency Range [GHz]	$T_{\mathrm{RX}}{}^{a}$ [K]	Polarization
		Nobeyama	
K	20 – 25	~ 85	LCP/RCP
Q	42.5 – 44.5	~ 111	LCP
		Tianma	
K	18.0 – 26.5	16 – 35	LCP/RCP
Q	39 – 47	35 – 50	LCP/RCP
		Nanshan	
K	22.0 – 24.2	~ 15	LCP/RCP
Q		(under evaluation)	
		VERA	
K	21.5 – 23.8	30 – 50	LCP
Q	42.5 – 44.5	70 – 90	LCP
		KVN	
K	21.25 – 23.25	30 – 40	LCP/RCP
Q	42.11 – 44.11	70 – 80 (40 – 50 for Ulsan)	LCP/RCP

[a]Receiver noise temperature

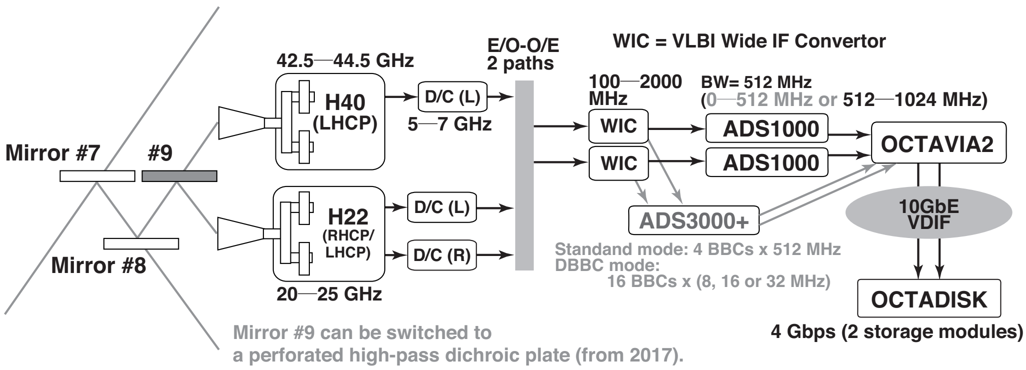

Figure 4: Flow diagram of signals from receiver to recorder for NRO45.

total system noise temperatures at K- and Q-bands are typically 70 and 110 K, respectively. The RF signal is firstly down-converted to IF range of 4 – 12 GHz and it is transferred by optical fibers to the observing room, where the signal is further down-converted to 0 – 1024 MHz (actually in 10 – 512 MHz and 512 – 1024 MHz) at the input of BBCs.

2.3.3 Brief Summary of NSRT26 Receiving System

Figure 6 shows a flow diagram of the VLBI receiving system in NSRT26. NSRT26 has the receivers for 5 frequency bands, L (1.4 GHz), S/X (2.3/8.4 GHz), C (5 GHz), K (22 GHz), and Q (43 GHz), while NSRT26 joins in EAVN observations at only K-band in 2019A semester. The K-band receiver is cooled HEMT receivers with dual circular polarizers. The observable frequency range and the typical receiver noise temperature are shown in Table 4. The total system noise temperatures at K-band is typically 42 K. The RF signal is down-converted with three stages, and analog-digital conversion and digital filtering of the IF signal is conducted using either the Digital Baseband

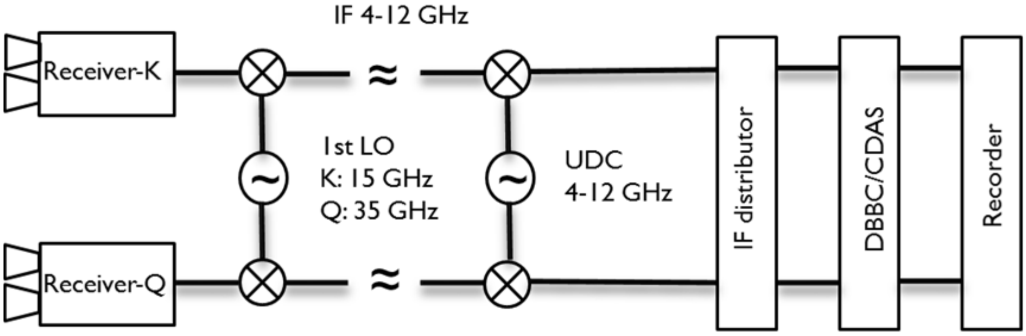

Figure 5: Flow diagram of signals from receiver to recorder for TMRT65.

