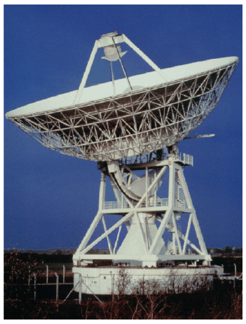
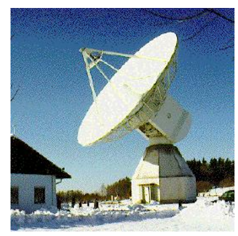




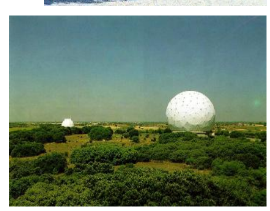
European Consortium for VLBI

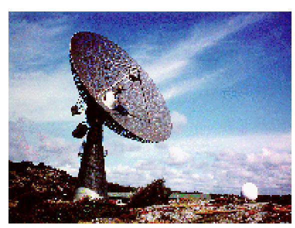
EUROPEAN vlbi NETWORK



Biennial Report 2005-2006







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Foreword by the Chairman of the Consortium

The European VLBI Network (EVN) is an interferometric array of radio telescopes which allows high-resolution radio astronomical observations of cosmic radio sources to the whole astronomical community world-wide. The EVN is the most sensitive VLBI array in the world, thanks to the collection of extremely large telescopes that contribute to the network. Besides, new telescopes are coming on line. The Observatorio Astronómico Nacional in Spain and the Istituto di Radioastronomia of the Istituto Nazionale di Astrofisica in Italy, are completing new impressive observing facilities. The 40-m dish in Yebes (Spain) and the 64-m Sardinia Radio Telescope in Italy will greatly increase the sensitivity of the array and will make the EVN more attractive for observations at millimetre wavelengths. Moreover, there are other stations in Latvia with the 30-m dish at Irbene, and in Ukraine with the 70-m dish in Evpatoria and the 22-m dish in Simeis which are willing to join the EVN for future observations. This expansion of the EVN to the East is also important to fill the gap between the European observatories and the two Chinese antennas which are part of the network. The EVN regularly observes with the Associate Members at Arecibo Observatory (Puerto Rico), and Hartebeesthoek Radio Observatory in South Africa. EVN observations are regularly scheduled with the USA Very Long Baseline Array and with stations of NASA's Deep Space Network. The EVN has also operated jointly with the VLBI Space Observatory Programme (VSOP) and is working towards a collaboration with the VSOP-2 project (both space programs led by Japan). The relationship between the EVN and the International VLBI Service for Geodesy & Astrometry has improved during the time of this report.

This Biennial Report covers the EVN activities for the period 2005-2006. Scientific, technical and operational activities of the member and associated institutes and the users are presented. Most of the report describes and highlights the impressive amount of science carried out with the EVN by its member institutes. The large number of publications on major astronomical journals and of contributions to many conferences based on EVN observations are listed at the end of the report. The scientific community is involved in the important document named EVN2015, which presents the future science to be conducted with the VLBI technique.

Significant enhancements on the technical side have been achieved in the past two years. It is worth mentioning here that the EVN has completed the introduction of disk-based recording systems which greatly improved the reliability of the network. Stations have now enough disk space to sustain 10 days of observing at 1 Gbps. Enormous progress has also been made in the prototyping of Digital Base Band Converters (DBBC). That project was endorsed by the EVN after a positive report by the Critical Design Review Committee appointed by the Consortium Board of Directors. The DBBCs will be adopted in future as standard VLBI data acquisition systems by the network.

A weak point in the network operations is represented by the difficulty of quickly changing the observing frequency. Despite of the agreement reached by the member institutes to upgrade the antennas, only a few stations do currently perform with frequency agility.

Nevertheless, the EVN is now able to plan for Target of Opportunity observations in case of rapid response required to the network by transient astronomical events. Huge progress has been made in electronic VLBI. Thanks to the EC funded programme EXPReS several EVN antennas are linked to the JIVE correlator with optical fibres. This moves towards real-time VLBI. On the one hand this means the death of the "traditional" VLBI, on the other it represents the future of EVN and again requires fully frequency agile stations.

In the two years period covered by this report the EVN member institutes and partners successfully carried on "RadioNet", an Infrastructure Cooperation programme funded by the Sixth Framework Programme of the European Union. The RadioNet programme incorporates a Transnational Access programme aimed at improving the service to the EVN user community. Several Network Activities further strengthen the cooperation among the network partners.

The EVN has demonstrated to be a vital, successful and attractive organization, an excellent example for a long-standing international collaboration between scientific partners at various institutes in and outside Europe. To this end, EVN is vitally dependent on national financial investments in support to radio astronomical observations and technical developments.

Franco Mantovani, Istituto di Radioastronomia, Bologna
Chairman, EVN Consortium Board of Directors

Marco Bondi, Istituto di Radioastronomia, Bologna
Secretary, EVN Consortium Board of Directors

1. The European Consortium for VLBI

The European VLBI Network (EVN) was formed in 1980 by a consortium of five of the major radio astronomy institutes in Europe (the European Consortium for VLBI). Since then, the EVN and the Consortium has grown to include 12 institutes with 16 telescopes in Spain, UK, the Netherlands, Germany, Sweden, Italy, Finland, Poland and China, a 16 station data processor at JIVE in Dwingeloo and a 9 station data processor at MPIfR in Bonn. In addition, the Hartebeesthoek Radio Astronomy Observatory in S. Africa and the NAIC Arecibo Observatory in Puerto Rico are active Associate Members of the EVN. Together, these individual centres form a large scale facility, a continent-wide radio telescope.

The EVN is linked on a regular basis to the 7-element Jodrell Bank MERLIN interferometer in the UK to create a very sensitive "regional network", and to the US NRAO Very Long Baseline Array and the NASA Deep Space Network to create a "Global Network". The EVN, in stand-alone or global mode, also observed together with the orbiting radio telescope HALCA launched in February 1997 by the Institute of Space and Astronautical Science (ISAS) in Japan as part of the first dedicated Space VLBI mission VSOP (VLBI Space Observatory Programme). Preliminary agreements between EVN and ISAS for the fore-coming VSOP-2 mission have been arranged.

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

<u>Radio Astronomy</u>

1) ASTRON, The Netherlands Foundation for Research in Astronomy, Dwingeloo, The Netherlands
2) Hartebeesthoek Radio Astronomy Observatory (HartRAO), S. Africa (Associate Member)
3) Institute of Radio Astronomy (INAF IRA), Bologna, Italy
4) Jodrell Bank Observatory (JBO), University of Manchester, Jodrell Bank, UK
5) Joint Institute for VLBI in Europe (JIVE), Dwingeloo, the Netherlands
6) Max-Planck-Institute for Radio Astronomy (MPIfR), Bonn, Germany
7) Metsähovi Radio Observatory (MRO), Helsinki University of Technology, Espoo, Finland
8) National Astronomical Observatory (OAN), Madrid, Spain
9) National Astronomy and Ionosphere Center, Arecibo Observatory, Puerto Rico (Associate Member)
10) Onsala Space Observatory (OSO), Chalmers University of Technology, Onsala, Sweden
11) Shanghai Astronomical Observatory, National Astronomical Observatories, Shanghai, P.R. China
12) Toruń Centre for Astronomy, Nicolaus Copernicus University, Toruń, Poland
13) Urumqi Astronomical Observatory, National Astronomical Observatories, Urumqi, P.R. China

<u>Geodesy</u>

14) Bundesamt für Kartographie und Geodäsie (BKG), Wettzell, Germany

The EVN Consortium Board of Directors (CBD) is a body whose membership consists of the Directors of the member institutes of the EVN. It meets twice a year to discuss EVN policy, operational, technical and strategic issues. The CBD elects a Chairman and vice-Chairman from its ranks who serve for a period of 2 years

2. Reports on Scientific VLBI-related Research

The scientific research carried out by various groups using EVN facilities cover a wide range of topics, from the Solar System and nearby Universe to the very distant objects. Here we present a summary of some of these studies starting with those dealing with far away Active Galactic Nuclei (AGN) and then moving as close as our Solar System.

2.1. AGN phenomena on the parsec scale

2.1.1 BL lac Objects and Quasars

A number of projects deal with the study of quasars and BL Lac objects. On the parsec scale all these objects show a compact core and a one-sided jet. In some cases, individual components in the jet can be tracked with multi-epoch observations to derive the kinematics of the relativistic flow.

A set of 37 ultra-high-resolution GMVA and VLBA images of the quasar NRAO 150 have been analyzed by Agudo (MPI) and collaborators. This monitoring program, which spans about 10 years, shows a counter-clockwise jet rotation of up to 11˚/yr in projection within the inner 61 pc of the jet (Fig. 2.1). This extreme jet swing, the fastest reported for an AGN, is associated with a non-ballistic superluminal motion of the jet within this region. These properties make NRAO 150 an ideal source for studying the jet wobbling phenomenon and hence the properties of the accretion systems in radio-loud quasars.

Britzen, Kudryavtseva, Ros, Witzel, Agudo, Meyer (MPI), Campbell (JIVE) and Metha, Aller and Aller (U. Michigan) have reanalyzed multi-epoch and multi-frequency VLBI observations of two BL Lac objects 0716+714 and 1803+784 over a period of 12 years. In contrast to previously discussed motion scenarios for these two objects, the position of the components, in the inner 6 and 12 mas respectively, can be fitted as stationary while significant smooth changes in their position angles are observed (Fig. 2.2).

