The EVN: Present & History

Bob Campbell, JIVE
(Joint Institute for VLBI ERIC)

- What is the EVN now?
  - (in global picture)
- How did we (in Europe) get here?
  - Stations, technologies, structures

Funded by the European Union. Views and opinions expressed are howver those of the author only and do not necessarily reflect those of the European Union or of the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
The ACME project has received funding from the European Union's Horizon Europe Research and Innovation Programme under grant agreement No, 101131928.

The EVN


Ny Alesund
Metsahovi
Onsala
Jodrell Bank
Westerbork
Cambridge
Irbene
Effelsberg
Torun
Wettzell
Robledo
Yebes
Medicina
Sardinia
Noto
Hartebeesthoek
Korean VLBI Network (4)
Urumqi
Tianma65
Shanghai
Kunming

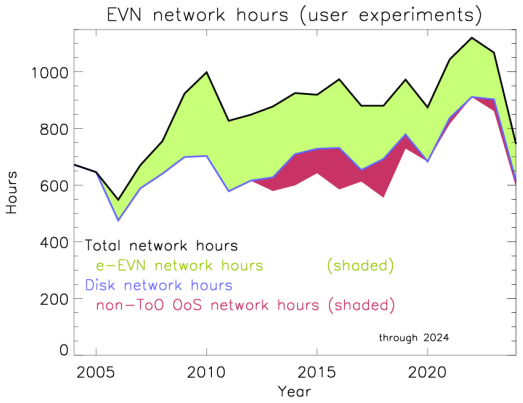

AVIAPTNR
EVN
OS 641
OS 376
VIA
HOT

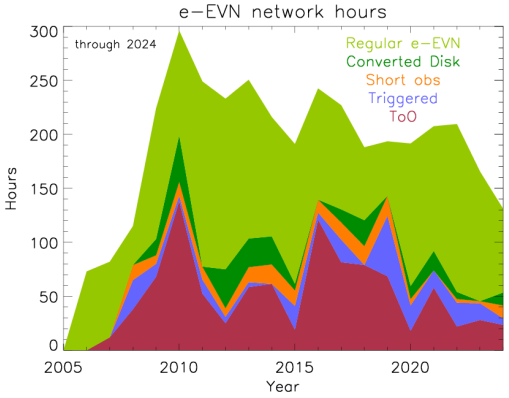
The EVN (European VLBI Network)

- **An open-skies facility**
- Composed of existing antennas
  - Generally larger (32m – 100m): more sensitive
  - Baselines from 260 – 10k km, down to 17 km with e-MERLIN
  - Heterogeneous, generally slower slewing
- Frequency coverage
  - Bands [GHz]: 0.3, 1.4/1.6, 2.3, 5, 6.0/6.7, 8.4, 22, 43
  - Current operational bandwidth: up to 512MHz (dual-pol)
  - Frequency coverage/agility not universal across all antennas
- Real-time e-VLBI experiments (one starts tomorrow !)
- Observing sessions
  - Three ~3-week sessions per year
  - ~10 scheduled e-VLBI sessions per year [1 – 2 – 3 days]
  - Target of Opportunity / Out-of-session observations
  - EVN-lite (limited sub-array potentially observing more often)

