e-VLBI & Other Developments at the EVN MkIV Data Processor at JIVE

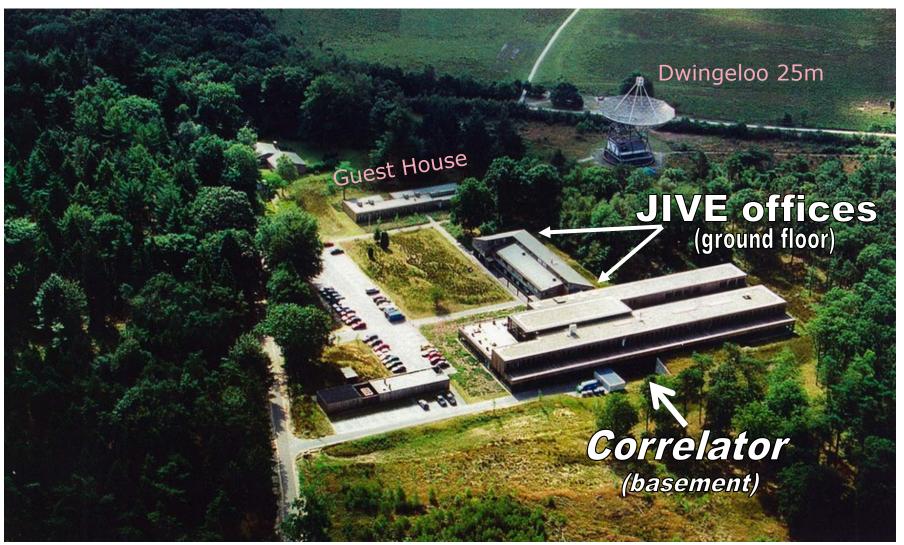
Bob Campbell & Arpad Szomoru, JIVE

EVN (astronomical) Correlation

- Astronomical Capabilities
- Input/Output Capacities
- New Stations
- Real-time e-VLBI
 - Chronology & Connectivity
 - EXPRes & Operational (astronomical) e-VLBI
- Software Correlation at JIVE



JIVE in Dwingeloo



Specific Correlator Capabilities

- □ 16 station, 32 GHz clock rate
- Full Stokes polarization output
- □ 1-, 2-bit sampling (include VLBAs @ 512Mbps in Gbps obs)
- Up to 2048 frequency points per SB/pol
- □ Full-correlator $t_{int} \ge \frac{1}{4}$ sec (half-corr $t_{int} \ge 1/8$ sec)
- Total observed rates up to 1Gbps
- \Box Oversampling (2, 4x Nyquist \rightarrow 500kHz filters)
- □ 5A, 5B playback (currently through 5A+ firmware)
- □ Real-time e-VLBI operation
- Recirculation (time-sharing correlator in low-BW obs)

Correlator Capacity (Spectral Resolution) $N_{sta}^2 \cdot N_{sb} \cdot N_{pol} \cdot N_{frq} \leq 131072 \cdot R$ $N_{sta} = (4,8,12,16); N_{pol} = (1,2,4); N_{chan} \leq 16; N_{frqmax} = 2048$ Recirculation: $R \leq 16MHz/BW_{sb}; N_{frqmax} = 12048$

5—8 Sta	1 SB	1 Pol	2048 Frq	
9—16 Sta	1 SB	1 Pol	512 Frq	
9—16 Sta	1 SB	2 Pol	2048 Frq	R=8 (BW _{sb} =2MHz)
9—16 Sta	8 SB	4 Pol	16 Frq	
	9—16 Sta 9—16 Sta	9—16 Sta 1 SB 9—16 Sta 1 SB	9—16 Sta 1 SB 1 Pol 9—16 Sta 1 SB 2 Pol	5-8 Sta1 SB1 Pol2048 Frq9-16 Sta1 SB1 Pol512 Frq9-16 Sta1 SB2 Pol2048 Frq9-16 Sta8 SB4 Pol16 Frq

Maximal Spectral Resolution (N_{frg}=2048)

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

Correlator Output Capacity

Raw output (local validity):

- lag-space correlation functions (32 kB/brd) + headers (16 kB/brd)
- $\Box \quad \text{Full-correlator min. } t_{\text{int}} = 1/4 \text{ sec (half-corr. min. } t_{\text{int}} = 1/8 \text{ sec)}$
 - Max. operational output rate = 6 MB/s
- Approximate FITS file growth rate:
- \Box 1.75 kf/t_{int} GB per hour of observation
 - κ ≈ 1–1.7 (fudge-factor for "efficiency" of FITS storage)
 - f = fraction of correltaor used