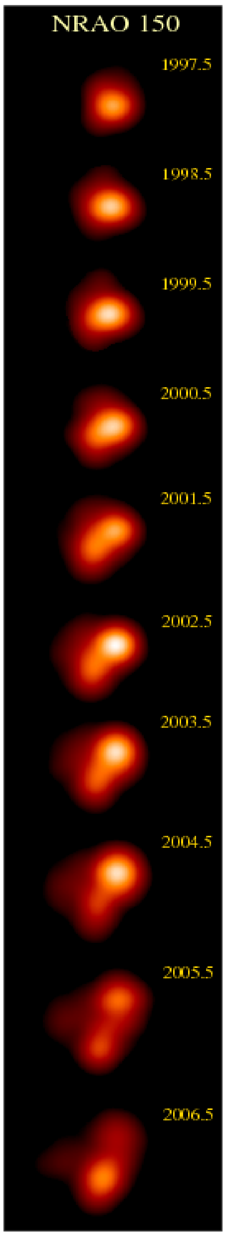


Figure 2.1: the extreme jet swing of NRAO150

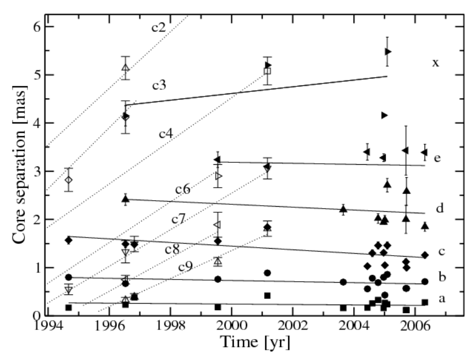


Figure 2.2: core separation at 15 GHz vs time for individual jet components in 0716+714. New and old component identifications shown in solid and dotted lines .

Frey (FÖMI SGO. Hungary), Paragi (JIVE), Mosoni (Konkoly Obs., Hungary), and Gurvits (JIVE) observed SDSS J0836+0054, the most distant radio-loud quasar known to date (at z=5.774), with the EVN at 5 GHz. The source is compact at the milli-arcsecond (mas) angular scale with a flux density of 340 microJy. The observations with the VLA made on the consecutive day support the conclusion that the radio emission from SDSS J0836+0054 is essentially confined within the central 40 pc. There is no indication that the quasar image is strongly magnified by gravitational lensing. The structure and radio luminosity of the source make it very similar to other powerful radio-loud AGN observed at much later cosmological epochs (much lower redshifts). Based on the phase-referenced VLBI observation, the accurate astrometric position of the source was obtained.

The radio source 0803+5126 is located in the field of the EGRET source 3EG J0808+5114. Chen, Gu, Shen, Fan (ShAO) observed 0803+5126 at 6 cm with the EVN array finding a core component with an extremely low brightness temperature plus an asymmetric two-sided jet structure suggesting a relatively weak beaming effect in radio emission (Fig.2.3). Based on the positional uncertainty of 3EG J0808+5114, its separation to various possible radio counterparts, and very low gamma-ray variability, it is reasonable to believe that 0803+5126 is the most probable radio counterpart of the EGRET source, making it the first EGRET-detected AGN to be associated with a two-sided jet structure on parsec scale.

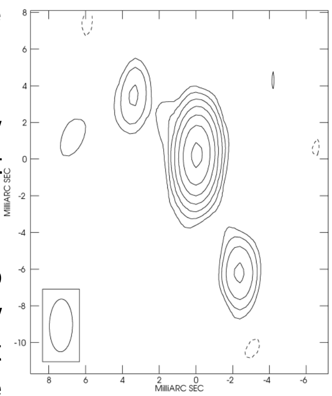


Figure 2.3: 6-cm VLBI image of 0803+5126 obtained with the EVN

Bignall (JIVE) is PI on an EVN+MERLIN project to study the BL Lac objects identified in the "Deep X-ray Radio Blazar Survey" (DXRBS) which had not previously been observed at high resolution. The newly identified BL Lacs tend to have properties spanning the range between "classical" X-ray and radio-selected BL Lac samples, and are expected to provide a more complete picture of BL Lacs in the context of unified models for radio-loud AGN. Sixteen target sources were observed over a 48-hour period in June 2005. Bignall worked with Landt (CfA), who visited JIVE in March 2006, and Reynolds (JIVE) on VLA and ATCA data for the entire DXRBS BL Lac sample of 44 objects. Many of the sources show complex extended structure and large misalignment angles of the jets between parsec and kilo-parsec scales.

Giroletti and Giovannini (IRA) have selected and observed with VLBI a sample of 30 nearby (z < 0.2) BL Lac objects estimating Doppler factors and discussing the multi-wavelength properties. Radio and optical nuclear luminosities (and fluxes) show a strong correlation (Fig. 2.4) indicating a common

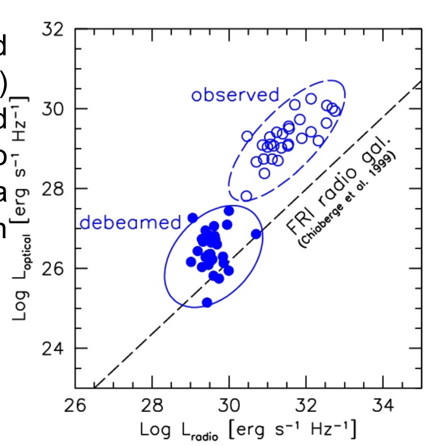


Figure 2.4: Optical vs radio luminosity in Giroletti's sample of BL Lacs. Open dots are observed luminosities, filled ones are those corrected for Doppler beaming assuming a viewing angle of 60 deg. The dashed line shows the radio-optical correlation found for FR I cores.

origin for the emission at both wavelengths, i.e. non-thermal synchrotron radiation. Moreover, the de-beamed luminosities of the cores are ruled by the same correlation as that found for low power radio galaxies, in strong support of the unification of BL Lacs and FR Is based on the orientation. They found a significant correlation between the mass of the central SMBH (estimated from the host galaxy magnitude) and the radio luminosity, both nuclear and extended, regardless of any common distance dependence. Finally, the de-beamed radio and X-ray luminosities follow quite well the fundamental plane of BH activity found for other super-massive and galactic BH, although some overall scatter and the LBL-HBL offset are present.

2.1.2 Low luminosity AGNs

At the low end of the radio power range typical for radio loud objects, there is a large population of objects (Low Luminosity AGN, LINERs and Seyfert-like nuclear regions) whose properties are not well-known and are currently studied with VLBI experiments.

Giroletti and Giovannini (IRA) are engaged in observations of Low Power Compact (LPC) radio sources with phase-referenced VLBI and VLA to determine rates and peculiarities of the radio emission in their cores. It is interesting to understand whether these sources are compact because they are young or rather because they are weak and not capable of growing any larger. Their data reveal flat spectrum, compact cores (down to a few mJy), a few one-sided jets, and in one case a hot spot. On the basis of these results, they rule out the presence of strong relativistic effects in these LPCs, which must be intrinsically small (<10 kpc); some of them are good candidates as frustrated or prematurely dying radio sources. This field is of great interest at the moment, as it is expected to provide insight on the fundamental physical properties at the basis of the different observed kind of activity in the nuclei of galaxies.

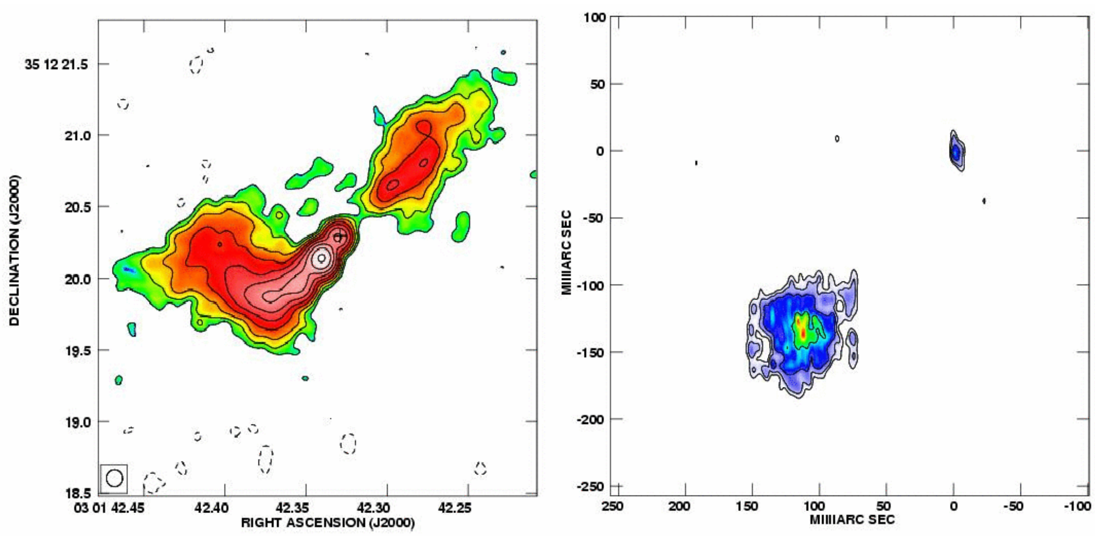


Figure 2.5: VLA (left) and VLBI (right) image of the radio source 0258+35

Figure 2.5 shows a VLA image of 0258+35 (left), which looks FRI-like, except that it is only 5 kpc from tip to tip, and the phase referenced VLBI data (right), which allow to identify the two prominent compact components in its inner region: one of them is a 7 mJy compact, flat spectrum (~0.0) core; the second one has a larger flux density, a steeper spectrum (~0.5) and it is more extended, so it is more likely to be a jet knot, partly resolved. It is worthwhile to stress the importance of phase referencing: any blind self-calibration would have caused a loss of information about the second component as well as a totally wrong measurement of the core flux density.