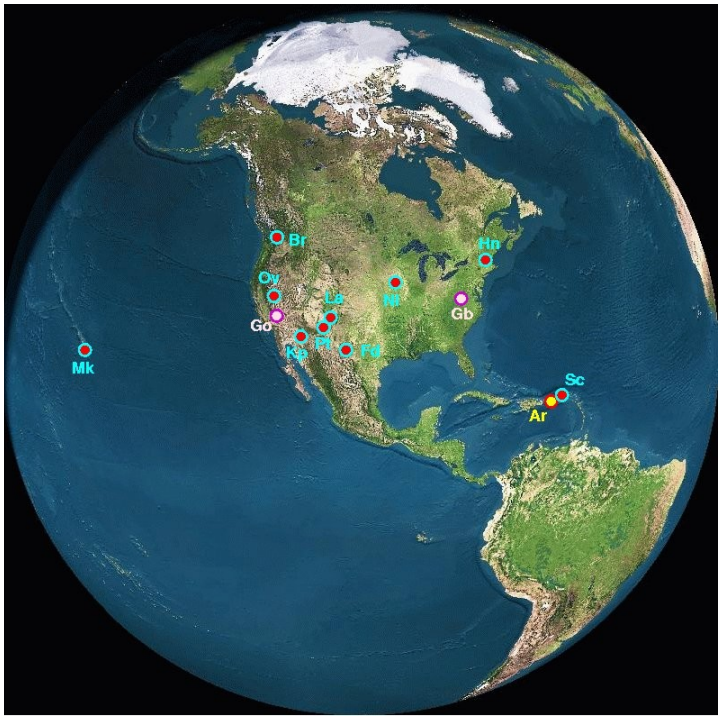
Real-time e-VLBI with the EVN

- Data transmitted from stations to correlator over fiber
- Correlation proceeds in real-time
  - Improved possibilities for feedback to stations during obs.
  - Much faster turn-around time;
    permits EVN results to inform follow-on observations
  - Denser time-sampling (beyond the 3 sessions per year)
  - EVN antenna availability at arbitrary epochs remains a limitation
- Disk-recorded vs. e-VLBI: different vulnerabilities
  - Recording e-VLBI while correlation runs permits multiple passes





The VLBA (Very Long Baseline Array)

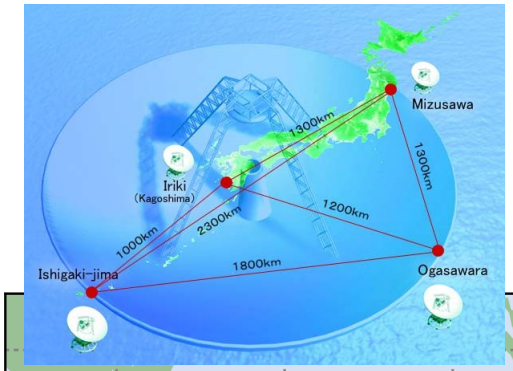


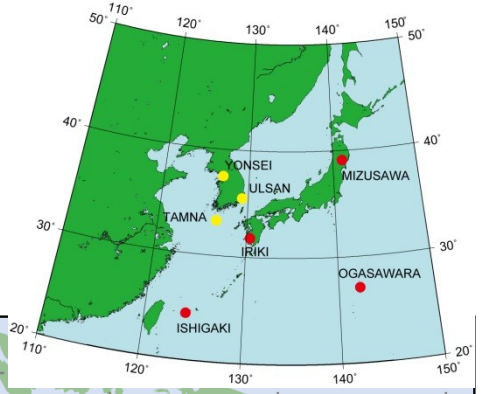
- Homogeneous array (10x 25m)
  - planned locations, dedicated array
  - Bslns ~8600–250 km (~50 w/ JVLA)
  - faster slewing
  - HSA (+ Ef + GBT + JVLA)
- Frequency agile
  - down to 0.329, up to 86 GHz
- Extremely large proposals
  - Up towards 1000 hr per year

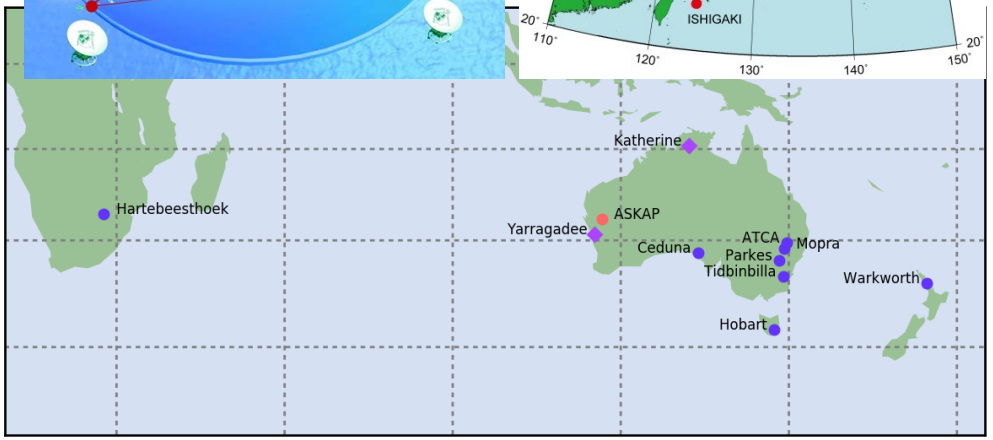
- Globals: EVN + VLBA (+ GBT + JVLA)
  - proposed at EVN proposal deadlines (1 Feb., 1 Jun., 1 Oct.)
  - VLBA-only proposals: 1 Feb., 1 Aug.
- **www.nrao.edu/facilities/vlba**

