Recent Developments at the Joint Institute for VLBI in Europe (JIVE)

Stefanie Muehle, Bob Campbell, Arpad Szomoru, JIVE

- > JIVE and the EVN
- > Correlators at JIVE
- real-time eVLBI and other applications

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The European VLBI Network (EVN)



Effelsberg, Wetzell (Germany) Westerbork (Netherlands) Jodrell Bank, Cambridge, and other MERLIN stations (UK) Yebes (Spain) Medicina, Noto (Italy) Onsala (Sweden) Metsahovi (Finland) Torun (Poland) Svetloe, Zelenchukskaya, Badary (Russia) Urumqi, Sheshan (China) Hartebeesthoek (South Africa) Arecibo (Puerto Rico)

non-EVN stations: Robledo (Spain), Ny-Alesund (Norway), VLBA (US), ...

The EVN: New stations, upgrades



The KVASAR network: Svetloe (Sv, 32 m) Zelenchukskaya (Zc, 32 m) Badary (Bd, 32 m)





- October 2008: first EVN experiments
- November 2009: officially joined EVN
- Since March 2010: regular participation in EVN user experiments (L, C, S/X)
 - November 2010: all stations fully integrated in ftp fringe tests

The EVN: New stations, upgrades





Kunming (Km, 40 m):

- first fringes with MarkIV in March 2011
- S, X (RCP), more receivers to come (C in 2011)
 Miyun (My, 50 m):
- major satellite tracking station
- S, X (RCP)
- Sardinia Radio Telescope (Sr, 64 m):
- under construction (P, L, ... W)

Yebes (Ys, 40 m): ■ S, X, C (5/6cm), K, (Q, W) Effelsberg (Ef/Eb, 100 m):

 first EVN tests with dBBC in network monitoring experiments in March 2011

Joint Institute for VLBI in Europe (JIVE)



located in NP Dwingelderveld, Dwingeloo, NL

JIVE: Core services

Correlation

e.g. correlation, quality assurance, logistics, infrastructure

User support

e.g. scheduling, pipeline products, data reduction

EVN support

e.g. network monitoring experiments, pipeline products

Hardware maintenance and development

e.g. disk packs, SU, correlators, computer clusters

Software maintenance and development

e.g. (post)correlation ops, MERLINcast, channel dropping

Real-time e-VLBI and network development

EVN archive

IDI-FITS, diagnostic plots and tables, pipeline results

JIVE: The correlator control room



JIVE: The EVN MarkIV correlator



JIVE: The EVN MarkIV correlator

Capabilities:

- 16 stations, observed rates up to 1 Gbps
- Mark5A, Mark5B playback
- 1-bit, 2-bit sampling (e.g. VLBA@512Mbps/EVN@1024Mbps)
- **Full-Stokes** polarization output
- Up to 2048 frequency points per subband/polarization
- $t_{int} \ge 1/4$ sec for full correlator ($t_{int} \ge 1/8$ sec for half correlator)
- **Oversampling** (500kHz filters)
- **Recirculation** (time-sharing correlator in low-BW observations)
- Multiple MERLIN out-stations as separate EVN antennas
- >16 stations through multiple passes
- Real-time e-VLBI operations
- Output data: **IDI-FITS** (record for a single experiment: 1028.7GB)

JIVE: The EVN MarkIV correlator

Spectral resolution:

$$\begin{split} \mathbf{N_{sta}}^2 \cdot \mathbf{N_{sb}} \cdot \mathbf{N_{pol}} \cdot \mathbf{N_{frq}} &\leq \mathbf{131072} \cdot \mathbf{R} \\ \mathbf{N_{sta}} &= (4,8,12,16); \ \mathbf{N_{pol}} = (1,2,4); \ \mathbf{N_{chan}} \leq 16; \ \mathbf{N_{frq}} \leq 2048 \\ \\ \textbf{Recirculation: } \mathbf{R} &\leq \mathbf{16MHz/BW_{sb}} \end{split}$$

Maximal Spectral Resolution: $N_{frq}=2048$, Δv in [m/s]

-	BW _{sb} [MHz]	Δv [Hz]	Δv_{1420}	Δv_{1665}	Δv ₆₆₆₈	Δv ₂₂₂₃₅	
	16	7813	1651	1408	351	105	
	2	977	206	176	44	13	
	0.5	244	52	44	11	3.3	(no recirc.)