□ Record for a single experiment: 1028.7 GB

Recirculation: min. $t_{int} \rightarrow (min. t_{int}) \cdot R$

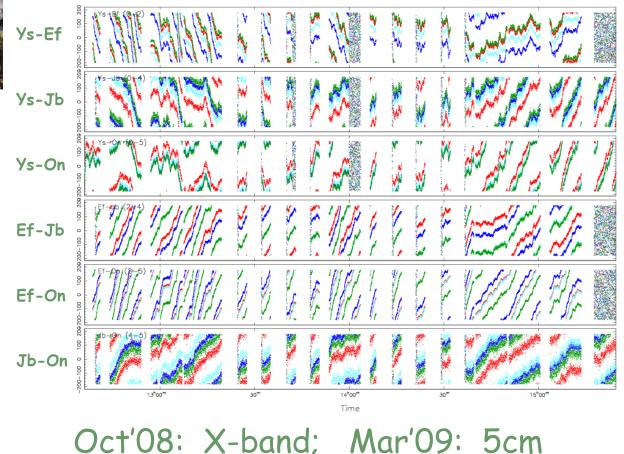
New Stations: Yebes 40m





Phs(t) for 4C39.25 in Jun'08 K-band NME {Ys,Ef,Jb,On}

Phase for n08k2.ms



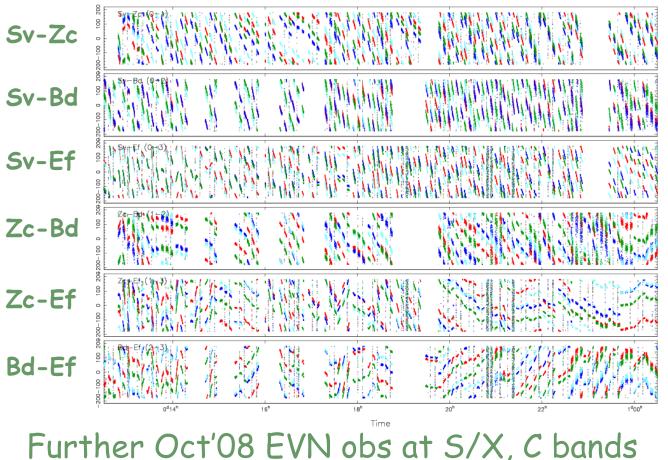
New Stations (to EVN): KVASAR





Phs(t) for phs.ref sources in L-band EK028C (Oct'08) {Sv, Zc, Bd, Ef}

Phase for ek028c.ms



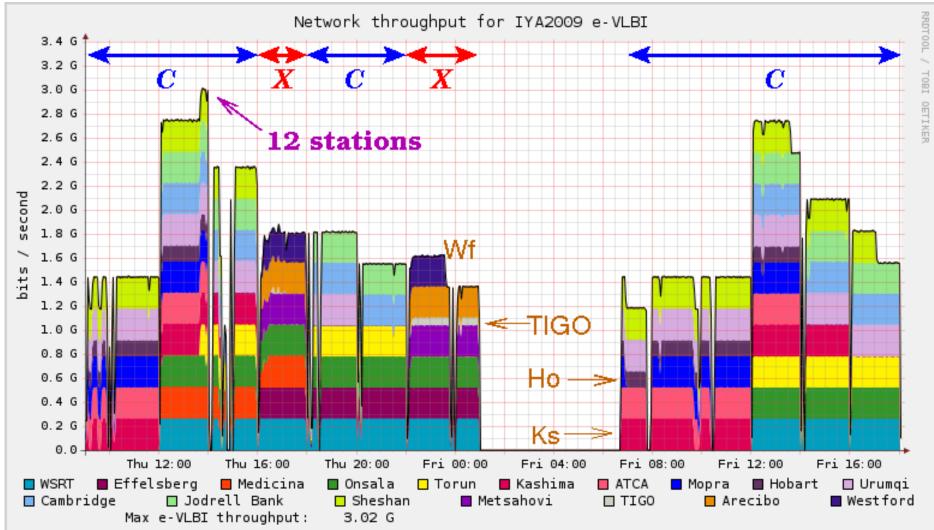
Real-time e-VLBI Chronology (I)