Asian / Australian VLBI Networks

- East Asian VLBI Network (radio.kasi.re.kr/eavn/main_eavn.php)
- Korean (KVN): 4 ants., simultaneous 22, 43, 86, 129 GHz
- VERA: 4 dual-beam ants., maser astrometry 22-49 GHz
  - KaVA == KVN + VERA (issues separate KaVA Calls for Proposals)
- Australian LBA: can propose joint EVN+LBA observations
  - www.atnf.csiro.eu/vlbi



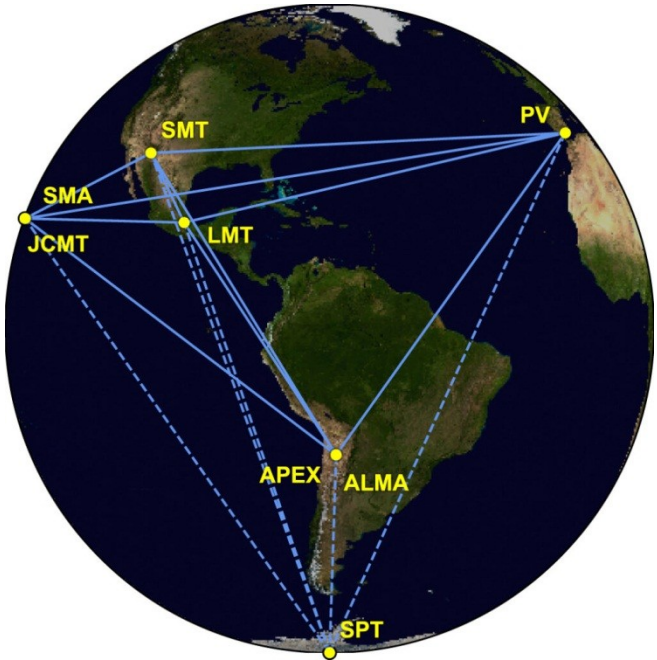




Higher-ν VLBI Arrays (+ ALMA)

- **Global mm VLBI Network (GMVA)**
  - Effelsberg, Onsala, Metsahövi, Pico Veleta, NOEMA, KVN, most VLBAs, Green Bank, ALMA (LMT, GLT)
- 86 GHz, ~2 weeks of observing per year
- Coordinated from MPIfR Bonn
- **www3.mpifr-bonn.mpg.de/div/vlbi/globalmm**

- **Event Horizon Telescope (EHT)**
  - NOEMA, IRAM 30m, JCMT, SMA, LMT, ARO/SMT, APEX, ALMA, SPT, GLT
- Proposing via ALMA calls
  - ALMA bands 6,7 (1.4, 0.88 mm)
- **www.eventhorizontelescope.org**



Global VLBI Alliance

EVN Operations

- Things begin with Proposals
  - Deadlines: 1 Feb, 1 Jun, 1 Oct (16:00 UTC)
  - Currently via NorthStar web-based tool (soon via ORP Polaris)
  - EVN + VLBA/VLA/GBT proposed via EVN proposal tool
- EVN Programme Committee reviews proposals
  - Passes grades along to the EVN Scheduler
- EVN Scheduler makes block schedules
  - JIVE assists PIs in making observing schedules
- Observations run in absentia
  - Correlation at JIVE (following liaison with the PI)
- JIVE makes FITS files, pipelines, and archives results
- JIVE provides user support for all stages
  - Data-reduction visits to JIVE supported by EVN TA
  - Broader support not tied to eligible observations via ACME WP3