Converter (DBBC) system or the Chinese VLBI Data Acquisition System (CDAS).

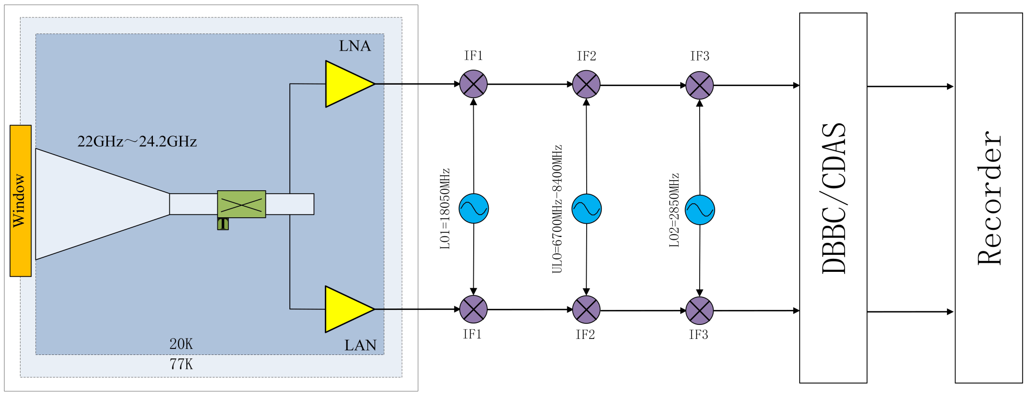

Figure 6: Flow diagram of signals from receiver to recorder for NSRT26.

2.4 Digital Signal Processing

In NRO45 system, the baseband signal output is 512–1024 MHz and the A/D samplers perform 2-bit digitization with four quantization levels. A maximum recording rate of 2048 Mbps is possible with a total bandwidth of 512 MHz.

Since the total data recording rate is limited to 1024 Mbps (see the next section), only part of the sampled data can be recorded onto hard disks. The data rate reduction is done by digital filter system, with which one can flexibly choose number and width of recording frequency bands.

Observers can select modes of the digital filter listed in Table 6 of the KaVA Status Report [1]. For EAVN observations in 2019A semester, however, three digital filter modes are available, 'GEO1K' and 'GEO1S' (16 MHz × 16 IF channels for both setup), and 'VERA4S' (32 MHz × 8 IF channels). Refer to Section 3.3 for more details.

2.5 Recorder

Currently KaVA/EAVN observations are basically limited to record with 1024 Mbps data rate. VERA and NRO45 have the OCTADISK recording system and Mark5B recorder is used at KVN, TMRT65, and NSRT26. OCTADISK and Mark5B are hard disk recording systems developed at NAOJ and Haystack observatory, respectively.

2.6 Correlator

The correlation process is carried out by KJCC (Korea-Japan Correlation Center) at Daejeon, Korea. Hereafter it is tentatively called "Daejeon correlator", and its basic specifications are summarized in Table 5. The Daejeon correlator can process the data stream of up to 8192 Mbps from maximum 16 stations at once. Currently, available data formats are 16 IFs × 16 MHz ("C5 mode" in the Daejeon correlator terminology) at K-band, and 8 IFs × 32 MHz ("C4 mode") at both K- and Q-bands, and 2 IFs×128 MHz ("C2 mode"). Minimum integration time (time resolution) of Daejeon correlator is 0.2048, 0.8192, and 1.6384 seconds for both C4 and C5 modes, and the number of frequency channels within each IF is 8192 for both modes (i.e. maximum frequency resolution is about 1.95 kHz). By default, the number of frequency channels is reduced to 128 (for continuum) or 512 (for spectral line) via channel integration after correlation. One may put a special request of number of frequency channels to take better frequency resolution. The number of frequency channels can be selected among 512, 1024, 2048, 4096, or 8192. Final correlated data is provided as FITS-IDI file.

