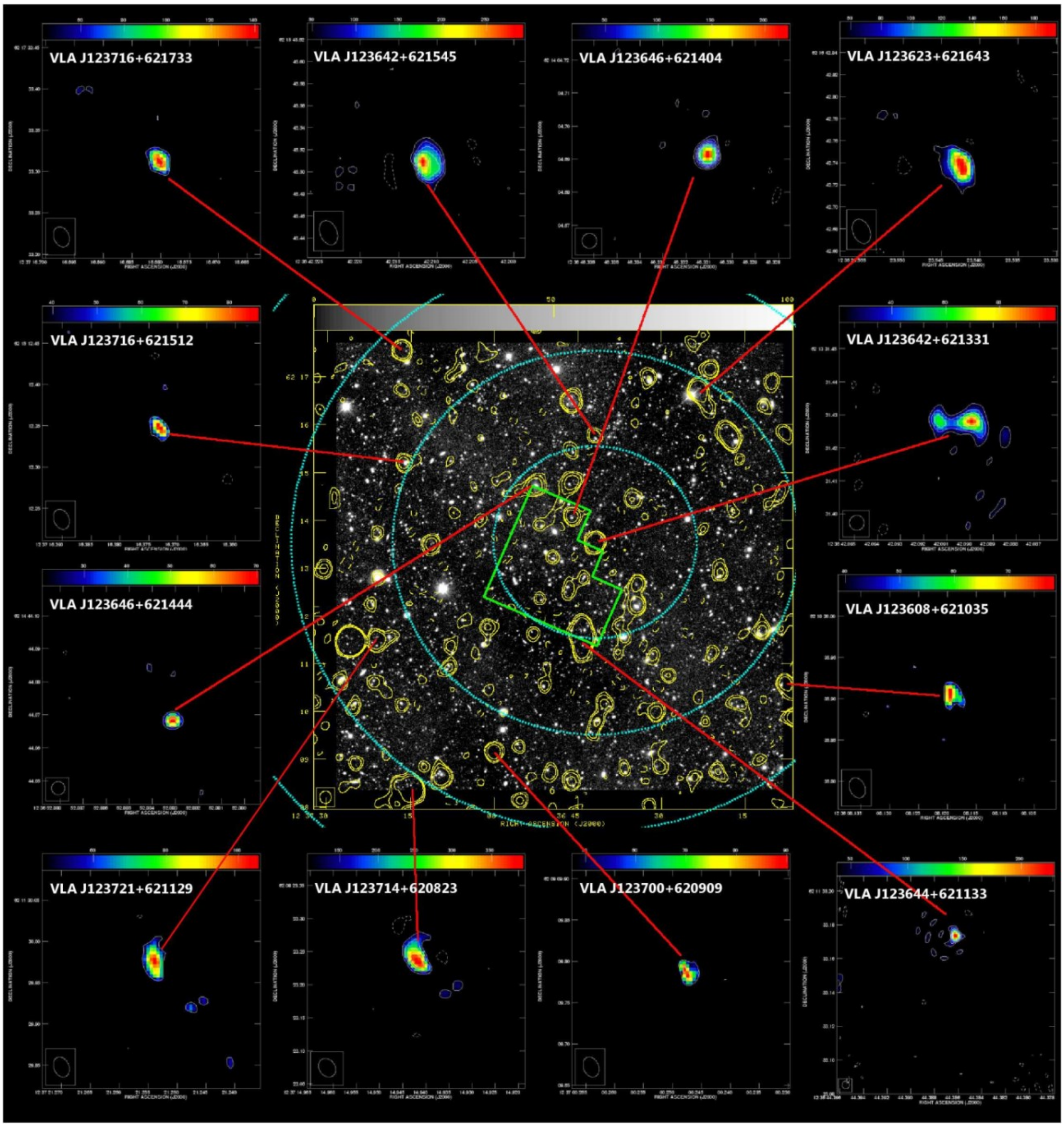
EVN Biennial Report 2011-2012



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1 Foreword from the EVN Consortium Board of Directors chairperson

The period covered by this biennial report has seen the European VLBI Network go from strength to strength in many areas. The network has continued to grow in size, with new telescopes participating, including the 32-m telescope at Irbene in Latvia, and the first experiment with three telescopes from the Korean VLBI Network. The three large antennas of the Russian Kvazar network have become a central part of the EVN, providing key baselines spanning the gap between central Europe and Asia/China. Indeed, the EVN has grown into a truly global network, and one of the experiments correlated in this period involved a total of 23 antennas. Now, VLBI baselines are no longer limited by the size of the planet, and following the successful launch of the Spektr-R spacecraft on 18 July 2011, the Radioastron mission has made successful observations at 18, 6 and 1.3cm with baselines up to 19 times the diameter of the Earth, in conjunction with EVN telescopes, opening up a new area of parameter space for the study of active galactic nuclei at the highest angular resolution.

The capabilities of the EVN have improved in other ways too: the new digital baseband converters, designed and produced by EVN colleagues in Bologna, are now being deployed at several telescopes and the correlation results show beautifully flat bandpasses with almost perfectly linear phase slopes across the band, greatly improving the quality of EVN data. The new software correlator (SFXC) at JIVE has now taken over all of the EVN Data Processing and includes new capabilities such as pulsar gating, more flexible spectral configurations and more efficient multi-centre correlation.

Real-time EVN observing continues to be in great demand, and the EVN Directors and Programme Committee have agreed to support more flexible out-of-session observing in addition to the scheduled e-VLBI days. The suite of telescopes participating continues to grow as new connections to key telescopes including Noto and Yebes have been installed. The EC-funded Nexpres project, led by JIVE, made huge leaps in e-VLBI capabilities, culminating in successful sustained data transfer at 4 Gb/s. The data path from e-MERLIN antennas, via its own dedicated optical network and correlator to JIVE has been demonstrated and is now being tested, paving the way to the full integration of e-MERLIN and the EVN with baselines from 10km to 10,000km.

All these developments help to sustain an impressive scientific output from the EVN, being carried out by a growing user base. New users are developing novel experiments taking advantage of the new observing modes and strengths of the EVN. The range and quality of science is clearly demonstrated by the highlights presented here, from experiments tracking spacecraft in orbit around Venus to high resolution studies of some of the most distant galaxies. Many users are supported by the Transnational Access Programme of the EC-funded RadioNet3, co-ordinated by Prof. dr Anton Zensus at MPIfR. The universally positive international review of JIVE and the EVN carried out by Prof Malcolm Longair and colleagues reinforces the quality of what the EVN offers in all its aspects from technical capabilities, to ease of use and user support, making it clear that the EVN is open to all astronomers, regardless of their technical background.

The scientists, users and technical specialists of the EVN came together in style at memorable EVN Symposium held at the splendid and historic Place de la Bourse in Bordeaux and organised by Prof Patrick Charlot and colleagues.

Of course, it is indeed the people who are the most important resource of the EVN, whether users, telescope operators or technical gurus. The EVN remains an organisation which has grown from the bottom up and relies on the effort contributed by the participating observatories as well as the skills and services provided by JIVE, and it is a pleasure to thank some of the key 'officers' of the EVN including the scheduler Dr Richard Porcas and the chair of the TOG Dr Walter Alef, who have served the cause with great dedication for many years, as well as the PC chair Dr Tom Muxlow, the new TOG Chair Dr Michael Lindqvist and the CBD secretary Dr Rob Beswick who has done all the hard work on this report.

Sadly, during this period we said farewell to some of the key figures in radio astronomy. Prof Andrey Finkelstein, who was the driving force behind the Kvazar network, and Prof Steve Rawlings who was a true champion of radio astronomy in general and the SKA in particular passed away and will be greatly missed by us all. And Sir Bernard Lovell, who pioneered so much of what became the new science of radio astronomy passed away in August 2012, having led the group which developed long baseline interferometry and established the first contact with colleagues in the then Soviet Union to sow the seeds of VLBI. He remains true inspiration to us all.

2 The European Consortium for VLBI

The European VLBI Network (EVN) was originally formed as a consortium of five of the major radio astronomy institutes in Europe in 1980. Since that point the EVN and its consortium has grown extensively to now include 13 institute members plus associate members. The EVN consortium operates a number of major radio telescopes spread throughout Europe, Russia, China and beyond as well as correlation of data at the Joint Institute for VLBI in Europe (JIVE) in Dwingeloo and the MPIfR in Bonn. The EVN regularly operates in tandem with the UK's e-MERLIN 7-station interferometer network, making it sensitive to a broader range of astronomical spatial scales, and with the USA's NRAO Very Long Baseline Array and NASA Deep Space Network to act as a global VLBI array. The combined instrument that is the EVN is the most sensitive VLBI array in the world and is able to conduct a wide range of world class high resolution radio astronomical science.

The Member institutes of the Consortium are (in alphabetical order):

- ASTRON, The Netherlands Foundation for Research in Astronomy, Dwingeloo, The Netherlands
- Bundesamt fur Kartographie und Geodasie (BKG), Wettzell, Germany *(Associate Member)*
- Hartebeesthoek Radio Astronomy Observatory (HartRAO), S. Africa
- Institute of Applied Astronomy (IAA), St. Petersburg, Russia
- Institute of Radio Astronomy (INAF IRA), Bologna, Italy
- Jodrell Bank Observatory (JBO), University of Manchester, Jodrell Bank, UK
- Joint Institute for VLBI in Europe (JIVE), Dwingeloo, The Netherlands
- Max-Planck-Institute for Radio Astronomy (MPIfR), Bonn, Germany
- Metsahovi Radio Observatory (MRO), Aalto University, Espoo, Finland *(Associate Member)*
- National Astronomical Observatory (OAN), Instituto Geografico Nacional, Madrid, Spain
- National Astronomy and Ionosphere Center, Arecibo Observatory, Puerto Rico*(Associate Member)*
- Onsala Space Observatory (OSO), Chalmers University of Technology, Onsala, Sweden
- Shanghai Astronomical Observatory, National Astronomical Observatories, Shanghai, P.R. China
- Toruń Centre for Astronomy, Nicolaus Copernicus University, Toruń, Poland
- Urumqi Astronomical Observatory, National Astronomical Observatories, Urumqi, P.R. China

The overall governance and policy of the EVN is set by the EVN Consortium Board of Directors (CBD) who meet biannually to discuss policy, strategic, operational and technical issues. Specific issues related to technical aspects of the EVN operations are considered by the EVN's Technical and Operational Group (TOG), and the EVN's scientific observing programme is peer reviewed for scientific excellence by the EVN Programme committee (EVN-PC).

3 Scientific highlights from the EVN

In recent years, the capabilities of the EVN have grown considerably from the addition of new telescopes such as the Russian QUASAR VLBI network and new antennas in China. These, together with improvements and enhancements to the existing stations, and the increased functionallity of the array from improved wide-field, multi-centre correlation techniques have transformed image sensitivity and fidelity. These enhancements have and continue to positively impact upon the range and quality of science that the EVN can undertake; and in this Biennial report, the science highlights listed come from almost all areas of astrophysics, spanning Cosmology to spacecraft tracking. Additionally, over the period of this Biennial report, these capabilities have resulted in the growth in the number and quality of proposals submitted by the user community, with the result that the oversubscription rate for the EVN, a prime indicator of the current and future health of the science output of the telecope, now stands around 2.2 to 2.5. The EVN produces some of the finest quality high resolution radio images available, and with the prospect of further large antennas joining the array in both Europe and the Asian regions, together with future enhanced sensitivity from increased observing bandwidths, the EVN will be the instrument of choice for the radio astonomy community for many years ahead.

3.1 Galaxies and cosmology

3.1.1 Black holes - no place left to hide!

Very sensitive, wide-field observations with a worldwide network of radio telescopes have uncovered black holes residing in the centre of dust obscured galaxies. In some cases, the amount of dust is so large that even x-rays from the accreting black holes are absorbed in these systems. This is the result of research done by astronomers Chi, Barthel and Garrett from Groningen and Dwingeloo, and is set to appear in an upcoming issue of Astronomy & Astrophysics.

Also in apparently normal galaxies, it seems black holes grow steadily by devouring matter. The bright, exotic radiation, usually the result of these so-called accretion processes, seems to be completely obscured in some galaxies. Only a network of highly sensitive radio telescopes can detect these processes is the conclusion of the Dutch astronomers. The suspicion that the faint radio waves, emitted by many galaxies in the distant early universe are the result of accretion by their black holes, has now been proven.

Traditional radio telescopes, such as the Westerbork Synthesis Radio Telescope (WSRT), cannot determine the exact nature of the radio emission. The technique of Very Long Baseline Interferometry (VLBI) is necessary, in which a network of radio telescopes in different countries or continents observes the same object. The many gigabytes of data of the individual telescopes are then combined. This method digitally simulates a radio telescope of thousands of kilometres in diameter, and as a consequence with a very high resolution and sensitivity.

Using such a VLBI-network of sixteen radio telescopes on two continents (Europe and the United States), a so far unimaginable record sensitivity and resolution could be reached, undoubtedly proving the accretion activity of the distant galaxies.

'We know many galaxies have black holes. Of course these need to grow to what they are now and it seems that, thanks to these VLBI-observations of the galaxies in the Northern Hubble Deep Field, we can now really observe this growth', say prof. Peter Barthel of the Kapteyn Institute of the University of Gronignen and prof. Michael Garrett of ASTRON, the Netherlands Institute for Radio Astronomy in

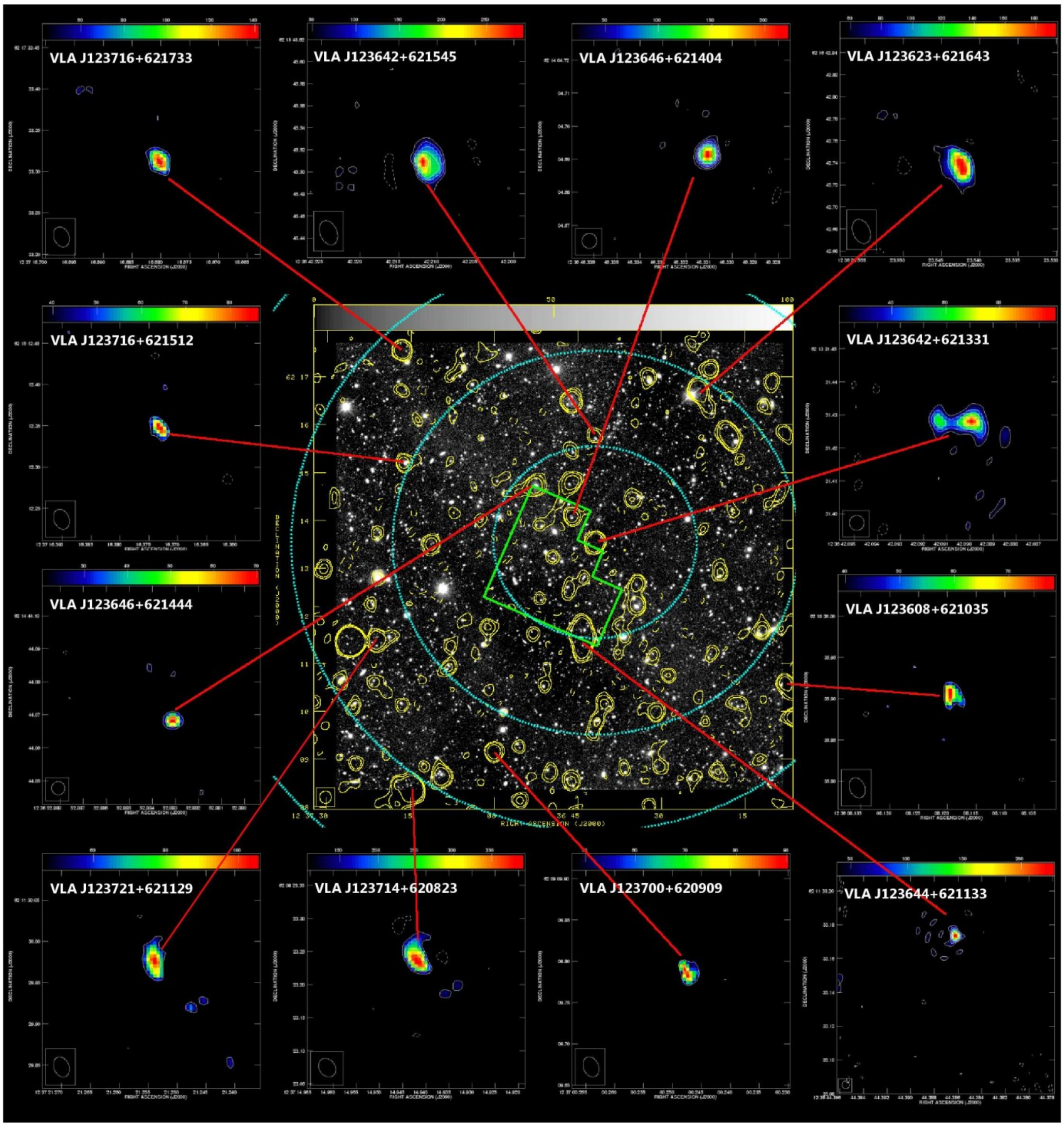


Figure 1: Black holes - no place to hide. Composite image of the radio (WSRT 1.4GHz)-optical image of the HDF-N and HFF, surrounded by postage stamp images of the twelve compact VLBI-detected radio sources.

Dwingeloo.

Barthel adds: 'We are proud of these results, but what is mostly in our minds is the fact that the one who had the largest part in this study is no longer with us.' Doctoral student Seungyoup Chi, from South-Korea, died from a serious illness in the year he would obtain his PhD doctorate in Groningen. 'This publication appears posthumous, also in his memory', say Barthel and Garrett, at the time supervisors of Chi. Chi, Barthel and Garrett 2013, A&A, 550, 68.

3.1.2 EVN observations of the farthest and brightest ULIRG in the local Universe

IRAS 23365+3604 is one of the farthest (252 Mpc) and brightest (L_{IR} = 1.35^{12} $L_{\odot}$) ultra luminous infrared galaxies (ULIRGs) in the local Universe. The resolution we attained using a maximum baseline length of approximately 7000 km is not enough to resolve individual compact sources (e.g. SNe, SNRs and AGN) from each other in the innermost regions of this ULIRG, however, by monitoring variations of total flux density and spectral index distribution, we have found that the nuclear region (~200pc in linear size) is composed of at least two zones dominated by distinct populations of radio emitters. One of the zones has a composite spectrum due to ongoing non-thermal activity (probably due to recently exploded SNe and the presence of an AGN); the other zone has a steep spectrum, likely dominated by an old population of radio emitters, such as SNRs.

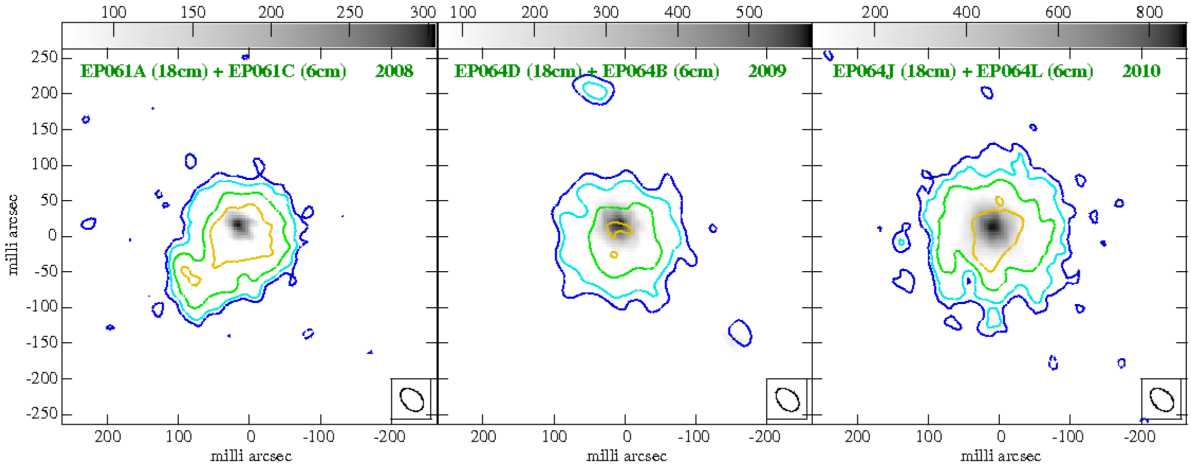


Figure 2: IRAS 23365+3604 18cm contours overlaid on grey-scale 6cm images in three different epochs with the EVN. The project codes (PI: M. A. Perez-Torres) are indicated in each figure.

3.1.3 Multi-epoch EVN observations of Arp 299-A

Arp299-A is a luminous infrared galaxies at a distance of 45 Mpc hosting recent and intense star-forming activity as indicated by the relatively high frequency of supernovae (SNe) discovered at optical and near-infrared (NIR) wavelengths in its outer, less extinguished, regions. The innermost 150 pc nuclear region of Arp299-A is so dusty that even NIR observations will miss a significant fraction of SNe. Only VLBI observations couple the necessary angular resolution and high sensitivity to detect new radio SNe, i.e. core-collapse SNe, allowing the measurement of the SN rate directly and independently of models.

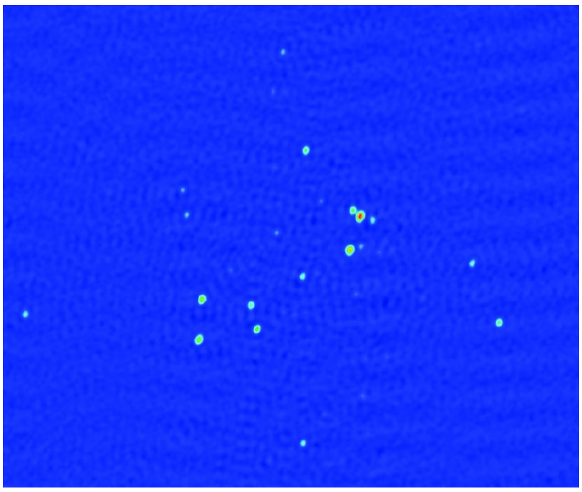


Figure 3: EVN image at 5 GHz of Arp299-A obtained by stacking all six epochs. The resolution is (10 x 8) mas. The peak is 907μbm^{-1} and the 1-σ sensitivity is 18.5 μJybm^{-1}.

The EVN has been monitoring Arp299-A at 6 cm with one observation every 6 months since April 2008, and partial results have been published in Perez-Torres et al. (Letters to A&A, 2009; see also EVN Newsletter No. 25 - Jan 2010) and Perez-Torres et al. (Letters to A&A, 2010; see also EVN Newsletter No. 28 - Jan 2011). The outcome of the first 6 epochs of observations is illustrated in Figure 1, which shows the EVN image at 5 GHz of Arp299-A obtained stacking all six epochs, the deepest image ever of Arp 299-A at this frequency.

Figure 3 has a resolution of (10 x 8 mas; i.e. 2.2 x 1.7 pc) and a 1-sigma sensitivity of 18.5 microJy/beam. Twenty-six compact sources are detected in a region of about (150 x 110) pc, eight of which are new objects. The radio luminosity, time variability behaviour and spectral index (derived using previous observations) of the compact objects are consistent with them being a mixed population of core-collapse SNe and supernova remnants (SNR). We find clear evidence for at least two new CCSNe in less than two years, implying a lower limit to the CCSNe rate in the nuclear region of Arp 299-A of 0.80 SN/yr. This value is essentially the CCSN rate expected for the whole Arp 299-A galaxy, indicating that most of the SN activity is taking place in a very compact, nuclear starburst, as previously suggested by us. The monitoring of Arp 299-A using the e-EVN and the full EVN is currently underway and more spectacular results from this supernova factory are expected (Bondi et al 2012, A&A, 539, 134).

3.1.4 Characterising and resolvong the RSNe and SNR of Arp220

VLBI observations of compact radio continuum sources in the prototypical nearby ultraluminous infrared galaxy Arp220 have shown this to be mixed population of powerful radio supernovae (SNe) and supernova remnants (RSNs). Seven previously unknown SNe were detected resulting in this ongoing study detecting the the largest number of SNe ever observed simultaneously in the same galaxy. (Batejat et al., ApJ 740, 95). These 2 and 3.5cm VLBI observations have resolved 17 of the RSNs in Arp220 for the first time (Figure 4), showing the lie on, and extend the diameter-luminosity correlation for RSNs to very small sources.

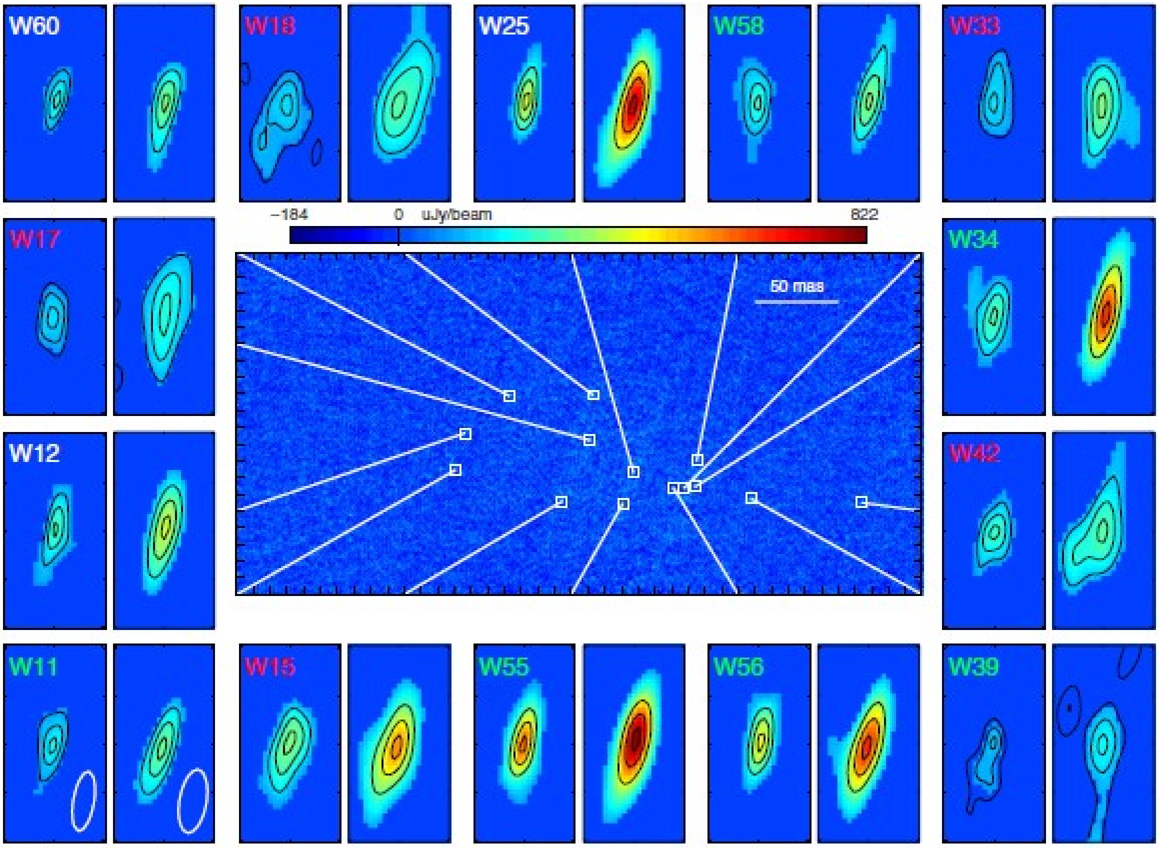


Figure 4: Resolving the compact radio SNRs in the Western nuclues of Arp220 with Global VLBI (Batejat et al 2011).

Additionally these VLBI observations of Arp 220 at 6 cm wavelength have revealed three sources with rapid (< 4 months) variability and possible superluminal motion (> 4c) of jet-like features near rapidly varying almost stationary components. The most likely explanation for the observed features is that they are microquasars or microblazars: binary-star systems in which one star has exploded and left behind a black hole, which draws gas from its companion, producing powerful jets that emit radio waves (Batejat et al., A&A 542, L24).

3.1.5 e-MERLIN and VLBI observations of the luminous infrared galaxy IC883: a nuclear starburst and an AGN candidate revealed

IC883 is a luminous infrared galaxy (LIRG; $L_{FIR}>10^{11}$ $L_{\odot}$) in an advanced merger stage. We have used e-MERLIN at a median central frequency of 6.9GHz, and the e-EVN at 5GHz, to observe contemporaneously the circumnuclear and nuclear regions of this LIRG (see the IC883 contour images in Figure 5. An AGN candidate source dominates the radio emission at both circumnuclear and nuclear scales, and yet, IC883 displays very active star formation as indicated by the detection of nuclear radio SNe and SNe discovered by near-IR observations. This work represents (Romero-Canizales et al 2012, A&A, 543, 72) the one of the first publications based on e-MERLIN and EVN observations.