JIVE: The software correlator (SFXC)

locally developed FX correlator vex-driven + file with corr. parameters Mark5A, Mark5B, VLBA, VDIF 1-bit, 2-bit sampling, full Stokes **IDI-FITS** as for Mk IV correlator essentially no limits for N_{freq}, t_{int} **multiple phase centers** in parallel pulsar gating/pulsar binning (incl. incoherent de-dispersion across each subband) now running on a dedicated 16-node, **128-core** cluster, to be doubled in 2011 • "real-time" processing currently for 9 stations at 512 Mbps, 1024 freq. pts software used for ftp fringe-tests since 2007, for some user exp. since 2010

- Real-time e-VLBI for:
- rapid turn-around
- urgency
- denser time-sampling

Image by Paul Boven (boven@jive.nl). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov)

Examples:

- X-ray binaries in flaring states
- Just-exploded suernovae, novae, γ-ray bursts
- Binary stars at specific orbital phases
- Monitoring SNe population/birth in starburst galaxies
- Pre-proposal detection experiments, reference-source search

- proposal-driven science obs., within standard submission cycles
- **24-hour** periods run on fixed dates (fit to station commitments)
- to date, 113 observations (879 hours since start of EXPReS)
- Most stations connected at **1024 Mbps**, else controlled cut of rate
- triggered observations, short observations, target of opportunity (ToO) observations (e-EVN or disk, some incl. Australian stations)
 (Note: first e-VLBI observation on 16 March 2006, 6 stations at 128 Mbps)

Tested Network Connections:

Station	Connection	Station	Connection					
Westerbork	2x 1 Gbps (dark fibre)	Yebes	1 Gbps (routed)					
Jodrell Bank	2x 1Gbps (LP)	Hartebeesthoek	2 Gbps (routed)					
Medicina	1Gbps (LP)							
Onsala	10 Gbps (VLAN)							
Torun	10 Gbps (routed)	ATNF	1Gbps (LP, e.g. At, Mp, Pa)					
Effelsberg	10 Gbps (VLAN)	Hobart	128 Mbps (routed, Tas-Aus)					
Sheshan	622 Mbps LP (via HK)	TIGO	64 Mbps (routed, reserved)					
Arecibo	256/512 Mbps (VLAN)	Kashima	256 Mbps/1 Gbps, (routed)					
Metsahovi	10 Gbps (routed)	Westford	256 Mbps/1 Gbps (routed)					

e-EVN growth and composition:

- disk-based network hours roughly constant (3 x 3 weeks)
 in 2010, 999 EVN network hours (disk-based + e-VLBI)
- about 300 e-EVN network hours in 2010

2010

almost half of e-EVN time spent on ToO observations

Opening of the International Year of Astronomy in Paris on 15/16 January 2009, 17 EVN and non-EVN telescopes in Europe, East Asia, Australia, N.+S. America

e-VLBI run on 9-12 March 2011:

- almost continuous run for 64.5 hours
- almost all stations at 1024 Mbps
- data rate > 7 Gbps most of the time (max. 8.82 Gbps)

 \mapsto setup + test time

e-VLBI run on 22-23 March 2011 (last week):

except for Sh and during clock search, all stations at 1024 Mbps

data rate > 8 Gbps most of the time until source sets at Sh and Hh

Applications: ftp fringe tests

Sampler statistics

U	1.445	- 14	41.	1.445	Intuitio	ang sige bit	ang mag bit
Mill SIM to LUIS For	82/5	11.475	31.075	10.02%	12/26	0.087	1.01
KRALICIAN-LA LUBI, Lap	17.30%	32.37%	30,27%	36.80%	120%	6.6071	1.000
HAR LONG , LOUIS, Kep	17.82%	31899.	31.9%	17.76%	1,2729	1.001	1.100
MALION-LA LIER Lap	11,271.	11476	31.875	18.18%	1,20%	1.068	6.003
MINI KIMIN LONG Prop	18.33%	314%	31.17%	17.866	1396	1.040	0.0903
NUM KING LINE, Logi	14.70%	31.395	3676	17.87%	1,2,5%	Lara	1.060
GERE SCHOOL STEER, Prop.	18.19%	8.0%	38.11%	16.81%	12796	1.01%	EART .
NUM ION-14, LUIR, Lep	0.016	0.7%	JUNE.	17.64%	1,279%	0.041	0.0001
BETS ISSN'S, LS R. Pop	0.05	11.996	31,6%	17.79%	13596	6.081	8.489
OUTS. ISING-La. L.E.B. Lap.	NIDPS	114%	11,67%	17.78%	13596	1.0909	0.4961
HE'S IGN'S, LIEB, Rep.	17.87%.	auges.	STORY.	0.016	12576	0.081	1.0001
BETS ICRO-Log LATER, Log-	SLFL.	0.075	32.975	16.62%	13/5%	0.066	1.000
BURLICHOLD BL. File	38.87%	114%	33.8%	17.66%	13/01	0.0994	1.000
NUMBER ADDRESS AND ADDRESS ADDR	17,075	11895	3185%	17.88%	12/9%	1.081	Caler
GINE COM-Lo, LATER, Prop.	Mairy.	11,20%	31806	17,00%	13/0%	1,081	1.4962
COMPLEXIBILITY OF LAND	9.876	20.000	3184%	17,81%	12/04	1.301	8.9691
He	10	14	. 45	++	Intelli	ang sign life	ang mag ki
GRAD SCHOOL LOUIS, Prop.	18.89%	32.475	33,38%	37.00%	1.1070	0.502	1.000
KINAL KOMPAN, LUISI, Lago	0120%	33.87%	20.09%	17.0PL	1.1974	1.0873	LIGHT