- 20apr06: 1st successful scheduled e-science run 16hr at 128 Mbps to 6 stations
- 25jun07: 4hr of 512Mbps from 6 stations
- 28aug07: Demo at 24th APAN conference (Xi'an)
 - 256Mbps on Sh-Mp, Sh-{Jb,Da,Mc,Tr,Wb}
 - ~10 minutes of Mp-Da fringes (longest RTe-|B|(?) 12304km)
- Boct07: Pa-Mp-At at 512Mbps sustained for >12hr
- 24jan08: 978Mbps for >3hr from {Mc,On,Tr}
 - Packet dropping (4.5%) while headers remain intact
- 5feb08: Ar at 128 Mbps (155 Mbps to mainland)
- Bapr08: e-science runs at 512 Mbps from here on

Real-time e-VLBI Chronology (II)

- 5-9may08: Hh at 64 Mbps (128 Mbps briefly); Hh-Ar fringes
 Tc-Ar fringes at 32 & 64 Mbps
- □ 21may08: 1st Ef participation in e-science observations
- 22may08: Demo at TERENA Networking conference (Bruges)
 - Mc, On, Wb, Ef, Ar (256Mbps), Hh, TIGO (On-Tc ~ 10840 km)
- 22jul08: Multiple MERLIN out-station multi-casting
- 9sep08: Ar at 512 Mbps (early AM local time)
- □ 13nov08: Ef, Wb, Mc, On, Tr, Jb, Cm, Kn, Sh @512; Ar @ 128
- 19nov08: Gbps without dropping packets {Wb, On, Ef}
- 4dec08: IYoA prep: At, Mp, Ks, Sh, Ur, Wf @256; Ho @ 128
- □ Very, very soon: Yebes 40m in tonight's e-science observations

Throughput Graphs



Int'l Year of Astronomy Opening Ceremony: 15jan09

(Tested) Network Overview

Station Connection

			1				
Westerbork	1 Gbps dark fibre	Station	Connection				
Jodrell Bank	2x1Gbps LP	ATNF	2x 1Gbps LP (At,Mp,Pa)				
Medicina	1 Gbps LP	Hobart	128 Mbps (Tas->Aus)				
Onsala	10 Gbps VLAN	TIGO	64 Mbps				
Torun	1 Gbps LP	Kashima	256 Mbps (1Gbps)				
Effelsberg	10 Gbps VLAN	Westford	256 Mbps (1Gbps)				
Sheshan	622 Mbps LP (via HK)	Hart	64—128 Mbps				
Arecibo	128 Mbps (512 early AM)						
Metsahovi	10 Gbps		to come: Sardinia,				
Urumqi	256 Mbps (via Sh/HK)		liyun, Kunming, Noto,				
Yebes	1 Gbps	Irbene,					

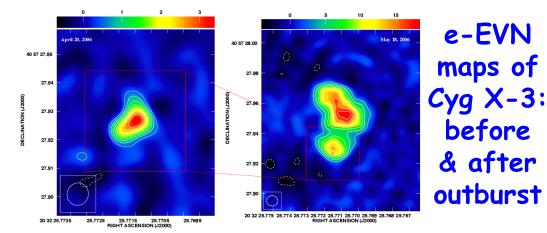
Real-time e-VLBI Science (I)

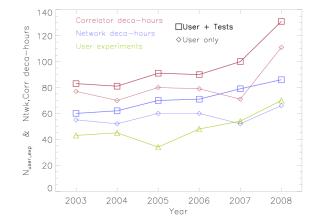
- Proposal-driven e-VLBI science observations
 - 1st observation = 20 Apr 2006 (6 stations at 128 Mbps)
 - 38 observations to date; 27 since the 18th WMEVGA (Vienna)
 - 18 different PIs
- □ **Topics** (rapid turn-around; urgency; denser time-sampling):
 - X-ray binaries in flaring states
 - GRBs or other transients detected in γ -ray/X-ray observations
 - Binary stars at specific orbital phases
 - Just-exploded supernovae
 - Monitoring SNe population/birth in starburst galaxies
 - OH/IR star astrometry
 - Gravitational lenses // AGN in a sub-mm galaxy?
 - Seeking IMBH in ULX source via compact radio emission
 - Check candidate reference sources prior to phs-ref obs.