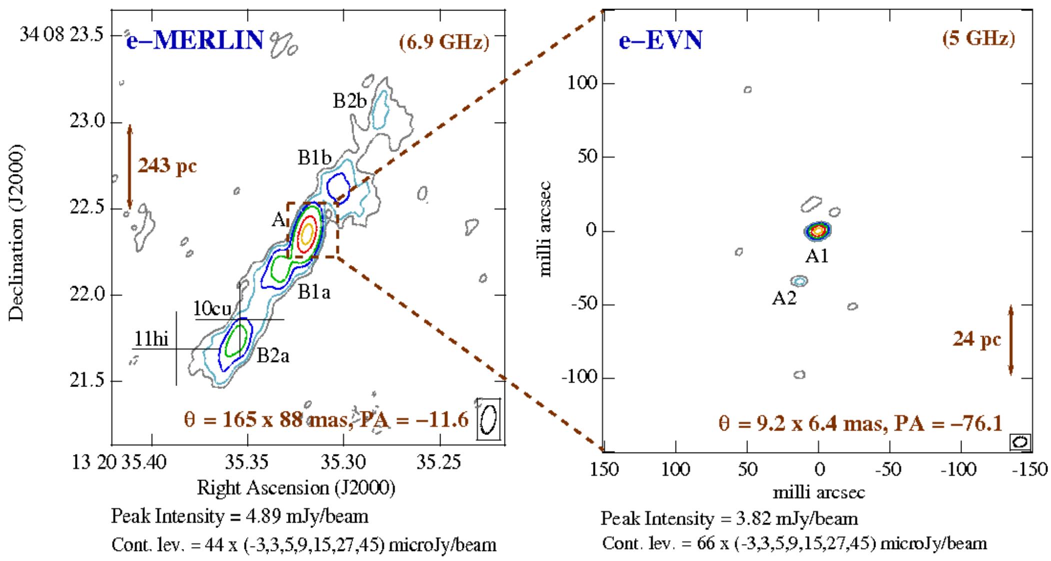


Figure 5: e-MERLIN and EVN imaging of the central region of IC883.

3.1.6 Resolved simultaneous observations of 1665 and 1667MHz OH masers in M82

The nearby starburst galaxy M82 has been well-studied over the years. Many radio observations have focussed on either the continuum objects (McDonald et al 2002; Beswick et al 2006; Fenech et al 2010; Gendre et al 2012), or the extent and velocity distribution of the gas (Wills et al 2000; Pedlar et al 2003; Seaquist et al 2006). Despite being known about since the 1970s (Rieu et al 1976), surprisingly little is known about the OH maser emission in this archetypal starburst.

Over the last ten years, we have carried out several studies of the OH gas in M82. Starting with a VLA A-array observation in 2002, intended primarily to investigate how the molecular gas (traced by the OH absorption) compares with the neutral HI gas in the central radio-bright starburst (Pedlar et al 2003), a catalogue of OH main line masers was compiled. Despite the observational setup being optimised for broad absorption features, and hence far from ideal for the detection of narrow maser features, several features were detected (Argo et al 2007). These low-velocity resolution observations were later followed up by higher spectral resolution observations, also with the VLA in

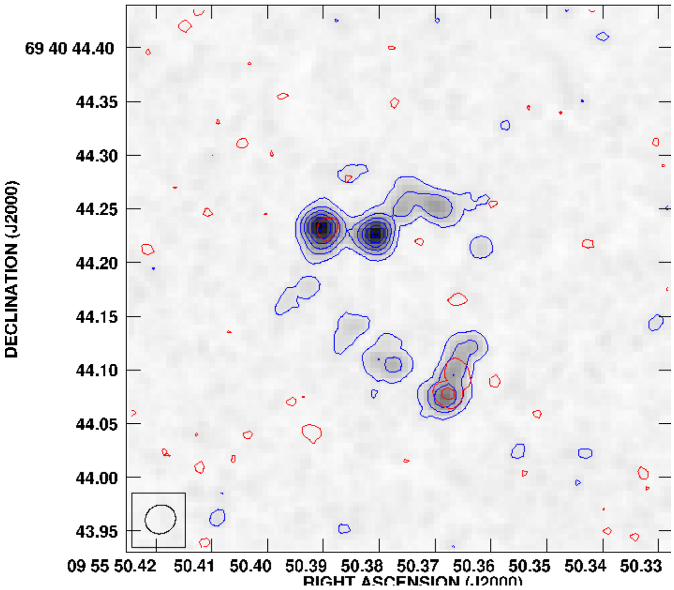


Figure 6: Resolved OH 1665 (Red) and 1667 MHz (Blue) masers in M82.

A-array. These follow-up observations (Argo et al 2010) showed that some of the maser spots were resolved in frequency, splitting into several velocity components. This fact, combined with brightness some 10^3 times greater than typical Galactic OH masers, supports the assertion that (at least some of) these so-called “kilomasers'' are in fact the superposition of numerous weaker (possibly Galactic-strength) maser regions within the VLA beam, although the exact nature of these masers (self-amplified narrow-beam masers, or amplified masers superposed on background continuum) so far remains unclear.

EVN observations at high spatial and velocity resolution have now confirmed that several of these maser regions are in fact spatially resolved on scales of a few milliarcseconds (Figure 6). The figure shows the brightest of the masers in M82 as observed with the EVN; red and blue contours show the 1665 and 1667 MHz emission respectively, superimposed on a map of the integrated 1667 MHz line emission. Several spatial components are clearly seen, as predicted from the VLA spectrum of the source which showed several velocity components for this source. In this case, all of the components are stronger at 1667 MHz than at 1665 MHz with most not visible above the noise in the lower line. The region is ~3.5 parsecs in diameter and is co-located on the sky with a known HII region, although no continuum emission is seen on EVN scales in these data. Investigations are underway comparing the maser emission with background continuum emission, and further observations are scheduled for the upcoming EVN session to investigate variability and morphological changes since the last observation.

3.1.7 Global e-VLBI observations of the gamma-ray narrow line Seyfert 1 PMN J0948+0022

The discovery of gamma-ray emission from the radio source J0948+0022 was one of the first big surprises revealed by the gamma-ray Large Area Telescope on board Fermi. This radio source is associated to a class of Active Galactic Nuclei not previously known to be gamma-ray emitters: radio loud narrow line Seyfert 1 galaxies. A large multiwavelength campaign was set up to understand its physical properties. In this framework, an ad hoc global network of electronically connected radio telescopes from Australia to the EVN was set-up; this was the first time a global e-VLBI network was used for science observations (Figure 7). Besides setting a milestone for e-VLBI development, these observations constrained the source brightness temperature to $>10^{11}$ K, implying relativistic beaming consistent with the gamma-ray emission, and revealed flux density variability, also supporting the radio-gamma

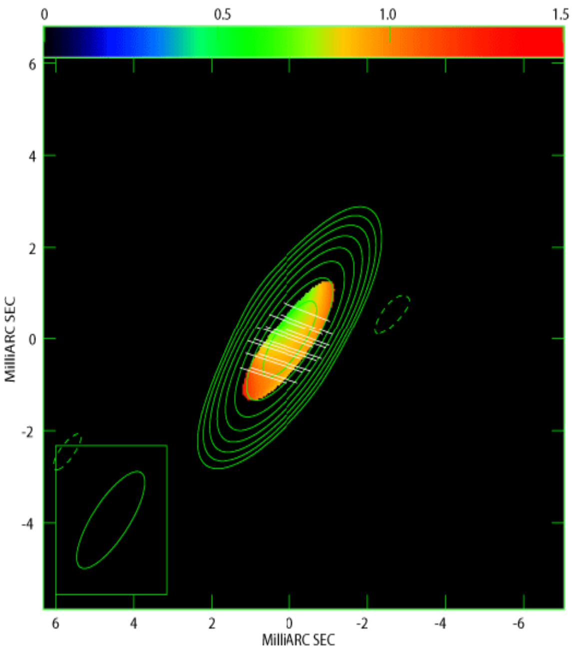


Figure 7: e-VLBI observations of the Gamma-ray emitting, radio source J0948+0022.

connection in this class of sources. Finally, linear polarization was revealed for the first time using the new Yebes radio telescope (Giroletti et al. 2011, A&A, 528, L11).

3.1.8 Physical properties of the nuclear region in Seyfert galaxies

Over the past decade, EVN observations have contributed to revealing compact radio emission in the central region of many low-luminosity AGN (LLAGN), such as Seyfert galaxies. However, we still do not know precisely the overall detection rate and even more the actual physical processes at work in these sources. Bontempi et al. (2012, MNRAS, 426, 588) reported on sensitive dual-frequency (1.7 and 5 GHz) new EVN observations of nine Seyfert galaxies, among the faintest and least luminous members of a complete sample of nearby (d < 22 Mpc) LLAGN. Radio emission on milliarcsecond scales was detected in the nuclei of four galaxies, setting stingent upper limits for the other five sources. In three sources (NGC 3227, NGC 3982 and NGC 4138), radio emission is detected at both frequencies and it is resolved in two or more components (Figure 8). On the basis of the brightness temperature and spectral index study, non-thermal emission from jets or outflows is the most natural explanation. In another case, the radio core could coincide with thermal emission from the hot corona, while the the five non-detected nuclei remain a puzzle that will require further, deeper observations.

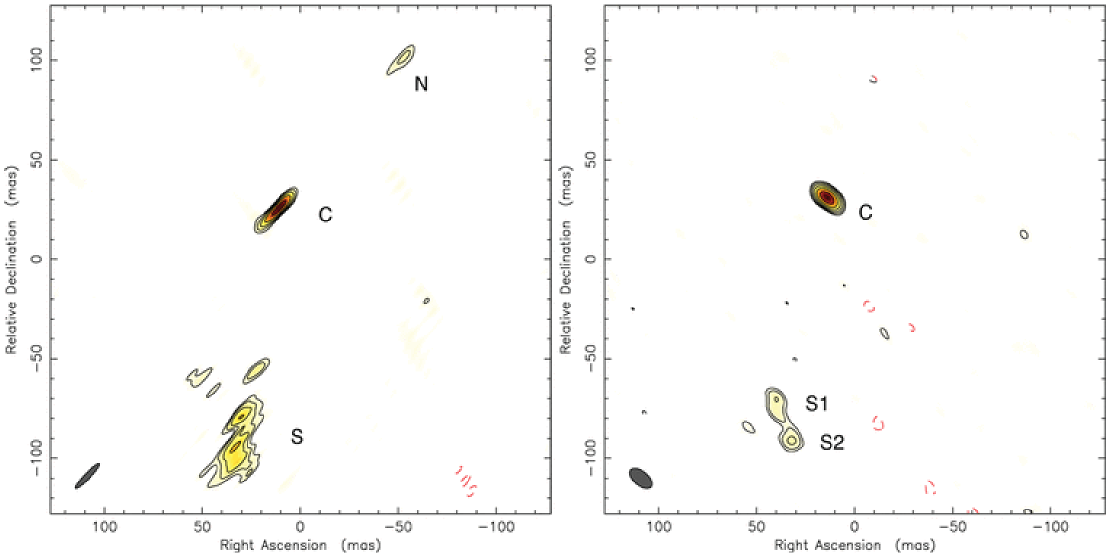


Figure 8: EVN images of NGC3227 at 1.6 and 5 GHz. Component C is the compact, flat spectrum, high brightness temperature core; the remaining components show outflowing material.

3.1.9 Radio-Quiet Quasars and AGN unification schemes

Radio structures of quasars are highly influenced by orientation effects predicted by the AGN unification scheme. As a result, depending on the angle between the line of sight and the jets, radio-loud quasars can be perceived either as core- (beamed) or lobe-dominated (unbeamed). Doppler beaming and boosting makes the first group ideal objects for VLBI studies.

And how about the milliarcsecond-scale structures of ``core'' components of radio-loud quasars with large-scale structures? Marecki & Swoboda carried out an in-depth, machine-aided search of FIRST survey aimed at finding triples identified with QSOs where a relatively bright central component was straddled with two lobes: one classical Fanaroff-Riley II type lobe with a hotspot and one diffuse relic devoid of a hotspot. The selection process was based on the elementary principle of radio interferometry: diffuse lobes were poorly imaged without short spacings. Specifically, we relied upon the assumption that VLA in B-conf. used to carry out FIRST survey failed to reproduce lobes well or even at all if they were diffuse. The FIRST image of one of our objects is shown in Figure 9 (Left).

We hypothesized that the prime cause of the asymmetry of these radio sources is that the nuclei of their host galaxies currently produce no jets. If a double structure of a radio source does not lie in the sky plane (but also is not beamed towards us) the light-travel time plays a role: the epoch in which we observe the far-side lobe is significantly earlier than the epoch of the near-side lobe and the magnitude of the lag is sufficient for a hotspot to disappear as well for a lobe to disperse considerably. The above means that the lobe asymmetry is a very valuable signature of a recent transition from radio-loud to radio-quiet state in quasars.

To prove that our targets have just switched off their activity in radio domain, we observed them with the EVN to check if they were similar to those in radio-quiet quasars. The observations carried out with eleven EVN stations - see Figure 9 (right) for the example - revealed that the nuclei of the quasars under investigation are not of a core-jet type that is characteristic for radio-loud quasars, either core- or lobe-dominated. We concluded that our quasars were radio-loud earlier, but now they have switched to the radio-quiet state. The lobes, which are no longer fuelled, are a historic record of that transition. What's more, here we have an opportunity to observe two well separated epochs of source's history each pertinent to each lobe.

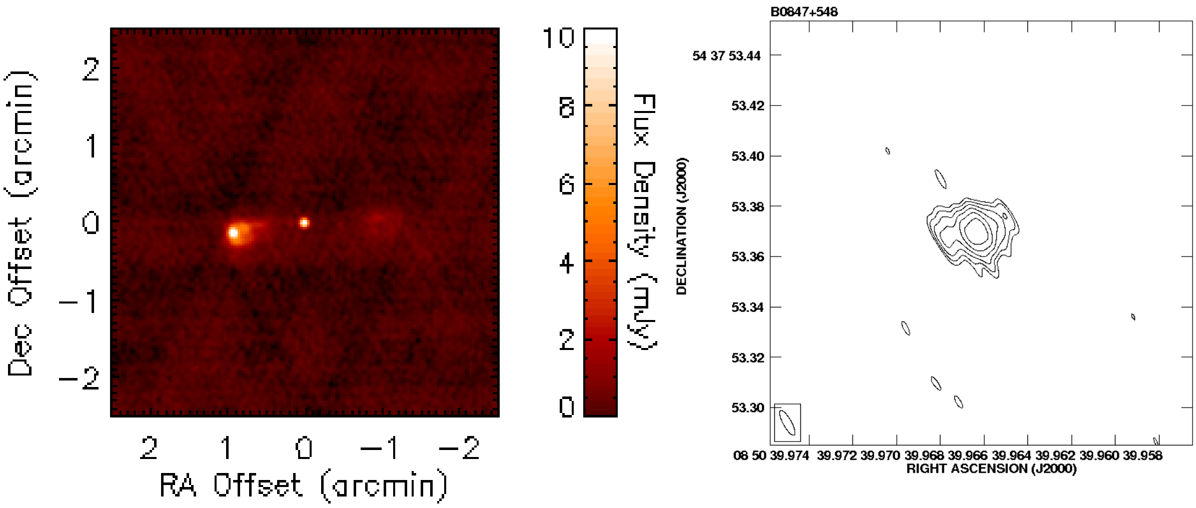


Figure 9: Left: FIRST image of a quasar B0847+548 with asymmetric large-scale structure: the eastern lobe is FRII-like while the western one is a relic. We claim that the central engine no longer produces jets, although, due to a light-travel time lag, the far-side eastern lobe still looks normal. Right: e-EVN image of the core of B0847+548. It is weak, diffuse and not of core-jet type as normally in radio-loud quasars. Instead, cores of this kind used to be identified with radio-quiet quasars.

3.1.10 The youngest radio galaxies — kinematics and dynamic evolution

Compact Symmetric Objects (CSOs) are a subclass of extragalactic radio sources whose morphology is remarkable for a compact central core (the location of active nucleus) and two compact mini lobes symmetrically located at each opposite side of the core, and the overall size is less than 1 kilo-parsec. The "youth model" attributes the small size of CSOs to that they are in the early evolutionary stage. Kinematics study of CSO hot spots give a direct determination of the age, by measuring the distance between two terminal hot spots and their separation speed.

An et al. (2012, ApJS, 198, 5) observed 10 newly-identified CSO candidates using the Chinese VLBI Network (CVN) and European VLBI Network (EVN). Together with archive VLBA data, proper motions of all ten sources were derived. Seven are confirmed as CSO, the other three are identified as core-jet sources. The expansion velocity is measured at an accuracy as high as 1.3 micro-arcsecond per year. The kinematical age determined from these proper motion and separation is in the range of 300—2500 years, supporting that these CSOs are young radio sources.

The actual evolution of CSOs is rather complex. An & Baan (2012, ApJ, 760, 77) reviewed current theoretical and modeling work of radio galaxy evolution. The structural and radiative characteristics of radio galaxies are determined by the jet power, the local environment of the host galaxy, and the evolutionary age. The initial conditions (jet thrust) set its starting position of the evolutionary tracks. The duration of the nuclear activity determines whether it can evolve into large-scale radio structure (either FR II or FR I). The host galaxy environment governs whether the evolution is smooth or bumpy. In reality, only a small fraction of the most powerful sources have chance to grow into large double-lobed galaxies. Many even most young radio galaxies will not grow large, they die before breaking through the ISM-IGM interface and their relics are confined within the host galaxy. In this sense, the 'youth' model describes the primary evolutionary track, while the 'frustration' model manifests a general and more complicate case.

3.1.11 C-band EVN observations of GPS

In 2011, Urumqi carried out a thorough analysis on the C-band e-VLBI observation of Gigahertz Peaked Spectrum (GPS) quasars 0507+179 and 1502+036 (Cui et al. 2011). This was the first time for Urumqi to utilise the e-VLBI data to do research. The 5 GHz VLBI images of 0507+179 and 1502+036 were produced for the first time (Figure 10). It shows that 0507+179 has typical core-jet structure while 1502+036 has an unresolved point-source structure. Those image structures are consistent with most other GPS sources with significant flux variations at centimeter wavelength.

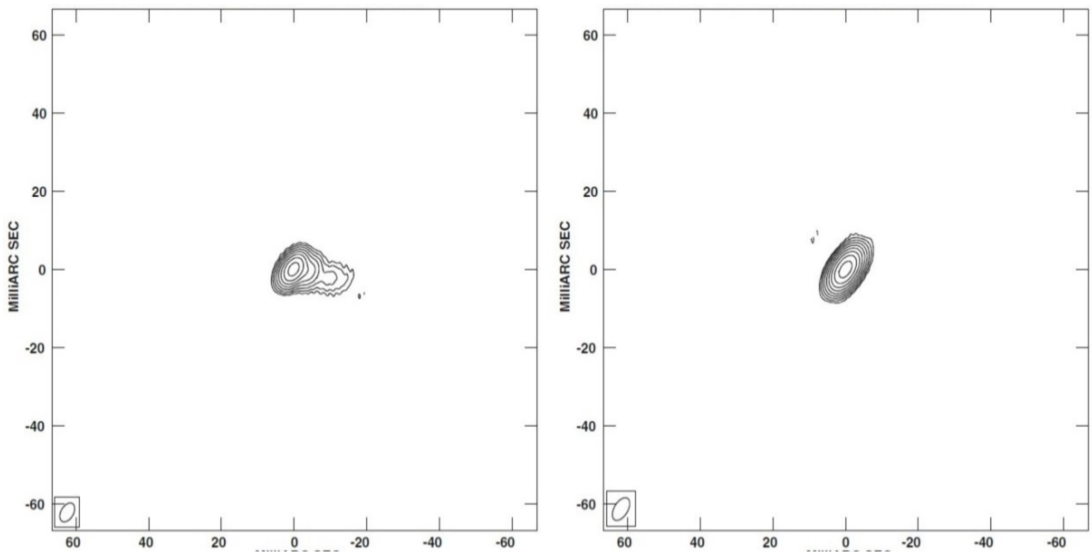


Figure 10: The 5 GHz VLBI image of GPS sources 0507+179 and 1502+036

3.1.12 Probing the nature of compact ultra-steep spectrum radio sources with the e-EVN and e-MERLIN

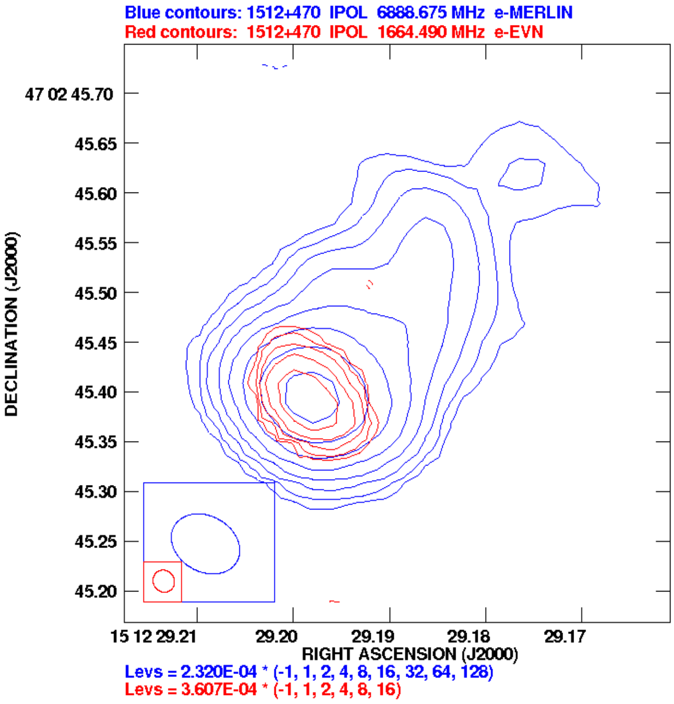


Figure 11: : e-MERLIN map of J151229+470245 at 6.9 GHz (blue contours) together with the e-EVN map at 1.4 GHz (red contours). Contours are plotted at −1, 1, 2, 4, 8, 16, 32, 64, 128 × 0.23 mJy beam^{-1} for the e-MERLIN data and −1, 1, 2, 4, 8, 16 × 0.36 mJy beam^{-1} for the e-EVN data. The boxes in the lower left indicate the size of the restoring beam for each *image.*

Ultra-steep spectrum (USS) sources are those with a radio spectral index of <-1.4. The subset of such sources which are compact on arcsecond scales have not been well-studied, and clues as to their nature are few. Suggestions which have been put forward include radio galaxies located near the epoch of re-ionisation, young obscured radio galaxies, steep-spectrum core AGN, and Galactic pulsars. In an attempt to narrow down the possibilities we have observed a small sample of such objects, selected for spectral index by comparing the VLSS and WENSS catalogues, and for arcsecond-scale compactness from the flux ratio between the NVSS and FIRST surveys. These observational results, published in MNRAS Letters (Argo et al., 2013, MNRAS 431, 58), show that these sources are a diverse group.

From the original sample of USS sources, five were selected for an exploratory VLBI survey. These sources were observed at 1.6 GHz with ten stations of the EVN in e-VLBI mode in June 2010 (programme EP070). At the same time, synthesis array data were recorded at Westerbork enabling an investigation of the compactness of the objects. Despite some rather large (for VLBI) pointing offsets, three of the USS sources were detected in the EVN observations recovering between 20 and 94% of the Westerbork-only flux densities. In March 2011, e-MERLIN commissioning observations of two of the sources were also carried out, using the available five stations equipped with the new C-band system.

The first of our detections, J072212+291042, is the weakest of the three VLBI-detections; the e-EVN observations show an unresolved source of ~2mJy, recovering only 27% of the simultaneous Westerbork flux density. Since the source is undetected with e-MERLIN at 6.6GHz to a 3-sigma limit of 0.12mJy/bm, this implies the spectral index remains steep (<-1.4) at these frequencies. With no catalogued counterparts at other wavebands, the nature of this source remains unclear. Given its properties, the most likely scenario is either a steep spectrum AGN core, or a Galactic pulsar. No known pulsar or pulsar candidate is listed at these coordinates, but further follow-up will allow us to test this scenario.

The only source in our sample to have an SDSS counterpart, J130612+514407 appears to be associated with a brightest cluster galaxy at a redshift of 0.2773. The EVN observations recover 94% of the Westerbork flux but, since the source was not observed with e-MERLIN, we do not yet know if the spectral index remains steep at higher frequencies. The SDSS association, together with corresponding 2MASS and ROSAT counterparts, suggest that the AGN core scenario is the most likely in this case.

The final VLBI-detection in this survey, J151229+470245 is something of an anomaly. Owing to an error in one of the catalogues used to compile the initial sample, the source turns out to have "only" a steep spectrum, but not ultra-steep. This makes it a peculiar compact steep spectrum source, rather than a USS source, but interesting nonetheless. The EVN results recover less than 21% of the simultaneous WSRT-only flux density, and show the source to be resolved on VLBI scales, elongated in a NE-SW direction. The e-MERLIN map (Figure 11) shows an apparent core-jet morphology, with the "core" coinciding with the (resolved) EVN source, suggesting that it is not an AGN core (see figure). The observed steep spectrum, low brightness temperature and lack of variability between VLA and WSRT epochs suggest lobe emission on 10-mas scales, rather than strong core emission. What makes this source peculiar is that it is an example of an infrared-faint radio source (e.g. Norris et al. 2006), and the first of these to show signs of being resolved on VLBI scales.

Whilst this is a small sample, and the data are clearly not sufficient to uniquely determine the nature of these sources, these results demonstrate that VLBI is a useful tool in attempting to understand this class of object. For our two VLBI-detected USS sources, significant flux is lost between Westerbork and EVN scales and further follow-up observations are planned at intermediate resolution. The unexpected results from this observational project show that compact USS sources are a diverse class of object where VLBI can provide vital clues as to their nature.

3.1.13 The parsec scale radio jet of M87 and its connection to high energy emission.

During 2011-12, the VLBI monitoring project on M87 has continued in conjunction with the high and very high energy observations by instruments such as the Fermi satellite and the imaging atmospheric Cherenkov telescopes. This project is aimed at constraining the site of high energy emission in the M87 jet, an ideal laboratory to study relativistic jets in AGNs in general (Figure *12*). During these two years, we gathered several more epochs and resulting in two papers discussing the viability for the high energy emission to be localized in the core (as also supported by multi-wavelength variability from the optical to X-rays, see Abramowski et al. 2012 ApJ, 746, 151) or in the jet feature HST-1 (as indicated by its structural evolution at high angular resolution presented in Giroletti et al. 2012, A&A, 538, L10).

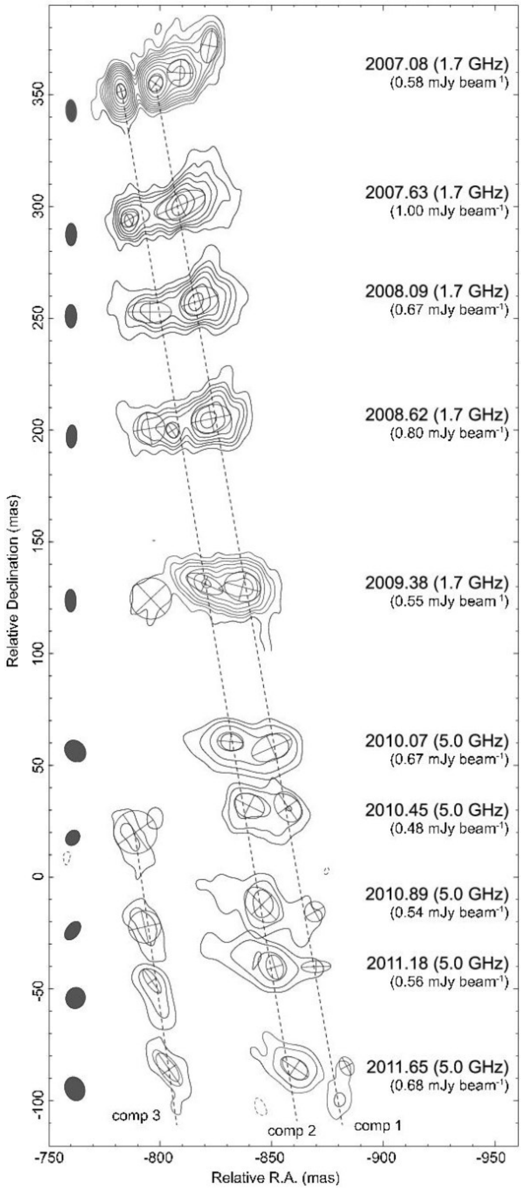


Figure 12: Multi-epoch campaign of VLBI images of the jet complex HST-1 running upto September 2011 (Giroletti et al 2012). These data reveal the emergence of a new feature and constrain its velocity to be apparently superluminal. The project has continuued into 2012.

3.1.14 VLBI imaging throughout the primary beam using accurate UV shifting

For Very Long Baseline Interferometry (VLBI), the fringe spacing is extremely narrow compared to the field of view imposed by the primary beam of each element. This means that an extremely large number of resolution units can potentially be imaged from a single observation. In Morgan et al. (2011, A&A 526, 140), we implement and test a technique for efficiently and accurately imaging large VLBI datasets. The DiFX software correlator is used to generate a dataset with extremely high time and frequency resolution. This large dataset is then transformed and averaged multiple times to generate many smaller datasets, each with a phase centre located at a different area of interest. We applied the method to an 8.4 GHz four-station VLBI observation of a field containing multiple sources. We achieved a high level of accuracy, making the method suitable even for the most demanding astrometric VLBI observations. One target source (1320+299A) was detected and was used as a phase-reference calibrator in searching for further detections. An image containing 13 billion pixels was constructed by independently imaging 782 visibility datasets covering the entire primary beam of the array (see Figure 13).