New 2 cm VLBA images of the inner radio jet of M 87 have been made by Kovalev (MPI), Lister (Purdue U.), Homan (Denison U.) and Kellermann (NRAO). They show a limb-brightened structure and unambiguous evidence for a faint 3 mas-long counter-feature which also appears limb-brightened (Fig. 2.6). Multi-epoch observations of seven separate jet features show typical speeds of less than a few percent of the speed of light, despite the highly asymmetric jet structure and the implications of the canonical relativistic beaming scenario. The observed morphology is consistent with a two stream spine-sheath velocity gradient across the jet, as might be expected from the recently discovered strong and variable TeV emission, as well as from numerical modelling of relativistic jets. Considering the large jet to counter-jet flux density ratio and lack of observed fast motion in the jet, it is concluded that either the inner part of the M 87 jet is intrinsically asymmetric or that the bulk plasma flow speed is much greater than any propagation of shocks or other pattern motions.

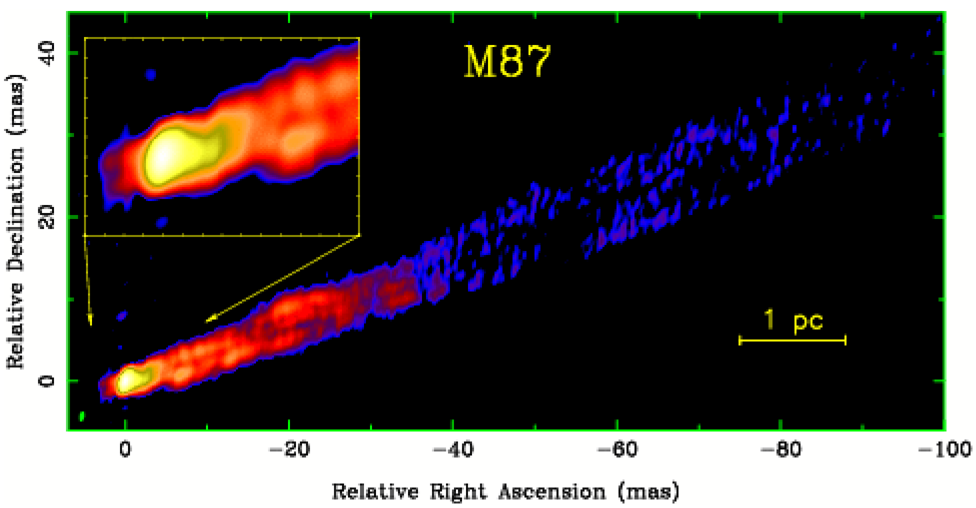


Figure 2.6: VLBA 15 GHz logarithmic false-color image of the M87 jet. The FWHM beam is 1.3x0.6 mas at P.A=-11 deg. The peak intensity is 1.0 Jy/beam and the off-axis noise 0.064 mJy/beam. The corresponding dynamic range is better than 15,000 to 1. The faint counter-jet (see inset) is seen extending to the south-east.

2.1.3 Young and/or frustrated radio sources

Different groups are deeply involved in the study of intrinsically small and young radio sources. Based on the selection criteria originally used to identify these sources, they are known as Compact Steep Spectrum (CSS), Giga-Hertz Peaked Spectrum (GPS) and Compact Simmetric Objects (CSO).

Studies of bright CSS quasar 3C309.1 continued as a part of Ph.D. thesis by M. Gawronski. The project includes VSOP observations at 5 and 1.66 GHz, VLBA at 15 GHz and archival at 8.4 GHz. M. Gawronski estimated the angle between the line of sight and the initial direction of the jet (~15.5 deg). Overall size of 3C309.1 was estimated as ~80 kpc and thus it is probable that 3C309.1 is a small FRII radio galaxy oriented close to the line of sight (Fig. 2.7). Moreover the superluminal motion of the innermost component was confirmed (7.0+/-0.5 c). The results were presented at 8th EVN Symposium (2006).

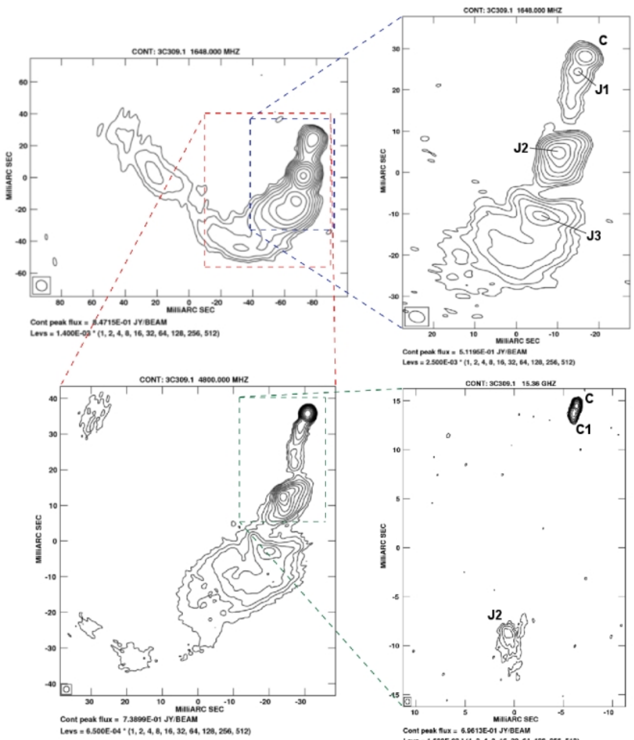


Figure 2.7: VLBI images of the CSS quasar 3C 309.1

Five new object of HYMORS (HYbrid MOrphology Radio Sources) class were discovered using VLA (Gawronski et al., 2006). The understanding of HYMORS phenomenon could be crucial in solving problem of FRI/FRII dichotomy. The cores of those sources were observed using VLBA at 1.6 and 5 GHz. The properties of the VLBI structures are investigated and currently being prepared for publication.

Reynolds (JIVE) worked with Liu Xiang (UAO) on the analysis of EVN observations of a sample of GPS radio sources, which aimed to find Compact Symmetric Objects (CSOs). CSOs play a key role in understanding the very early stage evolution of radio galaxies. Three sources from a sample of eleven GPS sources observed at 2.3/8.4 GHz were confirmed as CSOs, with the remainder being a mixture of CSO candidates, core-jet or single component sources. Fourteen GPS sources were observed at 5 GHz to study the polarization. Of these, two core-jet sources, 1433-040 and DA193 exhibit integrated fractional polarizations of 3.6% and 1.0% respectively. The other twelve sources had no clear detection of pc-scale polarization, confirming that GPS sources generally have very low polarization at 5 GHz. In addition, a component in the jet of quasar DA193 was estimated to have a superluminal motion of (3.3±0.6)/h c from observations over 5.5 years.

Evidence has been mounting recently that activity in some radio-loud AGNs (RLAGNs) can cease shortly after ignition and that perhaps even a majority of very compact (GPS and CSS) sources may be short-lived phenomena because of a lack of stable fueling from the black hole. Thus, they can fade out before having evolved to large, extended objects. Researchers at the TcfA led by A. Marecki are studying a sample of candidate weak and fading CSS sources. The observations have shown that young compact fading sources do indeed exist. The source 0809+404 is one of such example (Fig. 2.8). On the arcsec-scale, 0809+404 is dominated by a compact core and some diffuse emission visible on VLA images.

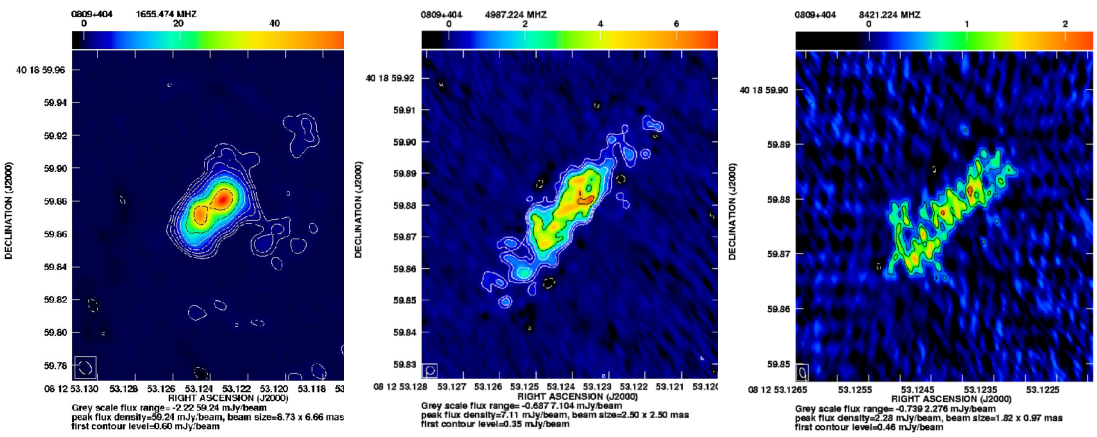


Figure 2.8: VLBI images of 0809+404 at 1.6 GHz (left), 4.9 GHz (middle) and 8.4 GHz (right). At 15 GHz the source is completely resolved out.

Multi-frequency VLBI observations show that the arcsec-scale core is made of diffuse emission and fades away at high frequencies.