EVN Proposal Classes

- Standard (no special time constraints)
  - Disk or e-VLBI or some combination
  - Can request out-of-session time (array composition = best effort)
- Triggered (responding to some predefined event(s))
  - Can override existing e-VLBI or disk observations
    - e-VLBI: 08 UT the day before the e-session
    - Disk: 1 week before start of pertinent frequency block
  - Extra information needed in proposal
- Target-of-opportunity
  - To respond to completely new event (not coverable by Triggered)
  - Time needed to organize the best possible array
- Short observation (exploratory: calibrators, proposal prep)
  - No "priority", no proprietary period
- EVN-lite (new since Feb 2023)
  - Limited EVN sub-array potentially observing more frequently

Early, pre-EVN Highlights

- First VLBI fringes using European telescopes
  - Jan/Feb 1968: Onsala – Greenbank – Haystack (5 & 1.6 GHz)
  - Jun 1968: Jodrell – Algonquin – Penticton (408 MHz)
  - Sep/Oct 1969: Simeiz–Greenbank (5 & 10.7 GHz)
  - Mar 1971: Jodrell–Onsala (1.6 GHz; 3C345)
  - Jun 1973: Effelsberg–Greenbank–Goldstone (2.3 GHz)
- Other VLBI fringes in the 70's
  - Hh ('70); Ro-Hh ('73); Dw ('76); phased-Wb ('78); Mh ('79)
  - 22 GHz: Nov '77; Oct '78 (Ef–On–Sm–Hs)
- 1975: various European antennas join in "US Network"
- 2 Oct 1976: first all-European VLBI observation
  - Ef–On–Dw; 1.6 GHz; 3C236 (correlation at NRAO)
- 6-9 Jan 1977: 2nd one; 1st all-Euro including correlation
  - Jb–On–Dw–Ef; 1.6 GHz; 3C309.1 a.o.; correlation at Bonn

Creation of the EVN

- 7 Apr 1975: Initial discussion in MPIfR cafeteria
  - I. Pauliny-Toth, E. Preuss, R. Booth, G. Miley (no minutes…)
  - Led to a series of (bi-)annual informal meetings
  - 1978 – Int'l VLBI Conference in Heidelberg (no proceedings)
- 5 Mar 1980: first "directors' meeting"
  - Jodrell, Leiden/Dwingeloo, Onsala, Bologna, Bonn (MPIfR & GIUB)
  - Formation of EVN Programme Committee
  - First proposal deadline = 15 May 1980
    - (sole expcetion to the beloved 1 Feb, 1 Jun, 1 Oct paradigm)
    - 136 cumulative PC meetings so far (I've attended the last 59 of these……☺)
- First EVN session = 3-9 Oct 1980 (Ef—On—Wb)
  - 6 user experiments; 2 ad-hoc (≥12 proposals)
- 1984: "EVN Consortium for VLBI" formed
  - 12 Feb 1985: First EVN CBD meeting
  - Full members commit ≥45 observing days per year

Station progress: 80's → 2003

- First EVN fringes in the 80's
  - Tr15m ('81); Wz ('83); Mc ('84); Sh ('87); Nt, Ys14m ('89)
  - Among the MERLIN out-stations: Kn ('80); De ('84)
- First EVN fringes (or joining the EVN) in the 90's ☾ 2003
  - Ur, Ny ('94); Tr32m ('96); Sv, Zc ('03)
  - Among the MERLIN out-stations: Cm ('90); Pi ('99); Da ('04)
  - Joining the EVN: Mh ('90); Hh, Ar ('01)
  - Agreement with JPL/DSN about Ro participation ('97)

- EVN symposia began in Oct '93 (Jodrell)
  - 2nd in '94 (Torun); held biennially since (barring COVID years)
  - EVN Users' meetings started earlier (Int'l VLBI Confs in '83, '92)
- EVN/JIVE VLBI schools began in Sep '88 (~Bologna)
  - Subsequently at JIVE '95, '97, '99 → then within ERIS