Table 5: Specification of the Daejeon Hardware Correlator[a].

Max. number of stations	16
correlation mode	C2[b] (128 MHz Bandwidth, 2 stream)
	C4 (32 MHz Bandwidth, 8 stream)
	C5 (16 MHz Bandwidth, 16 stream)
Max. number of corr./input	120 cross + 16 auto
Sub-array	2 case(12+4, 8+8)
Bandwidth	512 MHz
Max. data rate/station	2048 Mbps VSI-H (32 parallels, 64 MHz clock)
Max. delay compensation	± 36,000 km
Max. fringe tracking	1.075 kHz
FFT work length	16+16 bits fixed point for real, imaginary
Integration time	25.6 msec ∼ 10.24 sec
Data output channels	8192 channels
Data output rate	Max. 1.4GB/sec at 25.6 msec integration time

[a]For more details, see the following website:
`http://kvn.kasi.re.kr/status_report/correlator_status.html`
[b]This mode is not available for observations using NRO45 and TMRT65.

2.7 Calibration

Here we briefly summarize the calibration procedure of the KaVA/EAVN data. Basically, most of the post-processing calibrations are done by using the AIPS (Astronomical Image Processing System) software package developed by NRAO (National Radio Astronomical Observatory).

2.7.1 Delay and Bandpass Calibration

The time synchronization for each telescope is kept within 0.1 μsec using GPS and high stability frequency standard provided by the hydrogen maser. To correct for clock parameter offsets with better accuracy, bright continuum sources with accurately-known positions should be observed at usually every 60 – 80 minutes during observations. A recommended scan length for calibrators is 5 – 10 minutes. This can be done by the AIPS task FRING. The calibration of frequency characteristic (bandpass calibration) can be also done based on the observation of bright continuum source. This can be done by the AIPS task BPASS.

2.7.2 Gain Calibration

VERA, KVN, and NRO45 have the chopper wheel of the hot load (black body at the room temperature), and the system noise temperature can be obtained by measuring the ratio of the sky power to the hot load power (so-called R-Sky method). Thus, the measured system noise temperature is a sum of the receiver noise temperature, spillover temperature, and contribution of the atmosphere (i.e. so-called $T^*_{\rm sys}$ corrected for atmospheric opacity). The hot load measurement can be made before/after any scan. Also, the sky power is continuously monitored during scans, so that one can trace the variation of the system noise temperature. The system noise temperature value can be converted to SEFD (System Equivalent Flux Density) by dividing by the antenna gain in K/Jy, which is derived from the aperture efficiency and diameter of each telescope.

$T^*_{\rm sys}$ data (TY table) and antenna gain information (GC table) are provided with the ANTAB-readable format in AIPS. The TY and GC tables can be loaded by the AIPS task ANTAB, and these tables are converted to the SN table by the AIPS task APCAL.

On the other hand, $T_{\rm sys}$ measurement provided by TMRT65 and NSRT26 contains atmospheric opacity effects, thus the opacity correction should be applied to those data in the course of data reduction.

Alternatively, one can calibrate the visibility amplitude by the template spectrum method, in which auto-correlation spectra of a maser source is used as the flux calibrator. This calibration procedure is made by the AIPS task ACFIT (see AIPS HELP for ACFIT and Cho et al. (2017) [3] for more details). For an EAVN observation including TMRT65, NRO45, and NSRT26, we strongly recommend users to observe a maser source or a compact continuum gain calibrator for every $\leq$1 hr. This offers an additional cross-check of the amplitude calibration for TMRT65/NRO45. Along with this, these two telescopes will do regular antenna pointing scans for every $\leq 1 - 2$ hr.

As for TMRT65, moreover, frequent pointing check is necessary for observations at both K- and Q-bands. The pointing check is done semi-automatically with a continuum back-end system and the quality of pointing check is judged by on-site operators. We strongly recommend to keep at least 3 minutes for the pointing check itself with additional slewing time between target and pointing sources. For example, it is preferable to secure 5-min gap in total for the pointing check toward a pointing source with the angular separation of $\sim 15^\circ$ from the target.

