European VLBI Network

Cormac Reynolds, JIVE

EUROPEAN vlbi NETWORK

JOINT INSTITUTE FOR VLBI IN EUROPE

European Radio Interferometry School, Bonn
12 Sept. 2007


EUROPEAN
vlbi
NETWORK
Jodrell Bank Lovell (UK)
Onsala 20m (SE)
Onsala 25m (SE)
Dwingeloo (NL)
JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE
Jodrell Bank Mk2 (UK)
Metsähovi (FI)
Arecibo (PR)
Cambridge (UK)
Torun (PL)
Urumqi (CN)
Hartebeesthoek (ZA)
Westerbork (NL)
Wettzell (DE)
Seshan (CN)
Effelsberg (DE)
Medicina (IT)
Robledo (ES)
Yebes (ES)
Noto (IT)

EVN Array

- 15 dissimilar telescopes
- Observes 3 times a year (approx 60 days per year)
- Includes some of the world's largest telescopes
  - ~ 20 μJy noise-level in 1 hour of observing at 18cm
- Good u,v coverage with baselines from 200 – 2200 km in Europe, up to 9000 km with Chinese telescopes
  - Resolution at 5 GHz: 5 mas (Europe), 1.5 mas (+China), 1 mas (Global)
- Global VLBI (EVN + VLBA): coordinated observing, single proposal, single schedule, correlated together
- EVN + MERLIN: coordinated observing, single proposal, single schedule, 2 antennas in common

New Telescopes

Yebes 40-m

(base of) SRT 64m

Aspiring Telescopes

- EVN-compatibility Irbene 32-m tests
  - completed in 4th quarter 2006
  - autocorrelation (maser) signal at 12 GHz detected
  - no VLBI fringes; efforts will continue

Evpatoria 70 m

Irbene 32 m

- EVN-compatibility test with Evpatoria 70-m at 5 GHz
  - fringes (+improved Ev coordinates) found end 2006

Correlator Capabilities

- Located at JIVE, Dwingeloo, NL
- 1-, 2-bit sampling
- Cross-polarization
- Up to 1 Gb/s x 16 stations in full stokes
- Up to 2048 freq points per subband/poln
- Oversampling
- ¼ sec integration time
- Mk5 Disk recording
- Real-time e-VLBI operation
- Phase-cal detection

Correlator Capacity (Spectral Resolution)

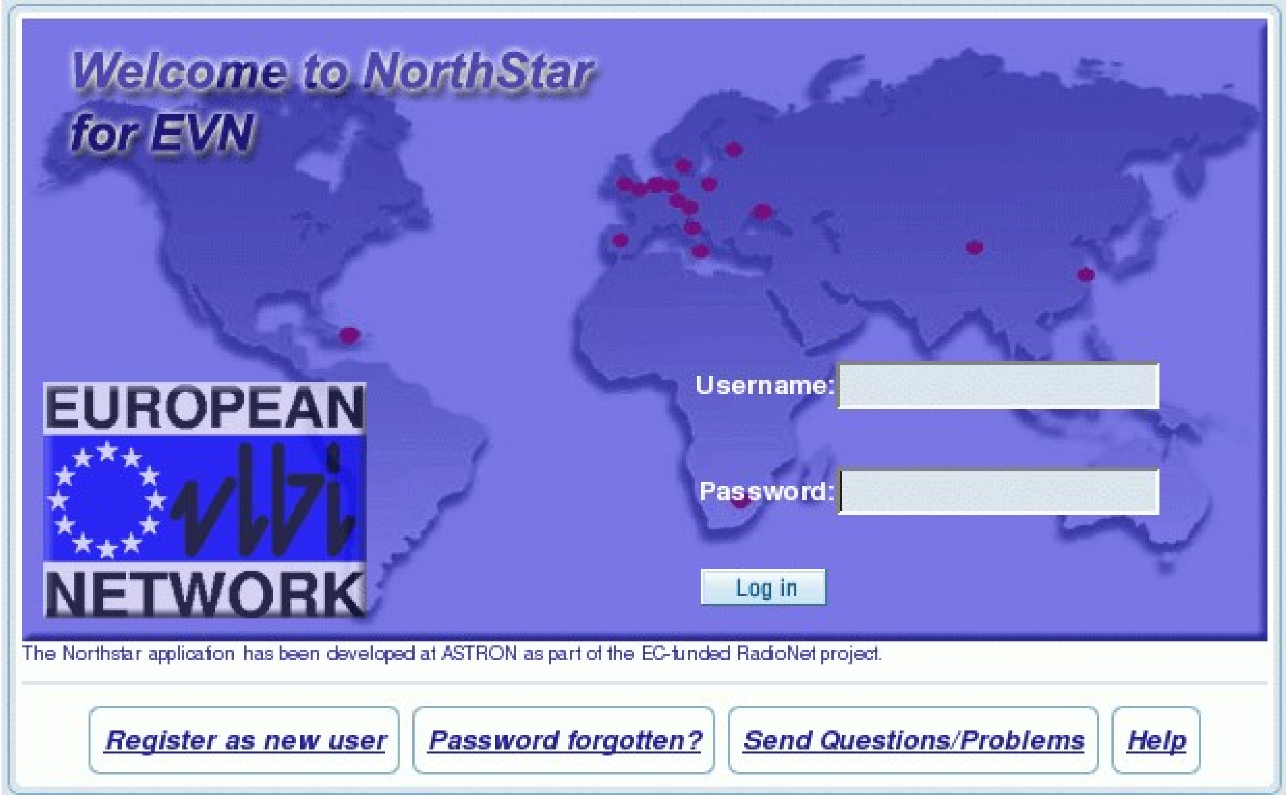
- 8 Station 1 subband 1 pol = 2048 Freq. points
- 16 station 1 subband 1 pol = 512 Freq. points
- 16 station 8 subband 4 pol = 16 Freq. points

Resulting Maximum Spectral Resolution

Bandwidth	$\Delta\nu$ [Hz]	Vel. res. at 6668 Mhz (Methanol)
16 MHz	7813	351 m/s
0.5 MHz	244	11