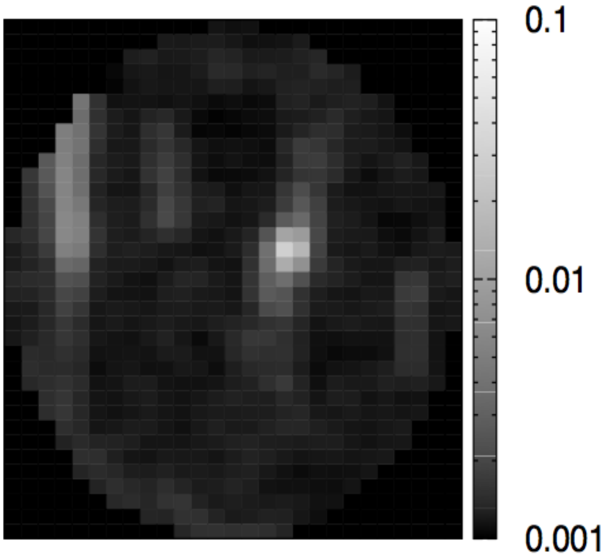


Figure 13: Image shows a map of the whole primary beam field observed in the project analysed with the u, v shifting technique (Morgan et al 2011, A&A 526, 140).

3.2 Stars and stellar evolution

3.2.1 Direct measurement of protostellar gas infall from the 3-D velocity field of methanol masers

VLBI studies of molecular masers provide an excellent tool to investigate the mass-accretion/ejection processes in high-mass star formation at small radii (10-1000 AU) from the protostars. In this work, we have reported a detailed study of the accretion and outflow structure around a protostar powering strong water and methanol masers in the high-mass star-forming

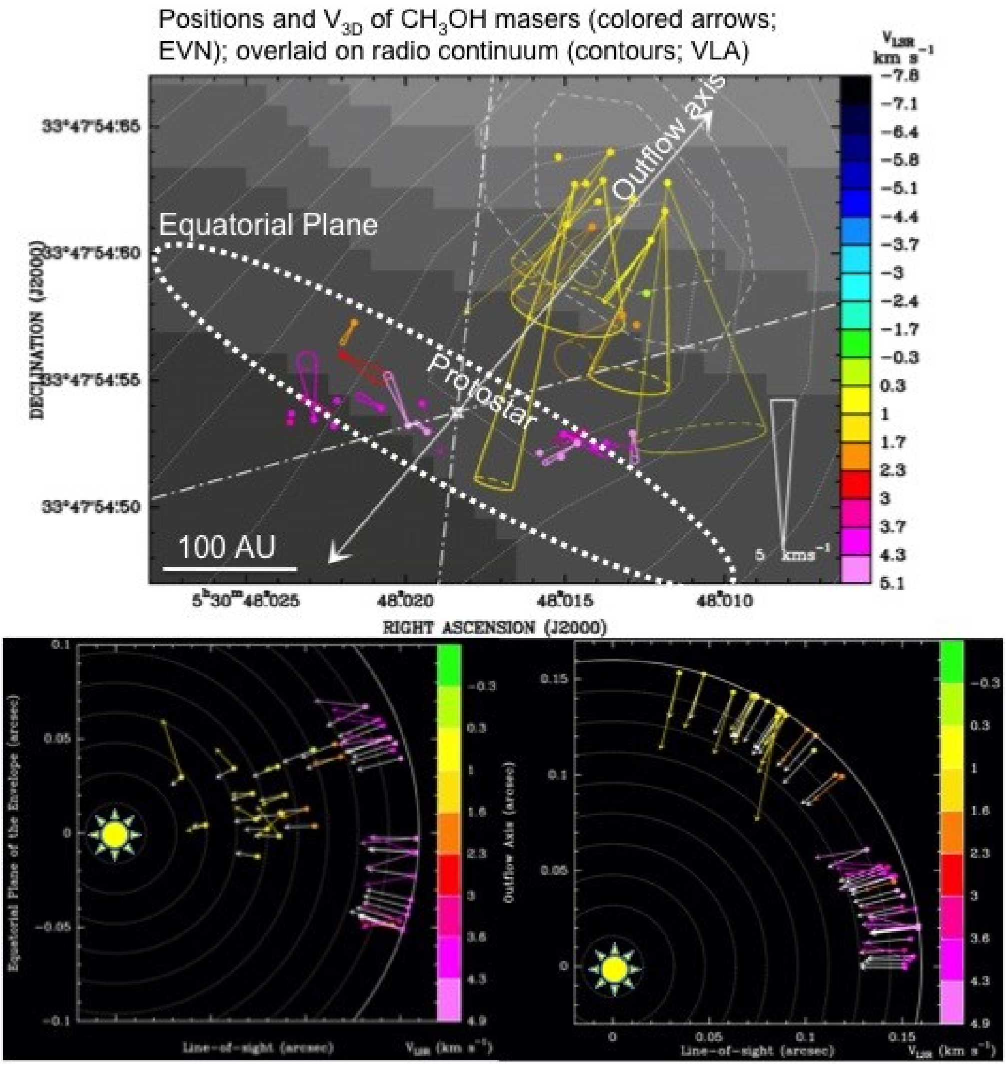


Figure 14: Gas infall from 3D velocities of methanol masers in AFGL 5142. Upper panel: The cones indicate orientation and uncertainties of measured proper motions and colors denote l.o.s. velocities. Contour maps show the 22 GHz (dotted line) and 8.4 GHz (dashed line) continuum emissions. The long white arrow identifies the axis of a molecular outflow observed in water masers, while the dashed ellipse represents the equatorial plane containing the protostar, perpendicular to the outflow. The velocities and the orientation of the proper motions towards the protostar, provide the most direct evidence to date of gas infall in a (massive) protostar. Lower panel: Measured (colour arrows) and best-fit model (black arrows) 3-D velocity vectors of methanol masers, projected onto the equatorial plane (left) and a plane containing the l.o.s. and the outflow axis (right), respectively. The modelled infalling envelope has a radius of 0.16 arcseconds or 290 AU and an infall velocity of 5 km/s.

region AFGL 5142 (D~1.8 kpc). In particular, 6.7 GHz Class II methanol masers were observed with the EVN at 3 epochs spanning six years, which provided us with the 3-D velocity field of circumstellar molecular gas with a resolution of ~0.005 arcseconds and at radii < 0.16 arcseconds (or 300 AU) from the protostar (Figure *14*). The methanol maser data acquired with the EVN provided, for the first time, a direct measurement of infall of molecular material onto an intermediate- to high-mass protostar from the 3-D velocity field of the circumstellar gas.

This research is published by Goddi, Moscadelli, Sanna 2011 A&A, 535L, 8

3.2.2 Water maser emission from high-mass star-forming regions

Anna Bartkiewicz (Torun), Marian Szymczak (Torun) and Huib Jan van Langevelde (JIVE) used six antennas of the EVN (Jodrell Bank, Effelsberg, Medicina, Metsähovi, Onsala, and Yebes) to study milliarcsecond morphology of water maser emission at 22.2 GHz in two high-mass star-forming regions. Targets were selected based on the VLA results; G31.581+00.077 and G33.641-00.228 were the brightest sources among 22 detections and likely related to the ring-like or arc-like methanol masers at 6.7 GHz (Bartkiewicz et al. 2011).

These observations were done in the 2010 October session and lasted in the phase-referencing mode for 8 h. Although the EVN observed at the low declination, the phase-referencing worked well and the absolute astrometry at the level of a few mas in RA and ca.20 mas in Dec was achieved. Obtained images with a beamsize of 2 mas x 1 mas at PA=-40 deg showed the rms of a level of 7 mJy/beam. Not only high angular resolution but also high spectral line resolution (ca. 100 m/s) enabled for detailed studies of small (a few AUs) regions nearby the massive young star. Water

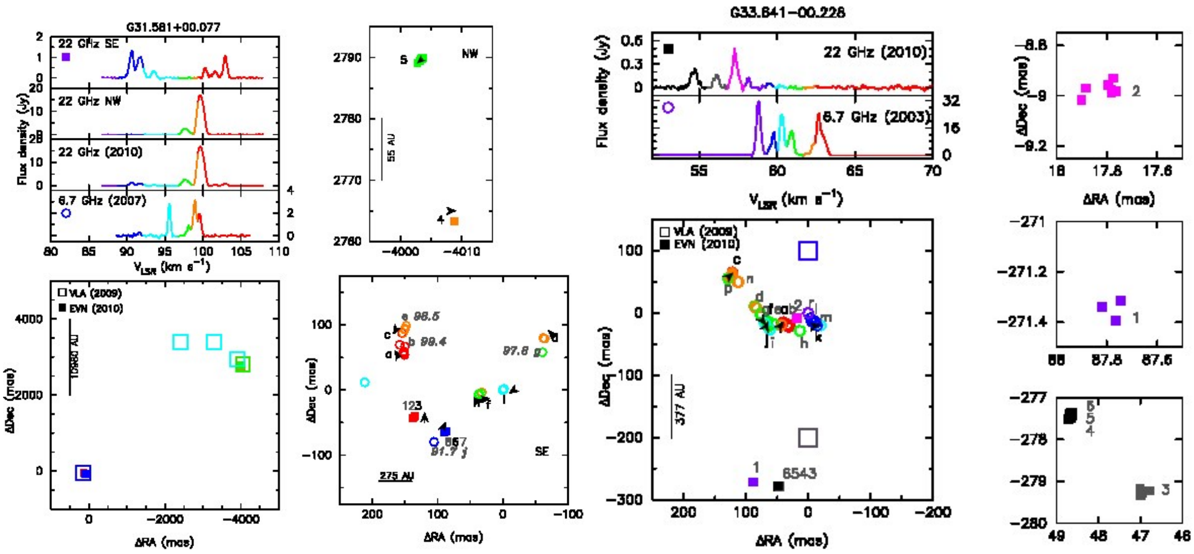


Figure 15: EVN observations of water maser positions in two high-mass starformation regions (Left: G31.581+00.077, Right: G33.641-00.228).

maser emission in G31.581+00.077 was separated by ca. 5" and both regions contained two clumps of maser spots offset by ca.50 mas (Figure 15 left). In the SE region the water masers were lying close to the methanol masers, hinting at a common origin, possibly in shocks close to the massive young star. The water-only region NW may indicate an outflow. Emission at both maser lines in G33.641-00.228 is also closely associated with each other (Figure 15 right). The major axis of water maser spot distribution is clearly perpendicular to the arc structure of methanol emission. Again, the outflow scenario is more plausible. Detailed studies of single spot groups at similar LSR velocities show that the water clusters exhibit higher velocity gradients than the methanol cluster. That again supports that the water maser arise in faster parts of environment around YSO like outflows. Figure

15 show comparison of the EVN results with the VLA ones as indicated at the left side of each spectrum.

These results from the pilot project encourage for further observations of another HMSFRs from the sample as well as for proper motion studies.

More details are described in Bartkiewicz, Szymczak and van Langevelde, 2012, Astronomy and *Astrophysics* 541, A72.

3.3 Transient Science

3.3.1 VLBI imaging of a flare in the Crab nebula: more than just a spot

An unusually strong and long-lasting high-energy flare was detected in late September 2010 in the Crab nebula by AGILE and Fermi/LAT. A putative flaring region was identified in follow-up observations with Chandra and HST - suggesting that the flare was located either in the jet or near the inner wisp of the nebula.

Based on the estimates of brightness and compactness of the putative flaring region, an EVN+MERLIN observation of the Crab nebula was made in November 2010 at 1.6 GHz (Figure 16), aiming at detecting and localising a radio counterpart of the flare. The observation was made in the e-VLBI mode, with seven EVN telescopes (Eb, Jb, Wb, Mc, On, Tr, Hh) and two MERLIN antennas (Da, Kn). Data were recorded at 1024 Mbps at the EVN antennas and at 128 Mbps at the MERLIN antennas.

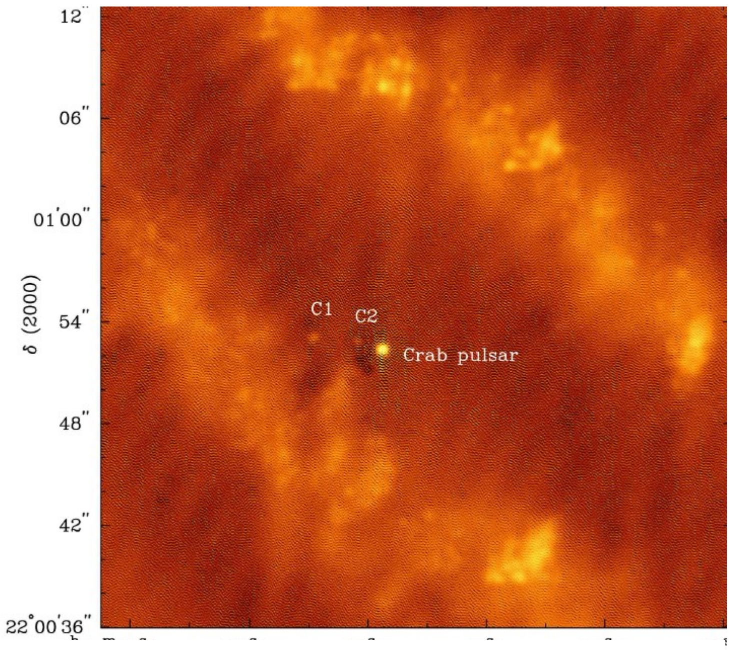


Figure 16: Image of the central region of the Crab nebula obtained from naturally weighted EVN+MERLIN data at 1.6 GHz, uv-tapered data on baselines up to 10Mλ. The image is obtained using a multi-scale CLEAN deconvolution and restored with a circular beam of 0."5 in size. The image has a peak flux density of 8.5mJy/beam and an rms noise of 0.16mJy/beam. The total flux density recovered in the image is 148mJy.

The 1.6 GHz data have enabled imaging the inner regions of the nebula on scales of up to ≈40", yielding arguably the largest structure ever imaged with VLBI. This hase become feasible thanks to extremely strong emission of the nebula, an increased sensitivity of e-VLBI observations, and effective *uv*-filtering of contributions from emission on larger spatial scales.

The emission from the inner "wisps" is detected for the first time with VLBI observations. A likely radio counterpart (designated "C1") of the putative flaring region observed with Chandra and HST is detected in the radio image, with an estimated flux density of 0.5±0.3mJy and a size of 0."2-0."6. Another compact feature ("C2") is also detected in the VLBI image closer to the pulsar, with an estimated flux density of 0.4±0.2mJy and a size smaller than 0.”2. Combined with the broad-band SED of the flare, the radio properties of C1 yield a lower limit of ≈0.5mG for the magnetic field and a total minimum energy of 1.2×10^{41} ergs vested in the flare (corresponding to using about 0.2% of the pulsar spin-down power).

The 1.6 GHz observations have also yielded an accurate absolute position of the Crab pulsar, and an estimate of the pulsar proper motion μ_α=-13.0±0.2mas yr^{-1}, μ_δ = +2.9±0.1mas yr^{-1}.

The results were published by A.P. Lobanov (MPifR), D. Horns (University of Hamburg), T.W.B. Muxlow (University of Manchester), A&A, 533, A10, 2011.

3.3.2 A self-absorbed compact jet in MAXI J1659-152

The hard X-ray transient MAXI J1659-152 was discovered by Swift/BAT and MAXI/GSC on 2010 September 25 (Mangano et al. 2010 and Negoro et al. 2010, respectively). Although initially this transient was mistaken for a GRB, the optical spectra and X-ray lightcurve evolution and timing properties soon showed signatures of a Galactic black hole X-ray binary system (BHXRB). Following the quick detection in the radio by the WSRT at 5 GHz, (van der Horst et al. 2010) we initiated e-VLBI (Target of Opportunity) ToO observations with the EVN at the same frequency. Our goal was a quick initial detection of the transient at high resolution, and looking for nearby secondary calibrators because the low declination made phase-referencing challenging for this object. We indeed detected the source (Paragi et al. 2010) and proposed further VLBA and e-EVN observations. We had secured a secondary calibrator and obtained an improved position for it, which was important for the follow-up observations (starting just a few days later), especially those that included the phased-array WSRT.

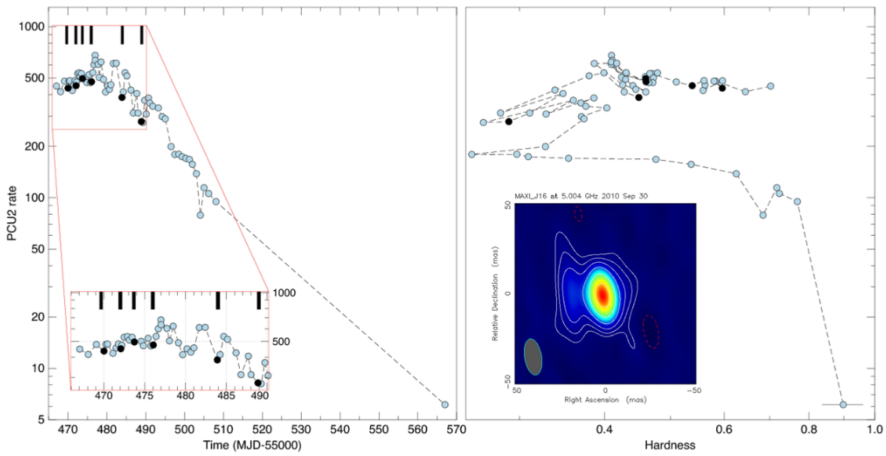


Figure 17: The first epoch e-EVN map is shown with the resolved structure as an inset to the RXTE X-ray light curve (left) and the hardness-intensity diagram (HID, right).

MAXI J1659-152 was rather special in the sense that it showed irregularly shaped dips in the X-ray light curve with a very short, 2.4h period. This is interpreted as the orbital period, the shortest one found in BHXRB so far. The companion star is likely an M5 red dwarf on a very close orbit to the black hole (Kennea et al. 2011; Kuulkers et al. 2012). Although the distance is not exactly known, it is between ~4-9 kpc, and the corresponding height above the Galactic plane is quite high (most likely exceeding 1 kpc). This makes the source a runaway microquasar candidate, which received a large kick velocity during the formation of the black hole in the system (Yamaoka et al. 2012; Kuulkers et al. 2013).

We carried out altogether 2 epochs e-EVN and 4 epochs VLBA observations between 2010 September 30 and October 19; the latest epoch was a non-detection. Unfortunately, this short period of radio activity did not allow us to constrain the kick velocity of MAXI J1659-152 well. We obtained 2 sigma upper limits of 115µarcsec/day in right ascension, and 37µarcsec/day in declination, over a time baseline of 12 days. These correspond to velocities of 1400 km/s and 440 km/s, respectively, assuming a source distance of 7 kpc. The unusually high uncertainty in right ascension was actually due to source structural changes in roughly E-W direction.

The closest VLBI epochs to RXTE measurements are indicated by the filled black circles. As can be seen on the HID and evidenced aslo by the X-ray timing properties (Munoz-Darias et al. 2011), MAXI J1659-152 underwent a full X-ray state transition. As BHXRB advance to the soft state in an outburst, the emission in their compact jets is first quenched. This is usually followed by bright, discrete ejecta at (mildly-)relativistic velocities, and their optically thin spectra dominate the radio emission for several days. We do not observe this in MAXI J1659-152. The flat radio spectral index, low polarization, compact radio structure and no high proper motion in relativistic ejecta all point to a partially synchrotron self-absorbed compact jet during the state transition of this BHXRB (Paragi et al 2013, MNRAS, 432, 1219)

3.3.3 A weak compact jet in a soft state of Cygnus X-1

Cygnus X-1 is one of the most famous black holes in the Galaxy and is a persistently strong source of highly variable X-ray emission. Monitoring the radio emission traces the rapid changes in the outflowing jet from the accretion disk and our work has been to study how the different X-ray "states" affects the outflow.

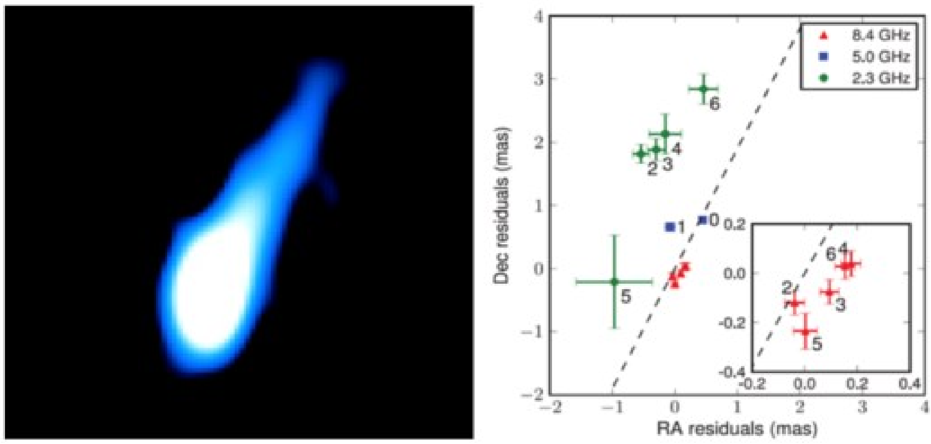


Figure 18: (Left) The one-sided jet of Cygnus X-1 that is always seen in the hard X-ray state as observed with the VLBA at 8.4 GHz. (Right) Astrometric VLBI positions of the unresolved core taken during the soft X-ray state. Although the jet appears quenched during the soft state, residual motion of the core clearly shows the source to move along the jet axis.

Hard X-ray states of Galactic black holes are known to produce relatively radio bright jets and VLBI observations of Cygnus X-1 can resolve an apparent one-sided outflow (Figure 18). However, soft states of these sources have shown the radio emission to become quenched despite an apparent increase in the overall X-ray luminosity; even though the accretion rate may increase, it is unknown why the jet launching mechanism becomes disabled.

Our work in June 2010 with the VLBA, EVN and MERLIN has shown the first direct evidence that a jet can remain in a soft state of a black hole, albeit at a much weaker radio luminosity. Using astrometric VLBI analysis and removing proper motion, parallax and orbital motion signatures, the residual positions show a scatter of >0.2 mas along the position angle of the known jet axis (see Figure 18 (Left)). High time-resolution X-ray observations with the RXTE-PCA were also taken during the radio-monitoring period to confirm the source had entered a soft state. This work has been published by Rushton et al 2011, MNRAS, 419, 3194

3.3.4 Revealing Transient Relativistic Ejections and the Core in the Galactic Black Hole Candidate XTE J1752-223

The X-ray transient XTE J1752-223 is a stellar-mass black hole candidate within our Galaxy. The figure below shows the European VLBI Network (EVN) and the NRAO Very Long Baseline Array (VLBA) imaging results during its first outburst. In 2010, we reported the detection of a transient and decelerating ejecta, marked as component A, observed in the first four epochs. Now, we present the new images in which a new transient ejection event associated with component C and later the reappearance of the radio core, marked as D, are revealed.

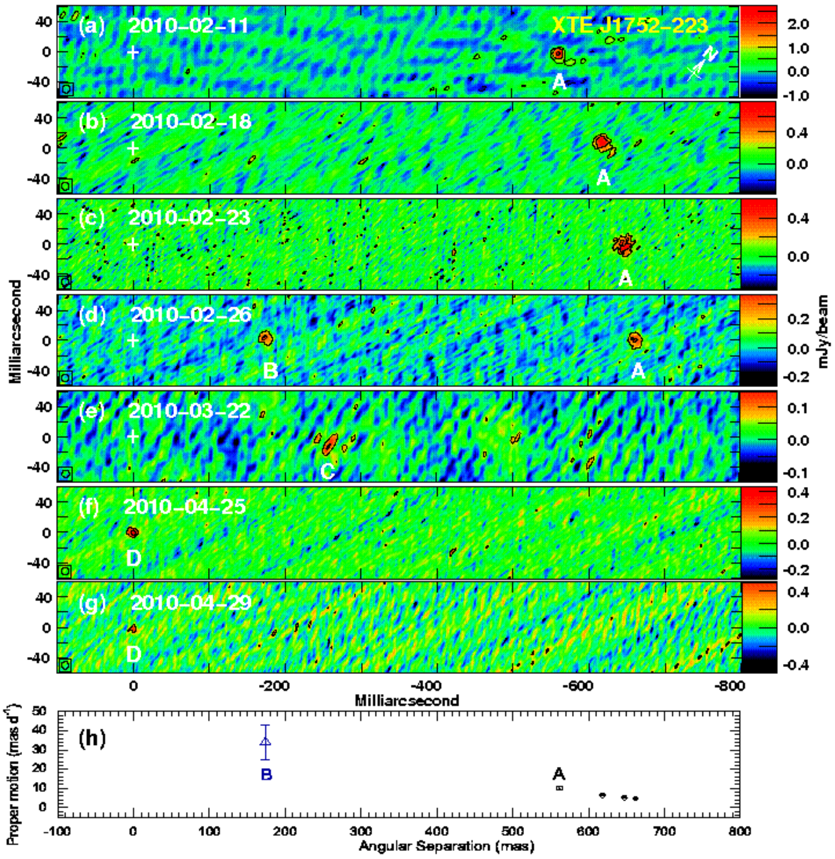


Figure 19: : EVN and VLBA images of the transient jet components A, B, C, and the re-activated compact jet D in XTEJ1752-223. The lower panel shows the proper motion versus angular separation for components A and B. All images are centred at the compact jet (0, 0) and rotated clockwise by 39°. The contours start from 3-σ off-source noise level and increase by factors of -1, 1, 2, 4. The size of the restoring beam is 10 mas.

We also find that the component B, the one closer to the core, had significant proper motion during the single observation it was detected, and this proper motion was in fact significantly higher than the one derived for the older component A. This further strengthens our previous finding that the jet strongly decelerates on 100 mas scales, which has never been observed in X-ray binaries before. Although the distance to the transient source is not well constrained, it is clear that these ejecta are at least mildly relativistic at the early stage of their evolution. The bottom panel summarises the proper motion evolution in components A and B.

These new results have been published by Yang et al 2013, MNRAS letters, 418, 2

3.4 Astrometry

3.4.1 High Precision Astrometry at mm-VLBI, and with Space VLBI, using SFPR

The Source Frequency Phase Referencing (SFPR) method is a technique designed to perform millimeter (mm) and submm-VLBI phase referencing in a simple and robust fashion, beyond the scope of application of conventional phase referencing (PR) techniques. SFPR readily compensates for the dominant (non-dispersive) tropospheric propagation medium effects that prevent the application of PR at frequencies larger than 43 GHz, and for the orbit reconstruction errors that limit astrometry with Space VLBI. This method has been in development since 2009, with regular updates in applications and understanding (Dodson & Rioja 2009, *VLBA Science Memo 31, arXiv: 0910.1159* Rioja & Dodson 2009 *VLBA Science Memo 32, arXiv:0910.1161*, Rioja & Dodson 2011, Rioja et al. 2011).

Its implementation consists of two steps, to eliminate non-dispersive and dispersive errors, respectively. The first step uses the antenna-based residual terms (phase, delay and rates) derived from the self-calibration analysis of the data at the lower reference frequency, to calibrate the same-source data at the higher target frequency, after scaling the phase values by the frequency ratio. This step removes all of the non-dispersive contributions, which arise in the main from the rapidly and wildly varying tropospheric propagation effects. We dubbed this step Frequency Phase Transfer (FPT). The second step uses the observations of another source to eliminate the remaining dispersive errors in the FPTed residual phases, in a similar fashion as done in PR. The FPT residuals are dominated by instrumental and ionospheric contributions. The estimated timescale of these variations are of the order of hours, even at the very highest frequencies. We have confirmed this with observations at frequencies as high as 129 GHz. Also we have confirmed that the FPTed residual visibility phases for different sources are indistinguishable even for angular separations as large as 10^{o}. Therefore the SFPR analysis preserves the astrometric registration between the maps of the observed sources at mm and sub-mm wavelengths.

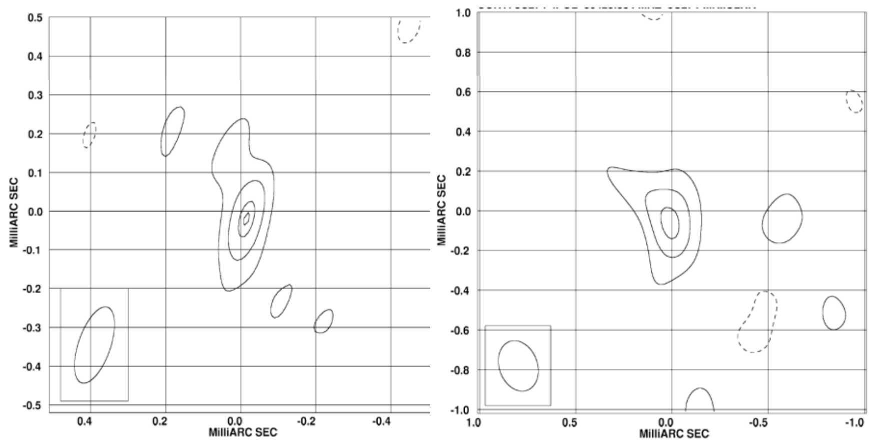


Figure 20: Left: Source-frequency phase referenced (SFPR-ed) map of 1308+326 at 86 GHz from VLBA observations at 43 and 86 GHz, along with a calibrator source, 1308+328, 14' away. Right: SFPRed map of M87 at 86 GHz from VLBA observations at 43 and 86 GHz, along with a calibrator source, 3C273, 10^{o} away.