Shen, Shang, Cai, Chen, Jiang, Chen (ShAO), Liu (URO), Jang, Kameno (NAOJ) and Hirabayashi (ISAS/JAEA) presented quasi-simultaneous multi-frequency (2.3, 5.0, 8.4 and 15.0 GHz) VLBI observations of the CSS superluminal source 3C138 (Fig. 2.9). For the first time, the

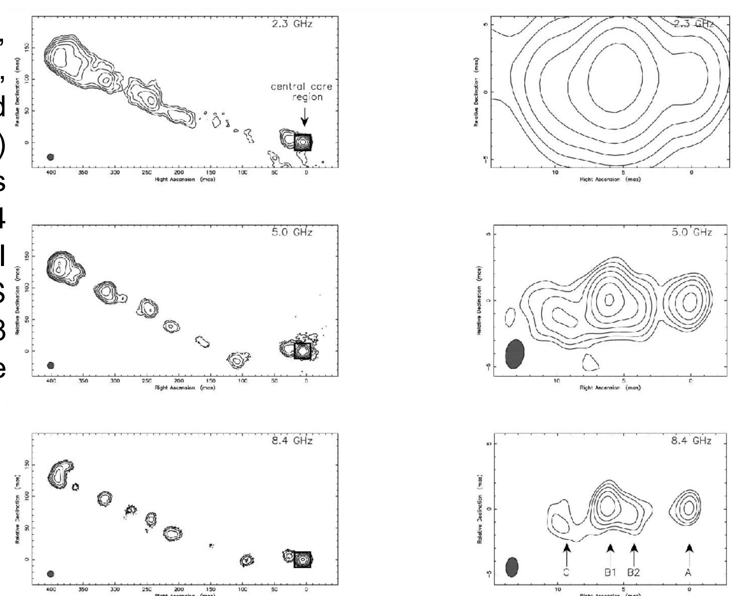


Figure 2.9: Images of 3C 138 at 2.3 GHz (upper panels), 5.0 GHz (middle) and 8.4 GHz (lower). On the left the large-scale images restored with a 10 mas beam, on the right the full resolution images of the core region.

spectral distribution of the components within its central 10 mas region was obtained. The observations enabled to identify the component at the western end as the location of the nuclear activity. The new measurements further clarify the superluminal motion of the inner jet components and reveal a convex spectrum in one jet component, implying the existence of free-free absorption by the ambient dense plasma.

Dallacasa, Stanghellini and Orienti (IRA) continue the study of young radio sources and their interaction with the local interstellar medium. In particular, they have selected a sample of High-Frequency Peaker (HFP) radio sources which are intrinsically compact extragalactic objects with a synchrotron radio spectrum peaking at frequencies well above a few GHz. They are interpreted to represent the youngest phase in the radio source evolution with typical ages of 100 - 1000 years. VLBI observations are used to eliminate from the sample possible contaminant objects.
The role of the local interstellar medium on the radio source growth has been investigated with multi-frequency VLBI observations of two very asymmetric (both in luminosity and arm-length ratio) CSOs. In both cases, the asymmetries are better explained in terms of jet-ambient influence rather than with a change of the hot-spot internal pressure.

EVN observations at 1.6 GHz have been obtained of 19 GPS sources from the Snellen (2002) sample by Liu (Urumqui) and collaborators (Fig. 2.10). They find that 80% of the objects show mini double-lobed (CSO like) structures, suggesting they are intrinsically small. Some new CSOs have been classified according to their symmetrical double lobe, size and stable source flux density.

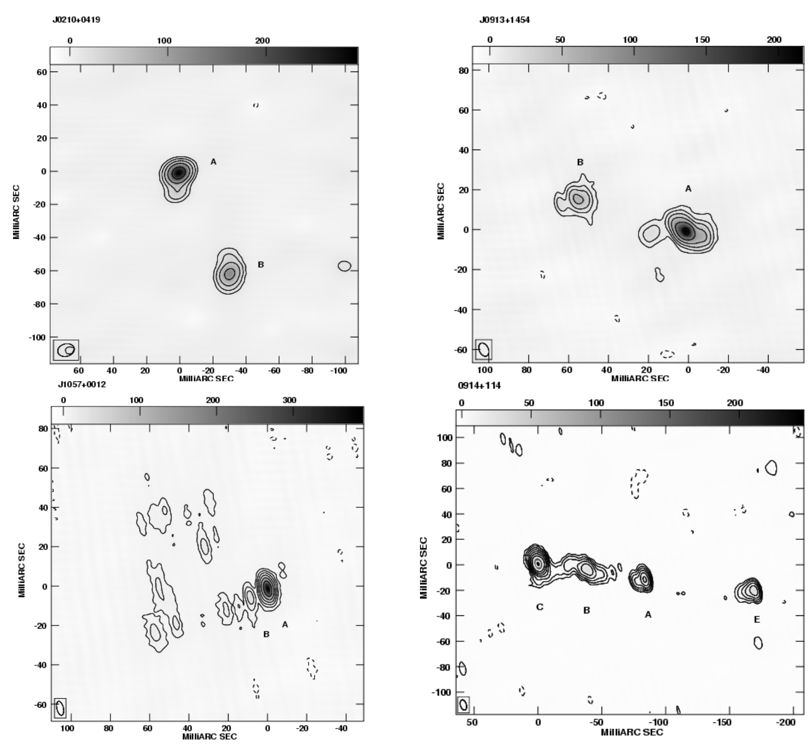


Figure 2.10: EVN *images of GPS sources from the Snellen catalog*

Rossetti, Mantovani, Dallacasa, C. Fanti and R. Fanti (IRA) have completed multi-frequency VLBI observations of the double compact sources in the Peacock & Wall catalogue identifying core-jet sources from possible CSOs.

2.2. Normal galaxies, starburst galaxies and supernovae

In March 2005, Garrett and Paragi (JIVE) participated in the first e-VLBI EVN continuum science demonstration observations. The target source of these observations was SN2001em, a supernova event that unexpectedly brightened in 2004, leading some to suggest that this source might be an example of a misaligned GRB and that the brightening was due to enhanced radio emission associated with the (now) non-relativistic jets. The e-VLBI observations of the source were dogged by various problems. By the time the software had been changed the source was setting for most of the e-VLBI antennas involved (Onsala, Westerbork, Arecibo and Torun; Jodrell Bank and Cambridge were shut down due to high winds earlier in the day). With all these problems only about 30 minutes of good data were obtained but it was still possible to detect the source on all baselines involving Arecibo. A tentative image of the SN2001em is presented below (Fig. 2.11).

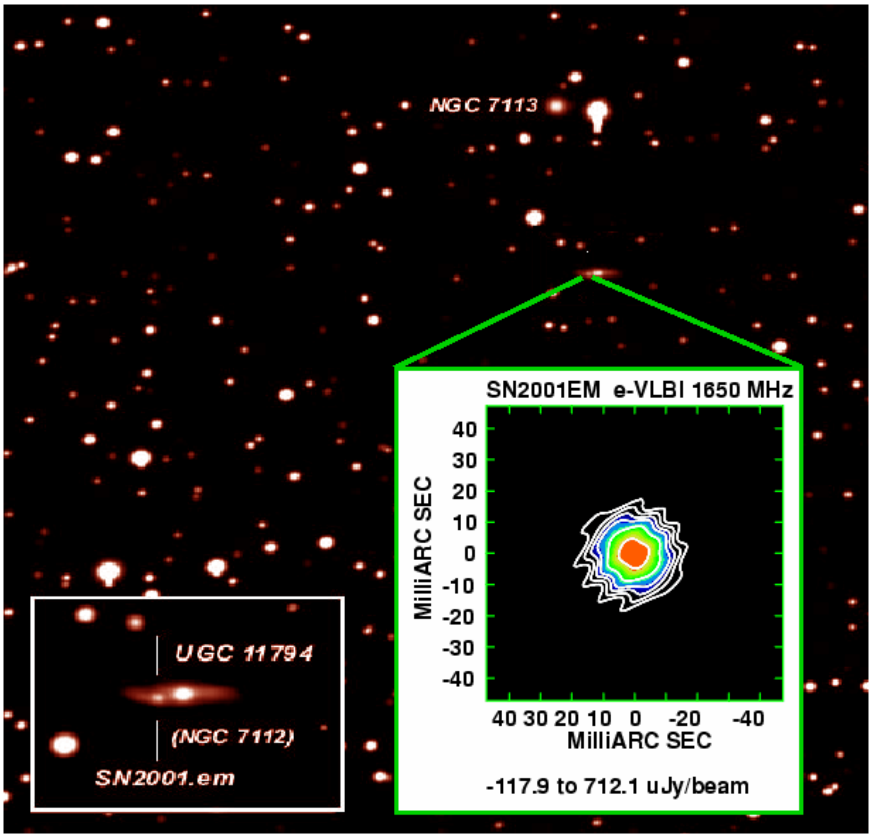


Figure 2.11: The tentative e-VLBI detection of SN2001em in NGC 7112

The type II-P supernova SN 2004et in the spiral galaxy NGC 6946 was observed by Martí-Vidal, Marcaide, Guirado (U. Valencia), Alberdi, Pérez-Torres (IAA-CSIC, Granada), Guirado (U. Valencia), Argo, Beswick, Muxlow, Pedlar (JBO), Shapiro (Harvard-Smithsonian CfA), Stockdale (Marquette U., Milwaukee), Sramek (NRAO, Socorro), Weiler (NRL), Vinko (U. Szeged, Hungary) and Ros (MPI) using a global VLBI array at 8.4 GHz on 20 February 2005, 151 days after explosion (Fig. 2.12). The VLA flux density was 1.23±0.07 mJy, corresponding to an isotropic luminosity at 8.4 GHz of (4.45±0.3)x10**25 erg/(sHz) and a brightness temperature of (1.3±0.3)x10**8 K. These observations reported an improved source position, accurate to about 0.5 mas. The VLBI image shows a clear asymmetry. From model fitting, a minimum expansion velocity of 15,700±2,000 km/s was estimated. This velocity is more than twice the expected mean expansion velocity estimated from a synchrotron self-absorbed emission model, thus suggesting that synchrotron self-absorption is not relevant for this supernova.

