GLOBAL eVLBI
an evolution pathway for VLBI into the SKA era

Huib van Langevelde
JIVE
Outline

• Programmatic aspects of e-VLBI
  • EXPReS; introducing e-VLBI
  • Introducing NEXPReS
    • Objectives of the new program

• Impact of e-VLBI on VLBI and radio astronomy
  • Some discussion on policies
  • And applications

• e-VLBI and the future
  • SKA pathfinder
  • evolving VLBI = Global VLBI
  • Competitive in the SKA era
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Starts with a European perspective

Ends with a Global perspective
EVN and JIVE

- EVN consortium with 20+ possible antennas
  - Ef, Mc, On, Jb, Nt, Tr, Wb, Sh, Ur, Hh, Ar, Mh, Ys, Sv, Ro, Ku, My, Wz, Sm, Ny, Ka
  - Ran by up to 14 different organizations
  - And 12 more antennas for “Globals” with NRAO

- Covering range of frequencies
  - Workhorse frequencies 18cm, 6cm,
  - Also available: SX, 5cm, 1.2cm
  - And at limited stations 90cm, 21cm, UHF, 50cm, 2cm, 0.7mm

- Reaching mas resolutions
  - From 15mas for 1.4 GHz EVN (can add MERLIN for brightness sensitivity)
  - To 1 mas at 5GHz with Asian, African or American baselines

- Sensitivity of 5μJy in 8hr at 1.4 GHz
  - Combination of Big Antennas and 1 Gbps bandwidth
  - Big antennas also vital for spectroscopy (mJy sensitivity)

- Operational approximately 60 days/year
  - 3 sessions augmented with e-VLBI once a month
Joint Institute for VLBI in Europe

- Promote the use and advance of VLBI for astronomy
  - Central correlation
  - User services
  - Network support
  - Innovation
  - EC liaison/representation

- Founded in 1993
  - Base budget from partners in 7 countries:
    - China, France, Germany, Italy, Spain, Sweden, United Kingdom, the Netherlands
    - Some funding agencies, some institute contributions
  - Hosted by ASTRON
  - Large number of external projects
    - Covering JIVE’s R&D and science ambitions

- Preparing for new funding cycle MOU
  - May take new form of European Research Infrastructure Consortium
• Hardware correlator
  • 1024 custom chips
  • 16x16 baselines, 0.25s
• The EVN software correlator at JIVE (SFXC)
• 9 stations 1Gbps real-time
  • Pulsar gating
  • Space craft applications
  • Spectral polarimetry
  • Many field of views
Turned into e-VLBI

• Started many times in many places
  • Fringe verification, modem lines
  • For EVN started with a pilot in 2004

• Really took off with EXPReS
  • Retrofit correlator to work real-time
  • Help solve last mile problem at telescopes
  • Work with NRENs on robust connectivity
  • Push to 1024 Mb/s limit
  • Change of VLBI culture in EVN

3.9M€ project, with additional resources from partners and additional NRENs. Started Q3 2006 ended Q2 2010
Observations

• Now an operational facility
  • Guaranteed 10 x 24h per year
    • And quite bit more in practice (>30%)

• Flexible ways to get into e-VLBI
  • Request e-VLBI for fast response
    • Can be approved by PC for existing sessions
  • Or for triggered proposals
    • To be submitted at regular proposal dates
    • Requires specific trigger criteria
  • Short requests <2hr
    • e.g. calibrator checks

• Target of Opportunities
  • EVN agreed to have substantially more of these
  • Or just because you prefer to e-VLBI
  • Or just because the EVN prefers to do e-VLBI
    • Because of logistics or (disk) resources
What we learned from EXPReS

• Besides building expertise and making new friends:
  • Bandwidths of 1Gbps and above not a problem
  • e-VLBI is probably even more reliable
    • By closing the loop in real-time
  • It can be applicable to Global VLBI
    • Local connectivity often the more serious problem
  • It did produce new science
    • Moreover, users think it is exciting and convenient

• But some questions remain
  • Will it be cost effective?
    • In many places, notably NL, still has the nature of collaborative project
  • Cannot accommodate all projects
    • Spectral line, mixed bandwidth
    • Multiple correlator centres
    • Some antennas in some experiments (Noto, Russian, Chinese)
    • Globals including NRAO, DSN
Cost effective?