Data Acquisition/Correlation → 2003

- Mark II – single 2 MHz channel
  - Essentially digital VCRs (TV recorders); ~4 hr per cassette
  - 1977-8: Mark II correlator in Bonn (3 station)
- Mark III – 56 MHz via 14 dual-sideband VCs (= BBCs)
  - Still 2MHz per channel
  - Tape = large 1" video tape reels (13 min per tape)
  - Dec 1982: Mark III correlator in Bonn (4 station)
    - Expands to 5 stations in 1990
  - 1993: Mark IIIA upgrade starts (12 13-min passes per tape)
- Mark IV – up to 1 Gbps via 16 16MHz channels
  - Same "format" of tape; now 14 22-min passes per tape)
  - 22 Oct 1998: Inauguration MkIV correlator at JIVE (16 station)
  - 2002: 1st EVN 512 Mbps observations
- Mark5 disk-module recorders
  - Operational transition tape → disk: 2003→ Jun 2005

Creation of JIVE

- 1986: large proposal to EC for 20-station correlator
  - Proved too large for EC budget(s)
  - Twinned proposal was successful; support to Mark IIIA upgrade
- 1992: 10^6 ECU from EC *Human Capital & Mobility* program "*Access to Large-Scale Facilities*"
  - 9 June 1993: Inauguration of Joint Institute for VLBI in Europe
  - A "*stichting*" under Dutch law
- Correlation at JIVE
  - 22 Oct 1998: Inauguration of EVN MkIV Data Processor at JIVE
  - 21 Jul 1997: 1st fringe; 21 Jul 1999: 1st production correlation
- Dec 2014: JIVE shifts to be an ERIC
  - ERIC = European Research Infrastructure Consortium
  - The "E" in JIVE: "in Europe" → "ERIC"
- **JIVE → correlation & user-support center for the EVN**

Station progress: 2004 →

- First EVN fringes 2004 → 2014
  - Bd ('04); Ys 40m ('08); Km,My ('09); Ir, KVNs ('12); Sr, T6 ('14)
  - Japanese stations at 5cm: Ym ('09); Vm ('10); Vs ('11)
  - New bands: Ys,Sh @ 5cm; Tr @ 1.3cm; KVNs @ 7mm
- First EVN fringes 2015 →
  - e-MERLIN out-stations as distinct stations ('17)
  - Santa Maria ('18); Kutunse ('17-18); Vr ('24); Ud,Ms ('23 @ 3.6cm)
  - MeerKAT ('24)
  - GMRT testing ('22-'25)
  - New bands: Km @ 6,5cm; Tr @ 3.6cm; Ur @ 5,0.7cm; Sr @ 6cm
- Miscellaneous station developments
  - Tr shifts to a remote maser (tests '15; operational '16)
  - Receivers with linear-polarization (Ef @ 5cm; T6 @ 1.6cm)
- New joint EVN + LBA proposal policy ('16)
  - 1st EVN + LBA (May/Jun '16); 1st global + LBA (May/Jun '17)

Real-time e-EVN Evolution

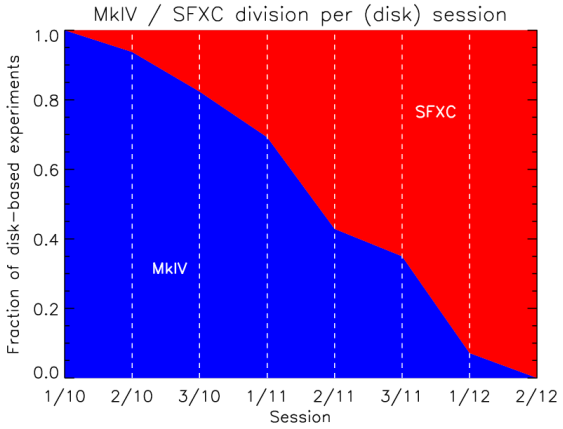
- First (test) image: Apr 2004; 3 stations, 32 Mbps
- First user experiment: Mar 2006; 6 stations, 128 Mbps
- First 512 Mbps: May 2008
- First 1024 Mbps: Jan 2010 (10 stations)
- First 2048 Mbps: Jun 2016 (7 stations in larger array)
- e-MERLIN out-stations in e-EVN: Sep 2018
  - Also first e-EVN fringes for Sr
- Correlate real-time & record onto FlexBuff
  - Enables multiple-pass correlation (spectral line, FRBs, etc.)
- E-Shipping – avoid physically shipping media
  - Quanta of recycling shrinks to station/experiment
  - 1st operational use Oct/Nov 2014