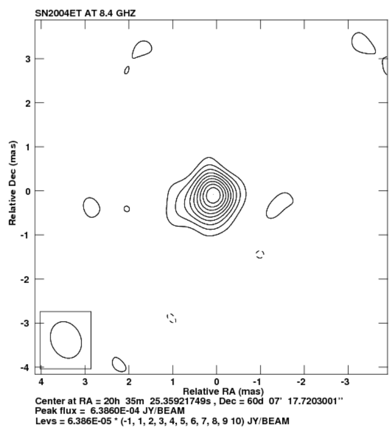


Figure 2.12: Hybrid map of SN2004et obtained from VLBI data model fitting two point sources to the visibilities.

Paragi, in collaboration with Garrett and Biggs (all JIVE), detected a radio source in the error box of the ultra-luminous X-ray source M82 X-1 with the EVN (Fig 2.13). The observations were carried out at 1.6 GHz using a data rate of 1 Gbps on 27 October 2005. From the VLBI-scale structure and especially from deep MERLIN observations (by Muxlow et al.), the association of this object to the ULX is unlikely. The non-detection of a radio counterpart indicates that the X-rays are not beamed relativistically in the source. Relativistic beaming was one of the scenarios to explain the highly super-Eddington luminosities in ULXs. Because of the huge luminosity, and the observed X-ray quasi-periodic oscillations, it is now generally believed that M82 X-1 is powered by an intermediate-mass black hole.

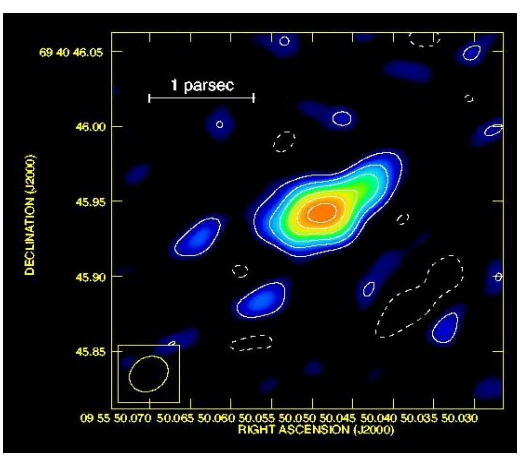


Figure 2.13: A radio source detected by the EVN in the position error box of the ultra-luminous X-ray source M82 X-1. The experiment took place on 27 October 2005 at 1.6 GHz, using 1 Gbit/s data rate. From the radio structure and other considerations it follows that the source is not related to the ULX. We derive an upper limit of 67 microJansky to the ULX, from which we estimate an upper limit to its black hole mass of about 500 solar masses. These observations show that M82 X-1 is likely not powered by an intermediate mass black hole (IMBH) of ~1000 solar masses as was believed earlier. A less massive IMBH or a stellar mass XRB with geometrically beamed X-ray emission are the alternatives.

They used the recently established formula for the black hole activity plane that relates the X-ray luminosity, radio luminosity and compact object mass, to estimate an upper limit of ~ 500 solar masses to the mass of the black hole in the system. It follows that the data do not support an IMBH with more massive than 1000 solar mass, as inferred from the X-ray observations. It is possible that M82 X-1 may be powered by a less massive intermediate mass black hole, or an X-ray binary accreting at highly super-Eddington rates, like the famous Galactic source SS433.

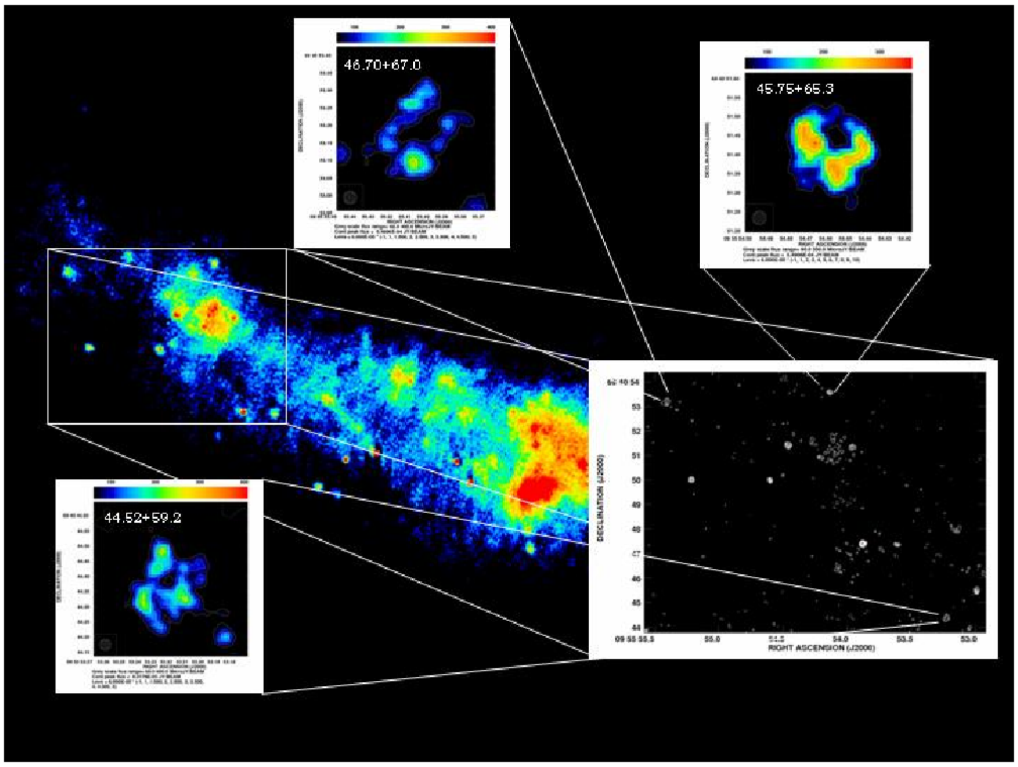


Figure 2.14: MERLIN and VLBI images of M82. The insets show the VLBI images of selected supernova remnants from the north eastern region.

M82 is considered to be the archetypal starburst galaxy and at a distance of 3.2 Mpc is one of the closest. As a consequence, it makes an ideal study ground of an extragalactic starburst environment. The first radio observations of this galaxy were made in the 1960's and subsequent high resolution observations in 1972 revealed a population of compact sources within the central kiloparsec. These sources were initially proposed to be either radio supernovae or supernova remnants (SNR), but the subsequent lack of radio variability distinguished them as SNR. Radio interferometry techniques are ideal for observing the SNR within this galaxy for several reasons. The extinction due to dust is extremely high, making it very difficult to observe these sources at optical wavelengths. All of the sources are observed with the same angular resolution and sensitivity, and the relative distance to the individual SNR will only differ by ~0.1% due to the large distance to the galaxy in question. Therefore, this population of sources has been observed using several of the world's interferometry networks including the VLA, MERLIN and global VLBI, and there are now known to be over 50 discrete sources present in the central kiloparsec, all resolved by either MERLIN and/or VLBI. They form a population of sources brighter, and more compact than Cassiopeia A and so are considered to be young and rapidly evolving SNR (Figs 2.14 & 2.15).

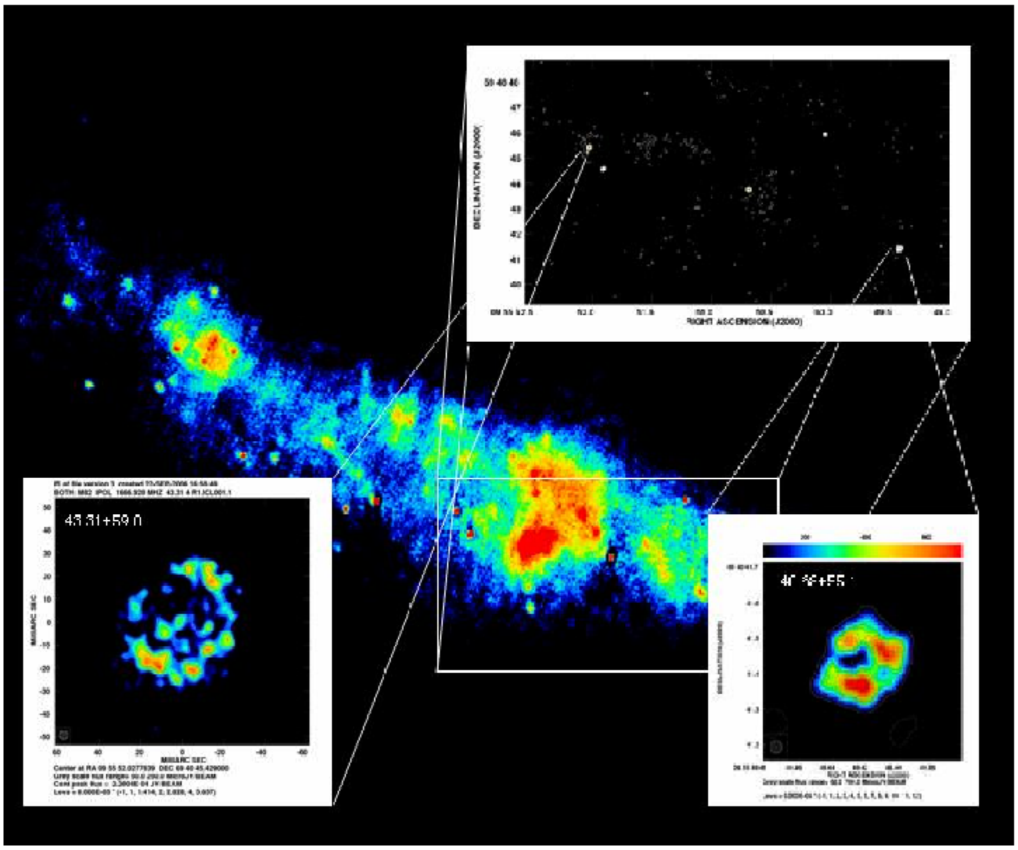


Figure 2.15: MERLIN and VLBI images of M82. The insets show the VLBI images of selected supernova remnants from the south western region.