The first demonstration was carried out using VLBA fast frequency switching observations between 43 and 86 GHz (Rioja et al. 2011). The observing schedule consisted of blocks of interleaving observations between 1308+326 and 1308+328, 14' apart, and M87 and 3C273, aprox 10^{o} apart.

Figure 20 shows the successful SFPR maps of 1308+326 and M87 at 86 GHz. We note that optimal SFPR performance is to be obtained with simultaneous dual frequency observations, as provided for example with the multi-channel receivers installed at Korean VLBI Network (KVN) telescopes.

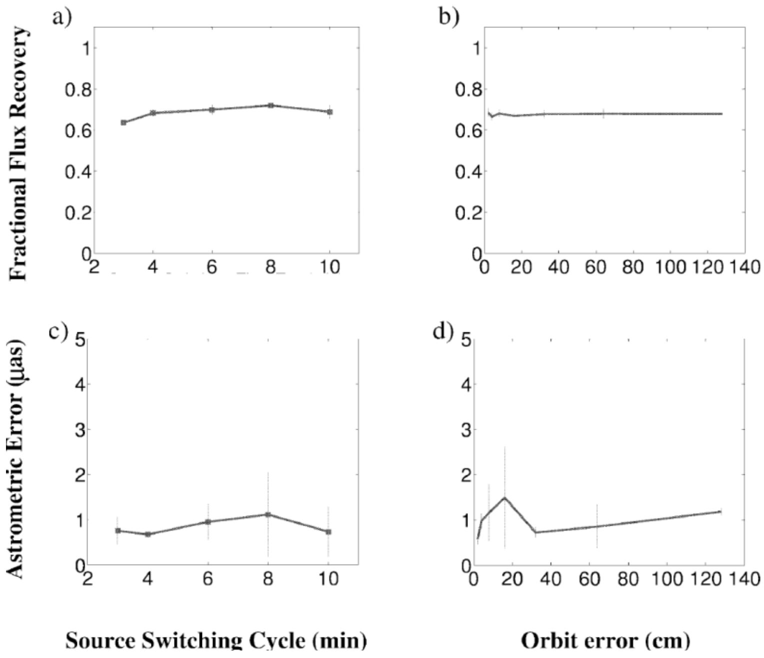


Figure 22: Fractional peak flux recovery (top row: a and b) and astrometric error (bottom row: c and d) quantities as a function of source switching cycle (left: a and c) and orbit error (right: b and d), measured from the SFPR maps at 43 GHz.

We also investigated the role of SFPR as a path to achieve astrometric measurements with Space VLBI (Rioja & Dodson 2009, Rioja et al. 2011). The application of PR techniques requires cm-level in the accuracy of the orbit reconstruction, which is hard to achieve. On the other hand, errors in the orbit reconstruction have a non-dispersive nature and hence are readily compensated for with the SFPR technique. We showed with simulations and realistic models of error contributions that a Space VLBI mission with SFPR capabilities would be able to produce phase referenced images, even in the presence of very large orbit errors (Rioja et al. 2011). Figure 22 shows the astrometric errors estimated from our simulation studies for observations with the VSOP-2 satellite at 22 and 43 GHz. The estimated astrometric errors are of the order of a micro arcsecond.

3.5 Space science

3.5.1 VLBI and space science

The JIVE Space Science and Innovative Applications (SpaSIA) group continued developments of the new technique of near-field VLBI for multi-disciplinary scientific applications. The method allows researchers to determine state-vectors of target sources (at present – spacecraft) with high accuracy. The interest of the scientific community traditionally not involved in radio astronomy studies (e.g. planetary scientists) to this technique is expected to translate in the near future into an enlargement of the user base of VLBI facilities.

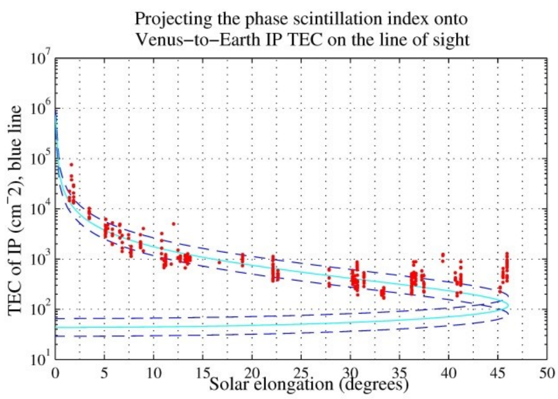


Figure 23: Total Electron Contents (TEC) along the line of sight toward the Venus Express spacecraft as a function of the Solar elongation angle. Blue lines correspond to the currently accepted theoretical model, red dots – PRIDE measurements based on the estimates of the scintillation index of the VEX' carrier signal at .4 GHz.

Over the reporting period, the SpaSIA group developed several key components of the near-field VLBI technique. These include all steps of near-field VLBI experiments, from experiment planning to post-processing. In particular, the team has developed a set of scripts, which allow efficient scheduling of near-field VLBI tracking experiments. In collaboration with the R&D group of JIVE, the software correlator SFXC has been upgraded with a set of special near-field modules. These modules include the correlator delay model able to support VLBI data processing of targets at distances from several astronomical units down to LEO satellites. The overall approach to near-field VLBI developed at JIVE is described in details in the paper published by the SpaSIA group in 2012 (Duev et al. 2012, AA 541, A43).

Over the reporting period, most of the EVN activities in the area of space science applications of VLBI were supported via EC FP7 projects EuroPlaNet (grant agreement 228319, completed in December 2012) and ESPaCE (grant agreement 263466, on-going) as well as collaborations between JIVE and Chinese radio astronomy observatories co-sponsored by the Royal Dutch Academy of Arts and Sciences (KNAW), the NWO, the Chinese Academy of Sciences (CAS) and Shanghai Astronomical Observatory (ShAO).

3.5.2 VLBI tracking of planetary and space science missions

The developments mentioned above enabled the JIVE team to carry out a number of VLBI experiments with various planetary and other space science missions. All these experiments are unified under the name PRIDE – Planetary Radio Interferometry and Doppler Experiment.

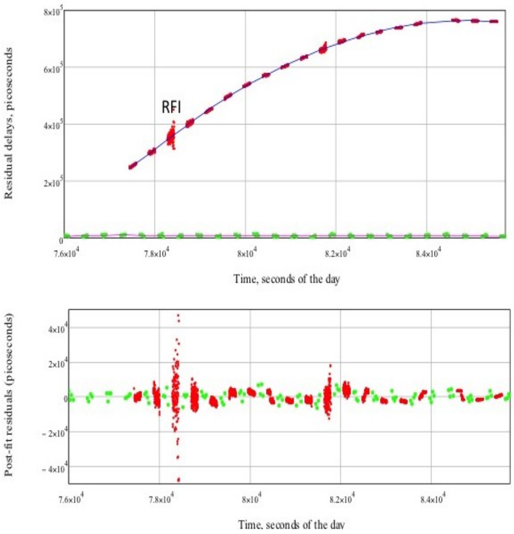


Figure 25: PRIDE tracking of the Herschel spacecraft at 8.4 GHz on the baseline Medicina-Wettzell (EVN experiment EC040, November 2012). Top: Residual baseline delay measurements for Herschel S/C (red) and Ref. Source (green). Bottom: Post fit residuals for the reference source (red), RMS noise ~270 ps, and Herschel spacecraft (green), RMS noise ~60 ps.

Over the reporting biennial period, the SpaSIA group continued PRIDE monitoring of the ESA's Venus Express (VEX) mission (see the JIVE Biennial Report 2009-2010 where these experiments were introduced). In the context of his PhD project (the thesis defended at the Aalto University, Helsinki, Finland, in April 2012), Guifré Molera Calvés worked on VLBI and radio spectroscopy studies of Solar System by means of VLBI tracking of the ESA's planetary science missions., Venus Express (VEX) and Mars Express (MEX). Most of the observational work was conducted with the Metsähovi radio telescope but also involved other EVN stations and was coordinated by JIVE. The three-year observing campaign resulted in a development of a model of the interplanetary plasma turbulence distribution at various distances and solar elongations of Venus with respect to the Earth. The results of the study are useful not only as a diagnostics of the interplanetary medium but also help to calibrate the near-field (and other) VLBI experiments. The extensive VEX observing campaign served as a means of verification and end-to-end test of future applications of PRIDE in other planetary and space science missions. The ultra-high-resolution spftware spectrometer developed as a part of the VEX observing campaign also contributed to a detection of a 22 GHz

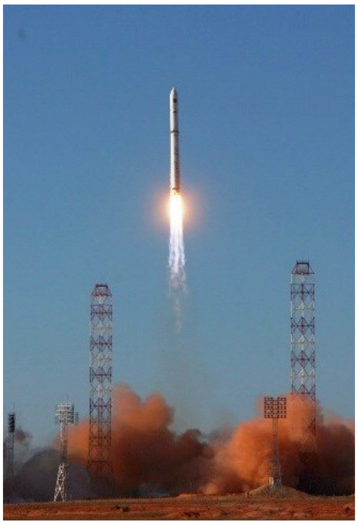


Figure 24: The launch of RadioAstron, 11 July 2011, Baikonur, Kazakhstan (the image courtesy of the Russian Federal Space Agency).

water maser line in the Saturnian system. It is currently used at JIVE for various applications.

In 2012, JIVE was invited by the Gaia Data Processing and Analysis Consortium (*DPAC*) to join preparatory activities for the ESA's astrometric mission Gaia scheduled to blast off in the second half of 2013. This mission will put on the 3D celestial map one billion stars. It will also charter extremely distant extragalactic objects as well as an order of ten thousand small bodies in the Solar System. Several scientific topics of the Gaia mission require a better-than-nominal accuracy of determination of the Gaia spacecraft state-vector during its 5-year tour of duty near the second Lagrangian (L2) point of the Earth-Sun system (about $1.5x10^6$ km from Earth in the anti-Solar direction). The task will be addressed by both optical and PRIDE observations of Gaia. In order to test the PRIDE technique for a target located in the vicinity of L2, a special test observation of another ESA spacecraft, Herschel, was conducted at 8.4 GHz in November 2012 as the EVN project EC040 (PI G. Cimò). The results of this test (**Error! Reference source not found.**) prove that PRIDE tracking of Gaia should meet the DPAC specifications and will be ready for support of Gaia science operations.

In a longer perspective, PRIDE technique has been proposed as a multi-disciplinary enhancement of the ESA large-scale JUpiter ICy moons Explorer mission, JUICE. The mission is scheduled to be launched toward Jovian system in 2022 and reach the destination around 2030. At the vicinity of Jupiter, the mission will conduct studies of the physical environment of the largest planet of the Solar System and investigations of the three Galilean moons, Ganymede, Europa and Calisto.

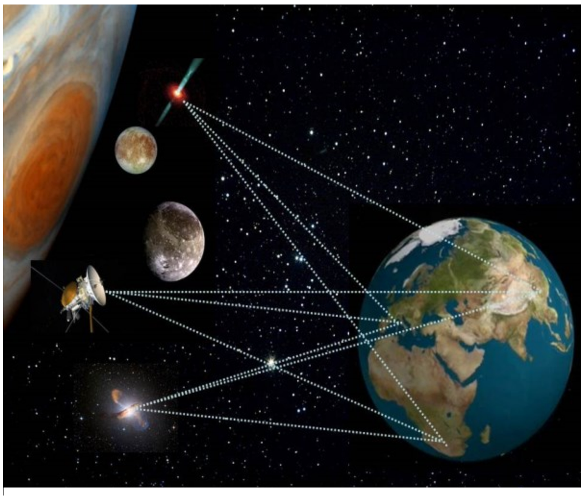


Figure 26: A generic configuration of PRIDE-JUICE.

PRIDE-JUICE (*Figure 26*) will into precise spacecraft trajectory measurements of the mission spacecraft as a multidisciplinary component of the JUICE science suite. Its prime "deliverable", a highly accurate determination of the spacecraft state vectors will be used for a variety of applications, ranging from celestial mechanics and astrometry to geodynamics and studies of the Jovian plasma environment. PRIDE-JUICE will also provide input into making ephemerides of the Jovian system more accurate – an important prerequisite for future exploration of the Solar System. PRIDE-JUICE is a direct descendant of the Huygens VLBI tracking experiment conducted under the JIVE's leadership in 2005.

At the time of this report writing, in addition to the JIVE contingent, the PRIDE-JUICE team included scientists from Belgium (Royal Observatory), France (Laboratoire d'Astrophysique de Bordeaux, Observatoire de Paris and CNES), Germany (DLR and TU Berlin), Hungary (FÖMI Satellite Geodetic Observatory), The Netherlands (TU Delft), Romania (Institute for Space Sciences), and the USA (UC Berkeley). But the team is likely to grow, not least via very natural involvement of EVN institutes.

The work of Dmitry Duev focused on astrometric applications of Space VLBI, using observations of several spacecraft including the ESA's Venus Express, RFSA's RadioAstron and GLONASS satellites. He developed an advanced signal delay model for near-field VLBI observations (including a tropospheric delay model based on ray-tracing through the Numerical Weather Models) together with the Jacobian formalism (first suggested by Sergei Pogrebenko) for spacecraft state vector estimation based on VLBI and Doppler observations. The software devised by Dmitry Duev has been successfully tested in various spacecraft VLBI tracking sessions. The research culminated in a successful PhD thesis defense at the Lomonosov Moscow State University (Russia) on 1 November 2012.

Applications of PRIDE technique for studies of gravity field were analysed in connection with the Phobos-Soil mission. In particular, the error propagation model through the PRIDE data processing pipeline was studied by Tatiana Bocanegra Bahamon as a part of her MSc thesis. The results of this work proved to be useful for analysis of applicability of PRIDE to other planetary missions.

3.5.3 Space VLBI: radioastron

On 18 July 2011, after several decades of development, the Russian Space VLBI mission RadioAstron was launched from the Baikonur spaceport in Kazakhstan (**Error! Reference source not found.**).

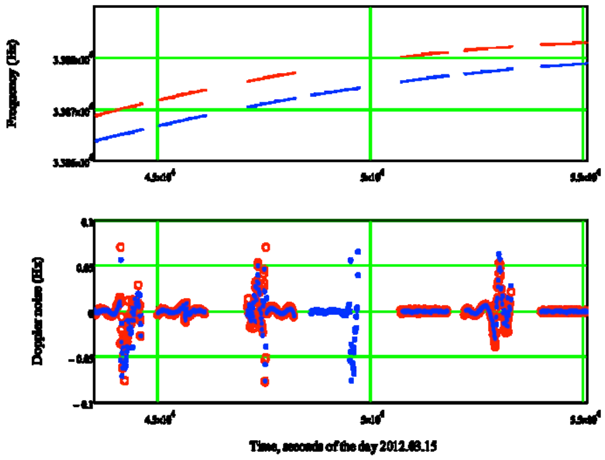


Figure 27: An example of PRIDE tracking of RadioAstron at 8.4 GHz during the experiment EK032 (March 2012). Top: Frequency detection within video-band (Wettzell – red, Onsala – blue) as a function of time. Bottom: Doppler noise of the post-fit residuals.

In the following 17 months through the end of 2012, the mission has successfully completed in-orbit check-out tests and switched to the Early Science Programme and later the Key Science Programme. The PRIDE technique described above was used for independent verifications of the RadioAstron orbit determination (OD) crucial for getting VLBI fringes on Earth-Space baselines (*Figure 27*). Moreover, by the end of 2012, it has become clear that the SFXC software developed at JIVE for near-field VLBI tracking can be used as a base for Space VLBI “incarnation” of SFXC. The work toward demonstrating RadioAstron VLBI fringes on extraterrestrial baselines using the SFXC software has begun at JIVE in the fall of 2012. By the time of this writing, the first tests of the SFXC in the SVLBI mode provided positive results. They pave the way for offering support to RadioAstron-EVN users in correlating their experiments at JIVE once the mission becomes open for users’ observing proposals. All these topics are discussed between the RadioAstron mission and JIVE (together with EVN and other international partners) at the RadioAstron International Science Council (RISC) that has JIVE representatives since its formation in the late 1980s.

4 EVN Network Operations

4.1 The EVN programme Committee (EVN-PC)

The EVN Programme Committee (PC) consists of 12 voting members populated from the EVN institutes (8) and "At Large" representatives from other European institutes (4). In addition the EVN Scheduler attends PC meetings as a non-voting member. Members typically serve on the committee for a period of around 2-3 years, and are then replaced by other representatives invited by the EVN Consortium Board of Directors. The PC meets three times a year - typically around a month after each proposal deadline, to discuss recent proposals received, to allocate a grade to each successful proposal, and to provide detailed feedback to each PI.

For the consideration of Global VLBI proposals, independent grades are provided by NRAO. In addition, 2 voting members from NRAO join the PC meetings for extended discussions. Target of Opportunity proposals received outside formal deadlines are circulated to PC members by the PC Chairperson; grades and feedback being returned to the PI typically within a few days.

The PC membership through 2011-12 is listed below, including all other representatives (non-voting) who contribute to the EVN PC’s process.

Table 1: List of members and roles of the EVN PC committee.

Member	Institute	Role
Anna Bartkiewicz	Torun, PL	PC member
Bob Campbell	JIVE, NL	PC member EVN correlator at JIVE
Marcello Giroletti	INAF-IRA, IT	PC member
Michael Lindqvist	Onsala Space Observatory, SE	PC member
Andrei Lobanov	MPIfR, Bonn, DE	PC member
Tom Muxlow	JBCA/*e*-MERLIN, UK	PC member PC chair from 1/06/11
Antonis Polatidis	ASTRON, NL	PC member
Zhi-Qiang Shen	Shanghai Observatory, CH	PC member
Tiziana Venturi	INAF, IT	PC chair upto 31/05/11 PC member upto 31/05/12
Jose Carlos Guirado	University of Valencia, ES	PC at-large member
Miguel Perez-Torres	IAA-Granada, ES	PC at-large member
Elmar Koerding	Radboud Univ. Nijmegen, NL	PC at-large member
Nektarios Vlahakis	University of Athens, GR	PC at-large member
Richard Porcas	MPIfR, Bonn, DE	EVN Scheduler
Mark Reid	CfA, USA	NRAO Review committee Chair
Mark Claussen	NRAO, USA	NRAO Scheduler

4.1.1 EVN PC meetings and proposal statistics

During 2011-2012 there have been a total of 6 EVN-PC meetings held in Noto (15th March 2011, Trimester 11A), Gothenburg (7th July 2011, Trimester 11B), Madrid (3rd November 2011, Trimester

11C), Bonn (3rd March 2012, Trimester 12A), Athens (3rd July 2012, Trimester 12B), Manchester (12th November 2012 – Trimester 12C).

The EVN operates an open-sky observing policy with proposals scheduled into 3 main observing sessions per year, plus regular (~monthly) additional e-VLBI days, a total of ~600hrs/year. Over the last 5 years on average 65 proposals are received per year. With the expansion of the array, submitted EVN astronomical proposal totals have nearly doubled in 6 years – dominated by increases in proposed conventional disk-based EVN time. The typical over-subsciption rate now stands at ~2.2.

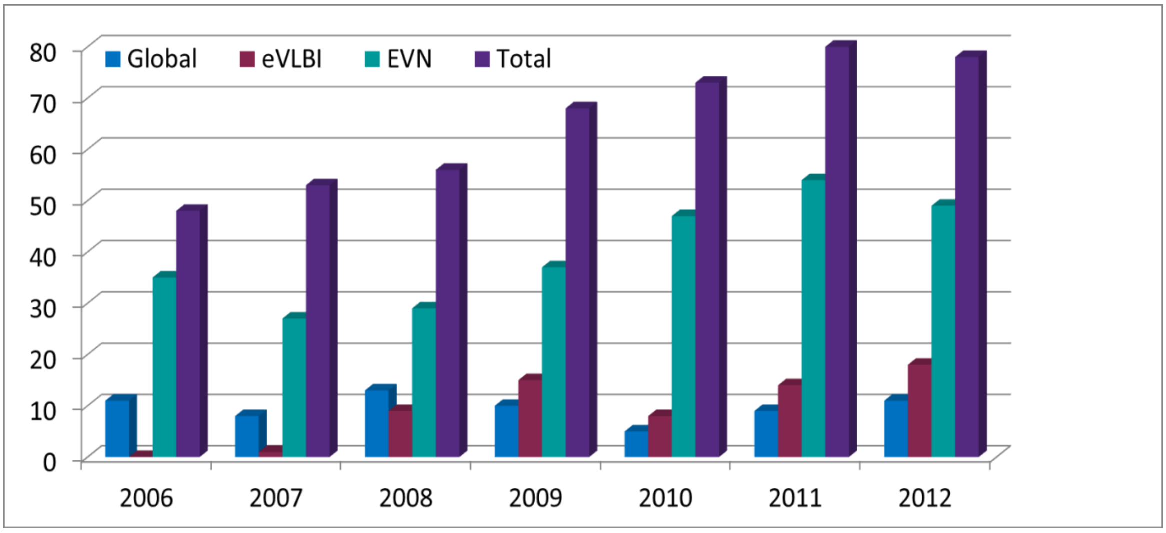


Figure 28: Total numbers of proposals submitted to the EVN PC between 2006 and 2012. Individual proposal counts are sub-divided into proposal classes.

4.1.2 EVN User community

There is a large international pool of users of the EVN and Global VLBI array which stretches significantly beyond the EVN member institutes and countries. In total (Principle Invesigator) PIs on

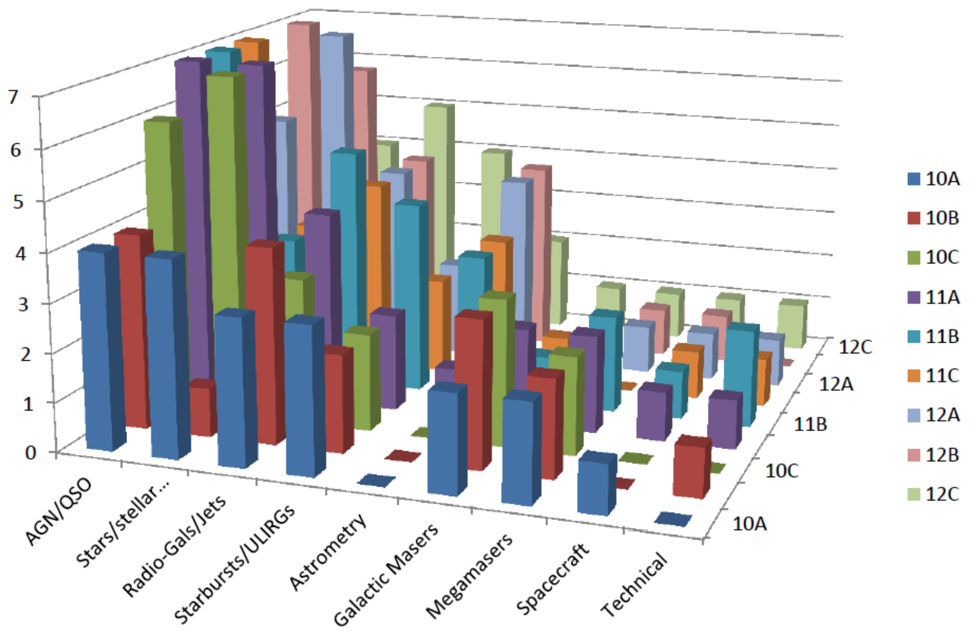


Figure 29: Breakdown of proposals as a function of science area.

proposals submitted to the formal EVN sessions in the period of 2011-2012 were resident in 18 different countries The largest majority of PIs are based within Europe.

4.2 Scheduling and operations

As in previous years, in each of 2011 and 2012 there were 3 major (disk-based) observing sessions, each of 3 weeks duration, and 10 e-VLBI runs of 24 hour duration. The basic parameters of these sessions are summarized in Table 2 and Table 3.

Table 2: EVN Sessions 2011-2012.

Session	Observing Dates		Length (Days)	Efficiency (%)	Wavelengths (cm)				
2011-1	24 February	17 March	21.0	51.5	18	5	6	13/3.6	
2011-2	26 May	16 June	21.2	46.0	5	6	90	21/18	1.3
2011-3	20 October	10 November	20.7	56.6	6	5	18	3.6	1.3
2012-1	23 February	15 March	21.4	41.6	5	36	1.3	18	6
2012-2	24 May	14 June	21.2	55.5	3.6/13	6	1.3	18	
2012-3	18 October	08 Novermber	21.1	60.1	18/21	6	3.6	5	1.3

Table 3: EVN e-VLBI runs 2011-12 (* used for disk Target of Opportunity [ToO]).

				e-VLBI Proposal type					
Session	Date	Wavelength	Hours	Normal	Short	Disk	ToO	Trigger	
11e01	25JAN11	18cm	15	1	1	-	1	0 sched	
11e02	15FEB11	18cm	12	1	-	-	1	0 sched	
11e03	22MAR11	6cm	10	2	-	-	1	1 sched	0 trig
11e04	12APR11	6cm	24	2	-	-	1	1 sched	0 trig
11e05	17MAY11	18cm	12	1	1	-	-	1 sched	0 trig
11e06	25AUG11	6cm	14	1	1	-	-	2 sched	1 trig
11e07	06SEP11	(1.3cm)*	(8)	-	-	-	-	0 sched	
11e08	17OCT11	6cm	12	2	1	-	-	2 sched	0 trig
11e09	23NOV11	6cm	13	-	-	-	1	2 sched	1 trig
11e10	14DEC11	18cm	14	1	2	-	-	2 sched	0 trig
12e01	10JAN12	6cm	10	1	3	-	-	2 sched	0 trig
12e02	07FEB12	6cm	17	2	-	-	-	2 sched	0 trig
12e03	20MAR12	6cm	4	11	-	-	-	2 sched	0 trig
12e04	17APR12	18cm	15	1	-	-	-	1 sched	0 trig
12e05	15MAY12	6cm	24	2	-	-	--	2 sched	1 trig
12e06	19JUN12	6cm	16	2	1	-	-	1 sched	0 trig
12e07	17SEP12	6cm	24	2	-	-	1	2 sched	0 trig
12e08	09OCT12	6cm	22	2	-	-	1	2 sched	0 trig
12e09	13NOV12	6cm	24	2	-	-	-	2 sched	0 trig
12e10	04DEC12	6cm	14	2	-	-	-	2 sched	0 trig

Observations in each disk–based session utilised at least 4 different observing bands (in some cases 5). The "observing efficiency" (time scheduled divided by total duration of the session) ranged from 42% to 60%. Efficiency is reduced by time lost due to receiver changes and features such as "GST bunching" (e.g. when many target sources are in the same Right Ascension range).

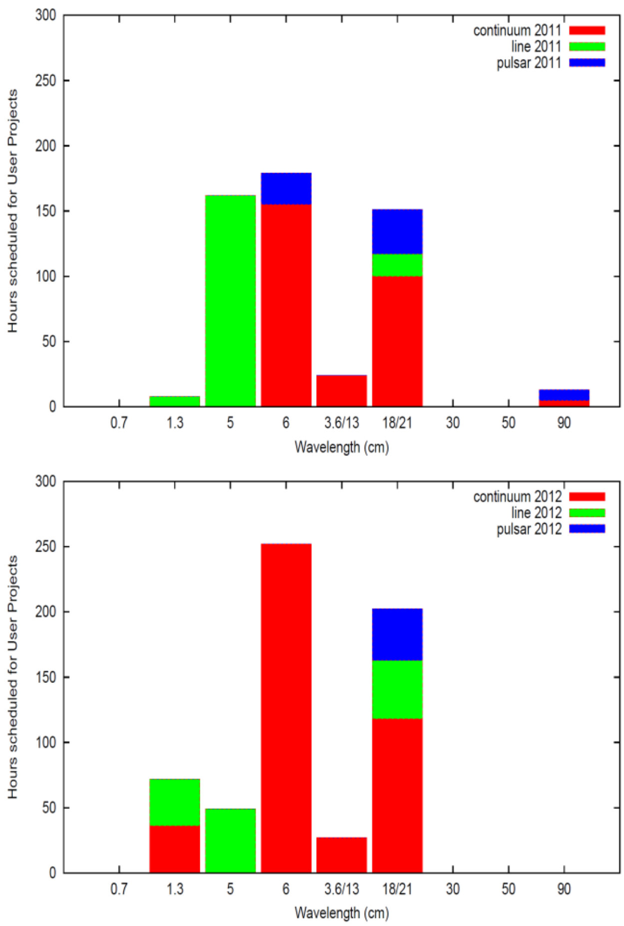


Figure 31: Distribution of observations by wavelength band and target class in 2011 and 2012.