Further correction is made for VLBI observations taken with 2-bit (4-level) sampling, for the systematic effects of non-optimal setting of the quantizer voltage thresholds. This is done by the AIPS task ACCOR. **Another correction should be applied to recover the amplitude loss, which are attributed to the combination of two steps of 2-bit quantization in the digital filtering at the backend system and**

characteristics of Daejeon correlator. This is done by multiplying the scaling factor of 1.3 (the best current estimation)[4] in the AIPS task APCAL (adverbs APARM(1) = 1.3, **OPCODE** = '', **and DOFIT** = 1) **or SNCOR (adverbs OPCODE** = **'MULA', and SNCORPRM(1)** = 1.3). **Note that this correction should be applied to all EAVN telescopes.** The amplitude calibrations with EAVN are accurate to 15% or better at both K- and Q-bands.

3 Observing Proposal

3.1 Call for Proposals (CfP)

We invite proposals for the open-use observations of EAVN. Please refer to the following KaVA and EAVN webpages for more details about the array and its performance, and how to prepare and submit a proposal.

`http://kava.kasi.re.kr/`

`http://eavn.kasi.re.kr/`

This EAVN open-use call is based on risk-share, and provides opportunities of VLBI observations at 22 and 43 GHz for astronomers in the world.

We support astronomers in preparation of proposals, scheduling of your observations, and data analysis. If proposers are not familiar with EAVN, they are recommended to include at least one collaborator from EAVN (VERA, KVN, Tianma, and Nanshan). The contact address for the support is `eavnhelp (at-mark) kasi.re.kr`.

EAVN observations are conducted with single polarization (LHCP) and the data are recorded with the data rate of 1 Gbps. NRO45's data are recorded with the data rate of 2 Gbps and reformatted to 1 Gbps data. The total observation time for EAVN is up to 100 hours, while NRO45 is limited up to 50 hours. In addition, NSRT26 is available at only 22 GHz and **EAVN proposers are asked to set an observation duration of no shorter than 6 hours per epoch if NSRT26 is included in your EAVN observations**. Therefore, TMRT65, NSRT26, and NRO45 will participate in EAVN observations together with KaVA according to scientific needs and their availability. Note that proposals submitted to EAVN can be assigned to KaVA according to the decision by the KaVA/EAVN Time Allocation Commttee (TAC).

In 2019A semester, EAVN accepts a request of usage of sub-array configuration (KaVA 7 telescopes and one or two telescopes from NRO45, TMRT65, and NSRT26), as well as EAVN full array configuration with 10 or 9 telescopes at 22 or 43 GHz, respectively. A proposer shall clarify the reason for the choice of sub-array configuration in the proposal.

The maximum request time per proposal is limited to 24 hours for EAVN. EAVN observations will be scheduled between 15th January 2019 and 15th June 2019, while NRO45 will be available until 15th May 2019 due to availability of the telescope.

The deadline of submission is at

08:00 UT on 1st November, 2018.

Detailed information on the EAVN call-for-proposal can be found in the following webpage:

`https://radio.kasi.re.kr/eavn/proposal_info.php`

3.2 Proposal Submission

The KaVA/EAVN proposal application form and proposal submission are available at both EAVN and KaVA websites. If you have any questions regarding to your proposal submission, contact to "`eavnprop (at-mark) kasi.re.kr`".

All submitted proposals will be reviewed by the referees and the KaVA/EAVN TAC will allocate the observing time based on the referee's rating results. **A proposal shall contain the coversheet (two pages), scientific justification including figures (maximum of two pages), and technical justification (maximum of one page) with the minimum font size of 10 points.** The results of the review will be announced to each PI in late December, 2018.

3.3 Observation Mode

EAVN provides opportunities of observations with two observing frequencies, 22 and 43 GHz. Both observation modes are conducted with single polarization and with the data recording rate of 1 Gbps (total bandwidth of 256 MHz). Two types of setup of the digital filter ('C4 mode' with 8 IFs $\times$ 32 MHz, and 'C5 mode' with 16 IFs $\times$ 16 MHz) are available at 22 GHz, while only C4 mode is available at 43 GHz. Available observing mode of EAVN is summarized in Table 6. Note also that an observation at 43 GHz is available from 15th January 2019 to 15th May 2019 due to the availability of NRO45, as mentioned in Section 3.1.