Up until recently the high resolution radio observations made using VLBI techniques have been limited to the study of the few brightest and most compact of the sources within M82. Whilst the extremely high resolution of VLBI observations has allowed these most compact objects to be studied in great detail, the larger more evolved and hence more diffuse population of objects in M82 have resolved away by VLBI techniques and only been detectable with courser resolution instruments, such as MERLIN.
Recent work by Fenech (JBO) & collaborators combining simultaneous observations using a 16 element global VLBI of array and MERLIN observations have allowed, for the first time, the structure many of the larger, fainter supernova remnants in M82 to be clearly resolved. These observations have provided images of M82 with resolutions ranging from a few mas to ~100 mas and have enabled the first detailed study of the population of discrete sources at 1.6 GHz.

While M82 is the best prototype of a nearby starburst galaxy the nearest example of a powerful ultra-luminous (L_LIR>10**12 Lsol) starburst is Arp220. This object lies at a distance of 77 Mpc and is over 30 times more luminous than M82. Since the discovery observations of Smith et al (1998) it has been known that there are groups of compact radio sources in both nuclei of Arp220, identified either as radio supernovae or supernova remnants. Monitoring at 18cm wavelength has continued over the last decade revealing a large population of weak compact sources (and some newly created bright sources). Lonsdale et al 2006 recently presented 18cm global observations showing one of the deepest VLBI images every made (map rms of only 5.6 microJy/beam). This image revealed a total of 49 compact sources in both nuclei (see Fig 2.16). In nearly all cases the luminosities of these sources exceeds those in M82. It was however concluded that this population could be explained as being due to a scaled up version of the starburst in M82.

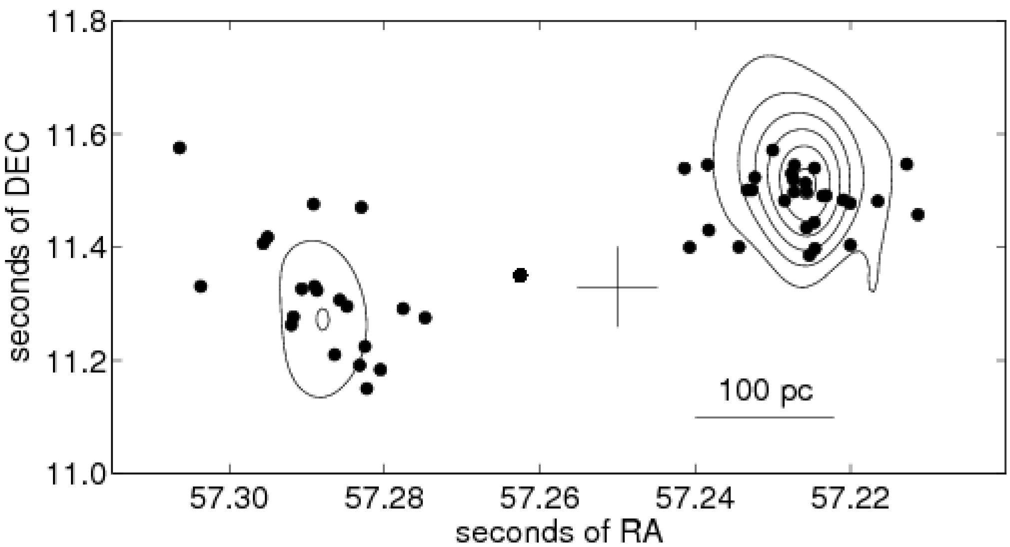


Figure 2.16: Overall view of the Arp 220 nuclear region (from Parra et al 2007). Filled circles show the positions of the 49 compact sources at 18 cm catalogued by Lonsdale (2006). Contours show a 6~cm delay--rate map obtained from a 10 minute scan with the Ar--Eb baseline. Contours are drawn 500 microJy apart. The data were tapered in time and frequency using a Chebyshev window to reduce sidelobes, resulting in a delay-rate beam of FWHM ~200 mas and a map noise of ~42 microJy.

In another recent development the Arp220 compact sources have for the first time been detected at wavelengths shorter than 18cm (Parra et al 2007). The first detection at 6cm wavelength was made in one of the first ever EVN 1Gbit/s observations which involved the Effelsberg, Westerbork and Arecibo antennas. Arp220 was observed as one of a large sample of starburst galaxies for only 10 minutes yet fringes on the Arecibo-Bonn baseline were easily detected. A delay-rate map (see Fig 2.16) was made showing that there was compact emission from both nuclei. A subsequent VLBA observation at three wavelengths (13cm, 6cm and 2cm, see Fig 2.17) detected a significant number of the already known 18cm sources plus some new objects. The detected sources show a wide range of radio spectra and appear to divide into two groups- one consistent with evolving supernovae (interacting with their progenitor winds) - the other more stable and identified as supernova remnants interacting with a dense ISM. The later sources were used by Parra as in-situ probes of the ISM implying large densities (>10**4/cm**3). The rate of appearance of new sources was found only to be consistent with the star-formation rate inferred from FIR emission if every supernova was of the most luminous type (type IIn). Various explanations were proposed for this result including that there is a very top heavy stellar initial mass function. Finally at 3.6cm wavelength one of the compact sources (W42) was resolved (diameter 0.9 pc) and found to have a large total stored energy, implying a very energetic initial supernova explosion.

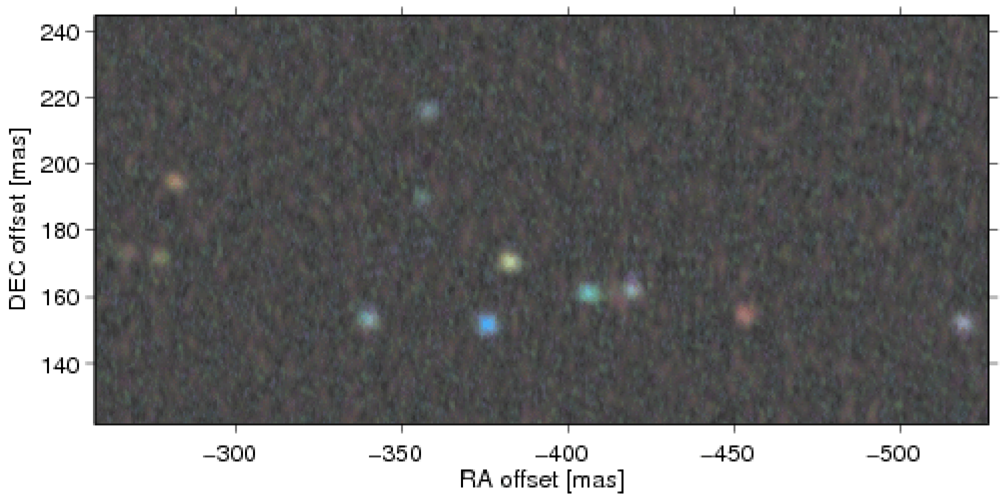


Figure 2.17: The short wavelength detected sources in the western nucleus of Arp220. This composite colour image displays in Red, Green and Blue the 13, 6 and 3.6 cm VLBA images made from data taken in January 2006. The axes of this image are in milliarseconds relative to the correlation position between the two nuclei.

2.3. VLBI surveys of extragalactic sources

A team composed by Garrett (JIVE), Barthel and Chi (both Groningen) analysed a wide-field, global VLBI data set, targeting a region of sky centred on the Hubble Deep Field (HDF-N). This huge data set comprises three 12-hour epochs of global VLBI data that included the participation of the 100-m Effelsberg, Green Bank and 76-m Lovell telescopes. The data were correlated at JIVE (in wide-field mode) generating 675 GB of data. The recording rate was limited to 128 Mbps in order to obtain fine spectral resolution and each epoch was correlated in 2 passes in both right (R) and left (L) hand circular polarization. The data were calibrated by averaging the data set and then applying the corrections to the unaveraged data set.
In this project, a total of 92 radio sources of Muxlow et al. (2005) were surveyed over a total of 201 arcmin^2 divided into four annular fields with different angular resolutions and sensitivities. The images in the HDF-N (Figs. 2.18 & 2.19) reach thermal noise levels of 7.3 microJy/beam with 4 milliarcseconds angular resolution. Above a 5σ threshold, 12 radio sources in HDF-N and HFF were clearly detected. Figure below shows four detections in HDF-N, including a new VLBI detection, and Figure on next page presents the other 8 radio sources detected in HFF.