• Shipping much cheaper than bandwidth at commercial rates
  • Lucky with blessing at European level
    • Dante’s Geánt
  • Made local providers supportive
    • Fantastic infrastructure SURFNET
  • Commitment of partners
    • Synergy with LOFAR

• Strategic issue for NRENs
  • Lightpath technology
  • will be economic and green
  • Link to SKA

• Test case for technology
• And policy issues
  • direct border crossings
We detected a source with a peak brightness of 422 mJy per beam at 5.6 times the off-source noise level of 75 mJy per beam, and the peak is 60 s, dec. The VLBI location of RA 12 h 43 min 27.975 s, dec. 44.74 arcsec is consistent with the VLA coordinates RA 12 h 43 min 27.973 s, dec. 44.677 arcsec at a lower resolution. The apparent position shift at 1.3 GHz on 2007 November 5–6 is some extended flux density detected near the supernova position. The off-source noise in the map is 13 mJy per beam, and the peak is 422 mJy per beam, and the peak is 60 s, dec.

Figure 1. The contours are drawn at 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 20 sigma of the EVN and EVN+ observations of SN 2007gr. The colours, the VLBI location of RA 12 h 43 min 27.975 s, dec. 44.74 arcsec, and the apparent position shift at 1.3 GHz on 2007 November 5–6 are consistent with the VLA coordinates RA 12 h 43 min 27.973 s, dec. 44.677 arcsec at a lower resolution.
We report on EVN observations of the radio source V407 Cyg, following its reported increased radio emission during its X-ray outburst (ATel #2431 and ATel #2514). The radio observations were carried out at 5 GHz by 9 telescopes for about 9 hours between 23h March 30 and 13h March 31.

Subjects: Radio, Transients, Variables, Stars

Related
2546 Discovery of coronal emission above 100GeV reported by MAGIC (ATel #2536)
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2511 Radio detection of V407 Cyg at 8.4GHz with OCRA-p on the Hartebeesthoek Radio Observatory (ATel #2536)

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Detection of Probable Jet Component to XTE J1752-233 with e-VLBI

ATel #2438; Catherine Brocksopp (MSSL), Jan Yone (Observatoire de Paris, Université Paris Diderot), Tassos Tsionis (ATNF, Radio Science), on 13 Feb 2010; 21:42

Password Certification: Catherine Brocksopp (Catherine.Brocksopp@mssl.ac.uk)

Subjects: Radio, Binaries, Black Holes, Transients

We report on EVN observations of the radio source XTE J1752-233, following its reported increased radio emission during its X-ray outburst (ATel #2438). The radio observations were carried out at 5 GHz by 9 telescopes for about 9 hours between 23h March 30 and 13h March 31.

Subjects: Radio, >GeV, AGN, Black Holes

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VLBI detection of V407 Cyg

ATel #2536; Giroletti (INAF/IRA), E. Kroedlin, S. Corbel (Univ. Paris Diderot & CEA Saclay), K. Sokoloska (MPRI/UAC, Leibsent), L. Fahrmann, P. Schinzel (MPRI), C.C. Cheung (SUNY/ NRL) on behalf of the Fermi-LAT collaboration.

Password Certification: Marcello Giroletti (giroletti@ira.inaf.it)

Subjects: Radio, Gamma Ray, Novae, Transients

We report on EVN observations of the symbiotic star V407 Cyg, following its classical nova outburst (CBET #2199, CBET #2201) and its surprise detection in gamma-rays (ATel #2387 and ATel #2396). The radio continuum observations were carried out at 5 GHz by 9 telescopes for about 9 hours between 23h March 30 and 13h March 31.

Subjects: Radio, Binaries, Black Holes, Transients

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EVN observations of the radio source V407 Cyg

ATel #2437; M. Giroletti (INAF/IRA), A. Cesarini (Washington Univ.), on 11,12

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Subjects: Radio, >GeV, AGN, Black Holes

We report on EVN observations of the radio source V407 Cyg, following its reported increased radio emission during its X-ray outburst (ATel #2437). The radio observations were carried out at 5 GHz by 9 telescopes for about 9 hours between 23h March 30 and 13h March 31.
e-EVN operations plots

- Disk-based network hours roughly constant
- 2010 e-EVN network hours now at 240.5
- Total network hours 2010 at 999

ToOs: half (49.5%) of the total e-EVN observing time in 2010
e-EVN operations plots

- Disk-based network hours roughly constant

**EVN Observation Proposals**

- EXPReS
- NEXPReS

- e-VLBI - Triggered
- e-VLBI - ToO
- e-VLBI - Scheduled
- Disk - ToO
- Disk - Scheduled


† Includes 2 of 3 scheduled observing sessions for 2011, and ToO observations through 20 June 2011.
EXPReS was concluded in Mar 2010