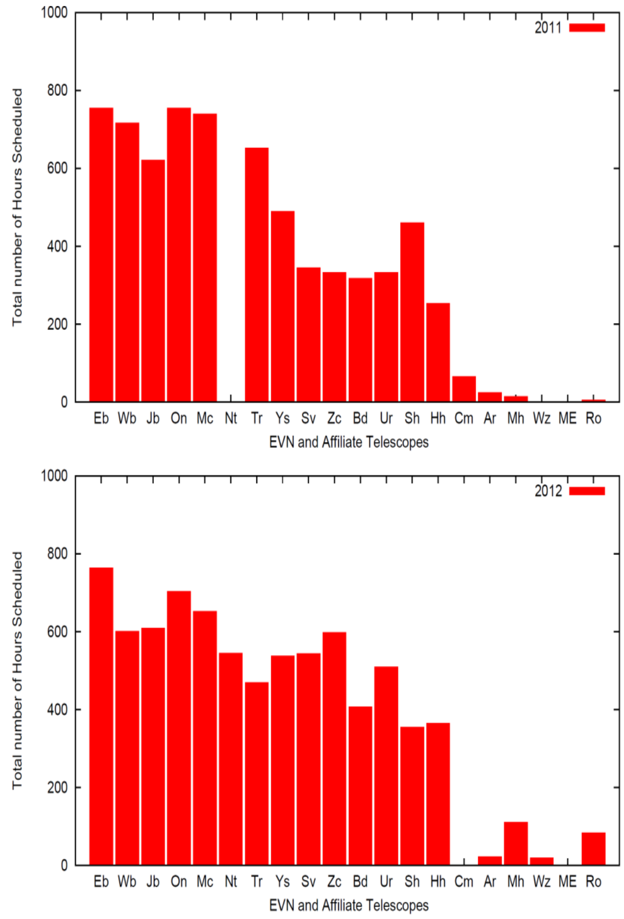


Figure 30: Time scheduled at EVN and EVN-affiliate telescopes in 2011 and 2012.

A small amount of e–VLBI observing was scheduled within some disk–based sessions in order to improve overall EVN observing efficiency.

Each e–VLBI run uses a single observing band – in practice either 6cm or 18cm, with just over 70% at 6cm. Most runs used more than 50% of the available 24 hours, with 20% using all the time. Three "trigger" observations were successfully observed in this period.

A detailed breakdown of the number of observations in various categories in each of the 6 disk–based sessions is given in Table 4 andTable 5. The vast majority of projects observed were "EVN–only" with correlation at the EVN correlator at JIVE. Plots of the amount of time used in the different wavelength bands and target object type in 2011 and 2012 are presented in Figure 32

A new feature in 2012 was EVN observing together with the Russian Space–VLBI mission RadioAstron for projects in its Early Science Program.

Table 4: Details of EVN sessions 2011.

	Session 2011-I			Session 2011-II			Session 2011-III		
	N-obs.	Hours	T-Bytes	N-obs.	Hours	T-Bytes	N-obs.	Hours	T-Bytes
Total	31	260.0	435.3	36	234.1	499.8	36	281.5	548.7
EVN-only	17	174.5	346.2	20	161.0	435.4	23	217.5	437.4
GLOBAL	3	44.0	56.8	5	37.0	36.2	3	28.0	79.2
Short Obs.	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Tests	11	41.5	32.3	11	36.1	28.2	10	36.0	32.1
User: cont	10	126.5	199.3	12	81.0	293.6	18	167.5	398.6
User: line	6	58.0	65.2	7	73.0	36.9	6	66.0	60.7
User: pulsar	4	34.0	138.5	6	44.0	141.1	2	12.0	57.3
Projects	17			19			19		
EVN-Corr.	16	104.5	300	26	176.3	86.3	23	183.0	452.4
Bonn-Corr.	4	39.0	95.0	5	38.0	0.0	2	14.0	66.4
VLBA-Corr.	2	38.0	39.4	0	0.0		1	8.0	29.9
e-EVN-Corr.	4	57.0		0	0.0	0.0	5	55.0	
ASC-Corr.	0	0.0	0.0	0	0.0		0	0.0	0.0
CAL-only.	5	21.5		5	19.8		5	21.5	
MERLIN	0			0			0		
Arecibo	1			4			2		
VLBA	3			5			3		
GBT	1			2			3		
VLA	0			0			0		
Robledo	0			1			0		
RadioAstron	0			0			0		

Figure 31 shows the amount of observing time scheduled during disk–based sessions in 2011 and 2012 at individual EVN and EVN–affiliate telescopes.

Of special note is the increasingly high number of projects using telescopes of the Russian QUASAR network (telescope codes Sv, Zc, Bd), following the accession of the IAA St. Petersburg to the EVN at the end of 2009.

The Noto telescope was not available in 2011 due to repairs to the azimuth track. Observations with MERLIN (code ME) were not possible due to the upgrade of the MERLIN correlator (eMERLIN). VLBI observations with the MERLIN Cambridge telescope were possible during 2011, but not in 2012 due to the loss of the radio link.

In addition to EVN proposals received at the normal proposal deadlines, a total of 23 additional observing time requests were received (9 short e–VLBI proposals, 14 target–of–opportunity proposals). Of these, 1 was subsequently withdrawn, 3 were scheduled *ad hoc* in extra time, and the rest were accommodated within the e–VLBI runs or disk–based sessions.

Table 5: Details of EVN sessions 2012.

	Session 2012-I			Session 2012-II			Session 2012-III		
	N-obs.	Hours	T-Bytes	N-obs.	Hours	T-Bytes	N-obs.	Hours	T-Bytes
Total	34	213.5	601.3	31	282.5	539.3	47	304.0	661.2
EVN-only	20	173.0	558.9	17	129.5	311.7	31	209.5	559.5
GLOBAL	0	0.0	0.0	3	120.0	191.6	4	58.5	60.8
Short Obs.	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Tests	14	40.5	42.4	11	33.0	36.0	12	36.0	40.9
User: cont	15	143.0	515.4	16	227.0	432.1	21	151.0	523.0
User: line	2	16.0	7.0	1	8.0	4.6	11	106.0	60.3
User: pulsar	3	14.0	36.5	3	14.5	66.6	3	11.0	37.0
Projects	14			14			19		
EVN-Corr.	23	150.0	551.8	19	136.5	404.9	38	254.5	637.7
Bonn-Corr.	1	6.0	29.9	2	78.0	134.4	4	31.0	23.5
VLBA-Corr.	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
e-EVN-Corr.	0	0.0		5	52.0		0	0.0	
ASC-Corr.	5	0.0	0.0	0	0.0	0.0	0	0.0	0.0
CAL-only.	5	21.5		5	16.0		5	18.5	
MERLIN	0			0					
Arecibo	0			0					
VLBA	0			3					
GBT	0			0					
VLA	0			0					
Robledo	0			2					
RadioAstron	5			0					

4.3 Technical developments

The Technical and Operations Group (TOG) is made up of the personnel at the EVN stations who provide the technical and operational expertise for operating the EVN as a VLBI array. They are also responsible for advising the EVN Consortium Board of Directors on all aspects of technical and operational issues relevant to the reliability and performance of the network. The TOG is also the body which implements technical and operational upgrades across the network.

Walter Alef of MPIfR chaired the TOG until December 2011 (vice-chair Michael Lindqvist of Onsala). From January 2012 the TOG is chaired by Michael Lindqvist (vice-chair Arpad Szomoru). The TOG met three times during the period of this report: at JIVE, Dwingeloo, the Netherlands, on January 28, 2011, at Arecibo Observatory, Puerto Rico, USA, on August 29-30, 2011, at Onsala Space Observatory, Sweden, on June 27-28, 2012. All meetings were supported by RadioNet3 (funded from the European Community's seventh Framework Programme under RadioNet3-FP7). Reports from the meetings are available on the EVN web-site (www.evlbi.org).

The main emphasis of the TOG activities during the period of this report was maintaining the high level of performance achieved in the previous years, improving the reliability of the operation as a whole, and the quality of the network calibration. The roll-out and site testing of the Digital Base-Band Converter (DBBC) Version 2 continued in the reporting period, albeit slower than planned. At the end of the reporting period 8 EVN stations have a DBBC2, however only Effelsberg did observe in production. The maximum data rate is therefore still 1 Gbps.

Significant points to be noted are:

- The CBD decided that each stations should spend 7000 €/year on the purchase of disks.
- The pool of spare parts for the Mark 5s was started.
- The calibration of the amplitude of the observed interference fringes could be improved even further; occasionally some stations show calibration errors of more than 10 %.
- The telescopes at Noto and Hartebeesthoek were repaired and continued their observations during the reporting period.
- 3 stations got first EVN fringes at 22 GHz during the reporting period (Torun, Svetloe and Zelenchukskaya).
- 2 Gbps (test) recordings on Chinese CDAS back-ends (session 2/2011)
- The KVAZAR stations started to use their R1002 digital backend.
- First KVN-EVN real-time e-VLBI fringes at 22 GHz, October 19, 2011.
- First EVN fringes to Irbene, April 12, 2012.
- All 3 KVN stations participate in K-band NME (session 3/2012)
- GM070 was correlated with 23 participating stations - The biggest VLBI experiment in the EVN history.
- A successful VLBI X-band test at a data rate of 2 Gbps was done in December 2012 (Onsala, Yebes and Effelsberg).

5 VLBI technical developments and EVN operations support at member institutes

5.1 ASTRON, Westerbork Synthesis Radio Telescope, The Netherlands

Operations: Westerbork participated in all EVN sessions of 2011 and 2012 as well as scheduled and Target of Opportunity eVLBI observations. The WSRT tied-array has been using 13 dishes as the remaining telescope was equiped with DIGESTIF, the prototype phased-array feed for the APERTIF system. This period saw the first participation in a 92cm VLBI session, using the MFFE receivers and the digital backend.

Starting from 2012, Westerbork participated in fringe finding observations for the RadioAstron space VLBI project, led by the Astro Space Center. Subsequently WSRT took part in regular RadioAstron experiments.

Technical Developments: After the replacement in the summer of 2010 of the receiver radomes (following the discovery that they trapped water), the sensitivity of the array improved again to its nominal level (Tsys reduced by 25% since 2010).

The digital VLBI backend (TADUmax) was used succesfully for both for single dish (RT7) and tied array observations. The Mark5 recorder and the Field System performed with no problems.

A more automated method to derive the station calibration has been in use since Session 2011-1. New software has been developed to reduce the WSRT correlator's Measurement Sets, supplied by the WSRT correlator, into ANTAB files, replacing a whole suite of scripts and time consuming manual procedures.

Software to enable the transition from eVLBI mode to recording mode and back was developed and the process is fully automatic and smooth.

5.2 Bundesamt fur Kartographie und Geodasie (BKG), Wettzell, Germany

The 20-m radio telescope in Wettzell (RTW) is an essential component of the Geodetic Observatory Wettzell (Fundamentalstation Wettzell, FSW) and is jointly operated by the Bundesamt für Kartographie und Geodäsie (BKG, Federal Agency for Cartography and Geodesy) and Forschungseinrichtung Satellitengeodäsie (FESG, Research Institute Satellite Geodesy) of the Technische Universität München (Technical University Munich). It is collocated to the other space geodetic techniques at Wettzell, like Laser Ranging Systems, receivers for the Global Navigation Satellite System, a large laser gyroscope and several complementary local systems for time and frequency, meteorology, hydrology and seismic. The BKG also runs the Transportable Integrated Geodetic Observatory (TIGO) in Concepción/Chile in cooperation with Chilean partners. Additionally it operates the German Antarctic Receiving Station (GARS) at O'Higgins base, together with the German Space Center (DLR) and the Institute for Antarctic Research Chile (INACH).

Figure 32: The telescopes of Wettzell: the new TWIN radio telescope Wettzell (TTW) and the 20m radio telescope during CONT11.

The 20-m RTW supports the geodetic VLBI activities of the International VLBI Service for Astrometry and Geodesy and activities of other partners, like astronomical observations or spacecraft tracking for the EVN. It is the most engaged geodetic VLBI network station within the IVS. The antenna participated to 271 24h sessions (including the continuous observation CONT11 over 15 days in the year 2011) and to 859 1h Intensive sessions to monitor UT1-UTC. Additionally it operated 15 hours of spacecraft tracking missions to Venus and Mars Express and 62 hours RadioAstron for the EVN. A special session for the EVN was dedicated to the monitoring of the supernova SN2011dh in M51 in the year 2012.

A first change from Mark5A to Mark5B and Mark5B+ was possible, by changing the second Mark4 formatter to support the new VSI-interface. Within a student project a Mark4-VSI version of the formatter was programmed, developing VHDL for a Xilinx-FPGA using the Xilinx-Software "ISE Webpack". The developed software runs on a specially designed VSI-formatter board. It was tested in integration tests during CONT11. Parallel to this development all Mark5 systems were upgraded and updated.

The usage of the EVN-PC for e-Transfer was continuously extended. Additionally the installation and test usage of e-Transfer for the 24h-sessions to Bonn, Haystack and Washington was installed and tested with up to 600Mbit per second. A combination of the Mark5 software "fuseMk5" and the communication protocol "Tsunami" is used on a regular Mark5B system. Meanwhile all R1 sessions are regularly sent to the Bonn correlator using e-VLBI techniques, which reduces the shipping costs tremendously.

In addition the installation and test usage of the new Digital Baseband Converters (DBBC) were forced. They offer the basis for a higher data rate with better data quality in a fully digital way especially also for the VGOS systems. Wettzell was one of the test sites for the DBBC. In cooperation with the developers at HATLab, the Max-Planck-Institute for Radio astronomy (MPIfR) and the INAF new DBBC components were tested, calibrated and adjusted. Several test data were correlated at the correlator Bonn to check the functionality and quality of the system. Additionally, new CoMo boards were ordered to upgrade to a standard version of the equipment.

The components of the servo system were overaged and on the market not available anymore. But it was possible to commission a replacement of the whole system, to upgrade it to a similar, modern technique as installed in the new Twin radio telescopes. The upgrade was done in the mid of 2013. Upgrades and repairs were also necessary for the Mark4 data acquisition rack. The revision of the replacement Dewar systems for Wettzell and O'Higgins were commissioned to the cooperation partners at the observatory in Yebes in Spain, where specialists updated the systems to a state-of-the-art design.

Regularly tasks and maintenance days (obtaining replacements for the hardware, 8-pack reparations, gear maintenance, exchange of motors after reaching their lifetime, NASA field system updates, cryo-system maintenance, servo replacements and improvements for e-VLBI issues) were scheduled for the usual maintenance work.

The new TWIN radio Telescope Wettzell (TTW): The Twin Telescope Wettzell project is Wettzell's realization of a complete VGOS conform antenna array. Design and construction was in the main focus until 2011, so that the buildings were finished in 2011. Additionally a lot of factory reviews were made at the beginning of 2011 (e.g. of the sub-reflector and servo systems). Therefore at the beginning of 2012 the final review for the telescopes was completely finished without any critical points.

Figure 33: The new control room and data center in the Twin operations building.

In detail the following items were performed:

- A photogrammetric survey of the reflector surface was made on June. It included the adjusting of the sub-reflector at an elevation of 58 degree. The adjusting optimizes the wave-length error.
- The TWIN is now in the geodetic survey of the observatory.
- All mechanical installations and assemblies were finished successfully on August. Therefore the telescopes are now fully maneuverable.
- An optimization of the servo system was started according to the local conditions.
- The construction of the multiband coaxial horn for S-, X- and Ka-band and the according Dewar was produced by the company Mirad (feed) and Callisto (Dewar). A big milestone was the final review of the first three-band feedhorn (triband horn from the company Mirad, Switzerland for S/X/Ka-band). The first test results offered an excellent receiving performance in combination with the ring-focus antennas of the Twin antennas. There were delays with the final review of the Dewar, because amplifiers for the S-band became defective during the tests. They had to be shipped back to the vendor and were replaced.
- Also the Elevenfeed for tunable frequencies between 2 and 14 GHz started in the labs of the company Omnisys in the year 2011. A final design review was held in June 2012. The constructive parameters were fixed, so that the construction of the feedhorn started.
- The computer and server room was populated with the water cooled racks. The network was installed in form of a completely separated network, following the idea of creating manageable network enclaves.
- The development of the new receivers is under progress in Wettzell. Several student projects to implement single parts of them were arranged very successfully.
- After then the first installations in the northern telescope TTW1, like air conditioning, helium flex-lines, communication cable to the operator building, etc., were made by the Wettzell team.

A special task was the organization of the IVS VLBI2010 workshop for technical specifications in March 2012. Local organizers were the BKG and the FESG/TUM. Several new technical issues were discussed and presented during this meeting. More than 80 participants from geodetic fields, industry and science attended the very successful meeting.

Participation at Novel EXplorations Pushing Robust e-VLBI Services (NEXPReS) project: The remote control software "e-RemoteCtrl" was also extended mainly by the TUM. In close cooperation to the developers of the NASA field system and with other test sites new features were established. Some sites (e.g. the new AuScope network in Australia) already use the software routinely. During CONT11 the software was used to control the TIGO VLBI telescope from remote during the night shifts. The development is funded in task 3 of work package 5 of the Novel Explorations Pushing Robust e-VLBI Services (NEXPReS) project and is organized in cooperation with the MPIfR. An appropriate authentication, a dedicated role management for different user types, different remote access states to shared telescopes, system monitoring and sophisticated graphical user interfaces were developed.

5.3 Hartebeesthoek Radio Astronomy Observatory (HartRAO), S. Africa

Following the return to service of the 26-m antenna in July 2010 (after repair of the south polar bearing), VLBI activities rapidly returned to an even higher level than before, but then tapered off as the backlog of experiments that were requesting Hartebeesthoek was completed. Data volumes continued to grow as experiment PIs requested wider bandwidth observations and in response the observatory contributed some 120 TB of recording media to the EVN pool in the form of 15 new 8 TB diskpacks.

This period also saw the observatory participate extensively as a full-fledged member of the e-EVN array and subsequently a full 1Gbps-capable dedicated layer 2 light-path was commisioned to JIVE in April 2012 over 10GE connectivity.

In 2011, a new 15-m VLBI antenna equipped with a cryogenic S/X coaxial receiver was commisioned to supplement the 26-m antenna, particularly for geodetic work. This has subsequently contributed extensively to PRIDE observations of the VEX spacecraft and has otherwise helped offload some of the 26-m observing schedule.

The receiver complement on the 26-m antenna remained relatively static, though several cryogenic amplifiers were replaced due to instability problems. Work on quantifying the 26-m antenna performance at K-band continued but progress was very slow over the period but did lead to a recommendation that an upgrade to a new cryogenic receiver would be warranted. The project to improve the control of the secondary reflector and the pointing model also saw little progress.

In contrast the VLBI acquistion equipment underwent significant renewal due to
additional capital funding being secured. This saw the purchase of a new iMaser 3000 hydrogen maser, two DBBC terminals with two associated Mark5B+ VSI-H recorders and 10GE networking equipment. Extensive parallel operation with the old analogue terminal during network monitoring experiments was used for evaluation and qualification of the new terminals.

Both the EFOS-28 hydrogen maser and the Mark4 VLBI terminal (which was upgraded to a 'Mark 5' terminal by the addition of a VSI-4 sampler module) were plagued by repeated component failures, particularly towards the end of the period, with adoption of the new hardware following shortly thereafter as a result. Following repair, the EFOS-28 maser (and our original EFOS-6 maser) are now operational as standby frequency references and can be used to lock the 15-m acquisition system so that a frequency offset can be introduced for local tie experiments.

In November 2011 the observatory hosted the 10th International eVLBI Workshop and in May 2012 the National Research Foundation (NRF) of South Africa (under whom we operate as a national facility) formally joined as a full member of the EVN consortium.

5.4 Institute of Applied Astronomy of Russian Academy of Sciences, QUASAR VLBI network, St. Petersburg, Russia

The QUASAR VLBI network was created in Institute of Applied Astronomy of Russian Academy of Sciences (IAA). The network consists of three VLBI stations – Svetloe (Sv), Zelenchukskaya (Zc) and Badary (Bd). Each station equipped with 32-m fully steerable radio telescopes RT-32 and co-located GPS/GLONASS, DORIS (Bd) and SLR systems.

The QUASAR network performs geodetic and astrophysical VLBI observations on domestic (IAA

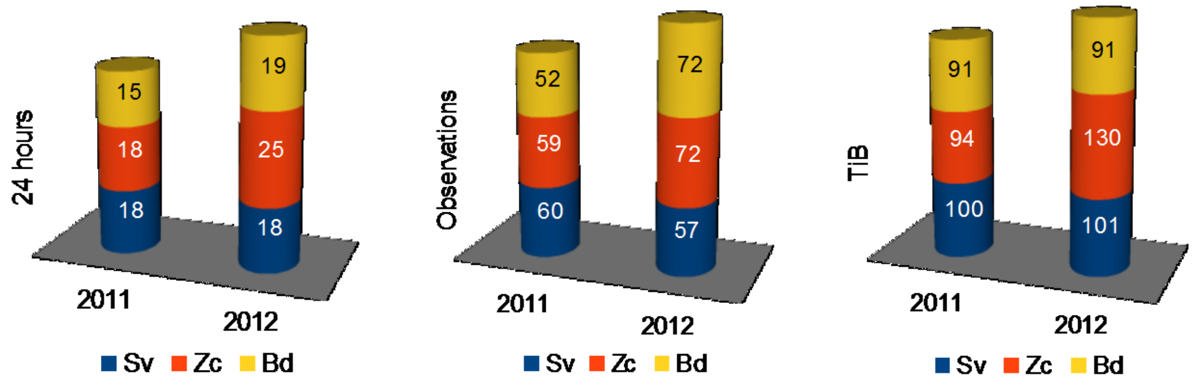


Figure 34: Statistics of EVN observations involving Sv, Zc and Bd Stations.

weekly 24-h EOP and daily e-VLBI 1-h UT sessions) and international projects with our partners: IVS; EVN and RadioAstron. During the period 2011 – 2012, each radio telescope of the QUASAR network participated in six EVN sessions at 18, 13, 6.2, 3.5 and 1.35 cm wavelengths with total duration 113 days.

IAA Correlator Center: All observatories have been linked by optical fiber lines with 270 Mbps average data transfer rate. To receive all this three data flows from stations the 1 Gbit line is available at St. Petersburg IAA Correlator Center.

The IAA Correlator Center is devoted to processing geodetic, astrometric, and astrophysical observations made with the Russian VLBI network QUASAR. The main data processing device of the IAA Correlator Center is the Astrometric Radiointerferometric Correlator (ARC). It was designed and constructed in the IAA in 2007 – 2009. The correlator has XF design and is based on FPGA technology. The ARC is a six-station, 15-baseline correlator. It is able to process up to 16 frequency channels on each baseline, for a total of 240 channels. The correlator processes two-bit VLBI signals with 32 MHz maximum clock frequency. The maximum data transfer rate from each station is 1 Gbit per second. The correlator requires VSI-H input VLBI signals, and it is equipped with Mark 5B playback terminals.

In 2011 the DiFX software correlator was installed in the IAA and began to be used in some astrophysical experiments. The DiFX is installed on a Sun Fire X4450 Server as a virtual machine under the VMware. In 2012, the DiFX software correlator became the main tool for a spectral radio source observation processing routine. We have started regular observing program in 1.35 and 18 cm wave lengths. Target sources are Orion KL, W49N, W3OH, and W75, and the experiment bitrate is 32 Mbps. The processing time for one second of real data is about eight seconds with DiFX using current facilities on a Sun Fire X4450 Server and its virtual machines under the VMware. The output data has a resolution from 1024 to 4096 spectral channels. Several experiments were observed with Simeiz station at 1.35 cm. Data from the Simeiz station were transferred by Internet directly to the IAA server, then processed with DiFX. We also used DiFX in test experiments of a new wideband DAS: a single IF channel of 512 MHz width with 2 Gbps total bitrate was successfully processed using DiFX.

Disk purchase: The QUASAR network as a single EVN unit should provide at least 150 TB to the EVN disk pool. In 2011-2012 the IAA has purchased 160 TB (20 packs of 8 TB). Thus the QUASAR network provided the EVN requirement for the minimum necessary amount of disk modules.

Antennas: In May 2012 the antenna drive (EPA) and control (RSKU-3) systems have been improved in all QUASAR stations. The velocity mode of the antennas was changed – the maximum slewing velocity by azimuth was reduced to 1 deg/sec and by elevation to 0.5deg/sec. The future schedules of EVN experiments should take into account the new limits of slewing velocities.

A number of tasks to improve the antenna design were carried out at Sv station. At the end of October 2012 the unscheduled replacement of a central azimuth bearing was made in observatory. As a result, the observatory did not participate in EVN 2012 Session 3 until the 26 October.

Correction of the subreflector initial position was made in Zelenchukskaya observatory in 2012.

In 2011 the rail track alignment was conducted at Bd station.

Receivers: The frequency convertors of the geodetic S/X receivers, as well as their local oscillators, were combined in a single device in all QUASAR stations. Theirs control system was updated too.

During the EVN 2012 Session 2 there was a problem with C-band cryogenic system at Sv station, so the experiments were carried out with warm C receivers.

The K-band receivers were installed in Bd station at the end of August 2012 and in September preliminary focusing and positioning of the antenna was performed. 1 October the first test of VLBI session in K-band was carried out on radio telescopes of the VLBI QUASAR network (Bd, Sv, Zc) and the fringes has been received. Currently the works on configuring radio telescope systems have been finished and K-band is available in normal operation mode.

Backends: From February 2012 the IAA data acquisition systems R1002 is fully functional in all QUASAR stations. Now they are used in all VLBI observations, including IVS, EVN, RadioAstron and domestic programs.

Recording systems: The Mark5B+ is the data recording system in all QUASAR stations.

H-masers: Since July 2011 the new Active Hydrogen Masers VCH-1003M were put into operation in all stations of the QUASAR network. VCH-1003M is a modern, high-performance maser with low phase noise option. It uses the latest technologies, including Stand-alone Auto Cavity Tuning (no external reference required), remote IP control, monitoring and self-diagnostics.

5.5 Institute of Radio Astronomy (INAF IRA), Italy

5.5.1 Medicina Station

During the Biennial 2011-2012 has seen many developments and renewing of the antenna system.

At the end of 2010 INAF provided us a special funding we required to renew many parts of the antenna. The plan of refurbishment will take four years in order to complete the following tasks:

1. Replace all the helium pipeline and add a new cryogenic compressor
2. Substitute the old coaxial cables with fiber optic in order to send the receivers band and control signals to the antenna control room
3. Replace the antenna elevation rack and pinion and refurbish the reduction gears
4. Substitute the old antenna lift with a new one
5. Replace the old subreflector drivers and motors with a new generation and rewrite the whole control software
6. Paint the antenna completely
7. Buy a new H-Maser

Our aim is to manage this maintenance keeping loss of astronomical experiments as low as possible.

Figure 35: (Left) Cooled parts of the dual feed. (Right) The dual-feed mounted on secondary of the focus of the antenna.

In 2011-2012 we completed item 1, 2 and 7 and started the design and management of items 4 and 5. Completion of all items is foreseen for 2014-2015.

During 2011-2012 a new dual-feed receiver in the 18-26GHz band has been developed (Figure 36). It has been mounted on the antenna in February 2013 (Figure 36) and soon VLBI fringe were detected at the session run 1.

In the same period a new cooling system has been installed both in the 6cm (4.3-5.8GHz) and 13/3.6 cm receivers.

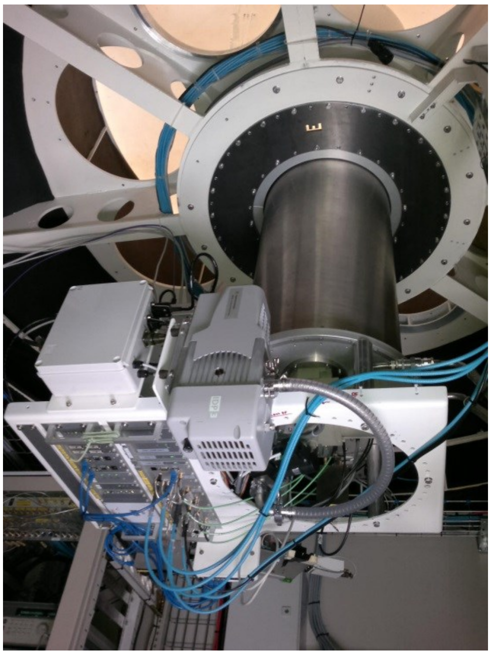


Figure 36: (Left) 5.7-7.7GHz in the beam-waveguide focus of the SRT, (Right) 7-beam in the Gregorian focus.

The VLBI data acquisition system is being to be equipped with a MK5C, by refurbishing the already in place MK5B+ and a DBBC has been delivered. The network link has been upgraded to 10Gbps from the radiotelescope to the GARR network backbone.

Figure 37: The DBBC and FILA10G replacement for the MK4 terminal.