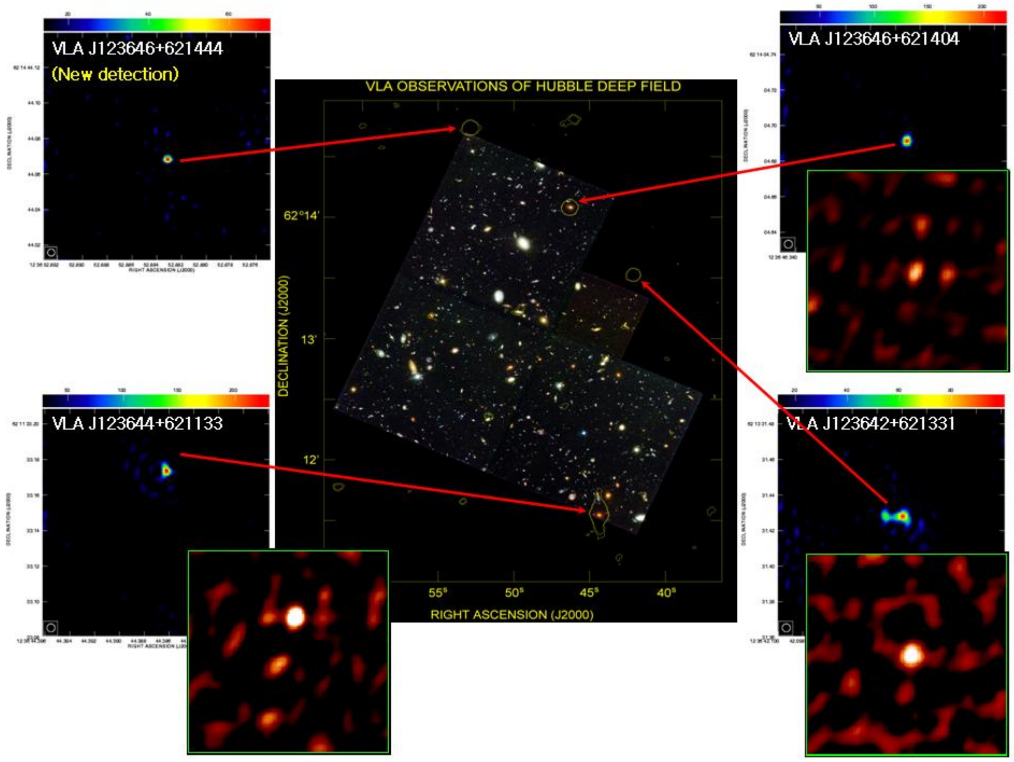


Figure 2.18: New global VLBI detections in the HDF-N (pseudo colors) together with sources that were previously detected by the EVN (flame colors). A VLA radio map (yellow contours, Richards et al. 1988) is superimposed on the deep HST image.

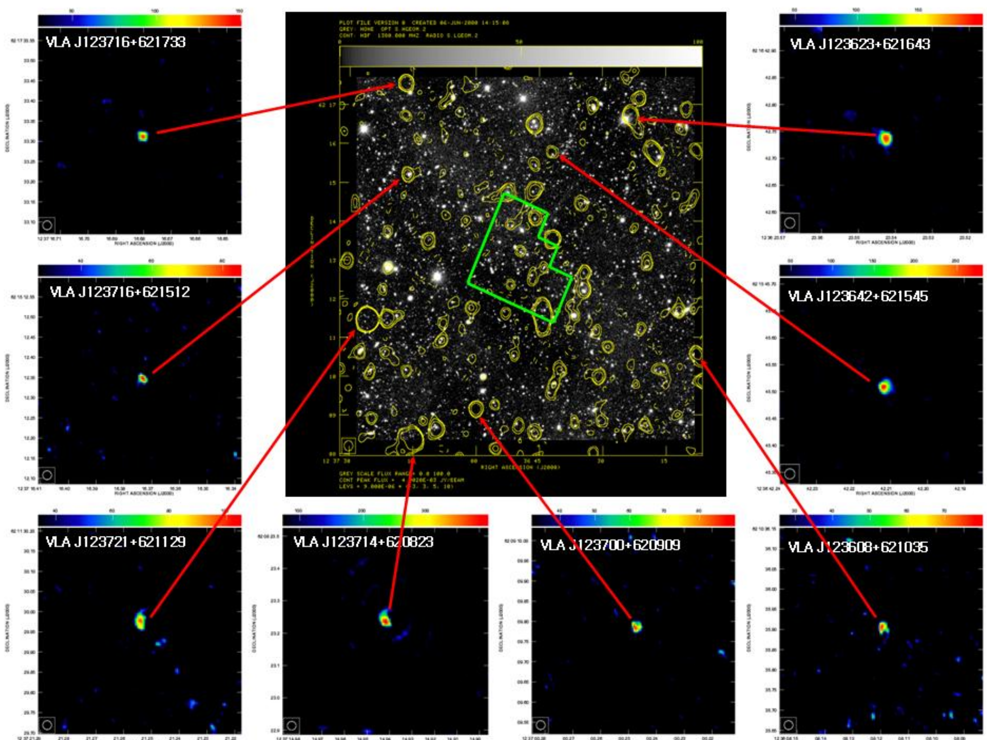


Figure 2.19: New global VLBI detections in the HFF (pseudo colors) together with WSRT radio map (yellow contours) superimposed on the CFHT I-band image (gray scale, Garrett et al. 2000). Both angular resolution and sensitivities of the images are degraded (tapered data).

A pilot project of the Deep Extragalactic VLBI-Optical Survey (DEVOS) has been conducted over the last three years by an international group led by S. Frey (FÖMI SGO, Hungary) and involving Gurvits and Garrett (JIVE). The ultimate goal is to get VLBI images of 10,000 of optically identified extragalactic radio sources. Going after VLBI detections in a FIRST-based sample of extragalactic sources, the yield was estimated to be 30%. This value will be verified by further DEVOS pilot observations and might become an important input for the SKA design study. A paper (Mosoni et al. AA, 2006, 445, 413) summarizes the results of the pilot phase of the project. The completion of this pilot also allows one to properly estimate observing resources needed for a full scale survey. Previously unknown sources for future in-depth studies were identified in the project.

Lee , Lobanov, Krichbaum, Witzel and Zensus (MPI) and Bremer, Greve and Grewing (IRAM) have conducted a new global VLBI survey of compact radio sources at 86 GHz. The main goal of the survey was to increase the total number of objects accessible for future 3-mm VLBI imaging by factors 3-5. The survey data attained the baseline sensitivity of 0.1 Jy and image sensitivity of better than 10 mJy. To date, a total of 127 compact radio sources have been observed. The observations have yielded images for 109 sources, and only 6 sources have not been detected. The remaining 12 objects have been detected but could not be imaged due to insufficient closure phase information. Flux densities and sizes of core and jet components of all detected sources have been estimated.

2.4. Gravitational Lenses

The gravitational lens effect acting on extended background sources potentially provides a unique opportunity to determine the mass distribution of a lensing galaxy to great detail and very accurately, because each multiply imaged component contributes its own constraints. Since the true (unlensed) structure of the background source is not known a priori, sophisticated modelling techniques must be used that can fit for the mass distribution and the source structure simultaneously. For interferometric radio data, the currently most successful method is LensClean, invented by Kochanek & Narayan in 1992 and developed by Wucknitz (JIVE). In order to interpret its results correctly and to develop further improvements, the noise and error properties of LensClean, which are partly inherited from Clean, have to be analysed (Fig. 2.20). Wucknitz continued the work on new deconvolution methods for interferometric observations of lensed sources. Markov-chain Monte Carlo methods were used to study systematic effects of trial methods and to explore the full range of possible source structures instead of limiting the interest to maximum-likelihood fits. The goal is to introduce regularisation constraints into radio lens modelling algorithms in an optimal way.

One of the most interesting applications for LensClean is the lens system B0218+357, which has been used to determine the Hubble constant from the time delays among its images. Global VLBI observations conducted at 90/50 cm extend the study of the Einstein ring to higher resolutions and will allow the investigation of mass substructure and propagation effects. Preliminary maps of B0218+357 are shown in Figure 2.21.