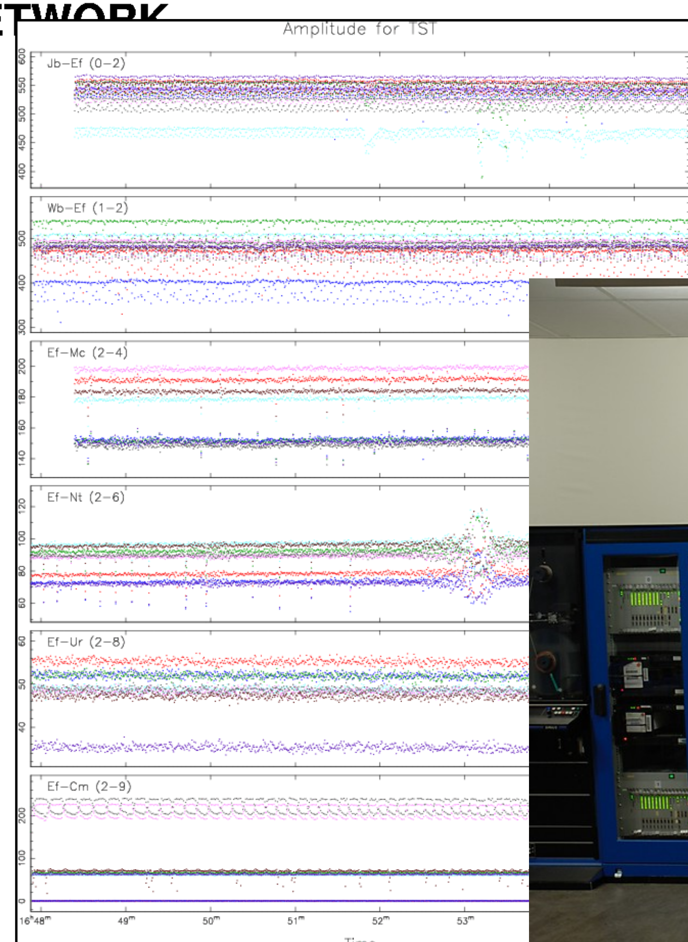
Proposing

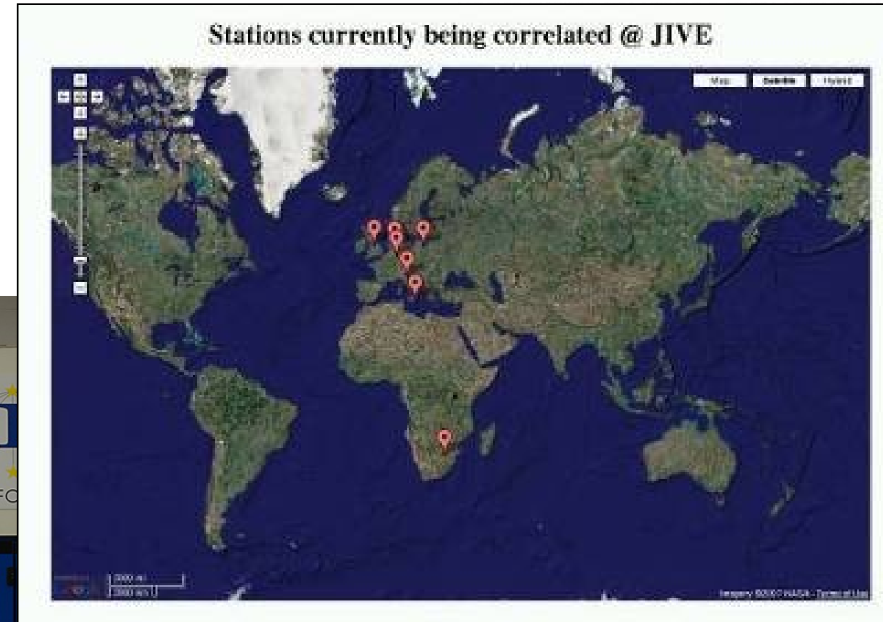
- NorthStar proposal tool (https://proposal.jive.nl)
  - Web based proposal submission
    - Improved consistency, LaTeX obsolete, easier handling
- Deadlines 3 times per year (1st Feb, June, Oct)
  - Assistance available from JIVE (http://www.evlbi.org/user_guide)

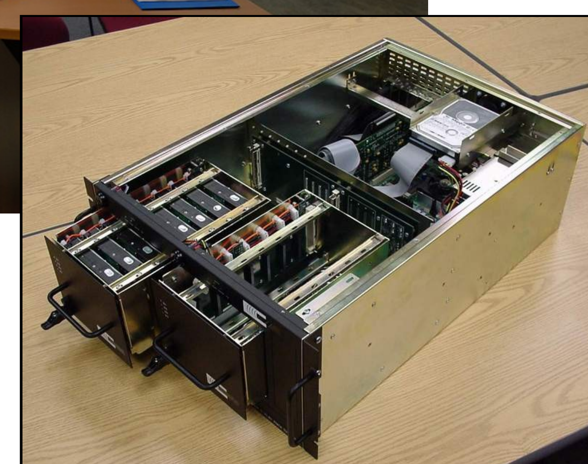


- Founded in 1993
  - Base budget from partners in 7 countries: China, Germany, Italy, Spain, Sweden, United Kingdom, the Netherlands
    - France will join in 2008
  - European subsidies to carry out innovative projects
- Located in Dwingeloo, the Netherlands
  - hosted by ASTRON
- Promote the use and advance of VLBI