At the end of 2012 the amount of disks capacity at Medicina station is 200TB. Medicina performs e-VLBI experiment routinely and since the end of 2011 participates at the Radioastron observations.

In these two years Medicina staff also completed most of his commitment in the commissioning phase of the Sardinia Radio Telescope, by installing receivers (Figure 37), back-ends, servosystems and antenna control software.

5.5.2 Noto Station

The antenna was stopped after the severe damage in the azimuth axis involving the wheels and track. Antenna grout remaking, new wheels and a new track have been financed by the Italian Ministry of Research, and the antenna azimuth axis has been repaired. The antenna was able to restart the observations with greater accuracy in pointing, particularly useful for the K and Q bands. The telescope alignment and the general set up has been performed in few weeks, and so the renewed Noto antenna was ready to start and observe in the first months of 2012.

Two receivers operating in the range 80-100 GHz for secondary focus have been acquired from IRAM and as soon as funds will be available they will be adapted to the antenna optics.

The SXL primary focus receiver developed in the last years was renewed in order to reduce its weight. The project of the broad-band receiver, operating between 2 and 14 GHz has been completed. The construction is planned in parallel with the new primary focus receiver.

An optical fiber link for e-VLBI activities has been financed by GARR (Italian Academic and Research Network). The station was operated successfully in e-VLBI with the Jive correlator at 1Gbps. The upgrade to 10Gbps was expected as next step of the network upgrade. Indeed a connection at 10Gbps is necessary for starting the observation experiments at 4Gbps, today possible with the latest implementation of the backend - network FILA10G interface (DBBC).

The DBBC system was upgraded from DBBC1 to DBBC2 and then gradually up to DBBC2010 in order to meet the VLBI2010 requirements. The system will have 8 IFs available, so to be able to observe in all the standard VLBI tunable modes and in the wide polyphase band with 2-4-8-16 Gbps output data rate. It fully replaced the MK4 terminal, not anymore in use, at the re-start of the antenna (Figure 38). New spectrometer functionality has been recently added to the DBBC system.

In July 2012 the DBBC3 project started, financed by Radionet3. The goal is to develop the next generation VLBI backend capable to handle up to eight 4 GHz IFs and to produce an output data rate of 32/64/128 Gbps for the wide band EVN astronomical and VGOS broad band geodetic observations.

5.6 Jodrell Bank Observatory (JBO), University of Manchester, Jodrell Bank, UK

Jodrell Bank Observatory performed a total of 251 EVN experiments during 2011-2012. Sixty-four experiments at 18/21cm, 51 at 6cm, 21 at 5cm, 15 at 1.3cm and 3 at 90cm were scheduled to use Jodrell Bank's Lovell, Mk2 and Cambridge antennas. Just prior to the February/March 2011 session a serious drive fault occurred on the Cambridge antenna which took it out of service for all of 2011 and part of 2012. Some, but not all, scheduled Cambridge observations were performed with the Knockin antenna. Prior to the October/November 2012 session the Lovell telescope suffered a critical wheel failure which took it out of operation for the duration of that EVN session. Hence, all experiments were performed using the Mk2 telescope. None of the experiments during 2011-2012 were joint MERLIN/EVN observations due to ongoing e-MERLIN commissioning.

Apart from wind, the primary causes of lost data continued to be associated with the Mark 5 data recorders. Other problems included warming receivers, occasional swapped polarisations, failed bias supplies, and regular but short encoder faults on the Lovell telescope. Although this period saw the replacement of much of the JBO observing infrastructure due to e-MERLIN commissioning, the observing statistics remained positive. A total of 1375.3h of telescope time was scheduled for EVN observations during 2011-2012. This consisted of 797.8h on the Lovell, 512.5h on the Mk2 and 65h on Knockin. In terms of waveband this was 560.8h at 18/21cm, 502.5h at 6cm, 203.5h at 5cm, 92.5h at 1.3cm and 16h at 90cm. The total reported data loss at the telescope for 2011-2012 was 49h42m (3.6%), i.e. a success rate of 96.4%.

During this period the home station VLBI telescope (Lovell and Mk2) and eVLBI have continued as normal during the complex change-over to e-MERLIN at JBO. Optical fibre-based IF transport from the Lovell and Mk2 telescopes to the VLBI observing room were installed. The new IF systems for e-MERLIN compatibility have produced EVN fringes at all standard observing bands. A stabilised noise CAL diode driver has been built and installed on the Mk2 telescope to provide better calibration reliability. Some scripts and software changes have been made to allow easier and more rapid switching between different telescopes and observing bands. Automation of e-VLBI schedule processing has also been improved. Some local improvements in receiver and down-converter hardware have been implemented to improve reliability.

There was limited progress in returning an e-MERLIN outstation (e.g. Cambridge) to the EVN. A recording of VDIF (VLBI) format data on the e-MERLIN correlator system has proved readable by JIVE and fringes between Knockin and Darnhall have been detected. This format may prove to be transmissible via fibre direct to the JIVE software correlator. Although one of JBO's Mark 5 recorders was upgraded to 5B, the VDIF format will not be recordable using the 5a/5b formats, but a Mark 5C+ or Mark 6 recorder will do. This requires a Streamstor 'Amazon' board plus 10GE interface. The e-MERLIN correlator has an internal data channel which is not used for e-MERLIN data, but which could be used to duplicate the data without rotational modelling, i.e. we would have both rotated and un-rotated signals, allowing combined e-MERLIN/VLBI observing. A third 1Gbps light-path ('UKL3') for e-MERLIN and eVLBI transport has been provided by JANET and tested.

JBO Staff Roles in EVN activities: Simon Garrington represented Jodrell Bank Observatory at EVN CBD meetings and on the JIVE board.He took over as Chair of the EVN CBD from1 July 2011. Rob Beswick took over as EVN-CBD Secretary and editor to the EVN newsletter from 1 July 2011.

Throughout this period Tom Muxlow was the JBO repressentaive on the EVN PC and the has acted as the EVN PC Chair from 1 July 2011. Muxlow and Beswick were also members of the EVSAG (e-VLBI Science Advisory Group).

5.7 Max-Planck-Institute for Radio Astronomy (MPIfR), Bonn, Germany

MPIfR STAFF ROLES IN EVN ACTIVITIES: Anton Zensus represented the MPIfR at the EVN CBD Meetings and on the JIVE Board. He took over as vice-Chair of the EVN CBD from 1 July 2011.

Richard Porcas was the EVN Scheduler for the period of this report.

Andrei Lobanov was the MPIfR representative in, and Secretary of, the EVN PC and attended PC meetings together with Richard Porcas. Lobanov and Porcas were also members of the EVSAG (e-VLBI Science Advisory Group).

Walter Alef was the Chair of the Technical and Operations Group until December 2011. Uwe Bach was the VLBI observing friend in Effelsberg and attended TOG meetings together wth Walter Alef.

Zensus, Porcas and Alef attended EVN CBD meetings.

EFFELSBERG ACTIVITIES: The Effelsberg 100m telescope took part in all EVN observing sessions and all e-VLBI runs during 2011-12. A new telescope control system, based on Linux and VME machines and initiated in summer 2010, was completed by 2011. It was successfully tested for VLBI observations using the the MKIV and VLBA terminals, and with single dish observing modes for continuum, spectroscopy, and pulsars.

In 2011 a new wideband receiver for low frequencies was installed at the prime focus at Effelsberg. It covers the range from 300 to 900 MHz and provides dual circular polarization. The 92cm (327MHz) band was tested successfully in EVN Session II, 2011 and with the Russian RadioAstron satellite (see below). Since the receiver provides the full 300-900 MHz range, simultaneous 50/92cm observations should be possible, in principle.

Following a request from Chris Jacobs at JPL, Effelsberg particpated in a test VLBI run at 32 GHz on August 11th, 2011, together with DSS-55 at Robledo. The Effelsberg "1cm" receiver has a single, linear polarization channel. Fringes were successfully obtained, following correlation at JPL.

On 18th May 2011 Efflsberg hosted celebrations marking the 40th anniversary of the 100m telescope. "First light" was received at 2.7GHz on 23rd April 1971 with drift scans on the radio source HB 21. The telescope was first driven while taking data for the 408 MHz radio continuum survey during the official opening on 12 May 1971. First VLBI fringes were obtained in June 1973 together with Green Bank and Goldstone at 2.3 GHz.

Recorders and backends: During the period of this report new digital VLBI backends were successfully integrated into the Effelsberg observing system. In 2011 Effelsberg was equipped with a new Field System PC, a DBBC2 unit and a Mark 5B+ recorder, which could be used in parallel with the old MKIV and VLBA teminals. The Feb/Mar EVN Session 2011 was recorded using both the MKIV and the DBBC, and the DBBC was used as the primary backend in the May/June EVN Session 2011. On July 4/5 Effelsberg participated in the geodetic observation EUR112 using both Mark IV and DBBC backends. This was the first time that all four IF channels and all FPGA boards were used to yield 14 BBC channels at Effelsberg. Just after EUR112 Onsala and Effelsberg performed a successful fringe test observation using the polyphase filter bank mode of the DBBC. In this mode a 512MHz wide IF of a single circular polarization is split into 16 x 32MHz channels and recorded at 2 Gbps on a Mark5B+. The observations were performed at X-band (RCP) over a frequency range of 8640-9120MHz. Subsequently, some problems were uncovered during the e-VLBI run in August, the special 1.3cm disk run in September and in the October 2011 GMVA session. The cause of these failures was identified as a broken PCI card in the DBBC internal computer, preventing communication with the DBBC boards. In 2012, following repair, the DBBC backend became the standard terminal for all EVN, e-EVN, global and geodetic VLBI observations. JIVE staff provided SCHED setup files adapted to the requirements of the DBBC for EVN sessions. Special station code was implemented at Effelsberg to allow the integration of the DBBC commands and use of NRAO-like continuous Tsys calibration at 80Hz.

In 2011 a complete VLBA-style digital backend (2 x RDBE units and IF switch box), together with a MK5C recorder, were installed in Effelsberg and test observations were made together with VLBA antennas in which the RDBE was configured in a dual-polarisation polyphase filter mode at 2Gbps. A FS facility to control the NRAO RDBEs was added as station code. One RDBE was used regularly to support 2Gbps observations with the VLBA and GBT as part of the High Sensitivity Array, using the polyphase filter bank mode.

RadioAstron fringe-search: Effelsberg participated in a number of the fringe test experiments with the Russian RadioAstron satellite. The first – and successful - fringe test was on November 15th, 2011, at 18cm wavelength, followed by first 6cm fringes on December 1st. The first 92cm fringes were found in an experiment with Arecibo, Westerbork and Effelsberg on January 25, 2012. On May 12th Effelsberg participated in a successful test experiment to produce first fringes at 1.3cm. The source was 2013+37. Subsequently, Effelsberg participated in 145 RadioAstron Early Science Program observations in 2012.

BONN Correlator: The Bonn VLBI correlator is jointly operated by the MPIfR, GIUB (Bonn) and the BKG (Frankfurt) within the MPIfR Division of VLBI Technologie, with Walter Alef as Division Head. All VLBI observations are processed using the DiFX software correlator running on a compute cluster. DiFX was developed at Swinburne University by Adam Deller et al, and adapted to the VLBA operational environment by Walter Brisken et al. The correlator is equipped with 14 Mark 5 units which can all play back Mark 5(A, B or C) data. Correlated data is archived in raw format and FITS. MKIV format and MKIV fringe-fitting is also available. (The MKIV correlator, operational from 2000, broke in early December 2010 and was declared beyond repair.)

On June 14th 2012 fringes were obtained using the Bonn DiFX correlator for the Radioastron 6cm fringe-test experiment observed on 1 December 2011. The source was BLLac.

Table 6: EVN observations correlated in Bonn (2011-2012).

Project Code	PI	Target
EY010D	Yan	PSR J1022+101
EM080B	Moldon	PSR J2032+4127
EW014	Wagner	OH in AGN Tori
EY013A	Yan	PSR B1257+12
EM077F	Mantovani	Blazars
GW022A	Wucknitz	pulsar scat.
GW022B	Wucknitz	pulsar scat.
EY010E	Yan	PSR J1022+1001
EY013B	Yan	PSR B1257+12
EY013C	Yan	PSR B1257+12
ER027	Rampadarath	M51 wide-field
EY013D	Yan	PSR B1257+12
GB073	Bourda	ICRF/GAIA
EY013E	Yan	PSR B1257+12
EG067A	Gwinn	PSR B1932+214
EG067B	Gwinn	Crab PSR
GK045A	Kovalev	2013+37, 2037+51
GK045B	Kovalev	2013+37, 2037+51

Table 7: Data recorded at EVN telescopes for RadioAstron ESP observations which have been copied in Bonn for shipment to ASC, Moscow, and also correlated in Bonn for ASC comparison.

Project code	PI	Title	Target
EG060A	Gwinn	Crab	Pulsar
EG060B	Gwinn	Crab	Pulsars
EK032A	Kovalev	0716+714	Core
EK032B	Kovalev	0716+714	Core
EK032C	Kovalev	0716+714	Core

OTHER VLBI ACTIVITIES: In 2012 first VLBI fringes were achieved with the APEX telescope in Chile at 230 GHz (1.3mm). The observations took place on 7 May, with the SMT (Mount Graham) and SMA (Mauna Kea) as partner telescopes. The 9447 km APEX-SMA baseline (7.2 G-lambda) constituted a VLBI resolution record. Fringes were obtained on all baselines on the bright quasar 3C279, using digital backends producing 2 Gbps. A DBBC and MK5C recorder were used at APEX. Correlation was performed at the Bonn correlator. This achievement is a very significant step towards the realization of a Global VLBI network at 230 GHz and the "Event Horizon Telescope".

In 2012 the MPIfR hosted a RadioAstron Key Science Programme Workshop in Bonn from December 3rd to 4th. The aim of the workshop was to to discuss the letters of intent submitted by various groups of investigators who intended to conduct extensive observational programs in the key science area of RadioAstron. (see: http://www.mpifr-bonn.mpg.de/KSPWorkshop2012)

5.8 Metsahovi Radio Observatory (MRO), Aalto University, Finland

VLBI Observational Activities:
2011 project team: Uunila, Rastorgueva, Molera, Mujunen, Ritakari, Wagner
2012 project team: Rastorgueva-Foi, Uunila, Mujunen, Ritakari

Figure 38: The new VLBI rack at Metsahovi.

Metsähovi performs both astronomical and geodetic VLBI observations in conjunction with three global networks of VLBI: the European VLBI network (EVN), the International VLBI Service (IVS; in collaboration with FGI), and the Global Millimeter VLBI Array (GMVA). Furthermore, Metsähovi has actively taken part in spacecraft VLBI tracking observations organized by Joint Institute for VLBI in Europe (JIVE) in cooperation with the European Space Agency (ESA) as well as real-time dUT1 experiments with Japan and Sweden.

VLBI Sessions in 2011-2012: In 2011 Metsähovi took part in eight geodetic VLBI sessions (in four EUROPE sessions and in four T2 sessions). The Global mm-VLBI Array (GMVA) observed two sessions, in May and October of 2011. Metsähovi only participated at EVN sessions measured at 22 GHz. Three EVN sessions were conducted at the station. In June 2011 one 22 GHz EVN ToO experiment was observed.

In 2012, Metsähovi took part in seven geodetic VLBI sessions (in three EUROPE sessions and in four T2 sessions). Metsähovi only participated at EVN sessions measured at 22 GHz. Three EVN sessions were conducted at the station. DBBC was used in parallel with the analog back-end during EVN Session 3/2012 in October 2012. Metsähovi also participated in tracking of Venus Express (VEX) and

RadioAstron space VLBI spacecrafts in 2012. VLBI spacecraft tracking for study of the interplanetary plasma scintillations was used in X-band as a part of EVN Planetary Radio Interferometry and Doppler Experiment (PRIDE). Metsähovi did not participate in the Global mm-VLBI Array (GMVA) sessions in 2012 due to the 86 GHz VLBI receiver re-furbushing.

Technical activities

Receivers:
Project team: Kirves, Mujunen, Oinaskallio, Kallunki, Rönnberg

86 GHz receiver: The 86 GHz receiver was originally obtained from the debt conversion between Finland and Russia. After multiple tries to make it operational, a new receiver was built from a scratch.

After October 2011 GMVA session the 86 GHz receiver was dismantled for modifications and improvements. Which gave an excellent opportunity to separate and check the front part for radiation pattern. The feedhorn was measured at a near field scanner facility at Aalto University campus in February. From the measured patterns it was evident that the quasioptics really distort the radiation pattern severely. One solution could be to move feedhorn 80-100 mm forward.

Another main problem with the receiver is its high dependency on the outside environment temperature. Therefore some detector types and the IF modules of the receiver were characterized. The outcome was that it is necessary to have a temperature stabilization for the IF part.

Addendum 4 to the Contract was agreed by the Finnish party in the middle of February 2011. The contents of this addendum was to set realistic dates and conditions in the view of finalizing the project. The addendum was nevertheless not signed by the Russian party. Several pointing calibration runs were performed both in the Spring and in the Autumn 2011, but satisfactory results were not achieved. Investigations continue with the stability and radiation pattern issues.

For testing purposes a phase locked 9 GHz programmable signal source was built from readily available modules. The cost of this was only some hundreds of euros. It was ready in two weeks time and the performance is quite good.

In 2012 it was decided that a major rebuild of the 86 GHz receiver was needed due to the fact that the original construction proved to be too unreliable if not even nonfunctional. Rebuild meant that the whole receiving chain starting from the Gaussian beam geometry and ending to IF bandwidth and detection needed to be thought over. Several new components were needed to substitute the Russian standard devices: directional coupler, power divider, harmonic mixer, phase lock circuitry, waveguide transition, a couple of new waveguides, new dewar flanges and several intermediate frequency components.

Mechanical parts to place the feed horn 80 mm forward were manufactured at site. They included lengthening of the dewar as well as the radiation shield and various parts to supports to mount the new parts firmly and thermally non-conductively to the surroundings. Some precision mechanics parts were manufactured at Precia Oy. Electrical components were ordered from well known manufacturers.

New LO system is still based on the Gunn oscillator but the PLL design was started from scratch. Because the observatory staff has no recent experience on designing such system, a related firm RF-shamaanit were consulted at the beginning. Phase locking system is build from a registry settable

PLL chip and a low noise active loop filter circuit already available today. The system fits in a small space.

In the autumn the modification of the feed system was ready and was measured at the near field scanner facility at Aalto University campus at Department of Radio Science and Engineering. The measurement results were as expected. Radiation pattern was improved clearly but still the mirror edge cuts the beam notably which was verified by calculating the beam width at the distance of the mirror. The consequence is seen as a diffraction pattern in the horizontal plane. The pattern is nearly undistorted between the angles ±7 degrees, the illumination angle of Metsähovi antenna sub-reflector, however. Therefore it is assumed that the feed would work now adequately. Rebuilding started in November with dewar dismantling, wash and assembly of the new parts.

22 GHz receiver: 22 GHz VLBI receiver appears to have some trouble with the signal level while not yet fully cooled down. The operation restores to normal when it reaches the nominal operating temperature around 20 Kelvin. The reason was later investigated and fixed.

VLBI instrumentation:
Project team: Ritakari, Kallunki, Mujunen, Kirves, Oinaskallio,
Uunila, Rastorgueva-Foi, Molera-Calvés (NL)

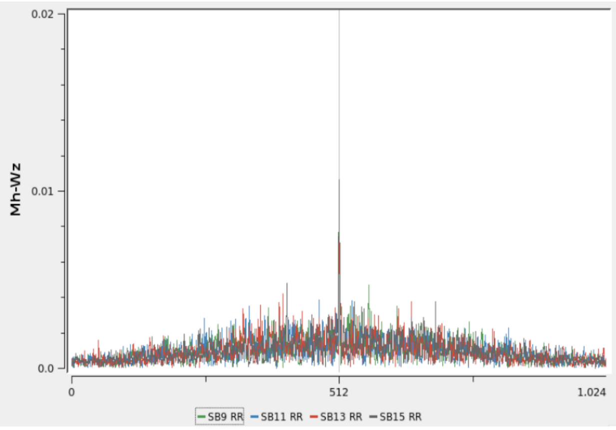


Figure 39: The first fringes with the dBBC.

The VLBA rack was reaching its end of life. During the years several BBC units have failed and spare parts are not anymore available. Two of the BBCs with failing VCO were restored back into operation by installing an ADF4350 synthesizer board in place of the original LO unit. This modification is supposed to hold up the old analog system until its replacement with the new digital BBC system in the year 2012. The first fringes with the new digital back-end were observed in December 2012 (Figure 40). Additionally, before the fringe test, the dBBC was tested successfully with the VEX observations. The results with the dBBC were substantially better than with an old analog system (both phase and frequency stabilities). The old rack was later retired and replaced with dBBC.

Mark 5A issues/Mark5B+: We have fixed our Mark5A 1 Gbps recording problems by changing a resistor (R25 to a 27-ohm one) in the Mark5A I/O board. We have purchased a Mark5B+ system, which is now in use.

Formatter issues:
Metsähovi has been suffering from formatter being out of sync problems during various sessions. After deploying the Mark5B+ and the DBBC these problems vanished.

Phase cal: Because the phase cal box is temperature dependent and because there has been a lot of drifting and phase jumps, the box was later temperature stabilized.

1PPS problems: The 1PPS distributor destroyed the Metsähovi 1PPS going to the VLBI equipment. A new distributor has been purchased. 1 pps distribution unit was replaced in 2012.

5 MHz distribution unit: Serious phase instability issues in VLBI measurements were noticed in Summer 2012. They were caused by corrupted reference signal (5 MHz) or more precisely 5 MHz distribution unit. This unit was replaced (in clock room) and, after this, the phase coherence problem vanished.

e-VLBI and EC FP7 NEXPReS:
2011 project team: Ritakari, Molera, Mujunen, Uunila, Turtiainen
2012 project team: Ritakari, Mujunen, Salminen, Uunila

Metsähovi is taking part in a 3-year EC FP7 CP CSA project called "NEXPReS - Novel EXplorations Pushing Robust e-VLBI Services" (Grant Agreement 261525). The project started in July 2010 and Metsähovi is leading its Joint Research Activity Work Package WP8, Work Package WP8, originally titled "Provisioning High-Bandwidth, High-Capacity Networked Storage on Demand" but later shortened to FlexBuff, is exploring ways to implement on-demand networked storage to match the multi-Gbps bandwidth and petabyteclass capacity requirements of VLBI in a distributed manner. Additionally, the work package addresses the use of such high capacity storage systems for the data archives of the future.

The objective of WP8 is to determine the best practical combination of commercially-available technologies which will serve the needs of evolving, multi-Gbps high rate data acquisition and processing. This includes determining both the most suitable hardware and operating system architecture and the most applicable user software architecture which can support multiple simultaneous high-speed input and output streams. The VLBI application is a forerunner in being able to fully exploit this unique capability when recording local real-time telescope data at a given station while providing access to previously made recordings.

In WP8 Metsähovi is responsible for the coordination of the work package and for providing the basic technologies and software upon which the storage systems are being built.

In 2011 NEXPReS WP8 Metsähovi have concentrated on developing the basic technologies to allow continuous, high-speed bidirectional buffering. A fully-COTS 4U platform was developed at relatively low cost and still offering generous disk space (36 disks, 72 TB or 20 hours of continuous 8Gbps recording) and excellent expansion potential (7 low-profile PCIe x8 expansion slots). On the software side we were able to identify and eliminate most of the bottlenecks that limited the performance of our disk recording system in the previous EXPReS project to 6Gbps with a 20-disk raid0 arrangement. We could confirm that the performance was limited by a single kernel thread flushing all data from block buffer cache to the single raid0 file system. We had tried to rectify this already in EXPReS by experimenting with "O_DIRECT" write option, which should bypass the buffer cache and the synchronizing kernel thread. However instead of an improvement, performance decreased. Further testing revealed that it is imperative to use O_DIRECT together with relatively large blocks in a single "write()" call (2–64MB or more). This allows the Linux kernel to effectively distribute the elementary hardware requests to multiple disks without causing too frequent completion waits which are otherwise inherent in the O_DIRECT mechanism.

As it is relatively straightforward to divide our data in successive large blocks we will get very limited benefit from using few large RAID arrays. If we instead give each disk spindle its own process and/or thread performing O_DIRECT "write()" calls with large enough block size, we will get maximum parallelism and utilization of available multiple CPU cores concurrently. In our tests with the low-cost preliminary hardware platform we already obtained more than 17Gbps using only 22 disks concurrently. This process only required 20% of the available capacity of six CPU cores.

Supporting simultaneous reading and writing presents two fundamental difficulties in today's disk systems. The first one is the limited bandwidth available throughout the system. Reading and writing simultaneously requires double the data streaming bandwidth in the internal data path, compared to the bandwidth needed for reading or writing alone. The second problem is caused by hard disk drive seek time: it takes a long time to move the magnetic head back and forth between two read and write areas of the disk. This problem can be alleviated with proper interleaving of reads and write. To minimize the effects of hard disk 8– 12ms seek times, one must stream in either read or write direction for much longer than this seek time (or full disk rotation time, approximately 8.3+1.1ms). For instance, read streaming for about 120ms gives the data from 10 rotations, then the seek required to switch to write streaming wastes only the time of one rotation. This will result in approximately 90% efficiency for the total read+write bandwidth. It is important to note that

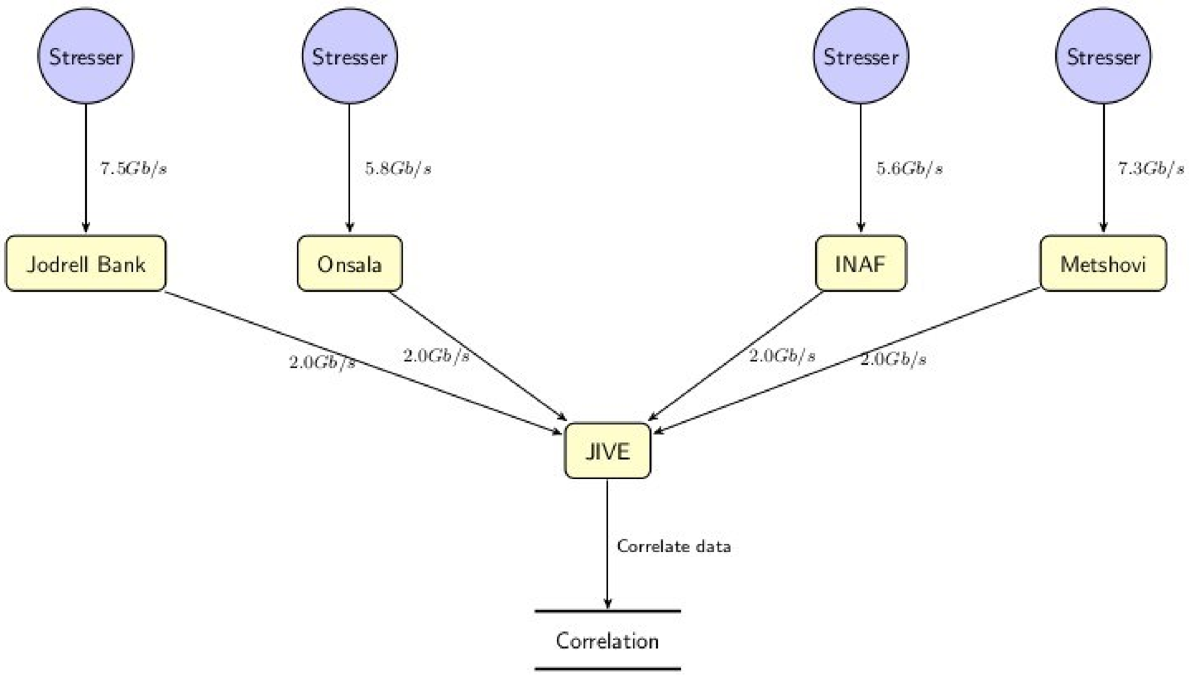


Figure 40: Multi-station high-speed streaming setup for "vlbistreamer".

simultaneous read and write will at least halve the available total bandwidth in a given system.

In 2012 we had one full-time software engineer devoting all his time to the development of "vlbi-streamer" data acquisition software. A large fraction of effort was spent also on assisting participating partners in installing and testing "vlbi-streamer" at their sites.

Work during 2012 in WP8 FlexBuff concentrated on testing and verification of the "vlbi-streamer" data acquisition application software running on generic, commercially available Linux platforms. Several test FlexBuff systems were (and are) available at partner sites, representing a wide variety of COTS Linux platforms, including several instances of both kinds of systems recommended in WP8 hardware study and also hardware RAID systems at partner INAF and computing center nodes at partner PSNC. "vlbi-streamer" software was exercised on all of them and it showed remarkable capability of adapting to the varying environments, still retaining its high-rate performance.

5.9 National Astronomical Observatory (OAN), Instituto Geografico Nacional (IGN), and the Yebes Observatory Madrid, Spain

The National Geographical Institute (IGN, Ministry of Development in Spain) is the host institution for the National Astronomical Observatory (OAN) and the Yebes Observatory (CAY), and operates a 40 meters radio telescope which participates in the observation sessions of the European VLBI Network.