Data Acquisition 2004 →

- Mark5: 8 normal disks in a bespoke chassis
  - Initial: 8x 120GB = 960 GB (+ natural expansion path)
  - Largest seen operationally in EVN = 8x 8TB
  - 1st 1Gbps user experiment Feb/Mar 2005
- FlexBuff: 36 or 90 slots; "regular" file system
  - More naturally aligned with e-shipping operations
  - 1st production correlation from FlexBuff Feb/Mar 2014
- Evolution towards digital back-ends (DBBC in EVN)
  - Ef first to shift (by May/Jun 2011); 7 more stations by 2014
  - First 1Gbps global experiment in 2014 (RDBEs on NRAO stations)
  - 2015: 1st obs with 32 MHz channels; 1st 2Gbps user experiment
  - 2020: 1st 4Gbps user experiment (1st 4Gbps global in 2023)
  - (Chinese) CDAS — 1st 2Gbps within EVN context (2011)
  - (NRAO) RDBE — 1st 1Gbps within EVN context (2013)

Correlator Evolution at JIVE (I)

- ENV MkIV Data Processor at JIVE
  - 16 stations (via tape, later Mark5 disk-pack playback)
  - Max. 1Gbps (but runs real-time regardless of input rate <1Gbps)
  - Max. 2048 frequency points per subband/pol
  - Byzantine rules for joint max. N{subbands, pols, frequency points}
  - Bespoke (irreplaceable) chips
- EVN Software Correlator at JIVE (SFXC)
  - Much more flexible, but not necessarily real-time
  - 1st user experiment correlated on SFXC: May/Jun 2010 session



Correlator Evolution at JIVE (II)

- Astronomy Gains enabled by SFXC
  - ~Arbitrary number of stations, total bit-rate, channel BW
  - Wide-field mapping (large N freq.pt. per SB/pol, short t_{int})
  - Multiple output phase centers per pointing
  - Pulsar gating/binning (1 gate, N equally spaced bins)
    - Incoherent and coherent de-dispersion
  - Spectral zooming
  - Choice of spectral-windowing function
  - Mixed input channel BWs (handling heterogeneous back-ends)
  - External model files can be passed (e.g., near-field target or orbiting antenna)
  - Geodetic style observations, outputting mark4-format data with total delays/phases
  - Phased-up mode → time-series for transients

Future

- Multi-band Rx's / wider IFs
  - 1.3cm / 7mm / 3mm
  - Higher total bit-rates (higher sensitivity)
  - Frequency phase transfer
- Developments in software correlation / archiving
  - More special-purpose correlation modes / features
  - FITS & Measurement Sets; Jupyter notebooks
- More stations: better sensitivity, *u-v* coverage
  - MeerKAT, GMRT, Thailand; SKA-VLBI
  - SKA-mid a natural fit with EVN geographically & ν
- Continued evolution in EVN observing "structures"

EVN Operational Links

- Main EVN web page: **www.evlbi.org**
  - EVN Users' Guide: Proposing (Obs.Planner), Scheduling, Analysis
  - EVN Archive
  - EVN Newsletters
- Proposals: due 1 Feb., 1 June, 1 Oct. (16:00 UTC)
  - **proposal.jive.eu**
- User Support via JIVE
  - **www.jive.eu**
  - **usersupport@jive.eu**
- Proceedings of the biennial EVN Symposia via:
  - **www.evlbi.org/meetings**

EVN Historical Links

- EVN / VLBI
  - Early history of the EVN in Porcas, 2010, *EVN Symposium #10*
  - Thomson, Moran, Swenson
  - geodetic VLBI: Ryan & Ma, 1988, *Phys. Chem. Earth*, 23, 1041
  - JIVE: Schilizzi, 2024, **www.youtube.com/live/CAyVfA93d7g**
- EVN Correlators
  - MarkIV
    - Schilizzi et al. 2001, *Exper. Astron.*, 12, 49 (EVN MarkIV)
    - Whitney et al. 2004, *Rad. Sci.*, 39, 1007 (Archit. & Algo.'s)
  - SFXC
    - Keimpema et al. 2015, *Exper. Astron.*, 39, 259
    - Keimpema et al. 2025, *Exper. Astron.*, in press