Operate and enhance data processor







JIVE Support Staff



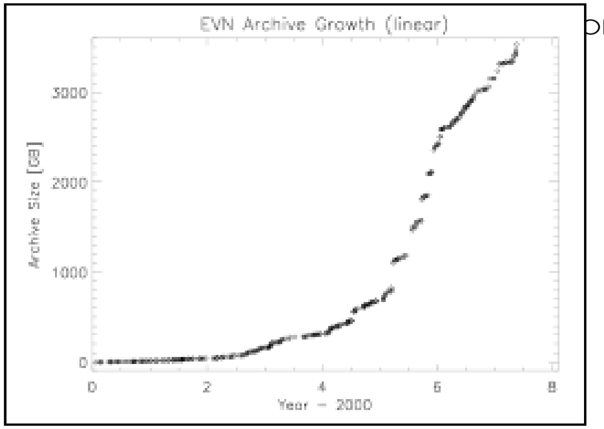
Support Scientists

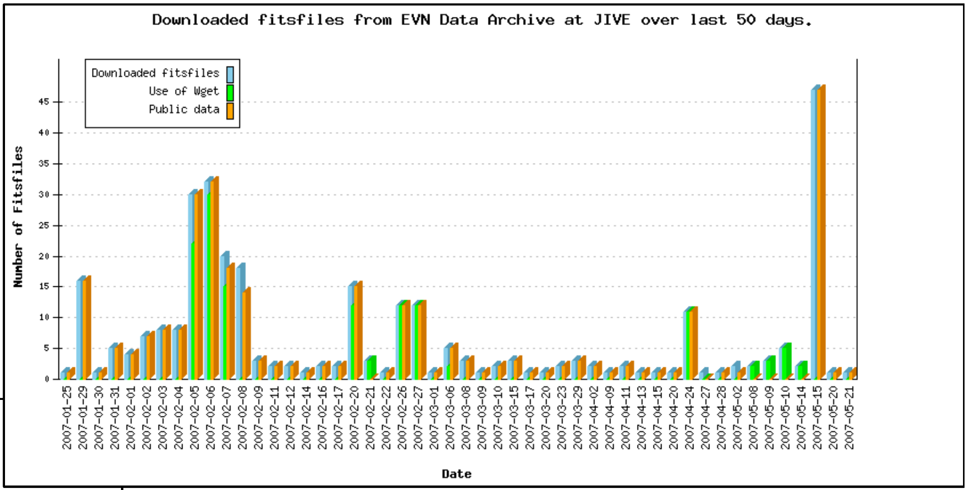


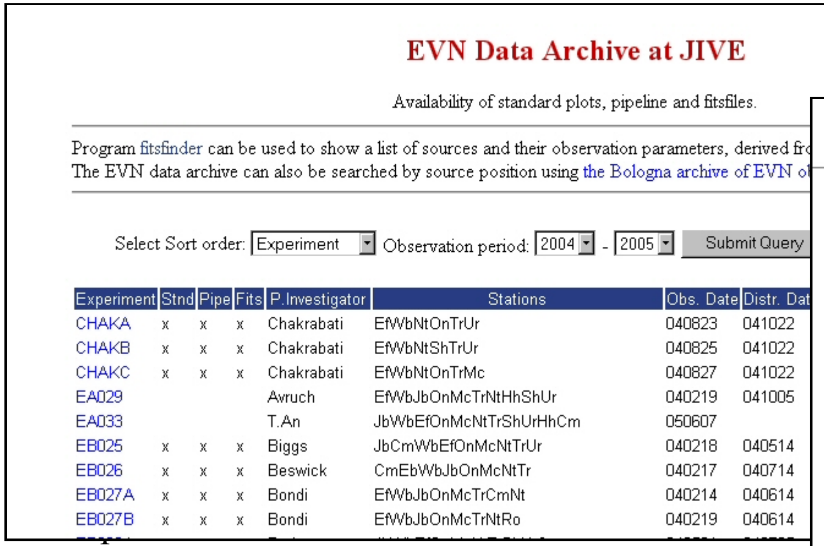
Correlator Operations

EVN Archive

- All output data on line
  - Couple TByte
    - Public one year after last epoch
  - Password protected by project
  - Together with calibration info
    - All meta-data, schedules etc.
    - Quality control plots
  - Preliminary images from pipeline
  - Searchable by position and observing setup (freq, bandwidth, telescopes, etc.)
- http://archive.jive.nl/







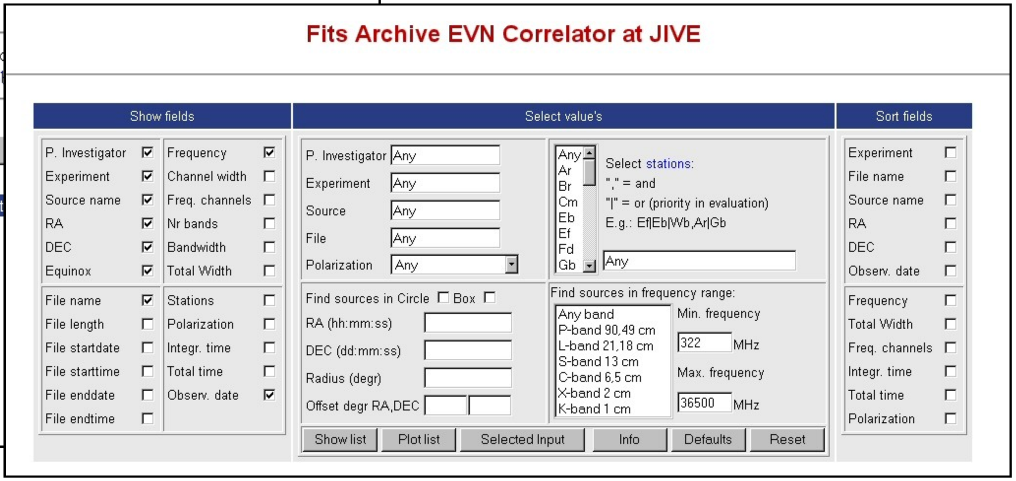
EVN Data Archive at JIVE

Availability of standard plots, pipeline and fitsfiles.

Program fitsfinder can be used to show a list of sources and their observation parameters, derived fr
The EVN data archive can also be searched by source position using the Bologna archive of EVN o