In 2011, IGN has signed an agreement with Spanish NREN (RedIRIS) to install a dark fiber and equipment to provide a 10 Gb/s connection. At the observatory, the network equipment required for this speed has also been installed. This connection has been used later for transferring VLBI data after observations and for real time eVLBI.

The DBBC from IRA-INAF has been installed and tested. The system with 2 IFs, two ADB boards and 2 COREs works correctly.

A lot of work has been done to improve the performance of the Yebes 40-m radio telescope, which has impact on its operations as single dish, as well as for VLBI. A new membrane was installed at the vertex. The older membrane did not work as expected at 3 mm and caused absorption and reflections. It was replaced by a new membrane with a dielectric material with better properties that increased the efficiency of the telescope at 3 mm.

Efficiency curves and beam maps as a function of elevation were obtained for different frequencies. The study showed that the 40-m suffers season astigmatism which affects observations above 45 GHz, and has important an effect at 3 mm. Astigmatism has a very negligible impact at low frequencies.

The 40m RT has been equipped with an 8 channel Fast Fourier Spectrometer for single dish observations. The FFTS allows 4 different configurations with different spectral resolution and bandwidths (from 100 to 1500 MHz).

5.10 National Astronomy and Ionosphere Center, Arecibo Observatory, Puerto Rico

During the period 2011 – 2012, Arecibo participated in 24 EVN observations. Most of these employed the legacy VLBA4 Data acquisition rack (DAR) and the Mark5A recorder. Even though, Arecibo's management changed hands from the 1st of October 2011, the VLBI commitment of the Observatory has been maintained by the new organization and the transition has no adverse effect on its participation in all VLBI observations.

Figure 41: VLBI recording equipment at Arecibo.

During this time, the Polyphase-filter-bank (PFB) mode of the RDBE-based DAR and the Mark5C recorder were brought into operations under the control of the FS. The Arecibo staff were assisted by Drs. Dave Graham, Uwe Bach from the MPIfR in this effort. Since late 2012, most of the HSA observations at Arecibo have been utilizing this mode. The DDC mode for the RDBEs will need some additional hardware and software, which will be installed in the near future.

Arecibo has also co-observed with the Russian space-radio telescopes RadioAstron during this period. A 12-m diameter antenna to aid in correcting for atmospheric phase fluctuations, has been installed and integrated during this period. Commissioning is underway. When fully functional, the 12-m telescope will help in phase referencing VLBI observations making these up to 50% more time efficient. It will also be used in geodetic VLBI, search of variable and transient sources, mapping the sky at C or X band, and for "hands-on" training of local and visiting students.

5.11 Onsala Space Observatory (OSO), Chalmers University of Technology, Onsala, Sweden

Operations: The Onsala Space Observatory (OSO) telescopes continued during 2011 and 2012 to play a full role within the global observing program for astronomical VLBI. In total 9 astronomical VLBI-sessions (6 EVN sessions and 3 global mm-VLBI sessions) were conducted. OSO is also regularly involved in e-VLBI sessions (typically 10 24 hour sessions per year) within the EVN. In addition, the Onsala 20m telescope has been used for 38 (including CONT11) and 40 geodetic VLBI experiments in 2011 and 2012, respectively, as part of the observing program of the International VLBI Service for Geodesy and Astrometry (IVS).

Since February 2009 Rüdiger Haas is the Technology Development Centers Representative in the Directing Board of the IVS. He is also since 2009 the IVS delegate to the Directing Board of the International Earth Rotation and Reference Frames Service (IERS). Within the IVS, Rüdiger Haas leads since 2009 the Task Force for the Intensives, and the IVS Working Group for Training and Education. Rüdiger Haas continued during 2011/2012 to serve as secretary for the European VLBI Group for Geodesy and Astrometry (EVGA).

Michael Lindqvist is the OSO representative on the EVN Program Committee and attended its meetings. Michael Lindqvist is chairman of the EVN Technical and Operations Group (TOG) since January 2012. He was the vice-chair of the TOG until December 2011.

Technical progress: In 2011 the geodetic VLBI campaign CONT11 with 15 days of continuous observations was performed at Onsala completely with real-time data transfer to the Tsukuba correlator in Japan and near real-time data analysis. As a result, a continuous 15 day long time series of earth rotation data could be determined in near real-time, while CONT11 was ongoing.

In 2011 we started to thoroughly test the modern digital backend (DBBC) for geodetic and astronomy operations. Several VLBI experiments were performed with parallel observations and recordings with the old Mark4-system and the new DBBC. The recorded data were correlated at the JIVE and Bonn correlators and inspected by both zero-baseline tests and standard astronomy/geodetic data analysis.

During the 2012, Radionet3 JRA DIVA work on developing wideband feeds and a backend (DBBC3) for VLBI began. OSO is also a partner in the EU-funded project NEXPReS, which is aimed at enhancing the scientific performance of the EVN. In particular, it will allow the introduction of an e-VLBI component to every experiment and thus improving the robustness and flexibility of the array. During 2012, the project has e.g. demonstrated the possibility of 4 Gb/s recording and real-time e-VLBI correlation of three EVN stations (including OSO). In addition, another important demonstration of triggered observation and correlation happened in May 2012. A pre-written observing schedule was transmitted to a workflow manager platform, developed in the project, which then re-transmitted it to the participating telescopes, whilst simultaneously processing the schedule ready to begin a correlation. At the start time specified in the schedule, the workflow manager then again contacted the telescopes and correlator to begin the observation, causing them to abort their current observations and observe the new source.

The 25 m telescope tracking problem was partially identified as an axial backlash in the polar unit. This has affected the data taken with the telescope, even in moderate wind speeds (> 7 m/s). A major repair of the polar unit was therefore made in May 2012. This included a removal of the 4-ton polar unit, control of the worm drive's gear condition, and replacement of its tapered roller bearings. The renovation has improved the pointing performance of the telescope considerably, but there are still some tracking issues to be resolved. This major repair was efficiently executed without impairing the scheduled observations.

On December 5, 2012, OSO, Yebes and Effelsberg performed a successful VLBI-fringetest observation at a data rate of 2048 Mb/s using their new digital VLBI backends, the EVN DBBC and the RDBE (from the National Radio Astronomy Observatory, NRAO, USA), in a poly-phase filter bank (PFB) configuration. This is a very promising result and a big step forward towards global VLBI observations at data rates of up to 2 Gb/s and beyond.

5.12 Shanghai Astronomical Observatory, National Astronomical Observatories, Shanghai, P.R. China

Observations: The Sheshan VLBI station is hosted by the Shanghai Astronomical Observatory, Chinese Academy of Sciences. During the period 2009-2010,Shanghai 25meter radio telescope (also known as 'SESHAN25' in geodetic community) participated in five EVN sessions at 18, 13, 6, 5, 3.6 and 1.3 cm bands. All systems worked well in these observations. Shanghai 25meter telescope was absent in the May 2012 session because of antenna maintenance. Shanghai radio telescope also participated in twenty-two e-VLBI sessions.

Update and Current status of equipments: At the present, two terminals are working well at the Shanghai VLBI station, VLBA and CDAS. The VLBA terminal includes a VLBA sampler, a VSI-C card together with a Mark5B+ recorder. The CDAS terminal consists of an DBBC and a Mark 5B+ recorder.

We have upgraded the MarkB+ Firmware Version to 12.06 (API 10.07, SDK 9.2), in order to be compatible with the 16TB module.

We brought five new diskpacks (5*4TB) and four (4*8TB) during the year of 2011 & 2012.

Personnel Changes of Sheshan VLBI Station: Dr. Jian Dong started his job in VLBI group since 2011, concentrating on the active surface and OTF observation pattern of the 65m radio telescope.

Xiuting Zuo, Yunxia Sun, Xiaocong Wu, Wen Guo, Yongchen Jiang and Ying Chen joined the VLBI group and mainly answered for routine operation.

e-VLBI: The Sheshan radio telescope participated in 512 Mbps e-VLBI observations organized by the EVN.

Prospects: Construction of a new radio telescope with a diameter of 65 meter started in early 2009, and the majority of the mechanical system was completed in October 2012. By design, Shanghai 65 m radio telescope with a diameter of 65meter, one of the largest steerable radio telescopes in the world, is a multifunction facility, conducting astrophysics, geodesy, astrometry, as well as space science. Shanghai 65m radio telescope has been installed with four cryogenic receiver systems (C(6cm), S(13 cm), L(18&21 cm), X(3.6 cm)). It is also equipped with multiple back-ends consisting of single dish terminal, VLBI terminal and etc. DIBAS is imported from NRAO for Pulsar and spectral line observations. For pulsar observation, it has 2 GHz bandwidth for coherent and 6 GHz bandwidth for incoherent, both with 64\128\256\512\1024\2048\4096 channels selectable; for spectral line observation, it has wide band (maximum 1.5 GHz BW) and narrow band (highest spectral precision 0.24 KHz). DBBC2 is the VLBI terminal for EVN observations. CDAS is a VLBI data acquisition system designed by SHAO. Inputs are 4 IFs, each with 512 MHz bandwidth; and outputs have 16 BBCs, with bandwidth of 0.5\1\2\4\8\16\32 MHz selectable, which are compatible with Mark5B+. DBBC2 is aslo a standard VLBI terminal, inputs are 2IFs, each with 512 MHz bandwidth; and outputs have 16 BBCs, with bandwidth of 1\2\4\8\16\32 MHz selectable, which are compatibale with Mark5B+. On August 3rd, 2013, the first fringe detection was performed between Shanghai 65m and GBT 110m, we had detected the interference fringes across the Pacific. We also had detected the fringes with CDAS & DBBC2 in C, L bands in EVN 2014 session I and II. We are now preparing to make it possible to open the radio telescope next year.

5.13 Toruń Centre for Astronomy, Nicolaus Copernicus University, Toruń, Poland

EVN Disk Sessions: The Torun Station (Tr) with its 32-metre radio telescope and Mark5A recorder has participated in all the 6 regular EVN sessions at wavelengths of 21, 18, 6 and 5cm during the period (133 experiments in all). A number of experiments were adversely affected by failing BBCs (which led to a loss of one or two channels and/or to instabilities). In the May/June and October/November 2012 sessions our observations were also affected by a number of failures of the telescope control system. They caused loss of three entire experiments and parts of a few others.

e-VLBI: Tr took part in all the e-VLBI scheduled experiments (regular plus Target of Opportunity [ToO]), and occasional test observations outside the schedules. We completely failed in two e-VLBI experiments due to problems with the C-band receiver.

Personnel Update: Our new director (head of the department of Radio Astronomy) is dr Krzysztof Katarzynski, who replaced prof. Marian Szymzak on this position as of 1 January 2012.

Hardware:A DDBC unit has been a required in July 2011, however because of lack of Mark5B recorder VLBI tests did not start before end of 2012. A new twin horn 22 GHz receiver system was installed on the antenna in the second half of 2012. It receives two circular polarizations. The system equivalent flux density has been determined to be about 500 Jy. During the K-band part of the October/November 2012 session we joined ftp fringe test of N12K4 to see, for the first time, fringes to Tr with this receiving system.

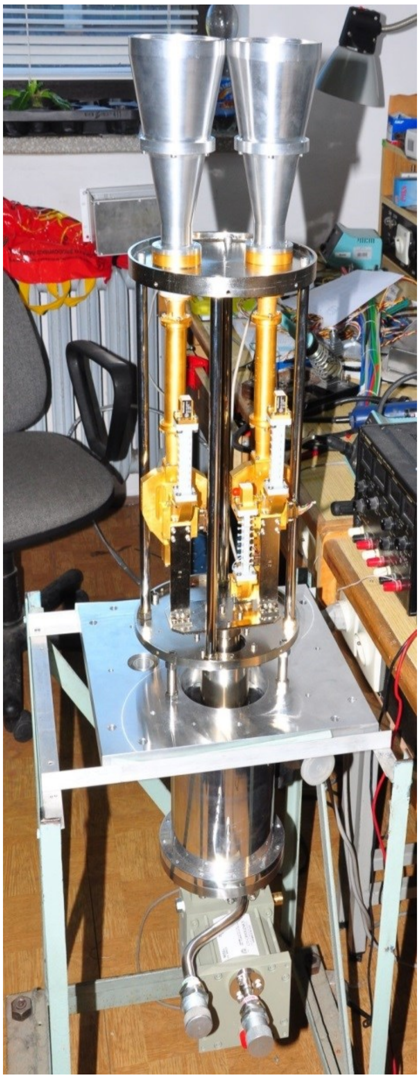


Figure 42: New Torun 22GHz receiver system.

5.14 Urumqi Astronomical Observatory, National Astronomical Observatories, Urumqi, P.R. China

Institutional status upgrade: From 2011 Urumqi Astronomical Observatory (UAO) has been officially renamed as Xinjiang Astronomical Observatory (XAO). It is still a key member of National Astronomical Observatories of Chinese Academy of Sciences (NAOC). The institute not only has its research area and personnel vastly expanded but also has more radio and optical outpost stations distributed around the local province. However, as a critical node within EVN and CVN, Nanshan station at Tianshan mountain in Urumqi county still runs the most important VLBI facility in NAOC.

Technical development: After the installation of 1.3 cm receiver (see Figure 1) in October 2011, we have receivers available at L-band (1.6 GHz), S/X-band (2.3/8.4 GHz), C-band (5 GHz) and K-band (22

GHz). All those bands are available for VLBI observations (see Table 1). The first successful fringe test of the 1.3 cm receiver was carried out in Session-I 2012.

A digital base band converting system called Chinese VLBI Data Acquisition System (CDAS) has been fully functional for both lunar satellite tracking and EVN VLBI observations. More EVN experiments are preferred to be scheduled for CDAS mode since the analog BBC is rather aged here.

Nanshan 25m telescope is currently fully functional but has reached its designed lifetime limit. A thorough upgrading programme will take place in 2013 and its observational schedule will be seriously affected then. The optical geometry will be modified to match the active subreflector and the supporting frame will be restructured with steel-pipe elements. The aimed surface accuracy is 0.15mm which will make future 3mm observation possible.

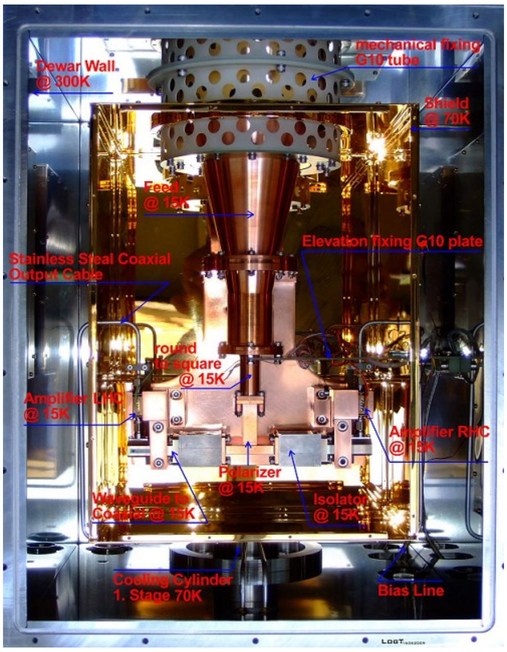


Figure 43: 1.3cm receiver at Urumqi.

Since the last e-VLBI test in 2009, Nanshan station still has a limited internet connection which has a bandwidth of 155Mbps. An upgrade to gigabit network connection is on its way.

Urumqi has now initialized a programme to build an 110m-diameter fully steerable Gregorian radio telescope on a site close to Qitai town which is about 200km east to Urumqi city. The telescope is currently named as Qitai Telescope (QTT). All the conventional radio bands L/C/S/X/K will be implemented to join the Chinese VLBI Network (CVN) and European VLBI Network in the future.

Table 8: Nanshan 25m Telescope specifications.

Band	Wave (cm)	Freq (MHz)	BW (MHz)	LO (MHz)	Pol	Type	T_{rec} (K)	T_{sys} (K)	Eff (%)	SEFD (Jy)
L	18	1400-1720	320	1300	dual	room	10	24	52	300
S	13	2150-2450	300	2000	dual	room	50	70	48	560
C	6	4750-5150	400	4620	dual	room	9	22	55	250
X	3.6	8200-9100	500	8100/8600	dual	cryo	20	50	50	350
K	1.3	22100-24200	500	22000-23700	dual	cryo	17	40	35	850

Operations: The VLBI experiments are directly run by operators who belong to the technical group, but they are coordinated by VLBI scientists who are mostly from radio-astronomical research group. Besides the three sessions of EVN observations, Urumqi also conducts about 10 VLBI experiments for

IVS every year. The China's Lunar Exploration Project (CLEP) has the highest priority to utilise the VLBI facility at Nanshan while IVS and EVN observations have the second. To coordinate the observation time allocation for other proposals, we have established Time Allocation Committee (TAC) to examine the proposed applications.

Some of analogue BBCs were found faulty in EVN observations. Since we have no backups, we plan to migrate to digital backends in the very near future. CDAS is currently a robust digital converting system that we have employed at Nanshan.

Even though the diskpack allocation is precisely calculated every time before an EVN session starts, we always encounter the situation that other VLBI observations have already recorded data on the disk to be used. This is caused by that the operators sometimes have difficulty to find extra disk to record when there are high priority observations needed to take place. So we are planning to increase our diskpack storage for local usage and EVN circulation.

6 Activities at Joint Institute for VLBI in Europe (JIVE)

Figure 44: Demonstration of the UniBoard prototype during the review of JIVE on March 5, 2012.

The Joint Institute for VLBI hosted an international review in March 2012, as a first step to arrive at a new funding agreement between its partners. The preparations in 2011 for this review included formulating the long-term strategy and writing various evaluation documents. Also, discussions concerning whether JIVE should transform into an ERIC (European Research Infrastructure Consortium, a legal entity with an EC basis) continued. The panel, made up of respected international experts, visited JIVE and evaluated the operations, research and development programme (Figure 45), as well as the scientific potential of the EVN and JIVE. In its report the panel expressed great confidence in JIVE. The panel endorsed the strategic priorities that JIVE set for its future development. Most notable was the observation of the panel that "VLBI has a very exciting and broad science case that the EVN can exploit, particularly in synergy with other SKA pathfinders".

After a number of meetings and negotiations, the positive outcome of the review was followed by a decision of the international partners to sign a two-year extension of the JIVE contributions agreement, recognizing this period as a transition to the establishment of an ERIC.

Very relevant in this process was the positive decision by the South-African NRF to become a

Figure 45: The JIVE board at the occasion of the NRF South Africa joining JIVE.

member of JIVE in May 2012. The Hartebeesthoek telescope has been a long-standing member of the EVN. However, with the construction of the MeerKAT and the ambition to start an African VLBI Network, this formal partnership could be the starting point for building up important new VLBI capabilities during the years that the SKA is being constructed, and even during its operation.

6.1 Enhancing the VLBI capabilities

An outstanding fact in the operations of JIVE in the years 2011 and 2012 was the transition of EVN correlation from the Mk4 to the EVN software correlator at JIVE (SFXC). As a consequence an increasing number of VLBI capabilities could be offered by the EVN facility. The software correlator started with a focus on special modes, like wide field, pulsar gating and spectral line modes, but with increasing computing resources becoming available, it had taken over all correlation by the end of 2012, including e-VLBI. Notably, the results of the first tests of new VLBI digital equipment at the telescopes were obtained on the SFXC, considerably improving the sensitivity by capturing data at 2 and 3 Gbps.

These correlator upgrades have a strong synergy with JIVE's on-going push to make e-VLBI a more robust, flexible and sensitive technique. This effort was subsidised by the EC through the FP7 NEXPReS project. This project has been focusing on methods to implement the best of both worlds: e-VLBI data streaming in real-time, as well as transparent caching if the data is needed (again) in a later stage. In this project the consortium members are also pioneering methods to allocate connectivity bandwidth on demand. The progress of the project was rated excellent by the EC's review panel in September 2012.

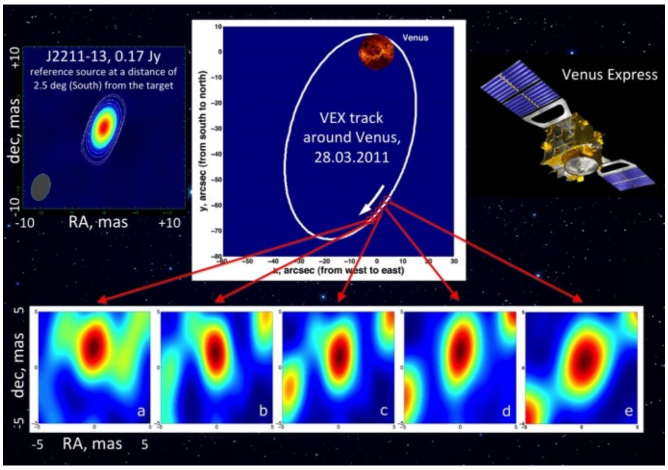


Figure 46: Accurate VLBI observations of the Venus Express spacecraft X-band radio signal demonstrate the capabilities of obtaining spacecraft state-vectors with unsurpassed accuracy.

A highlight for the NEXPReS participants and all e-VLBI operators around the world was the global e-VLBI meeting in November 2011 in South Africa (Figure 46). The meeting and its location were particularly suitable in view of the regional ambitions to develop an African VLBI Network based on decommissioned communication dishes in various African countries.

With considerable help of the JIVE management in shaping the proposal, the RadioNet3 project launched in January 2012, seamlessly connecting with the RadioNet FP7 programme. Both provide the vital Trans National Access funds, which are deployed to implement user support for VLBI in Europe. Besides, RadioNet3 also supports JIVE's efforts in developing user software and in commissioning an FPGA based correlator, based on the so-called UniBoard concept. In 2011, the first prototype was delivered and first fringes were reported in 2012. As part of the follow-up RadioNet3 programme, UniBoard[2] will investigate even more powerful and energy efficient solutions for future correlator and beam-forming applications, for example for the SKA.

Several externally funded programmes support the development of techniques for near-field VLBI observations of planetary and other space missions. JIVE collaborates with international partners to facilitate such experiments in order to enhance the science return of current and future space missions. Among the experiments carried out were the measurements of the orbit of the Venus

Express (e.g. Figure 47). Later experiments measured the aerodynamical forces on the Venus Express while skimming the Venus upper atmosphere

Actual measurements were made of the RadioAstron orbiting radio telescope, in order to refine its state vector and obtain fringes on space baselines based on these precise determinations.

6.2 JIVE relocation

After having been for almost 19 years in the 1980 wing of the ASTRON buildings, JIVE moved to the new 2012 wing in December. The new wing has room to house all JIVE staff on a single corridor and will have better meeting and visitor facilities.

6.3 Science Operations and Support for the EVN

6.3.1 Production Correlation

Table 9 and Table 10 summarize projects observed, correlated, distributed, and released in 2011 and 2012. They list the number of experiments as well as the network hours and correlator hours for both user and test/NME experiments. Here, correlator hours are the network hours multiplied by any multiple correlation passes required (e.g., because of continuum/line, separate correlation by subband/pol to maximize spectral resolution, etc.). Note that the instances of multiple correlator passes is largely reduced when using SFXC, since it does not have the explicit maximum spectral capacity limitation of the MkIV. Some experiments still have separate continuum and line passes, to keep the output FITS file size more manageable. Thus the "Network hours" and "Correlator hours" values have grown closer together. The "Correlator hours" statistic for SFXC does not reflect the fact that, unlike the MkIV, SFXC may correlate some experiments faster or slower than real-time depending on their sizes.

Table 9: Summary of Projects observed, correlated, distributed, and released in 2012.

	User Experiments			**Test & Networking Monitoring**		
	N	Network hours	Correlator hours	N	Network hours	Correlator hours
Observed	89	701	979	2	91	91
Correlated	71	535	728	28	92	92
Distributed	76	585	797	24	80	80
Released	77	619	789	27	88	88
e-EVN experiments	38	249	249			
e-EVN ToOs	7	53	53			

The most significant feature of the correlation environment over this biennial period has been the shift away from the MkIV correlator to the EVN software correlator at JIVE (SFXC) as the primary workhorse for EVN correlation. Figure 48 shows the evolution of the fraction of (disk-based) experiments per session correlated on the MkIV and on SFXC. SFXC was already processing its first experiments (requiring pulsar gating) in the latter half of 2010. The transition to SFXC over 2011 was gradual, because the MkIV continued to process multi-epoch projects that had begun on it; only one such observation remained in the first session of 2012. By session 2/2012, all disk-based observations were correlating on SFXC. e-EVN observations took longer to shift away from the MkIV, because of concerns about the ability of SFXC to keep up with 9-10 stations at 1 Gbps. The Technical Operations and R&D group had overcome those concerns by the regularly-scheduled e-EVN day in December 2012, and all e-EVN observations since then have also correlated on SFXC.

Table 10: Summary of Projects observed, correlated, distributed, and released in 2012.

	User Experiments			Test & Networking Monitoring		
	N	Network hours	Correlator hours	N	Network hours	Correlator hours
Observed	87	711	801	31	96	96
Correlated	85	728	916	26	82	82
Distributed	76	673	861	31	94	94
Released	72	634	828	30	91	91
e-EVN experiments	29	233	233			
e-EVN ToOs	4	25	25			

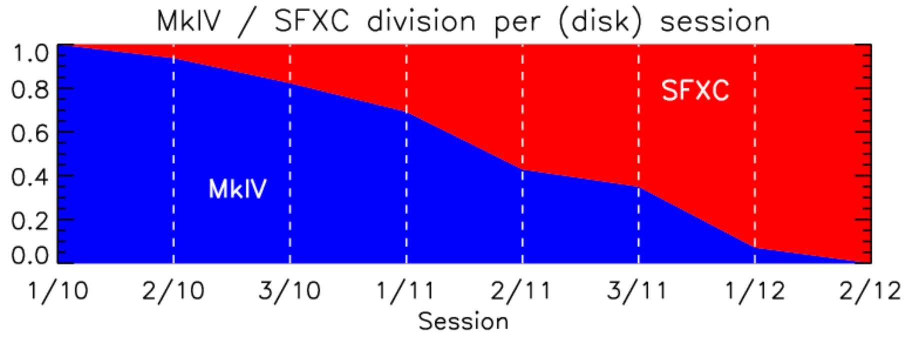
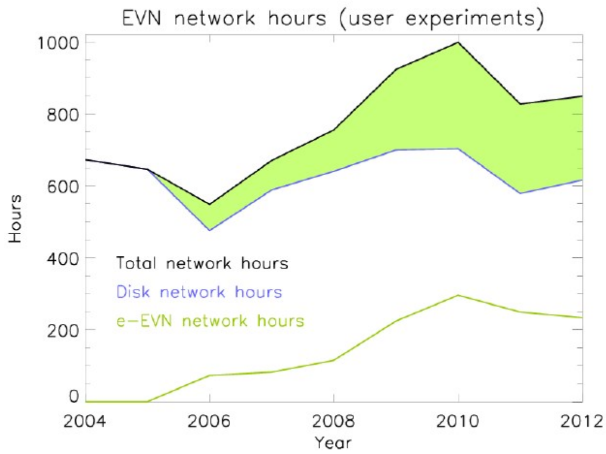


Figure 47: Fraction of disk based experiments correlated on the MkIV and on the SFXC, per session.

e-VLBI observations have remained a cornerstone of the EVN. The total e-EVN hours were down somewhat from their high in 2010, arising mostly from fewer targets of opportunity (ToO) observations using e-VLBI. There were 11 of these (but also 11 disk-based ToO observations—ones requiring multiple correlator passes or stations not having e-VLBI connections). Still, over the biennial period, 34% of the observed EVN network hours correlated at JIVE were e-EVN



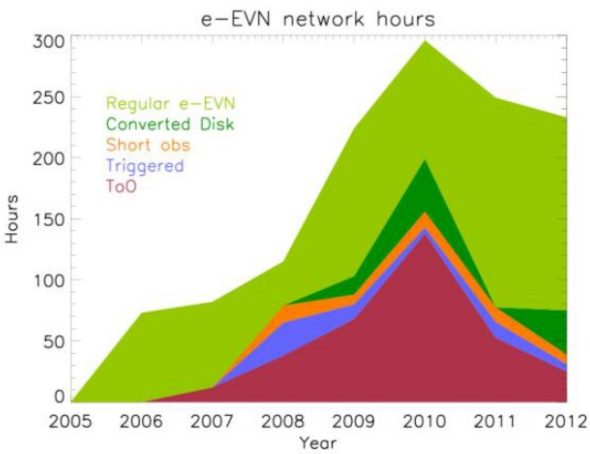


Figure 48: Left: Annual EVN network hours, with the contributions by e-EVN observatiosn shown by the shaded area. Right: Division of annual e-EVN network hours into categories.

observations. There were a growing number of e-EVN observations conducted during regular EVN (disk) sessions. This can provide the opportunity to get longer e-EVN observations than would be possible in the regularly-scheduled e-EVN days. A 48-hour e-EVN observation took place in session

1/2011. In terms of e-EVN network improvements, Noto joined for the first time in June 2012 at 512 Mbps, and by September 2012 could sustain 896 Mbps (i.e., channel-dropping one of eight 16MHz subbands in a Gbps mode). Hartebeesthoek, Medicina, and Yebes all improved to being able to sustain a full Gbps.