Table 6: Available observing mode of EAVN.

Frequency	22 GHz	43 GHz
Telescope	KaVA, NRO45, TMRT65, NSRT26 (10 telescopes)	KaVA, NRO45, TMRT65 (9 telescopes)
Backend mode	C4, C5	C4
Recording rate	1 Gbps[a]	
Polarization	Left-hand circular polarization (LHCP)	
Correlator	Daejeon Hardware Correlator	

[a] NRO45's data are recorded with 2 Gbps and reprocessed to 1 Gbps.

3.4 Possible Conflict/Duplication with KaVA Large Programs

In order to avoid conflict and/or duplication of the targets with existing KaVA Large Programs (LPs), proposers are highly recommended to visit the KaVA LP webpage where KaVA LPs and their source lists are presented:

`https://radio.kasi.re.kr/kava/large_programs.php.`

Proposals to be submitted for this opportunity should not have the same scientific goal with LPs, while it is fine to propose same sources with LPs if your proposal has a different scientific goal with LPs.

3.5 Target of Opportunity (ToO) Observations

ToO proposals with only KaVA can be submitted. We do not accept ToO proposals with EAVN full array.

3.6 Angular Resolution and Largest Detectable Angular Scale

The maximum angular resolution for EAVN observations is 0.55 mas at K-band for VERA-Ogasawara – Nanshan baseline and 0.63 mas at Q-band for VERA-Mizusawa – VERA-Ishigakijima baseline. The synthesized beam size strongly depends on UV coverage, and could be higher than the values mentioned above because the baselines projected on UV plane become shorter than the distance between telescopes. The beam size can be calculated approximately by the following formula;

$$\theta \sim 2063 \left(\frac{\lambda}{[\mathrm{cm}]}\right)\left(\frac{B}{[\mathrm{km}]}\right)^{-1} [\mathrm{mas}], \tag{1}$$

where λ and B are observed wavelength in centimeter and the maximum baseline length in kilometer, respectively.

The minimum detectable angular scale for interferometers can be also expressed by equation (1), where the baseline length B is replaced with the shortest one among the array. Because of the relatively short baselines provided by KVN, ∼300 km, KaVA is able to detect an extended structure up to 9 mas and 5 mas for the K- and Q-bands, respectively.

As for an EAVN array which adds TMRT65/NRO45 to KaVA, the longest/shortest baselines remain the same as those of KaVA, so the maximum angular resolutions and the largest detectable angular scales are basically the same, although their detailed values in a synthesized image are dependent on the scheme of UV weighting as well as the UV coverage. As for an EAVN array which additionally includes NSRT26 at K-band, the longest baseline length extends to 5100 km (primarily along the east-west direction). This enhances the maximum angular resolution at K-band by a factor of ∼ 2.2 compared to that of KaVA.

3.7 Sensitivity

When a target source is observed, a noise level σ_{bl} for each baseline can be expressed as

$$\sigma_{\mathrm{bl}} = \frac{2k}{\eta}\frac{\sqrt{T_{\mathrm{sys},1}T_{\mathrm{sys},2}}}{\sqrt{A_{e1}A_{e2}}\sqrt{2B\tau}} = \frac{1}{\eta}\frac{\sqrt{SEFD_{\mathrm{sys},1}SEFD_{\mathrm{sys},2}}}{\sqrt{2B\tau}}, \tag{2}$$

where k is Boltzmann constant, η is quantization efficiency (∼ 0.88), T_{sys} is system noise temperature, $SEFD$ is system equivalent flux density, A_e is antenna effective aperture area ($A_e = \pi\eta_A D^2/4$ in which A_e and D are the aperture efficiency and antenna diameter, respectively), B is the bandwidth, and τ is on-source integration time. Note that for an integration time beyond 3 minutes (in the K band), the noise level expected by equation (2) cannot be attained because of the coherence loss due to the atmospheric fluctuation. Thus, for finding fringe within a coherence time, the integration time τ cannot be longer than 3 minutes. For VLBI observations, signal-to-noise ratio (S/N) of at least 5 and usually 7 is generally required for finding fringes.