Select Sort order: Experiment Observation period: 2004 - 2005 Submit Query

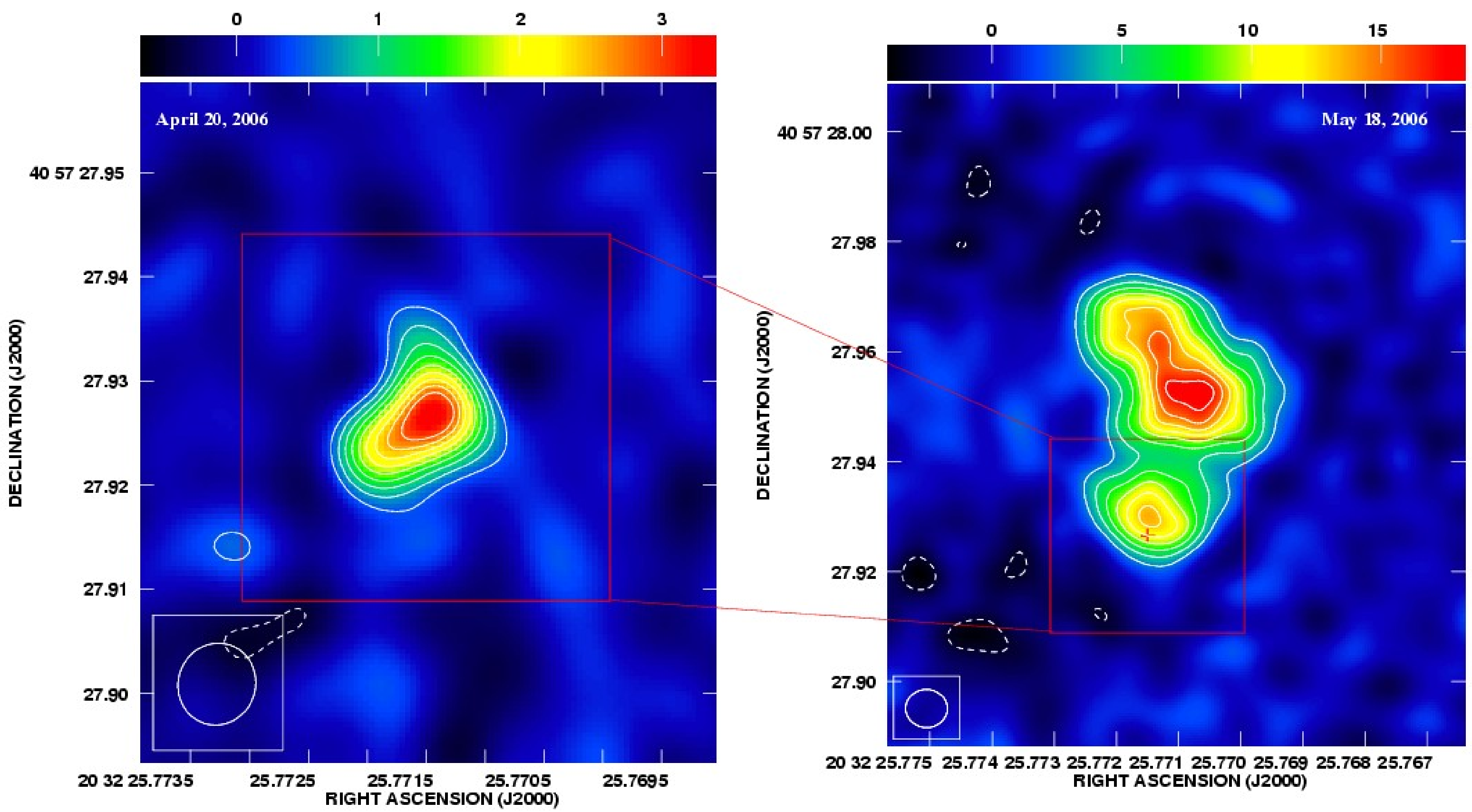
Experiment	Stnd	Pipe	Fits	P.Investigator	Stations	Obs. Date	Distr. Dat
CHAKA	x	x	x	Chakrabati	EfWbNtOnTrUr	040823	041022
CHAKB	x	x	x	Chakrabati	EfWbNtShTrUr	040825	041022
CHAKC	x	x	x	Chakrabati	EfWbNtOnTrMc	040827	041022
EA029				Avruch	EfWbJbOnMcTrNtHhShUr	040219	041005
EA033				T.An	JbWbEfOnMcNtTrShUrHhCm	050607	
EB025	x	x	x	Biggs	JbCmWbEfOnMcNtTrUr	040218	040514
EB026	x	x	x	Beswick	CmEbWbJbOnMcNtTr	040217	040714
EB027A	x	x	x	Bondi	EfWbJbOnMcTrCmNt	040214	040614
EB027B	x	x	x	Bondi	EfWbJbOnMcTrNtRo	040219	040614



RadioNet Trans-national Access

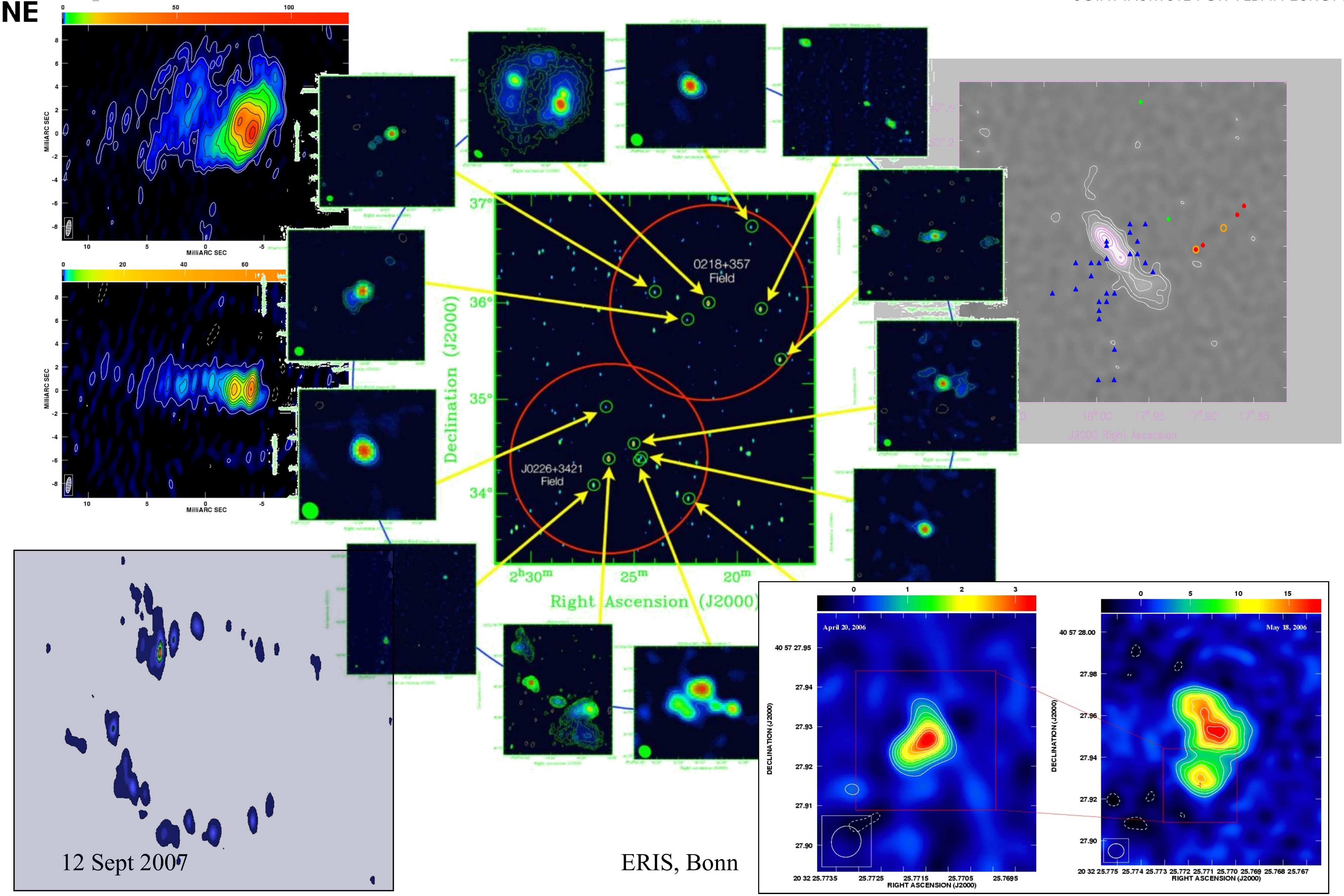
- Travel Support (data-reduction visits; preferably students or first-time users)
- Publications: 70 papers resulting from TNA-supported observations since 2004