Real-time e-VLBI Science (II)

- Evolution of e-VLBI procedures
 - Currently run on fixed dates (fit other station commitments)
 Working towards more flexible scheduling
 - Proposals originally due 2-weeks prior to each e-date
 - Now within standard proposal submission cycles
 - Proposal Class for "triggered" observations
 - Target of Opportunity Proposals
 - in 2008: 4 e-EVN, 3 disk-EVN ToO observations

Working towards dynamic control of schedules being observed





Software Correlation at JIVE

□ SFXC (based on correlator for tracking Huygens descent*)

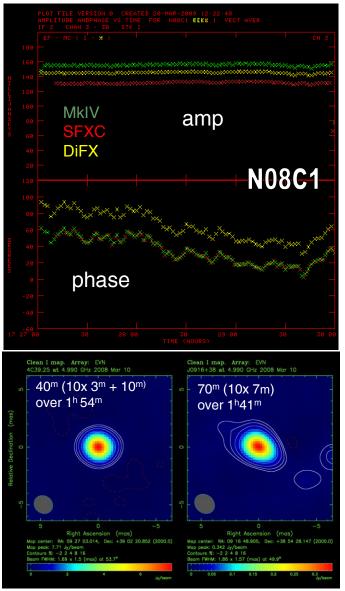
- VEX-driven + simple config. file with correlation parameters
- Conversion into IDI-FITS in place
- Phases match EVN MkIV correlator (better SNR than 5A)
- Speed comparable with DiFX
- ftp fringe-tests in NMEs since 2007
- □ FABRIC: "gridification" in progress (w/ Poznán)
- SCARIE (with UvA [Amsterdam], SARA)
 - Integration into GÉANT AutoBAHN BW-on-demand (e-delivery)
 - Integration with Internet2, on 60-node cluster at UvA

* <u>www.jive.nl/docs/resnotes/resnotes.html</u> (all 3 listed) <u>www.mrc.uidaho.edu/entryws/full/programme_detailed.html</u> (C-4.6)

Software Correlation at JIVE (pix)