A resultant image noise level σ_{im} can be expressed as

$$\sigma_{\mathrm{im}} = \frac{1}{\sqrt{\Sigma\sigma_{\mathrm{bl}}^{-2}}}. \tag{3}$$

If the array consists of identical antennas, an image noise levels can be expressed as

$$\sigma_{\mathrm{bl}} = \frac{2k}{\eta} \frac{T_{\mathrm{sys}}}{A_e \sqrt{N(N-1)B\tau}} = \frac{1}{\eta} \frac{SEFD}{\sqrt{N(N-1)B\tau}}, \tag{4}$$

where N is the number of antennas. Using the typical parameters shown in Table 7, baseline and image sensitivity values of EAVN are calculated as listed in Tables 8 and Table 9 (baseline and image sensitivities of KVN, VERA, and KaVA, as well as EAVN, are also shown for reference).

Table 7: Parameters of each telescope.

Station	K-band			Q-band		
	T_{sys} [K]	η_{A}	SEFD [Jy]	T_{sys} [K]	η_{A}	SEFD [Jy]
KVN	100	0.6	1328	150	0.6	1992
VERA	120	0.5	2110	250	0.5	4395
TMRT65	60	0.5	100	66	0.5	110
NRO45	100	0.61	285	200	0.53	655
NSRT26	42	0.6	364	–	–	–

Table 8: Baseline sensitivity of EAVN.

	K-band					Q-band			
	KVN	VERA	TM65	NRO45	NS26	KVN	VERA	TM65	NRO45
KVN	6.1	7.7	1.7	2.8	3.2	9.1	13.6	2.2	5.2
VERA	–	9.7	2.1	3.6	4.1	–	20.2	3.2	7.8
TMRT65	–	–	–	0.8	0.9	–	–	–	1.2
NRO45	–	–	–	–	1.5	–	–	–	–

Note: 1σ baseline sensitivity values are listed in unit of mJy, which assume an integration time of 120 seconds and a bandwidth of 256 MHz for the calculation. In the case of narrower bandwidth of 15.625 KHz (for maser emission), sensitivities can be calculated by multiplying a factor of 128.

Figures 7 and 8 show the system noise temperature at Mizusawa and Ulsan, respectively. For Mizusawa, receiver noise temperatures are also plotted.

Note that the receiver temperature of VERA includes the temperature increase due to the feedome loss and the spill-over effect. In Mizusawa, typical system temperature in the K-band is $T_{\mathrm{sys}} = 150$ K in fine weather of winter season, but sometimes rises above $T_{\mathrm{sys}} = 300$ K in summer season. The system temperature at Iriki station shows a similar tendency to that in Mizusawa. In Ogasawara and Ishigakijima, typical system temperature is similar to that for summer in Mizusawa site, with typical optical depth of $\tau_0 = 0.2 \sim 0.3$. The typical system temperature in the Q-band in Mizusawa is $T_{\mathrm{sys}} = 250$ K in fine weather of winter season, and $T_{\mathrm{sys}} = 300 - 400$ K in summer season. The typical system temperature in Ogasawara and Ishigakijima in the Q-band is larger than that in Mizusawa also.

The typical system temperature in the K-band at all KVN stations is around 100 K in winter season. In summer season, it increases up to $\sim$ 300 K. In the Q-band, the

Table 9: Image sensitivity of EAVN.

Array	$N_{\rm ant}$	$N_{\rm bl}$	K-band	Q-band
KVN	3	3	320	480
VERA	4	6	360	750
KaVA	7	21	155	268
KaVA+TMRT65	8	28	60	85
KaVA+NRO45	8	28	89	169
KaVA+TMRT65+NRO45	9	36	42	65
KaVA+TMRT65+NSRT26	9	36	44	–
KaVA+TMRT65+NSRT26+NRO45	10	45	35	–

Note: $N_{\rm ant}$ and $N_{\rm bl}$ are the numbers of telescopes and baselines for each array. 1σ image sensitivity values are listed in unit of μJy, which assume an integration time of 4 hours and a total bandwidth of 256 MHz for the calculation. In the case of narrower bandwidth of 15.625 kHz (for maser emission), sensitivities can be calculated by multiplying a factor of 128.

typical system temperature is around 150 K in winter season and 250 K in summer season at Yonsei and Tamna. The system temperature of Ulsan in the Q-band is about 40 K lower than the other two KVN stations. This is mainly due to the difference in receiver noise temperature (see Table 4).