year	N_{exp}	N_{hour}	N_{user}	N^{new}_{user}
2004	115	4186	129	53
2005	131	4084	125	50
2006	96	3178	129	60



Cyg X-3 during a radio outburst (Tudose +)

EVN Science



ERIS, Bonn

EUROPEAN VLBI NETWORK

*e*VLBI & EXPReS

JIVE JOINT INSTITUTE FOR VLBI IN EUROPE

EXPReS = Express Production Real-time *e*VLBI Service

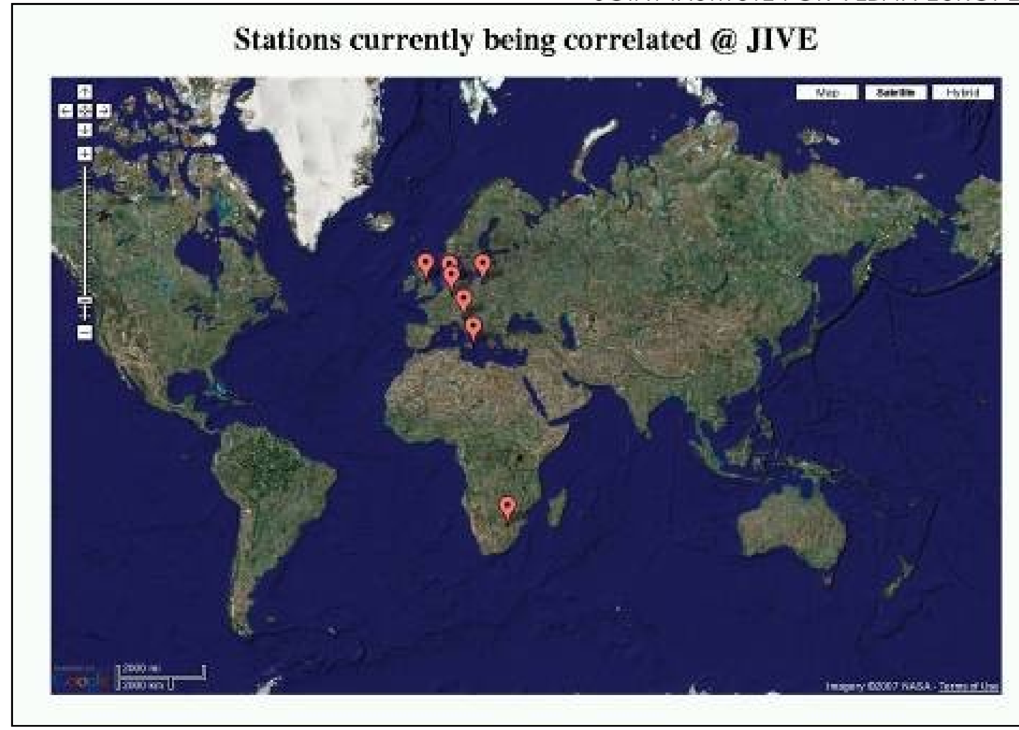
- Upgrade EVN to *e*EVN
  - Help solve last mile problem at telescopes
  - 16 * 1 Gbps real-time production e-VLBI facility
  - Software in field and correlator to become ‘real’ real-time
  - Inclusion of *e*MERLIN telescopes in *e*EVN (and vice-versa)
- And look beyond 1 Gb/s
  - More capacity on digital sampling, more bandwidth
    - As being implemented for e-MERLIN in UK
  - Hardware (PC-based) and protocols for transport
  - Correlator with more capacity: distributed correlation