-	C		3	1	R)		a h	ttp:	//w	ww.e	/lbi.org/t	og/ftp_	fringes/	N08L3	/scan32	2/index	html			▼ ▶	G - Google	
openSUSE	۰	Ge	ettir	ng S	Star	ted	6	La	tes	t Hea	dlines											
<u>ex file</u> Integ	gratic	on	1000	88 A 8	1000				28.25	ntegr	ation: 20	008y30	1d16h3									
N08L3	Cm	E	-	_	_	orre				rWt	Cm-E1	Ef-Jb	Ef-Mc	-	Ef-On							
I637.99MHz, USB, Rcp-Rcp	A		A						A		4.771 <u>A P</u> offset: 41	<u>1174</u> <u>A P</u> offset: 0	758.7 <u>A P</u> offset: -1	640.3 <u>A P</u> offset: -3	907.9 <u>A P</u> offeet: 1	<u>17.12</u> <u>A P</u> offset: -1	985.5 <u>A P</u> offset: 1	487.4 <u>A P</u> offset: -5	<u>1332</u> <u>A P</u> offset: -17			
637.99MHz, USB, Rcp-Lcp	Cro	ss	ha	nds							5.354 <u>A P</u> offset: 34	<u>138.9</u> <u>A P</u> offset: 0	<u>122.1</u> <u>A P</u> offset: -1	93.29 <u>A P</u> offset: -3	<u>139 A</u> P offset: 1	<u>15.12</u> <u>A P</u> offset: -1	<u>99.17</u> <u>A P</u> offset: 1	<u>107</u> P offset: -5	<u>349.2</u> <u>A P</u> offset: -17			
637.99MHz, USB, Lcp-Lcp	A	A	A	A	A	A	A	A	<u>A</u>	A	5.393 <u>A P</u> offset: -26	<u>1147</u> <u>AP</u> offset: 0	<u>623.5</u> <u>AP</u> offset: -1	<u>592.8</u> <u>AP</u> offset: -3	<u>1008</u> <u>A P</u> offset: 1	<u>15.78</u> <u>A P</u> offset: -2	<u>900.6</u> <u>AP</u> offset: 1	<u>508.9</u> <u>A P</u> offset: -5	1420 AP offset: -17			
637.99MHz, USB, Lcp-Rcp	Cro	ss	ha	nds							5.264 <u>A P</u> offset: 12	58.96 <u>A P</u> offset: 0	<u>151.7</u> <u>A P</u> offset: -1	28 <u>A</u> P offset: -3	<u>14.73</u> <u>A P</u> offset: 1	<u>14.46</u> <u>A P</u> offset: -2	<u>111.3</u> <u>A P</u> offset: 1	78.75 <u>A P</u> offset: -5	60.82 <u>A P</u> offset: -17			
645.99MHz, USB, Rcp-Rcp	USB, <u>A A A A A A A A A</u>					746.3 <u>A P</u> offset: 2	<u>1069</u> <u>A P</u> offset: 0	<u>739.1</u> <u>AP</u> offset: -1	<u>693.2</u> <u>AP</u> offset: -3	<u>944.6</u> <u>AP</u> offset: 1	<u>15.37</u> <u>AP</u> offset: -2	<u>1106</u> <u>AP</u> offset: 1	<u>495.9</u> <u>AP</u> offset: -5	<u>1426</u> <u>A P</u> offset: -17								
I645.99MHz, USB, Rcp-Lcp	Cross hands									78.77 <u>A P</u> offset: 1	<u>154.9</u> <u>A P</u> offset: 0	<u>158</u> <u>A</u> <u>P</u> offset: -1	<u>113.7</u> <u>A P</u> offset: -3	<u>93.89</u> <u>A P</u> offset: 1	<u>14.39</u> <u>A P</u> offset: -2	<u>115.9</u> <u>A P</u> offset: 1	<u>107.2</u> <u>A P</u> offset: -5	368.2 AP offset: -17				
645.99MHz, USB, Lcp-Lcp	A	A	A	A	A	A	A	A	<u>A</u>	A	<u>656.8</u> <u>A P</u> offset: 2	<u>998,1</u> <u>A P</u> offset: 0	<u>639</u> <u>A</u> P offset: -1	<u>619.1</u> <u>AP</u> offset: -3	<u>948.9</u> <u>AP</u> offeet: 1	<u>15.97</u> <u>AP</u> offset: -2	<u>967.2</u> <u>A P</u> offset: 1	<u>478.6</u> <u>A P</u> offset: -5	1278 AP offset: -17	0.00025 (sto	1,rcp)-(st09,rcp) (chi usb —
645.99MHz, USB, Lcp-Rcp	Cro	ss	ha	nds							350.2 <u>A P</u> offset: 2	56.05 <u>A P</u> offset: 0	<u>140 A</u> <u>P</u> offset: -1	45.97 <u>A P</u> offset: -3	<u>21.67</u> <u>A P</u> offset: 1	<u>14.43</u> <u>A P</u> offset: -2	<u>118.1</u> <u>A P</u> offset: 1	75.31 <u>A P</u> offset: -5	53.11 <u>A P</u> offset: -17	0.00015		γ
653.99MHz, USB, Rcp-Rcp	A	A	A	A	A	A	A	<u>A</u>	A	A	<u>1013</u> A P offset: 0	<u>1162</u> <u>A P</u> offset: 0	774 <u>A</u> P offset: -1	527.3 <u>A P</u> offset: -3	802 A P offset: 1	<u>19.33</u> <u>A P</u> offset: -1	965.9 <u>AP</u> offset: 1	<u>493.3</u> <u>AP</u> offset: -5	<u>1252</u> <u>A P</u> offset: -17	5e-05		
653.99MHz, USB, Rcp-Lcp	, Cross hands									<u>267.8</u> <u>A P</u> offset: 0	<u>187.1</u> <u>A P</u> offset: 0	<u>176.1</u> <u>A P</u> offset: -1	85.53 <u>A P</u> offset: -3	<u>136.8</u> <u>A P</u> offset: 1	<u>13.2</u> <u>A P</u> offset: -2	89.19 AP offset: 1	<u>107.7</u> <u>A P</u> offset: -5	340.8 AP offset: -17	õ	200 400 600	800 1000 1200	
653.99MHz, USB, Lcp-Lcp	A	A	A	A	A	A	A	4	A	A	<u>1072</u> A P offset: 0	<u>1093</u> <u>A P</u> offset: 0	<u>683.2</u> <u>A P</u> offset: -1	570.7 <u>A P</u> offset: -3	<u>914.3</u> <u>A P</u> offeet: 1	<u>14.77</u> <u>A P</u> offset: -1	886.8 <u>A P</u> offset: 1	<u>470.1</u> <u>AP</u> offset: -5	<u>1225</u> <u>AP</u> offset: -17			
653.99MHz, USB, Lcp-Rcp	, Cross hands										654.6 <u>A P</u> offset:0	83.64 <u>A P</u> offset: 0	<u>161.7</u> <u>A P</u> offset: -1	59.53 <u>A P</u> offset: -3	31.8 <u>A P</u> offset: 1	<u>16.24</u> <u>A P</u> offset: -1	<u>155.1</u> <u>A P</u> offset: 1	50.62 <u>A P</u> offset: -5	64.4 A P offset: -17			

ftp fringe-test results web interface





Networks and telescopes used for IYA2009 24hr e-VLBI. Image by Paul Boven <boven@live.nl>. Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

www.evlbi.org

www.jive.nl

www.expres-eu.org