3.8 Calibrator Information

The NRAO VLBA calibrator survey is very useful to search for a continuum source which can be used as a reference source to carry out the delay, bandpass, and phase calibrations. The source list of this calibrator survey can be found at the following VLBA homepage,

`http://www.vlba.nrao.edu/astro/calib/index.shtml.`

For delay calibrations and bandpass calibrations, calibrators with 1 Jy or brighter are strongly recommended as listed in the VLBA fringe finder survey:

`http://www.aoc.nrao.edu/~analysts/vlba/ffs.html.`

Interval of observing calibrator scans must be shorter than 1 hour to track the delay and delay rate in the correlation process.

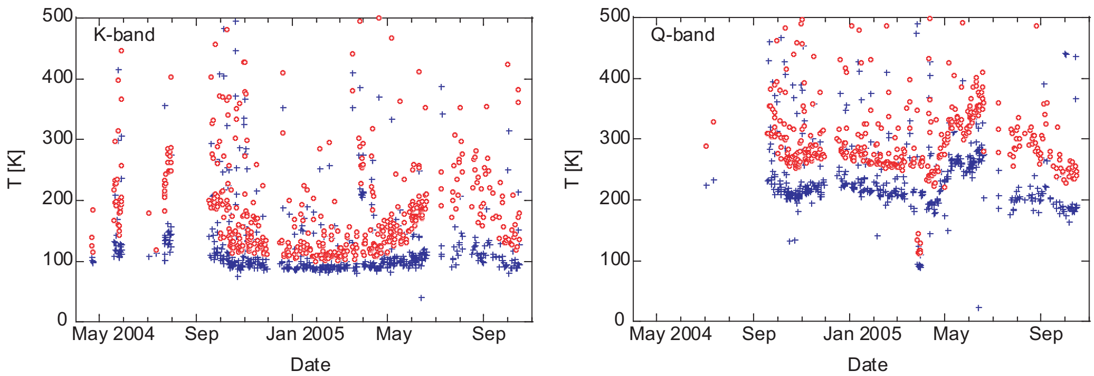

Figure 7: The receiver noise temperature (*blue crosses*) and the system noise temperature (*red open circles*) at the zenith at K-band (left) and Q-band (right) in VERA-Mizusawa station.

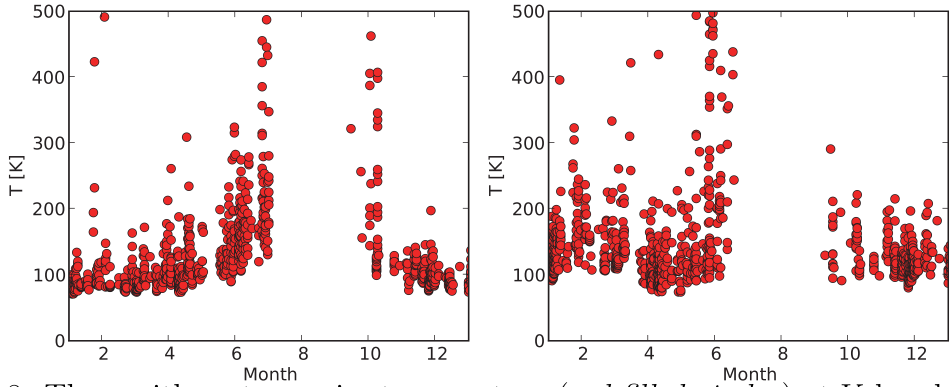

Figure 8: The zenith system noise temperature (*red filled circles*) at K-band (left) and Q-band (right) in KVN-Ulsan station.

3.9 Data Archive

The users who proposed the observations will have an exclusive access the data for 18 months after the correlation. After that period, all data for EAVN open-use observations will be released as archive data. Thereafter, archived data will be available to any user upon request. This policy is applied to each observation, even if the proposed observation is comprised of multi-epoch observations in this season.