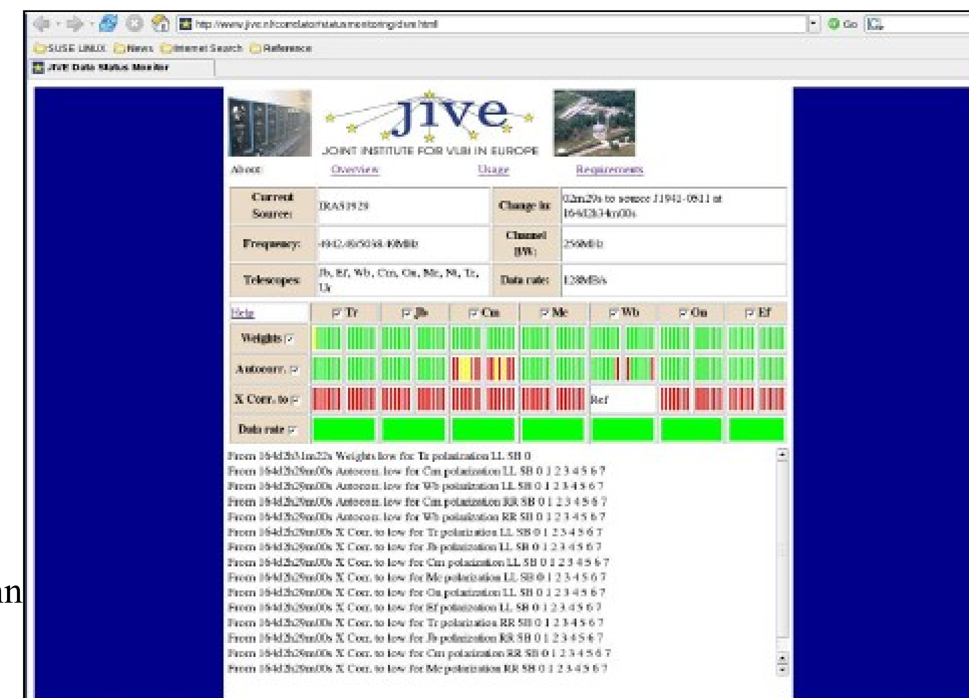
Telescopes Participating in EXPReS

Copyright: EXPReS
Telescope photos used with permission

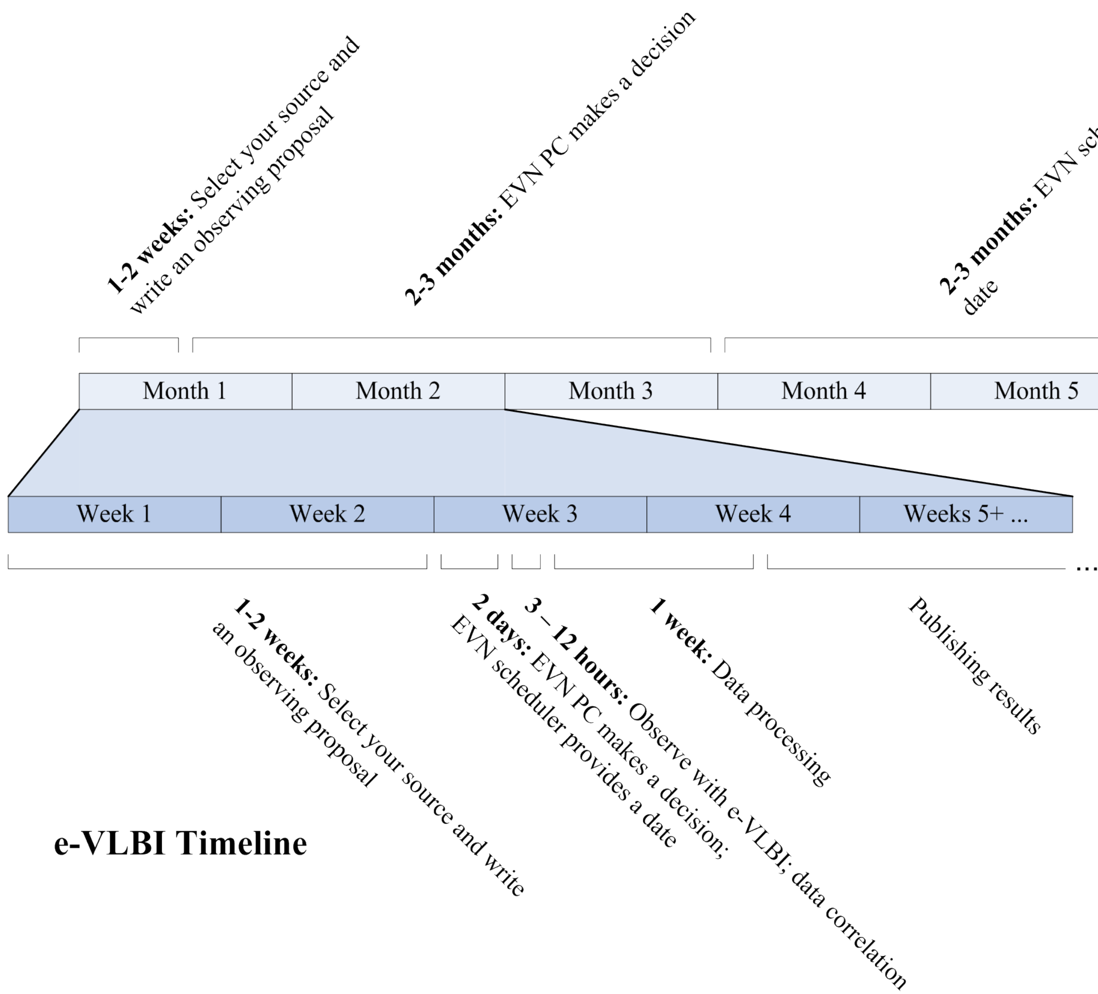
Why eVLBI?

- Rapid response
  - Immediate analysis of data
  - Coordination with current and future observatories (e.g. LOFAR, eMERLIN, Chandra, GLAST, SKA)
- Immediate feedback
  - More robust data
  - Adaptive observing
- Less consumables (no disks)
  - Constantly available VLBI network
    - Monitoring
    - Spacecraft tracking
- More bandwidth becoming available





Traditional VLBI Timeline



Test cases:

- Data processing took 1-2 weeks with first images **within 48 hours**
- Publication took less than 2 months

eVLBI: connect the telescopes

- Requires Internet with special characteristics:
- Typical VLBI uses 64 MHz bandwidth in 2 pols
  - Nyquist sampling: 2 x 2 x 64 MHz = 256 M samples/s
  - At 2 bits/sample: 512 Mbit/s
  - current disk systems do up to 1Gbps
- Need to have fiber across the world
  - Often the “last mile” is the bottleneck
  - Needs real digging of new cables
  - Needs to stream across many routers, fire-walls, networks
- Occasional losses are not a problem
  - Quite different than other Internet applications
  - Could use different protocol than TCP/IP
- Need to re-engineer correlator
  - was not built for real-time operations

Current *e*VLBI Status

- Technical tests:
  - 6-station fringes at 256 Mbps
  - 3-station 512 Mbps fringes (Cm, Wb, On)
  - first fringes using new 5 GHz receiver at Mc

- Current connectivity:
  - Ar: 64 Mbps in the past, but <32 Mbps this year
  - European telescopes: 128 Mbps always, 256 Mbps often, 512 Mbps to Wb, Jb and On

