e-VLBI: a telescope larger than Europe

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Acronyms/Organizations involved

• **VLBI**: Very Longs Baseline Interferometry
  - A radio-astronomical technique with telescopes thousands kilometers apart to obtain highest possible resolution

• **EVN**: European VLBI Network
  - Consortium of (European) Telescopes
    - Arecibo, Puerto Rico, Cambridge (UK), Effelsberg (D) Jodrell Bank (UK), Medicina (I), Metsahovi (FI), Noto (I), Onsala (S), Shanghai (CN), Torun (PL), Urumqi (CN), Westerbork (NL), Yebes (ES), KVASAR telescopes (RU)

• Joint Institute for VLBI in Europe
  - Institute established in 1993
  - Funded by NWO (NL), ASTRON (NL), STFC (UK), INAF (I), ICN-IG (ES), OSO (S), CAS (CN), CNRS (F), MPG (D)

• **EXPReS**: EXpress PRoduction e-VLBI Service
  - EC project funded, started in 2006, 3.9M€, closed last month
  - Partners: most radio-telescopes in Europe
    - But also in Australia, South-Africa, Chile, China
  - DANTE and a selection of NREN’s: SURFNet, AARNET, PSNC
Connected radio-interferometry reaches arcmin-arcsec resolution

Based on distributed clock signal and central processor

Westerbork Synthesis Radio Telescope

JIVE & ASTRON headquarters in Dwingeloo, the Netherlands
VLBI: digital processing

- To reach the faint end of the universe...
  - Need many big telescopes
  - And as much frequency space as you can get
  - Bandwidth!

- Bandwidth for sensitivity
  - 2 x 128 MHz bandwidth
  - Noisy data: 2 bits/sample
  - 1024 Mb/s, more is preferred
  - Bits are not sacred

- Supercomputer correlates
  - Information on all baselines
  - Up to 16 telescopes
  - Based on custom chip
    - Dedicated in 1998
Sending hard-drives around the world

Typically have a few thousand going around

Recording on Linux PC platform
Harddisk recorder based system
Parallel writing on 8 disk system
Now turn to e-VLBI!

- PC based recording
  - Also allows Internet transmission
  - Upgrade EVN to e-EVN
    - Started with a pilot in 2004

- And was boosted with EXPReS
  - Retrofit correlator to work real-time
  - Help solve last mile problem at telescopes
  - Work closely with NRENs on robust connectivity
  - Push to 1024 Mb/s limit
  - Bring in the big telescopes
  - And start the revolution in radio-astronomy culture
Establish connectivity through Europe on GÉANT2

Greatly catalysed by having EC funded project

All come together on the Dutch SURFnet6

Large bundle from Amsterdam to Dwingeloo
Competitive facility

- 9 telescopes regularly on line, interesting for science
  - Sustained operations at 512Mbps, 1 Gbps to be advertised

Size of bubble set by number of telescopes participating, height by station sustained bit-rate
Robust? As robust as normal VLBI
24 hr long up-time
Protocol research:
- TCP/UDP
- Buffer size
- Frame length
- Data packaging
Dedicated light-paths
Now sustained 24hr observing runs now possible

Can be run by a single post-doc

More reliable as recorded VLBI
Did a global, round-the-clock, demo at IYA opening, Paris
Featured in IYA 24-hour webcast

• Demo, 2 times 10 hours
• Real-time results displayed
  • NEMO Amsterdam
  • Observatoire de Bordeaux
  • Arecibo observatory
  • Onsala observatory

First live results with Yebes40m in Spain.
e-VLBI science

- e-VLBI is booming now!
  - Had several e-VLBI runs this year
  - Some use trigger conditions
  - Or so-called Target-of-Opportunity
  - And big telescopes available

- Required a cultural change in observing policies
  - Peer review process is careful
  - The sky is open to anybody
  - The telescopes are involved in other programmes as well
  - Extra support offered

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EVN detection of Aql X-1 in outburst

ATel #2317: V. Tudose (ASTRON), Z. Paragi (JIVE), J. Miller-Jones (NRAO), M. Garrett (ASTRON), R. Fender (SOTON), A. Rushton (JBO), R. Spencer (JBO)

on 29 Nov 2009; 12:21 UT

Password Certification: Valeriu Tudose (vtudose@science.uva.nl)

Subjects: Radio, Binaries, Neutron Stars, Transients, Stars

The X-ray binary Aql X-1 has been in outburst in the last few weeks (ATEL #2288, #2296, #2299, #2302, #2303).