Successful NEXPReS proposal kicked off in July 2010
New project: NEXPReS

- Aims for
  
  - Allow multiple correlator passes
  - Buffer for more reliable operations
    - addressed by simultaneous recording
  - Be more sensible about resource allocation
    - Bandwidth on demand, limit physical shipping
  - Reach for higher bandwidths (10 - 40 Gbps)
  - But also:
    - Continue to connect more telescopes
    - NEXPReS maintains expertise
      - Collaborations with NRENs
    - ‘owns’ the e-VLBI operations and outreach
    - Also some LOFAR transport and storage issues
    - And link to SKA development
New project: NEXPReS

- Aims for
  - Correlate in real time what you can,
  - Correlate later what you need

- Allow multiple correlator passes
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NEXPRеСS project info

- 15 partners (cf. 19 in EXPReS)
  - Of which 3 choose not receive funds from EC
  - Good mix from astronomy-networking-HPC communities
  - High level of partner-contributed effort

- Kicked off in 2010 with EVN symposium
  - Had to fit project within 3.5 M€ envelope

- Passed Year 1 review with good marks
  - Some issues on spending profile
  - Metrics of success hard to define
  - And consortium agreement

- NEXPRеСS Consortium Agreement now done
  - Money flowing any day now...
2 Joint Research Activities aiming at innovating future operations
Distributed correlation in

2 Service Activities
focus on new operational astronomical features:
Higher bandwidth, dynamically cached transport, increasing flexibility of observations

2 user community networks continue from EXPReS
Astronomy use and policy
Network providers/telescope operators

2 special Networking Activities
Management & Outreach
Essential for success
Service activities

- Cloud correlation
  - Overhaul of local network
  - Flexibly connecting playback,
  - Fibres & correlators
- Control code
  - Allowing mixed rate operations
  - Making various playback units flexibly usable
  - Uniting correlator interfaces
- Transparent buffering
  - Working on JIVE Mk5 control code
  - For use in the field
  - And at the correlator

- Work on Bandwidth on Demand
  - Enabling 4 Gbps
  - And connectivity infrastructure

Talk by Szomoru
Talk by Boven
Talk by Huisman
Joint Research Activities

• Distributed correlation
  • Continued look at distributed correlation
  • But moving away from Grid
  • Looking at resources in own domain

  talk by Kettenis
  talk by Jekabsons

• High bandwidth storage
  • Feeding into the caching demands
  • But also at massive (distributed) archives

  talk by Mantovani
Network activities

• Management
  • Doing all the nasty stuff
  • Including dealings with EC
    • On finances for example

• EVN-NREN
  • Interactions with Networking experts
  • Had first meeting in Aveiro, Pl

• EVSAG
  • e-VLBI Science Advisory Group
  • On policies and operational issues
    • Overlaps with EVN-PC
  • Meeting in Madrid last week

• Outreach & Dissemination
  • Maintains internal information
  • And external outreach material
    • Display booth
    • e-VLBI/JIVE film
NEXPRIReS impact on EVN policies

• Still some real-time issues under consideration
  • More dedicated e-VLBI sessions required
    • For normal proposals, triggered proposals
  • More readiness for ToO opportunities
    • Not necessarily e-VLBI
  • In NEXPRIReS more, new options may occur:
    • Same real-time/transient opportunities
      • But including those that require multiple correlations
      • And reaching 4Gbps data rates

• And in the future:
  • Distinction between real-time and disk recording will vanish
    • Must define when science objectives are met
    • Release data and re-correlate decisions
  • Consumables bottleneck/logistics disappear
    • Can have continuous array, small telescopes, distributed correlation
  • Flexibility of array improves
    • Can adapt schedules to observing conditions
    • Or react to automated, external triggers!
New opportunities

• In addition, new requests from (new) user communities
  • Could impact on policy discussions
    • RadioAstron, space applications
    • Monitor programmes/astrometry/joint observations
    • Triggers set by other observatories (link with LOFAR)

• Worried about exploding the procedures?
  • Already complex for telescope & correlator operators
  • Also complex for users!
  • Data ownership for triggers, concurrent observations

• Can we address this by (yet) new services?
  • Offer smaller sub-arrays?
  • More e-VLBI days, leading to “VLBI every Friday”
    • And some telescopes on Thursday as well?
  • Central scheduling?
VLBI for Space applications...

BepiColombo

ExoMars

MarcoPolo-R?

Phobos-Soil

Huygens

VEX SFXC near-field fringes Duev, Keipema et al. 2011

Mh-Wz, 8.4 GHz

PRIDE: Planetary Radio Interferometry & Doppler Experiment
VLBI for Space applications...