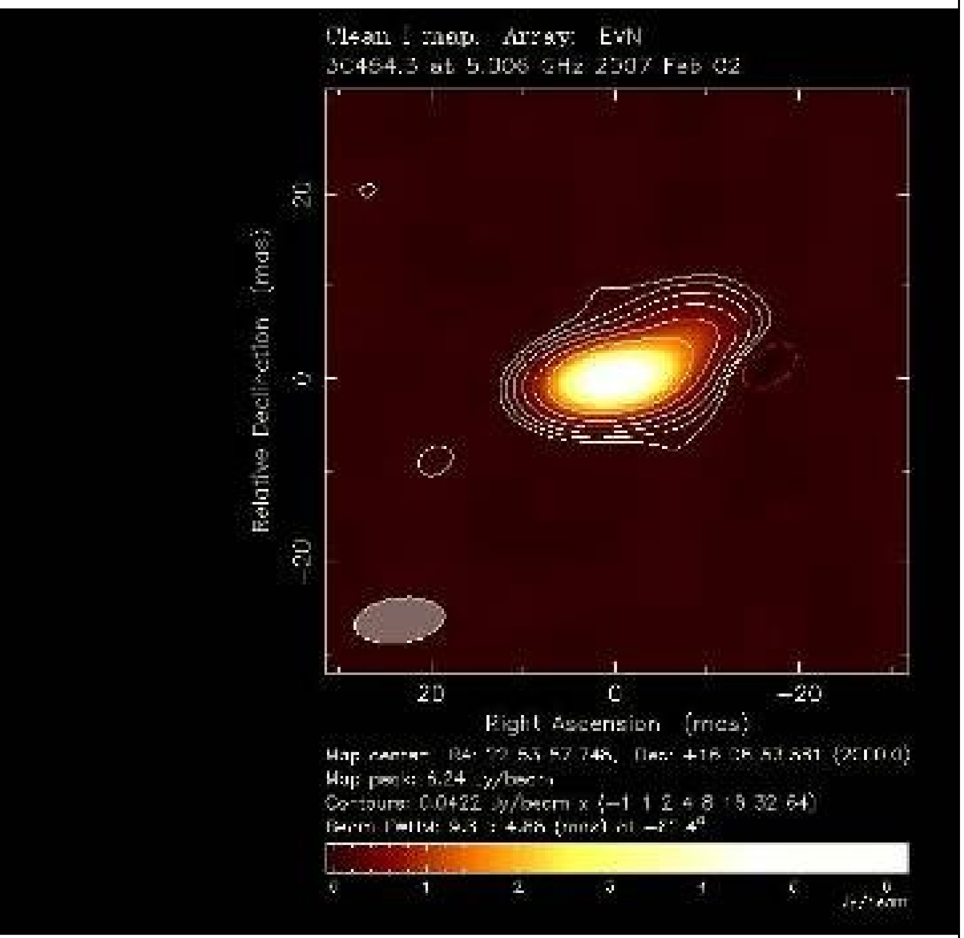
And other continents...

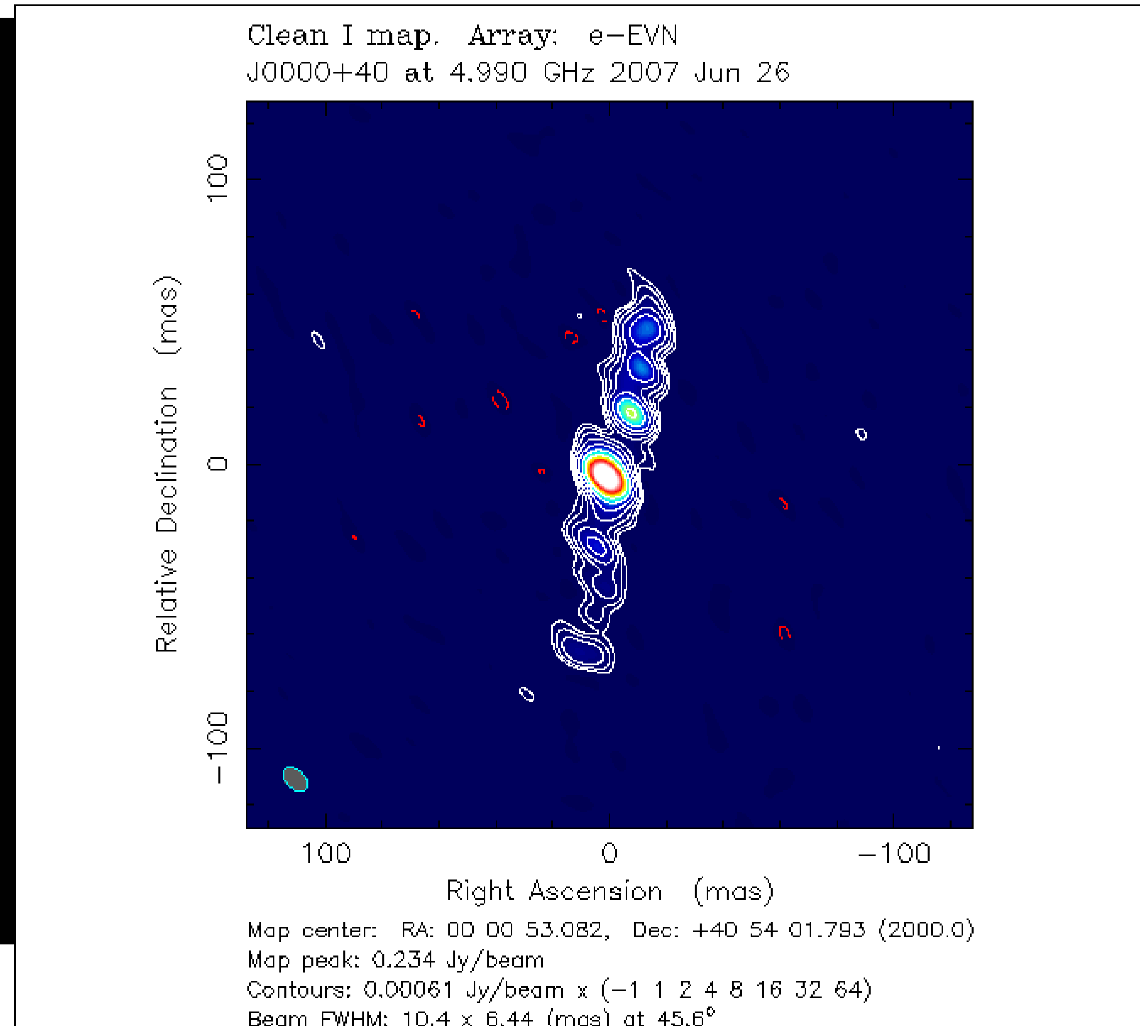
e-VLBI science

- 12 e-VLBI science projects accepted in first year:
  - 2 failed
  - 3 Target of Opportunity (Cygnus X-3, GRS1915+105)
  - 3 determination of compactness of calibrator or target
  - 3 part of multi-wavelength campaign
  - 1 adaptive observation of 16 X-ray binaries (no detections..)
- Rapid access to EVN provides clear benefit to users
  - Important for calibrator/multi-wavelength projects
- New observing policy
  - Support of spectral line as well as continuum observations
  - Opportunities for triggered observations (only continuum)
  - Short observations (< 2hrs) may be requested from PC chair to check compactness of sources, up to three weeks before actual run

e-VLBI results

First 512 Mbps images





First eEVN Astronomy Publications

Mon. Not. R. Astron. Soc. 000, 1–4 (2006) Printed 15 September 2006 (MN LaTeX style file v2.2)