We observed the system on 2009 November 19 between 14:30-19:00 UT at 5 GHz with the European VLBI Network (EVN) using the e-VLBI technique. The participating radio telescopes were Effelsberg (1 Gbps), Medicina (896 Mbps), Onsala 25m (1 Gbps), Torun (1 Gbps), Westerbork...
First eEVN observations of Arp299

Arp 299 2.3 GHz (13 cm) milliarcsec

VLBA+GBT

2002 Apr 29

Pérez-Torres, Polatidis et al., in preparation

200 pc
eEVN at 5 GHz

Pérez-Torres, Polatidis et al., in preparation
6, 13, 16 Nov 2008
Supernova factory in Arp229A

Burst of star-formation leading to numerous
• SNe hidden by dust

Closely spaced EVN e-VLBI observations
• new radio sources appear, SNe or remnants
• 26 radio sources in the central 150pc

Further monitoring constrains
• the star-formation rate
• initial mass-function

SN2007gr

- Nearby type Ic supernova
- e-VLBI within 20 days
  - detection at 400 µJy/beam level
  - mas accurate position
- Two months later EVN+GBT:
  - weak detection at offset position
  - indicating superluminal motion?
- VLBI vs. WSRT total flux:
  - mildly relativistic (>0.6c) expansion!

First direct detection of relativistic expansion in a supernova
Scientific motivation

- Rapid response for rapid variability
  - Fast response to requests
  - Immediate analysis of data, adapt observing parameters
  - Coordination with current and future observatories
    - GLAST, LOFAR

- Immediate feedback
  - More robust data

- Fewer consumables, logistics
  - Constantly available VLBI network
    - Monitoring: for example astrometry
    - Spacecraft tracking

- Growth path for more bandwidth
  - More sensitivity

- European SKA pathfinder
Link to Space applications could be very important

Now called EJSM

Huygens

Chang'E
First tests with Russian telescope at Badary
Performed when correlator cooling failed...
What’s next?

• Science calls for more sensitivity and more telescopes
  • While keeping the newly acquired functionality of e-VLBI

• Make all VLBI e-VLBI?
  • And boost the bandwidth to 4Gbps, 10Gbps, 64 Gbps
  • Useful bandwidth at high frequency
    • or multiple bits for robustness at lower frequency

• Can make all VLBI experiments have e-VLBI component
  • Do e-VLBI with telescopes that can, for direct results and feedback
  • Do e-shipping where the bandwidth is limited
  • Play back recorded stations when scientifically required

• And (continued) development of:
  • High bandwidth storage
  • Streaming computing for correlation
Spotted on one of numerous visits to Brussels:

Where should we invest our money?

Waar moet ons geld naartoe?

Europe : où investir notre argent ?

In die Zukunft investieren – aber wie?
NEXPReS:

- Submitted new proposal
  - Novel EXplorations Pushing Robust e-VLBI Services

- Core activity to cache data
  - at correlator and telescopes
    - Not just back to recording
    - is more like ‘cloud-transport’
  - Relevant for LOFAR, other SKA pathfinders, SKA
    - Storage also relevant for archives

- Research resource allocation,
  - “Bandwidth on Demand”
    - To reach high bandwidth

- Continue interdisciplinary work
  - with DANTE and NRENs
    - In order to connect more telescopes
Relation to SKA project

- SKA Square Kilometer Array
  - Global radio-astronomy ambition

- E-VLBI is a SKA pathfinder
  - long-range connectivity,
  - real-time radio-astronomy
  - Shared technology interests:
    - Correlators and digital processing
    - Calibration & data processing
    - Cheap telescopes...
  - Overlap in science expertise and training

- Complementary VLBI science case for 2015
- Also challenges in continuity of funding
  - In training the right number of people
- Future VLBI could benefit from SKA development
Other activities at JIVE

• Obviously, operations of the EVN correlator
  • Archive on-line and >1.5 year old data public
  • Comes with diagnostic plots, calibration, very preliminary images

• EVN Access support funded by EC
  • User support from proposal to analysis, visitor facilities

• Technology development, e-VLBI and more:
  • Correlator software algorithms, tailored for clusters and Grid
  • Also for dedicated hardware: FPGA based

• Software for data processing
  • ALBUS project on large data processing problems
  • Developed ParselTongue “AIPS talking Python”
  • ALBiUS project on interoperability between data processing systems