Network Monitoring Experiments:

- done in each EVN session after each change of receiver
- ftp fringe tests and technical time for tests (new telescopes/setups/modes/...)

ftp fringe tests:

- each station sends a few sec of data via ftp to JIVE (automated feature in SCHED)
- near real-time correlation on SFXC (clocks based on extrapolation of gps values)
- output: various diagnostics
- immediate feedback (skype, web-interface)
- chance to fix problems/improve setup at stations before start of the user experiments
- results stay available on the web for future reference

Applications: ftp fringe tests

Web interface provides for each channel: fringe plots, S/N, plots of autocorrelation amplitude and baseline amplitude + phase, offset from assumed clock value, sampler stats

Vex file -- Integration time: 4s -- Start of the integration: 2011y060d14h13m56s0ms

N11M1	Auto	correla	tions		Cross correlations													
	Ef Hh Jb N	Ac On S	h Tr W	/b Ys	Ef-Hh	Ef-Jb	Ef-Mc	Ef-On	Ef-Sh	Ef-Tr	Ef-Wb	Ef-Ys						
6640.52MHz, LSB, Rcp-Rcp	2222	2 1	1 2	1	<u>89.67</u> <u>A</u> F offset: -1	0133.4 A P	4.47 <u>A P</u> offset: -148	<u>143.4</u> <u>A</u> <u>P</u> offset: -10	<u>60.98</u> <u>A</u> <u>P</u> offset: -1	<u>282.9 A P</u> offset: 0	<u>105.7 A P</u> offset: 0	<u>397.7</u> <u>A</u> P offset: -1						
6640.52MHz, LSB, Rcp-Lcp Cross hands					<u>5.584</u> <u>A</u> <u>F</u> offset: -1	4.691 <u>A P</u> offset: 102	4.656 <u>A</u> P offset: 91	<u>18.96 A P</u> offset: -10	4.22 <u>A P</u> offset: -33	5.674 <u>A P</u> offset: 31	<u>4.228 A P</u> offset: -117	46.93 A P offset: -1						
6640.52MHz, LSB, Lcp-Lcp 1 1 1 1 1 2 2 1 2					85.26 <u>A</u> F offset: -1	127.4 <u>A P</u> offset: -1	<u>225.8 A P</u> offset: -1	<u>143.9 A P</u> offset: -10	<u>58.36 A P</u> offset: -1	<u>287.5 A P</u> offset: 0	<u>117 A P</u> offset: 0	<u>393.9 A P</u> offset: -1						
6640.52MHz, LSB, Lcp-Rcp	Cross hand	ds			4.164 A F	0.372 A P	<u>5.647 A P</u> offset: -31	14.97 A P	6.141 <u>A P</u> offset: -5	<u>25.97 A P</u> offset: 0	<u>6.055 A P</u> offset: -74	<u>19.67 A P</u> offset: -1						
6640.52MHz, USB, Rcp-Rcp	2222	2 1	1 2	1	88.54 A F	139.6 A P	<u>3.882 A P</u>	<u>134.9 A P</u>	62.31 A P	<u>267.3 A P</u>	<u>99.44 A P</u> offset: 0	<u>370.7 A P</u>						
6640.52MHz, USB, Rcp-Lcp	Cross hand	ds	1 1		6.649 A P	4.557 A P	<u>3.999 A P</u>	20.58 A P	4.594 A P	6.581 <u>A P</u>	<u>5.607 A P</u>	40.4 <u>A P</u>						
6640.52MHz, USB, Lcp-Lcp	1 1 1 1	1 2	2 1	2	101.8 A F	117.9 A P	212.2 A P	<u>135.2 A P</u>	50.28 A P	292.2 A P	<u>109.4 A P</u>	<u>399 A P</u>						