First e-VLBI observations of GRS1915+105

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ABSTRACT
We present results from the first successful open call e-VLBI run on the X-ray binary GRS1915+105. e-VLBI science makes possible the rapid production of VLBI radio maps within hours of an observation rather than weeks, facilitating a decision for follow-up observations. 6 telescopes observing at 5 GHz across the European VLBI Network (EVN) were correlated at Joint institute for VLBI in Europe (JIVE) in real time. Data rates of 128 Mbit s^{-1} were transferred from each telescope, giving 4 TB of raw sampled data over the 12 hours of the whole experiment. Throughout this, GRS1915+105 was observed for a total of 5.5 hours, producing 2.8 GB of recorded visibilities of correlated data. A weak flare occurred during our observations, and we detected a slightly resolved single component of 2.7 by 1.2 milliarcsecond was detected at a position angle of $140° \pm 2°$. The peak brightness was 10.2 mJy per beam, with a total integrated radio flux of 11.1 mJy.

Key words: ISM: jets and outflows - X-ray binaries: individual (GRS1915+105).

1 INTRODUCTION

The use of the Internet for VLBI data transfer offers a number of advantages over conventional recorded VLBI, including improved reliability due to real time operation and the possibility of a rapid response to new and transient phenomena. Decisions on follow up observations can be made immediately after the observation rather than delayed by potentially weeks due to problems in shipment of tapes/discs to the correlator. The first open call with a suitable GST range for observations of GRS1915+105 using the e-EVN (European VLBI Network), gave us the opportunity to test e-VLBI under operational conditions. A number of test runs over the past few years have shown that 128 Mbit sec^{-1} data rates can be obtained reliably to the 6 telescopes; Cambridge, Jodrell Mk2, Medicina, Onsala, Torun and Westerbork, within Europe, currently connected via national and international research networks to the Joint Institute for VLBI in Europe (JIVE) correlator. Currently Effelsberg is not connect to the e-EVN network, limiting the sensitivity and resolution of the current array. Steps are currently being taken to improve the reliability of 256 and 512 Mbit s^{-1} connection, with EXPReS's[1] goal to develop a stable 1 Gbit/sec production capacity network.

Microquasars are ideally suited for study by e-VLBI real time techniques since they often have flares associated with the ejection of radio emitting clouds in the form of jets. Time-scales are in the range of hours to days at cm wavelengths, and decisions about subsequent observations, if for instance an ejection has been detected, needs to be taken quickly.

GRS 1915+105 was first discovered in 1992 (Castro-Tirado et al. 1992) by the WATCH instrument on the GRANAT satellite. The system has a low mass, K-M III star (Greiner et al. 2001b) companion and 14 (±4) $M_\odot$ black hole (Greiner et al. 2001a). It was the first galactic source to display superluminal motion, and is well known for its rapid

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[1] Express Production Real-Time e-VLBI Service see : www.expres-eu.org

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First e-VLBI observations of Cygnus X-3

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ABSTRACT
We report the results of the first two 5 GHz e-VLBI observations of the X-ray binary Cygnus X-3 using the European VLBI Network. Two successful observing sessions were held, on 2006 April 20, when the system was in a quasi-quiescent state several weeks after a major flare, and on 2006 May 18, a few days after another flare. At the first epoch we detected faint emission probably associated with a fading jet, spatially separated from the X-ray binary. The second epoch in contrast reveals a bright, curved, relativistic jet more than 40 milliarcsecond in extent. In the first, and probably also second epochs, the X-ray binary core is not detected, which may indicate a temporary suppression of jet production as seen in some black hole X-ray binaries in certain X-ray states. Spatially resolved polarisation maps at the second epoch provide evidence of interaction between the ejecta and the surrounding medium. These results clearly demonstrate the importance of rapid analysis of long-baseline observations of transients, such as facilitated by e-VLBI.

Key words: accretion, accretion discs – stars: individual: Cygnus X-3 – ISM: jets and outflows – radiation mechanisms: non-thermal – techniques: interferometric.

1 INTRODUCTION

The X-ray binary Cygnus X-3 was first detected in X-rays by Giacconi et al. (1967). The infrared (e.g. Becklin et al. 1973) and X-ray fluxes (e.g. Parsignault et al. 1972) show a periodicity of 4.8 hours which is interpreted as the orbital period of the system. The nature of the compact object is not known (Schmutz, Geballe & Schild 1996; Mitra 1998). As for the companion star, there is compelling evidence pointing toward a WN Wolf-Rayet star (van Kerkwijk et al. 1996; Fender, Hanson & Pooley 1999; Koch-Miramond et al. 2002).

Giant outbursts and large flares have been observed at radio wavelengths in Cygnus X-3 since 1972 (Gregory et al. 1972). In quiescence the soft X-ray emission is correlated with the radio emission, while the hard X-ray is anti-correlated with the radio; in a flare state, the situation is reversed: the hard X-ray correlates with the radio and the soft X-ray emission is anti-correlated (Watanabe et al. 1994; McCollough et al. 1999; Choudhury et al. 2002).

Radio observations made during such large flares at different resolutions with the Very Large Array (VLA), MERLIN, Very Long Baseline Array (VLBA), and European VLBI Network (EVN) (Geldzahler et al. 1983; Spencer et al. 1986; Molnar, Reid & Grindlay 1988; Schalinski et al. 1995, 1998; Mioduszewski et al. 2001; Martí et al. 2001; Miller-Jones et al. 2004) directly show or are consistent with two-sided relativistic jets (with the notable exception of the VLBA observations of a flare in February 1997, when the jet was apparently one-sided; Mioduszewski et al. (2001)).

2 OBSERVATIONS

One of the aims of e-VLBI is to enable mapping with long-baseline networks of radio telescopes in a manner which makes it possible to map transient phenomena, such as microquasars, in near real-time. This will provide the ability to make informed decisions about the optimum observing strategy to employ (frequency of observations, array composition, calibrator selection, etc.) and the need for repeated mapping observations, as well as greatly simplifying the ob-

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e-EVN: the future

- Aim: 16 * 1 Gbps production e-EVN network
  - Lightpaths across GÉANT: point-to-point connections between JIVE and telescopes.
  - Guaranteed bandwidth, no need to worry about congestion..
  - Depending on connectivity of stations, choice of configurations with specific data rates
- Towards a true connected-element interferometer