4 Observation and Data Reduction

In 2019A semester, observations and user supports for EAVN will be carried out on the basis of the current KaVA's operation scheme.

4.1 Preparation of an EAVN Observation

After the acceptance of proposals, users are requested to prepare the observing schedule file two weeks before the observation date. The observer is encouraged to consult a contact person in the KaVA/EAVN Array Operation Center (AOC) and/or the assigned support scientist to prepare the schedule file under the support of the contact person and/or the assigned support scientist. The schedule submission should be done by a stand-alone vex file. The examples of KaVA vex file are available at the KaVA web site:

`http://radio.kasi.re.kr/kava/kava_observing_preparation.php`

Detailed information about preparation and submission of a schedule file for TMRT65 and NRO45 will be announced when distributing the proposal review results.

On your schedule, we strongly recommend to include at least two fringe finder scans, each lasting 5 or more minutes at the first and latter part of observation in order to search the delay and rate offsets for the correlation.

For EAVN which includes the large telescopes (TMRT65 and NRO45), regular pointing check is necessary at both 22 and 43 GHz. You should leave a 8 – 15 min gap every $\leq$ 1 – 2 hr in your schedule file to allow this. Pointing check is done by the local operators. In addition, we strongly recommend to include frequent scans of a maser source and/or a bright compact continuum source located within 15° from the target. This allows a cross check of the amplitude calibration for TMRT65 and NRO45 along with the usual a priori method.

We request PIs to specify their correlation parameters at the beginning of the vex file for proper correlation processing. In particular, PIs who request for sub-array or dual-beam observations for KaVA should provide a frequency matching table for the correct correlation.

4.2 Observation and Correlation

KaVA/EAVN members take full responsibility for observation and correlation process, and thus basically proposers will not be asked to take part in observations or correlations. Observations are proceeded by operators from each array and telescope, and correlated data is delivered to the users in approximately two months including the time for media shipping to KJCC at Daejeon.

After the correlation, the user will be notified where the data can be downloaded by e-mail. After one month later of a correlated data distribution to PIs, disk modules which contains raw observing data can be recycled without notice. Therefore, PIs should investigate the correlated output carefully. For re-correlation or raw data keeping of the data, PI should provide adequate evidence in order to justify his/her request. If there is an issue related to correlated data, PI should consult a support scientist first or the correlator team (`kjcc (at-mark) kasi.re.kr`), and not to ask KJCC members directly.

4.3 Data Reduction

For KaVA/EAVN data reduction, the users are encouraged to reduce the data using the NRAO AIPS software package. The observation data and calibration data will be provided to the users in a format which AIPS can read.

As for the amplitude calibration, we will provide "ANTAB" files which include the system temperature information measured by the R-sky method and the information of the dependence of aperture efficiency on antenna elevation. If the user wants weather information, the information of the temperature, pressure, and humidity during the observation can be provided.

At present, both KaVA and EAVN do not support astrometric observations. In case of questions or problems, the users are encouraged to ask the contact person in KaVA/EAVN members and/or the assigned support scientist for supports.

4.4 Further Information

The users can contact any staff member of EAVN by e-mail (see Table 10). Note that your EAVN proposal should be submitted to the following EAVN proposal submission site.

`https://radio.kasi.re.kr/eavn/proposal_info.php`

Table 10: Contact addresses.

Name	E-mail address	Related Field
Inquiry about proposal submission	eavnprop (at-mark) kasi.re.kr	Proposal submission in general
User support team	eavnhelp (at-mark) kasi.re.kr	User support in general
Operation team	eavnobs (at-mark) kasi.re.kr	Observation related requests/questions schedule submission
Correlator team	kjcc (at-mark) kasi.re.kr	Correlation related requests/questions correlated data distribution

References

[1] KaVA Status Report for 2019A:
`https://radio.kasi.re.kr/kava/status_report19a/node3.html`

[2] NRO web site: `http://www.nro.nao.ac.jp/~nro45mrt/html/index-e.html`

[3] Cho, I. et al. 2017, PASJ, 69, 87

[4] Lee, S.-S. et al. 2015, JKAS, 48, 229

[5] Oyama, T. et al. 2016, PASJ, 68, 105