BepiColombo

ExoMars

MarcoPolo-R?

VEX SFXC near-field fringes Duev, Keipema et al. 2011

Huygens

PRIDE: Planetary Radio Interferometry & Doppler Experiment

Mh-Wz, 8.4 GHz
EM081c: On, Wz, Mc, Ma, Ys, Mh, Sv, Zc

J2211-13, 0.17 Jy reference source at a distance of 2.5 deg from target

3C446, 2.5 Jy Fringe Finder at a distance of 15 deg from target

VEX track

8.4 GHz 2011.03.28

Cimo, Duev, Molera et al. 2011, in preparation
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Next? More VLBI!

- Increasing data rate will not stop any time soon:
  - New stations: Africa, Goonhilly, Madeira, Brasil....
  - Joint observations with e-MERLIN
  - Joint observations with ALMA

- Need for better sensitivity, more digital bandwidth
  - with more bit sampling against interference

- And increasing number of space applications

- Science synergy with new survey instruments

- For aperture arrays much more data
  - eg APERTIF@WSRT 25 interferometers simultaneous
First 3Gbps fringes with Chinese tels. Combining CDAS and Mk5

First correlation of European - Korean baselines at K-band
Needed: next generation correlator

• Aiming for 32 station 10+ Gbps FPGA correlator
  • Flexibility of software correlator
  • Power consumption should be much better

• Currently funded for EVN correlator prototype (2012)
  • Also WSRT Apertif and LOFAR beam-forming
  • And feeding into the SKA programme
  • Continued development in RadioNet3 for new chip technology
Future 2: clock distribution

- VLBI depends on availability of extremely accurate clock and frequency standard ($10^{-15}$)
  - All telescopes must have 100k€ maser clock
    - In principle can be distributed over dedicated fibre

- Investigate clock distribution on public network
  - Requires dedicated wavelength and stable amplification
  - To measure return loop

- Will improve stability, operations
- And many more VLBI sites!
Let's go Global!

• While VLBI is ever greater....
  • ... some of us are encountering some issues
  • Maybe these issues are getting larger during the SKA process
    • Certainly with the current economic developments

• In Europe we do not run VLBI on national levels
  • Besides the baseline length...
  • The critical mass user community is not on national level

• Some of this discussed in context VLBA future

quote by Brisken
VLBI future science case

• Science case has been developed
  • http://www.evlbi.org/publications/publications.html

• Some highlights include:
  • Nature of starburst/AGN in cosmological fields
  • The fate of black holes/radio quiet AGN
  • Jet physics close to the event horizon
  • Determining star burst activity, resolving SNR’s
  • The accretion physics in transient radio sources
  • The detailed 3D kinematics of star formation
  • The role of magnetic fields in stellar life cycle
  • The nature of the ISM in active galaxies
  • Fundamental distances from astrometry
  • Pulsar astrometry
  • Monitoring spacecraft in the solar system
VLBI Future

• Unique science: long baselines and high frequencies
  • Keep up with EVLA/MERLIN sensitivity
    • Going for 4Gbps in 2011
    • Follow up LOFAR, MeerKAT, ASKAP

• Even in the SKA era
  • At least for phase I
  • Most certainly phase II
    • And this molecular astrophysicist is very worried about phase III
  • Spacecraft applications (and geodesy) need Northern Hemisphere coverage

• Global baselines for better images
  • And better time coverage
  • Data quality and image fidelity for SKA users

• Only single (or two) user communities for all of us
  • Critical mass reached on continental scale or larger
Synergy with the SKA

• Future VLBI to be based on e-VLBI advances
  • Sensitivity, Robustness, Flexibility

• Lots of overlap with SKA technology
  • Benefit from digital components
  • And even antennas
  • And processing software
  • Synergy with other SKA pathfinders

• Need SKA story to maintain funding...
  • Training aspects, home telescope, outreach
Finally

• User community is the most precious asset
  • Make sure the interfaces are uniform and robust
    • User software, User support, Training, Proposal handling, Scheduling
  • Do not increase number of interfaces to different networks
    • but reduce and simplify
    • We do not have a user community to run 6 different networks
  • e-VLBI is helping us to foster user involvement
    • Gets the excitement of astronomical observation into VLBI

• Should build on these e-VLBI meetings
  • Could have a wider topic, they already have
  • BTW, next EVN symposium is in Bordeaux, October 2012

• Pushing technology is part of the mission
  • e-VLBI has helped keeping us visible

• Long-term common goal?
  • Global VLBI array which react flexible on user demands
    • Needed to satisfy scientists used to SKA/ALMA
The End