Figure 49 (left) shows the evolution of annual EVN network hours since 2004, with the contribution of e-EVN represented by the shaded area (the green line denotes the number of e-EVN hours by itself). Figure 49 (right) focuses on the e-EVN experiments, showing a division of annual e-EVN observing hours into different categories: target-of-opportunities (ToO), triggered observations, short (≤2hr) exploratory observations, experiments proposed for disk recording, but conducted in e-VLBI (after consultation with the PI), and the standard e-EVN observations in regularly scheduled sessions. By their nature, all e-EVN observations correlate at JIVE.

6.3.2 Logistics & Infrastructure

The disk-shipping requirements are derived from the recording capacity needed by a session (from the EVN scheduler) and the supply on-hand at the stations (from the TOG chairman). The EVN and VLBA stations follow different sets of guidelines:

a) the EVN policy that stations should buy two sessions' worth of disks, hence the disk flux should balance over the same 2-session interval.
b) the VLBA's need for sub-session turn-around, which essentially requires pre-positioning the difference between what NRAO stations will observe in globals to be correlated at JIVE and what EVN stations will observe in globals to be correlated in Socorro.

Following distribution to the stations for session 3/2012, the cumulative flux-balance summing over both EVN and NRAO stations was with 10 TB of zero (a typical EVN session has been in the range 600-700 TB).

In this period, EVN experiments have continued to go to three different correlators (JIVE, Socorro, Bonn). A principal goal in planning the pre-session disk-pack distribution is to avoid individual packs containing data for more than one correlator. Thus in the disk-distribution plan the load for each target correlator for each station is computed separately. Packs on-hand at a station are applied to one of these individual-correlator loads prior to calculating what replenishment is required from JIVE. The specific set of packs (how many of each of the various available capacities) for each station/target correlator then takes into account minimizing both shipping costs and unused capacity.

The current play-back line-up is 14 Mark5As, 2 Mark5Bs, 1 Mark5B+, and 7 Mark5Cs. The MarkIV correlator is still limited to a maximum of 16 stations. Correlation on SFXC bypasses the station units, so is entirely divorced from the 16-station limitation. Further, the A/B/C flavour of the Mark5 unit is immaterial to SFXC correlation. Thus the effective maximum array-size for single-pass correlation is currently 24. Among the standard EVN stations, Effelsberg, Westerbork, Yebes, Urumqi, Shanghai, Hartebeesthoek, Badary, Zelenchukskaya, and Svetloe currently provide Mark5B recordings (as do typically Irbene, Kunming, the Japanese stations, and KVN stations among the non-EVN stations correlated in this biennial period). The need to retain a number of Mark5A units depends only on the contingency that the MkIV correlator would be needed (e.g., e-VLBI with more stations than SFXC could handle at a given time). Since SFXC can now keep up with 12 stations at 1 Gbps, this eventuality is not particularly pressing.

Occasionally an incoming pack may have an individual bad disk. JIVE maintains a small bench stock of disks of various sizes, to be able to replace a bad disk locally if that is the most appropriate course of action (in light of warranty status, urgency of recycling, etc.). In such cases, the pack's "owner" would provide a new disk to replenish the bench stock.

6.3.3 Astronomical Feature enhancements with SFXC

SFXC has now correlated many user experiments that would have been impossible or at best much less efficient on the MkIV:

- 4 spectral-line experiments having more than 2048 frequency points per subband/polarization (record so far = 8192)
- 17 spectral-line experiments with cross-polarizations, which are done more accurately in SFXC
- 7 pulsar gating experiments (record minimum period so far = 16.45 ms)
- 15 experiments with multiple phase centers (spanned fields range from 25" to 10'; record number of multiple phase centers so far = 50)
- 4 experiments having more than 16 stations (record so far = 23)

There is some overlap among the above list (e.g., an experiment used both pulsar gating and multiple phase centers). There have been 22 other user experiments that SFXC was able to correlate in a single pass, but which would have required multiple MkIV passes, even though they exceeded no individual MkIV limitation in terms of only number of stations or frequency points.

SFXC avoids a physical limit of the MkIV, in which a single interferometer (baseline/subband/polarization) could not exceed the capacity of a single correlator board. In local validity, this meant no more than 2048 frequency points per interferometer. With SFXC, the selection of observing/correlation parameters is greatly simplified for the PI: one now can set the subband bandwidth and number of frequency points directly from the desired velocity spacing and continuum sensitivity. Besides the possibility of increased spectral resolution, SFXC also offers spectral-line observations the advantages of station-based fringe-rotation and the ability to select the spectral-windowing function (default = Hanning, but uniform, Hamming, and cosine are available—the MkIV provided only uniform). A more esoteric improvement pertains to cross-pol spectral-line observations, which are growing in popularity with the demonstration that methanol and OH masers provide the ability to map out the magnetic fields around massive proto-stars. The MkIV applied (baseline-based) fringe-rotation entirely to one station (always the first station as fed to the correlator from the station units), but for the fourth polarization, it would swap the order of the stations in the baseline (e.g., in Ef-Wb, polarization LR would be Ef(L)-Wb(R) with fringe rotation done to Ef; but RL would be Wb(L)-Ef(R) with fringe rotation done to Wb). This asymmetry between the fringe-rotation zero-point for the two cross-hands polarizations was never repairable in AIPS. It is avoided altogether in SFXC.

The combination of an essentially arbitrarily large number of frequency points and an arbitrarily small integration time in SFXC makes it a much more powerful wide-field mapping correlator, one that could map an area on the sky on the order of the single-dish beams without appreciable bandwidth- or time-smearing. The price of course is huge data sets (one can see in the growth of the archived FITS files in Figure 53 that there are a higher number of very large experiments once the transition to SFXC has been completed). Multiple phase-centre correlation performs an "internal" correlation with a very large number of frequency points and a very small integration time (current records are 32k frequency points and 4.864ms), but then outputs only subsets of this initial wide field using more traditional values for frequency points and integration times. The most popular applications for multiple phase-centre correlation have been following an in-beam phase-referencing calibrator (this sometimes requires different schedules for the small and large telescopes, the latter ones still having to slew between the two close sources) and investigating a population of sources (e.g., from FIRST or NVSS) that happen to lie in the field of the principal VLBI target.

SFXC provides pulsar-gated correlation, which never attained operational availability on the MkIV. A number of independent bins can be placed within a single gate, defined by a start/stop phase with respect to the pulsar period. Each bin could produce a separate FITS file. Traditional gating corresponds to 1 bin.

6.3.4 EVN support activities

Automatic-ftp fringe tests are included in all network monitoring experiments (NMEs) at the beginning of each new frequency sub-session within EVN sessions, or as a separate fringe-test observation when the NME does not appear first in the schedule or falls well outside working hours. Under the control of sched and the field system, a specified portion of a scan is sent directly to the SFXC cluster at JIVE. Multiple ftp transfers per experiment provide the opportunity to iterate with the stations in investigating any problems identified. Use of ftp transfer and near-real-time correlation permits stations that don't have a full e-VLBI connection to participate. A Skype chat session during the ftp fringe-test observations provides even more immediate feedback between the station friends and the JIVE support scientists. Correlation results go to a web page available to all the stations, showing baseline amplitude and phase across the band as well as autocorrelations. The web-based results from the first and probably the second ftp transfer would be available to the stations before the end of the NME. These ftp fringe tests continue to be very successful in identifying telescope problems and helping to safeguard user experiments by allowing the station friends to take care of any such problems before the actual astronomical observations begin.

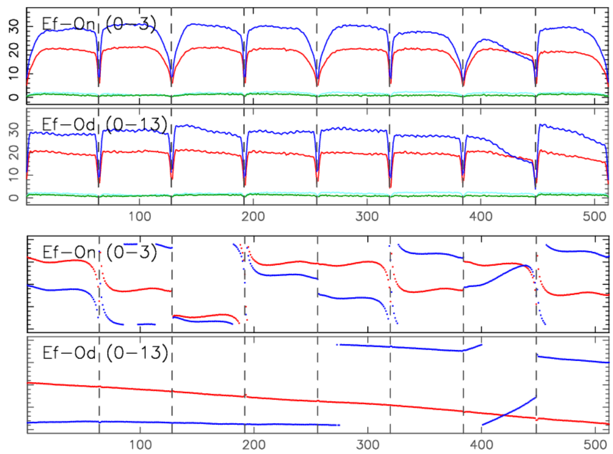


Figure 49: Amplitude and phase vs. frequency on the baselines Ef-On (Onsala with a mark4 formatter) and Ef-Od (Onsala with a DBBC) for the session 1/2012 L-band fringe-test experiment F12L1.

The EVN pipeline runs under ParselTongue providing greater scope for future development due to the improved coding environment. The pipeline scripts are available from the ParselTongue wiki (RadioNet) and should provide a good basis for other (semi-)automated VLBI reduction efforts. All experiments, including NMEs, run through the pipeline, with results being posted to the EVN Archive. The pipeline also provides stations with feedback on their general performance and in particular on their gain corrections, and identifies stations/frequency bands with particular problems.

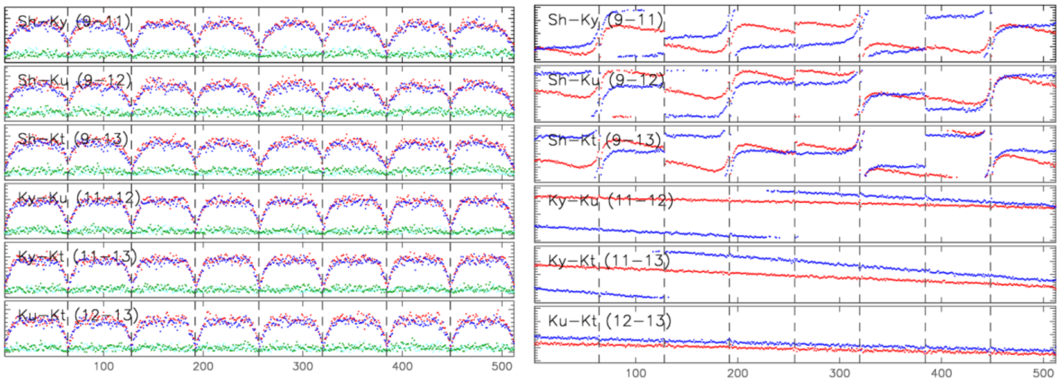


Figure 50: Amplitude and phase vs. frequency on the baselines among the three KVN stations and Shanghai for the session 3/2012 K-band NME N12K4.

The transition from the analog mark4/vlba4 formatters to digital back-ends has gathered pace in this biennial period. Effelsberg recorded session 1/2011 in parallel onto the DBBC, and has used the DBBC for all observations starting in session 2/2011. Further parallel-DBBC testing has taken place in Onsala, Hartebeesthoek, Noto, Yebes, and Metsahovi. This has been in the "Digital Down-Converter" personality, which can mimic the BBC-tuning and subband-bandwidths available on the existing back-ends. Figure 50 shows a comparison of Ef-On and Ef-Od baselines (comparing the mark4 formatter and DBBC back-end at Onsala, while Ef is using the DBBC). The passband is flatter on the DBBC-DBBC baseline, and the phase across the entire range of BBCs is much flatter, with no phase shifts between BBCs apriori (no phase-cal alignments applied in this plot). Extracting calibration information remains one of the last stumbling blocks for more stations permanently moving over to the DBBC. 2 Gbps fringes on the Chinese digital back-end CDAS were achieved in October 2011. The KVAZAR stations shifted to their R1002 digital back-ends in session 1/2012. Previously, they each had a unique configuration, so this transition improves consistency – especially avoiding Gbps C-band quirks such as the Svetloe cut-off at 5000 MHz and internal down-converter interference costing one of eight subbands at Zelenchukskaya.

There have been quite a few new VLBI stations participating in user experiments. VERA Ishigaki-jima participated for the first time in some methanol-maser astrometric observations, starting in session 1/2011 and continuing throughout all of 2011. Like the other VERA stations, this is not under field-system control, and provides Mark5B-format disk-packs generated by translating from their native VERA recording tapes. Without a field-system log to control the antennas or associate bytes on the pack with scan start times, they record continuously, moving the antenna under local control to match the schedule. For correlation, the byte/scan associations were computed from knowing the begin/end times of the recordings (per individual original VERA tape). Kunming obtained Gbps fringes in the X- and S/X-band NMEs in session 2/2011, using the Mark4 back-end that was originally at Wb. The first K-band fringes from the KVAZAR stations Svetloe and Zelenchukskaya came in a ToO in September 2011. Two Korean VLBI

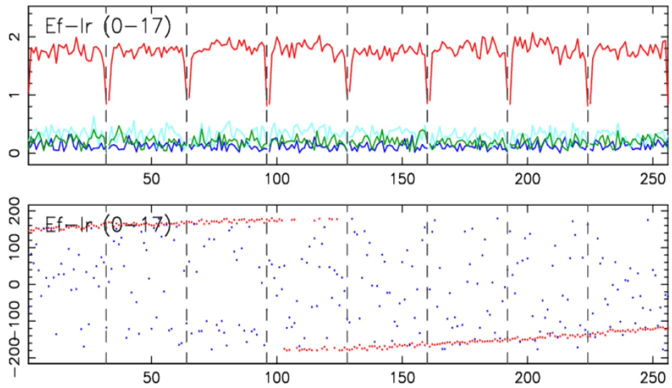


Figure 51: Amplitude and phase vs. frequency on the baseline Effelsberg - Irbene for the session 3/2012 C-band NME N12C4. Irbene had only RCP available, a known feature of these observations.

Network stations (Yonsei, Tamna) participated in their first test with EVN stations in October 2011, an e-VLBI observation at 512 Mbps. All three KVN stations (also Ulsan) got fringes in the K-band NME in session 3/2012. Figure 52 shows the fringes on the baselines formed among the three KVN stations and Shanghai (fringes were also visible on Korean-European baselines, but were weaker due to the length of these baselines). Irbene obtained its first fringes during a test observation in April 2012 (C-band, 512 Mbps), and got fringes in both the C- and L-band NMEs in session 3/2012. Figure 2.6 shows the fringes on the baseline Effelsberg-Irbene, with both stations having a DBBC back-end.

6.3.5 PI support

The EVN Archive at JIVE provides web access to the station feedback, standard plots, pipeline results, and FITS files for experiments correlated at JIVE. Public access to the FITS files themselves and derived source-specific pipeline results is governed by the EVN Archive Policy –the complete raw FITS files and pipeline results for sources identified by the PI as "private" have a one-year proprietary period, starting from distribution of the last experiment resulting from a proposal. PIs can access proprietary data via a password they arrange with JIVE. PIs receive a one-month warning prior to the expiration of their proprietary period.

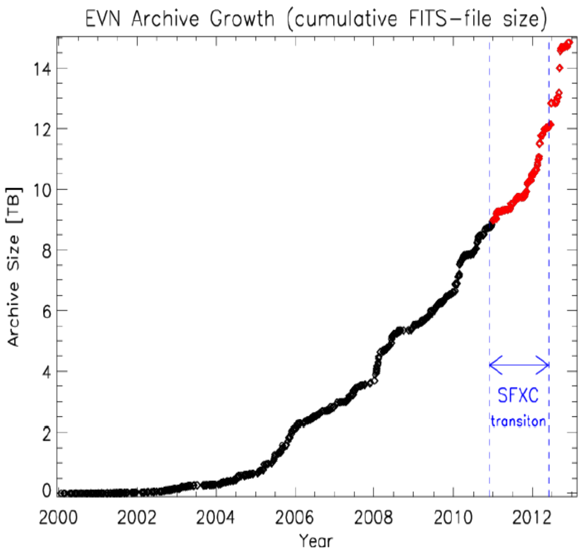


Figure 52: Growth in the size of FITS files in the EVN archive. Experiments archived in this biennial period are plotted in red. Vertical blue lines demark the date of archiving the FITS files from the first SFXC correlation and that from the last MkIV correlation of a disk-based observation, bounding the transition period in populating the archive from the two correlators.

The Archive moved onto a bigger, more powerful machine (the EVN pipeline also runs on this machine). It has 33 TB of available disk space, which it shares with the pipeline work area (currently using around 2.3 TB). The total size of the FITS files in the archive at the end of 2012 was 14.84 TB (a 5.87 TB gain in the two-year period); Figure 53 shows the growth of the FITS-file size in the EVN archive size over time. A pick-up in the number of very large experiments can be seen following completion of the transfer to SFXC.

The science operations and support group continues to contact all PIs once the block schedule is made public to ensure they know how to obtain help with their scheduling. There were 12 first-time EVN PIs in 2011 and another 9 in 2012. The group also checked schedules that PIs had posted to VLBEER, before the stations downloaded them. In some cases, this led to a dialogue with a PI about fixing a specific problem or improving some observational tactic. There were a couple instances in which last-minute casualties at the stations led the group to re-make schedules after the PIs had already uploaded them, most notably in session 3/2012. Jodrell1 suffered an azimuth wheel casualty, so all of its schedules (24) were shifted to Jodrell2, including re-introducing the smaller antenna into scans that Jodrell1 intentionally missed in fast cycle-time phase-reference observations. Medicina saw in the L-band sub-session that they were not able to record Gbps observations, so the schedules for their remaining C-band and X-band Gbps observations were remade using 1-bit sampling (hence, bit-rate falling to 512 Mbps).

The preferred IF/BBC associations for stations using digital back ends can fail the various checking rules in the NRAO scheduling program “sched”, so the Science Operations and Support group have continued to provide PIs of experiments with plug-ins for their sched-input files each session that properly specify the current station set-ups while allowing sched to run without complaint. JIVE personnel provided new code to sched to handle the KVAZAR R1002 digital back end, and are working towards the same for the DDC personality of the DBBC.

JIVE continued to provide maintenance for the EVN-specific portion of the NorthStar Proposal Tool. The most significant action in this area was in the organization of the available "facilities" within the EVN portion: merging the separate EVN+MERLIN and e-EVN facilities into one. Now e-EVN observing can be requested on an "observation" basis within a single EVN+MERLIN proposal, allowing proposals that contain some parts using e-VLBI and some parts using disk-based observations, presenting the correct choice of frequencies and telescopes for each such observation.

6.3.6 Operations throughput plots

Figure 54 presents the size of the correlator queue at different stages in the processing cycle, showing a snapshot at the end of each week. Three experiment statuses are plotted, in units of correlator hours summed over all the experiments in each status. The red line shows the experiments that remain to be correlated. The blue line shows the experiments whose data (FITS files) remain to be distributed to the PI. The green line shows the experiments that have yet to be released (in principle, release can happen 2 weeks after release, but in practice it is delayed closer to the time before the following session when packs are needed to replenish the stations, leading to a blocky pattern for the green line).

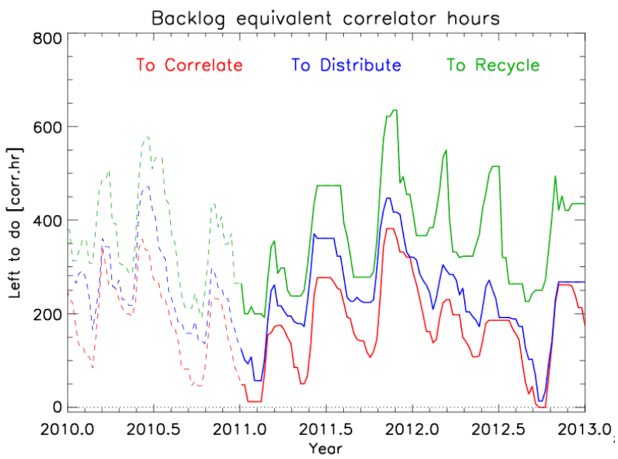


Figure 53: Size of various correlator queues, measured in correlator hours.

6.4 Technical operations, and R&D at JIVE

As in previous years, the JIVE members of the Technical Operations and R&D group were involved in many nationally and internationally funded projects during the period 2011 - 2012. The EC-funded NEXPReS project, which kicked off in July 2010, picked up steam with the hiring of two software engineers at JIVE. Through the ShAO-NWO collaborative agreement, which was set up in order to stimulate the technical and scientific collaboration between Shanghai Observatory and JIVE, a Chinese PhD student spent most of these two years at JIVE working on, among others, pulsar gating modules for the next generation EVN correlator, successfully defending his thesis at ShAO along the way. The RadioNet FP7 UniBoard project formally ended June 30 2012, to be followed by the start of RadioNet3 UniBoard[2] on the first of July 2012. The NWO-funded ExBoX project, aimed at creating larger computing systems for correlation and beamforming based on the UniBoard, ran its course by the end of 2012.

On top of their regular activities, several staff members were in charge of work packages in these projects, including the management of deliverables, the organisation of demonstrations often involving many international partners and the writing of quarterly and yearly reports. In addition staff members were involved in liaising with research networks and EVN partners, participation in international panels and representations at many international meetings.

Traditionally, the maintenance and improvement of the MarkIV hardware correlator and supporting hard- and software has been at the center of activities of the Technical Operations and R&D group. Throughout the reporting period however operations have shifted from the MarkIV to the EVN software correlator at JIVE (SFXC) to such a degree that all efforts are now geared towards the development of new SFXC features and the debugging and commissioning of the UniBoard-based next generation EVN correlator.

6.4.1 Data processor maintenance

With the actual use of the MarkIV hardware correlator limited to e-VLBI by early 2012, maintenance of the correlator and associated hardware like the Station Units dwindled to the occasional replacement of a power supply. Supporting systems like the cooling system, paternoster, fire alarm and extinguishing systems were maintained and regularly serviced. A replacement of the JIVE correlator cooling system was discussed with ASTRON, in view of the installation of a heat exchanger servicing the entire Dwingeloo building complex including the new wings that are currently under construction. With the doubling of the SFXC hardware and addition of many new computer systems, replacement of the somewhat underprovisioned power supply to the JIVE cellar became necessary. The migration of equipment to the newly installed electricity distribution board with its own high-capacity connection to the central mains was done in-house over a period of several months, to minimize disturbances to the operational system.

7 EVN meetings

Over the past two years numerous small to large conferences and meeting have been organised which have showcased the unique scientific capabilities of the EVN. Below we summarise a few of these key meetings, including the biennially organised EVN symposium which has successfully brought together VLBI scientist from around the globe for 2 decades.

7.1 The 11th European VLBI network Symposium and Users' Meeting (Bordeaux, October 2012)

The 11th European VLBI Network Symposium was held in Bordeaux from the 9th to the 12th of October 2012. The purpose of the symposium was to share and publicize the latest scientific results and technical developments from VLBI, space VLBI and e-VLBI. The conference was attended by a total of 122 participants originating from 47 institutes in 19 countries world-wide. Of these, 96 participants were from Europe while 26 participants came from outside Europe. Germany had the largest number of delegates (22 participants), followed by France (15 participants), The Netherlands (13 participants) and Japan (11 participants). More than 20 students at the PhD level (or at a lower level) attended the symposium.

Figure 54: Group photo of the participants in the 11th EVN symposium. The photo was taken at "Place de la Bourse", one of the major historic squares in Bordeaux, in the vicinity of the conference centre. Other pictures are available from http://evn2012.obs.u-bordeaux1.fr.

The program of the meeting consisted of 71 oral presentations (including 9 invited speakers) spread over the 3.5 days of the conference along with 43 posters. The program was organized in 11 scientific sessions covering a very wide range of topics in stellar, galactic and extragalactic astrophysics as well as in astrometry and planetary science. The Scientific Organizing Committee also encouraged presentations addressing synergy between (e-)VLBI and other new or planned radio facilities (ALMA, LOFAR, e-MERLIN,...) or instruments at other wavelengths (Fermi, CTA, Gaia,...).

Several of these were the subject of invited talks. Additionally, the program comprised an EVN Users Meeting on one of the evening to foster interaction between the EVN users and the EVN organization. The meeting was chaired by Tom Muxlow, the Chair of the EVN Program Committee. A number of aspects, from proposal evaluation to data correlation, were addressed and fruitful discussions came up.

The program also included social activities during one of the afternoon. One of these was the traditional football match opposing an international team of symposium participants to the local team. Experience of the international team prevailed and they beat the local team 3-0. Those not fans of football could enjoy a guided tour of Bordeaux in parallel during that afternoon. Following these events, all participants gathered in the evening for the conference dinner, which was held in a "Chateau" in the vicinity of Bordeaux, overlooking vineyards. The dinner was preceded by a guided tour of the winery which drew much attention.

The symposium reached its end with the closing speech given by the Chair of the EVN Consortium Board of Directors, Simon Garrington, who highlighted the big steps forward and the fantastic science done by a growing global VLBI community. Proceedings of the symposium are on their way and will be published by the Proceedings of Science.

I would like to warmly thank the members of the Local Organizing Committee and Scientific Organizing Committee, along with our sponsors, with RadioNet3 on first hand, for making this symposium a memorable event.

Patrick Charlot, SOC Chairman

Figure 55: Participants at the 41st YERAC in front of the Lovell telescope.

7.2 The 41st Young European Radio Astronomers Conference (Jodrell Bank Observatory, July 2011)

41st Young European Radio Astronomers Conferences (YERAC) was hosted at Jodrell Bank observatory between 18-20th July 2011. This was yet another extremely successful YERAC, gathering together the 'next generation' of radio astronomers from across Europe. This ever-popular event, limited by venue space, saw 50 early-stage reserachers and many new postgraduate students to hear from a series of invited speakers who gave an overview of radio astronomy, including EVN, within Europe, and have the opportunity to present their own work to their peers. No doubt many long-lasting and future collaborations between this next generation were spawn at the meeting over a few drinks!

7.3 4th European Radio Interferometry School (Rimini, September 2011)

The 4th European Radio Interferometry School (ERIS) was hosted by the Institute of Radio Astronomy (INAF) with the support of RadioNet FP7, and it was held in Rimini, in the week 5-10 September 2011.

Figure 56: The European Radio Interferometry School (ERIS) 2011.

The main purpose of the European Radio Interferometry Schools is to make the new generations of radio astronomers familiar with radio interferometry and radio data handling and analysis. Beyond the short term goal, ERIS is actually the first step in the knowledge transfer, a critical step to ensure the growth and development of the radio astronomy. The format of the school followed the previous editions, and it included both lectures and tutorials, where the participants had a chance to play with the interferometric data themselves. LOFAR and ALMA data handling were part of the program, and the participants had a chance to work and play with brand new data sets taken with the new frontier radio interferometers at the two ends of the radio spectrum.

A total of 100 participants, including lecturers and students, gathered in Rimini, and shared an intense and very fruitful week. Students came from all over the Europe, but also from China, India, South Africa, Mexico and South America, and formed a large and very good group. The strong motivation of students, the generous availability of all lecturers and the warm and friendly hospitality of Rimini ensured a very successful school.

7.4 Locating Astrophysical Transients

The Locating Astrophysical Transients workshop (13-17 May 2013) was held in the Lorentz Centre in Leiden, the Netherlands. A group of 55 astronomers with diverse backgrounds in astronomy met to discuss the state of the art in transient science. The focus was on how to answer key questions in high energy astrophysics using radio interferometric techniques, with a special emphasis on joint multi-band observations. As the workshop was organized in Europe, specifically Netherlands, extra attention was given to the progress of e-VLBI in the European VLBI Network, the most recent LOFAR transient and long-baseline results, as well as the large-field-of-view Apertif developments at Westerbork. These were mixed with talks on optical transient search projects, X-ray transients, and on gamma-ray astronomy up to TeV regime, spiced up with introductory talks on the theoretical background of high energy emission and relativistic jets. Each session featured a limited number of talks and provided ample time for open discussion. We were particularly interested in follow-up strategies in existing transient surveys (in any bands), with the aim to use that expertise carry out transient searches and/or follow-up observations. One session was fully devoted to automated triggering of VLBI observations. The sessions were organized around scientific topics: the known transient types of neutron stars, black hole binaries, cataclysmic variables, supernovae, gamma-ray bursts, tidal disruption events (and other transient accreting phenomena near massive black holes), and possible sources of gravitational waves. On the fourth day there was a closed session for the NEXPReS e-VLBI Science Advisory Group, to discuss the various inputs received from the participants, and to find ways of improving the EVN further. The last day was even more forward looking, with a focus on SKA precursors and the future of long-baseline (transient) science in the SKA era.

Figure 57: Delegates from the Locating Astrophysical Transients workshop and eVSAG face-to-face meetings in Leiden 2012.

In the workshop summary Steven Tingay mentioned several figures of merits of scientific workshops. The main one, second only after the the workshop dinner, was the number of slides branded "EMBARGOED". We certainly got a peek at some stunning forthcoming results and many cell phone cameras semi-secretly captured those secret slides. For example, two of the talks were about results to be published in Science soon, one of them e-EVN related - so stay tuned!

The organizers thank to the Lorentz Centre for the excellent venue and organization, as well as to RadioNet and NEXPReS for additional financial support without which the workshop would not have been such a great success.

Zsolt Paragi and Joeri Leeuwen (Scientific Organizers) for the SOC: Felix Aharonian, Francisco Colomer, Rob Fender, Bryan Gaensler, Stefanie Komossa, Chryssa Kouveliotou, Gijs Nelemans, Steven Tingay

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