6640.52MHz, USB, Lcp-Rcp	Cross hand	ds			4.169 A P	8.147 A P	4.87 A P	17.55 A P	3.942 A P	28.69 A P	4.92 A P	26.12 A P						
6656.52MHz, LSB, Rcp-Rcp	4 4 4 4	4 3	3 4	3	72.66 A F	134 A P	206.9 <u>A P</u>	140.6 A P	62.49 A P	297.3 <u>A</u> P	<u>101.3 A P</u>	<u>356.1 A P</u>						
6656.52MHz, LSB, Rcp-Lcp	Cross hand	ds	1 1		6.054 A P	4.143 A P	4.397 A P	22.51 A P	5.378 A P	5.012 A P	<u>3.747 A P</u>	<u>33.12 A P</u>						
6656.52MHz, LSB, Lcp-Lcp	3333	3 4	4 3	4	90.4 A P	96.2 A P	<u>186.1 A P</u>	140.3 A P	53.68 A P	305.4 <u>A P</u>	<u>113 A P</u>	<u>384 A P</u>						
6656.52MHz, LSB, Lcp-Rcp	Cross hand	ds			7.451 A P	4.948 <u>A P</u>	9.365 <u>A P</u>	<u>15.71 A P</u>	4.644 A P	32.09 A P	<u>4.772 A P</u> offset: 15	22.69 <u>A P</u>						
6656.52MHz, USB, Rcp-Rcp	4 4 4 4	4 3	3 4	3	78.33 A F	135.9 A P	208.3 <u>A P</u>	135.2 <u>A P</u>	59.11 A P	283.8 A P	<u>103.7 A P</u>	<u>335.3 A P</u>						
6656.52MHz, USB, Rcp-Lcp	Cross hand	ds			8.361 A F	4.504 A P	4.008 A P	<u>19.9 A P</u>	4.912 A P	<u>10.6 A P</u>	5.414 A P	<u>36.28 A P</u>	30	(st02,1cp)-(st1	1,lcp) ch) usb —	-
6656.52MHz, USB, Lcp-Lcp	3333	3 4	4 3	4	89.67 A F	89.81 A P	173.4 A P	145.7 A P	51.94 A P	280.2 A P	<u>109.6 A P</u>	<u>368 A P</u>	20					
6656.52MHz, USB, Lcp-Rcp	Cross hand	ds	<u> </u>		4.871 A F	7.416 A P	<u>10 A P</u>	17.06 A P	5.364 A P	28.52 A P	<u>4.816 A P</u>	20.05 A P	15					-
6672.52MHz, LSB, Rcp-Rcp	6666	6 5	56	5	86.15 A F	133.5 A P	<u>176.8 A P</u> offset: -1	131.7 A P	57.01 A P	282.9 A P	<u>103.9 A P</u> offset: 0	<u>358.4 A P</u> offset: -1	10					-
6672.52MHz, LSB, Rcp-Lcp	Cross hand	ds			5.27 <u>A P</u> offset: 27	4.232 A P	<u>3.931</u> <u>A P</u> offset: - 180	25.37 A P	5.404 A P	8.527 A P	<u>4.333 A P</u> offset: 113	27.67 A P	5					1
6672.52MHz. LSB. Lcp-Lcp	5 5 5 5	5 6	6 5	6	<u>93.66 A F</u>	<u>119.8 A P</u>	<u>203.6 A P</u>	<u>128.7 A P</u>	<u>50.92 A P</u>	<u>260.2 A P</u>	<u>102.6 A P</u>	<u>377 A P</u>	0	200 4	400	600 800	1000	1200

Applications: ftp fringe tests

JIVE and the EVN: A Summary

- The capabilities of the European VLBI Network (EVN) continue to grow with upgrades at existing stations and new stations within and beyond Europe
- Correlators at JIVE:
 - > MarkIV (hardware): 16 stations, 1024Mbps, special modes
 - SFXC (software): pulsar gating/binning, multiple phase centers, 9 stations/512Mbps real-time, to be expanded
- Special applications:
 - real-time e-VLBI: fast & frequent, up to 1024Mbps/station within the EVN
 - > ftp fringe tests: near real-time system monitoring and tests