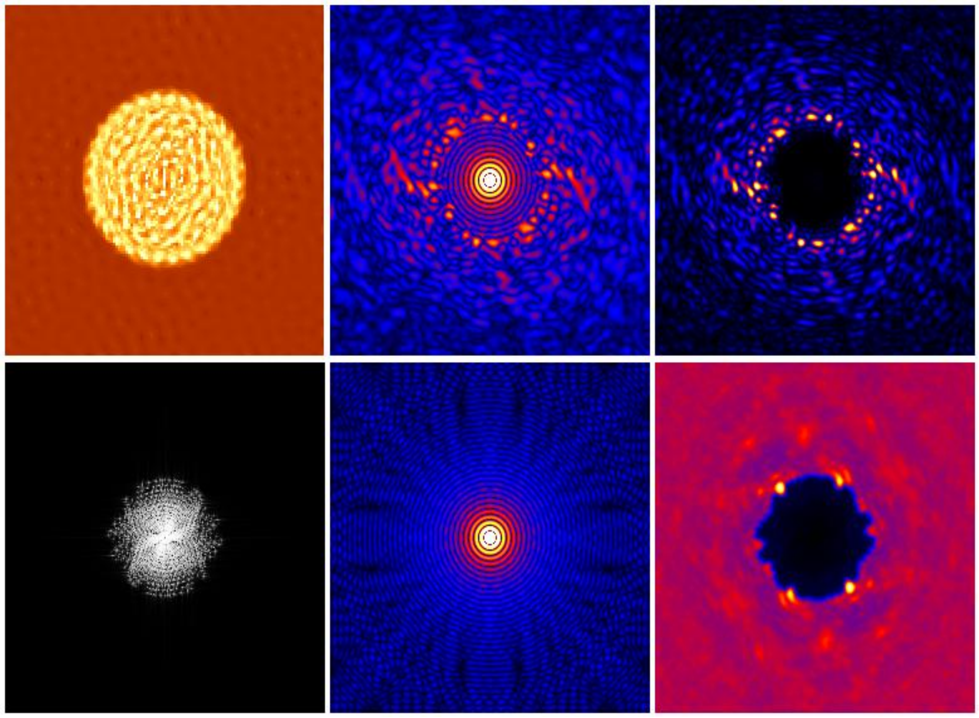


Figure 2.20: Illustration of Clean simulations to study the noise properties. The images show the mean Clean result (without Clean beam deconvolution) in, from top left, (a) image and (b) uv-space, (c) the systematic error in uv-space, (d) the uv-coverage, (e) the model in uv-space, and (f) the mean statistical error in uv-space. The model source was a uniform disc of constant surface brightness.

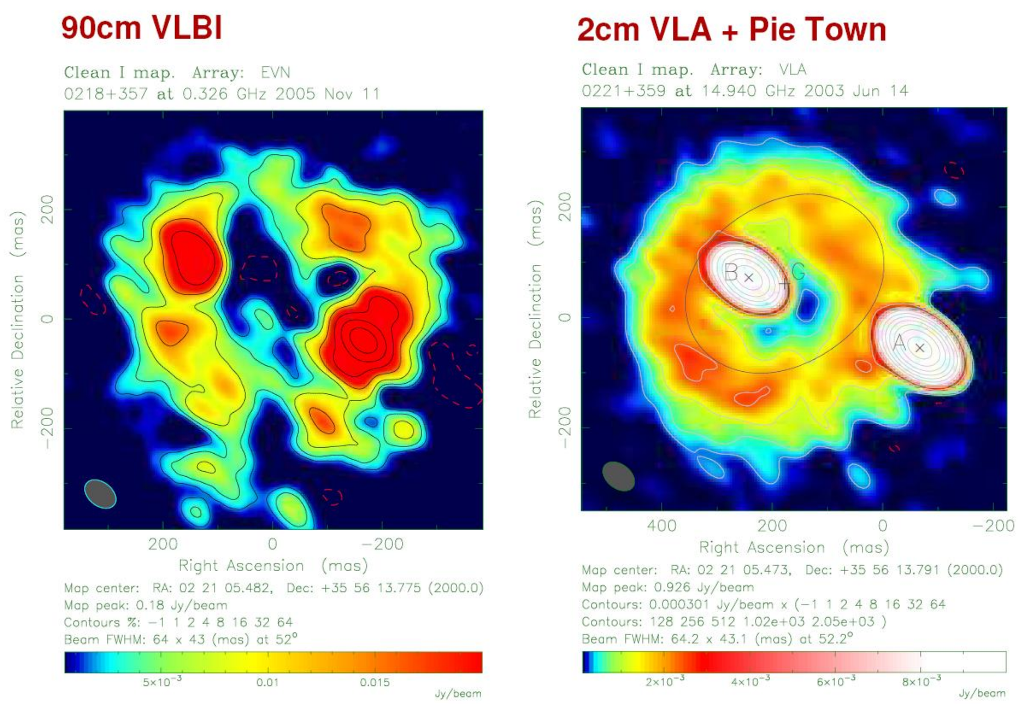


Figure 2.21: Left: Preliminary map of B0218+357 at 90cm observed with a VLBI array consisting of the VLBA, Jodrell Bank and the Westerbork phased array. Right: VLA+Pie Town map at 2cm for comparison. Even though the details in the 90cm map are still uncertain we can already see significant differences which are partly due to frequency-dependence of the source structure and partly due to propagation effects (scattering and free-free absorption)

The ionosphere, although relatively well behaved during the observations, produced phase fluctuations which make phase referencing difficult. Together with Mittal (MPIfR, Bonn), Wucknitz investigated further the frequency dependence of the flux density ratio in B0218+357. It became clear that magnification gradients together with the frequency-dependent source structure cannot explain the observed effects. Free-free absorption in the ISM of the lensing galaxy, on the other hand, fits the observations very well.

The gravitational lens system CLASS B2108+213, whose image separation is consistent with a lens consisting of a galaxy group, is being used by McKean, More and Porcas (MPI) to investigate the structure and composition of a group dark matter halo at high redshift for the first time. Optical spectroscopy with the W. M. KeckTelescope has been used to obtain the stellar velocity dispersion of the main lensing galaxy, and to identify 45 galaxies of the group. The stellar velocity dispersion constrains the core properties of the lens potential and the group galaxies are incorporated into the mass model as sub-haloes. Extended emission from the two radio-loud lensed images, from Global VLBI imaging made at 5 GHz in February 2006, provide additional constraints to the lensing mass model at kpc-scales (Fig. 2.22). X-ray imaging of the B2108+213 system was made in August 2006 and will be used to look for hot gas associated with the lensing group.

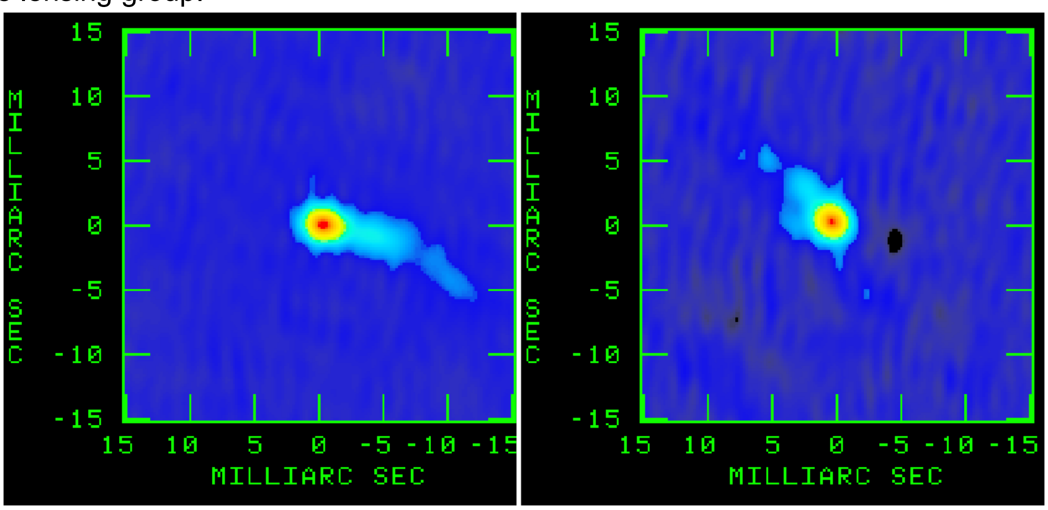


Figure 2.22: Global 5 GHz VLBI images of the core-jet structure iof B2108+213 in image A (left) and image B (right).

Mittal and Porcas (MPI) and Wucknitz (JIVE) have continued their VLBI investigations of the gravitational lens B0218+357, whose 2 images have an anomalous frequency-dependent flux density ratio (Fig. 2.23). Neither the centroids nor the peaks of their flux-density distributions show sufficiently large frequency-dependent position shifts to experience different magnifications from simple isothermal ellipsoid models of the lens potential. A detailed examination of the interactions of the image brightness distributions with the magnification from such models can also not explain the effect. A frequency-dependent source size could in principle interact with mass substructure in the lens but a simple model of this cannot reproduce the observed change of flux density ratio with image size. However, free-free absorption in a dense molecular cloud along the path of image A, known to be present from radio spectroscopic observations, can indeed reproduce the difference between the radio spectra of images A and B. Refractive scattering by a screen only partially covering image A might also reproduce the observed anomalous frequency-dependent flux density ratio, but there is little evidence that image A suffers strong scattering compared with image B.

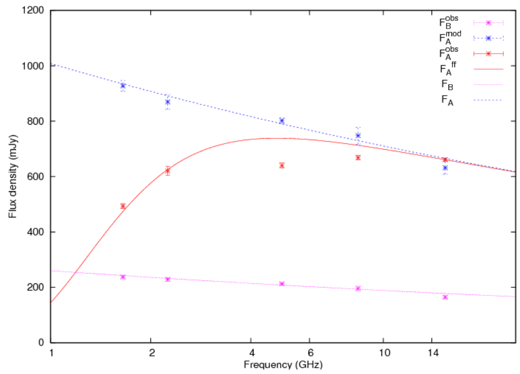


Figure 2.23: Observed spectrum of B0218+357 image B (purple), lens-modeled spectrum of image A (blue) and observed spectrum of image A (red); the solid red line represents a fit of free-free absorption by a giant molecular cloud along the path to image A.

The gravitational lens system B2016+112 is a quadruply imaged system where A and B are two images and region C shows a pair of merging partial images in the radio. This region near the lens critical curve is expected to have unusually high magnification. High resolution Global VLBI observations at 1.7 GHz and 5 GHz, and 8.4 GHz HSA observations made in April 2006 by More and Porcas (MPI) and Garrett (JIVE) reveal a much richer structure in both A and B images than has been seen before (Fig. 2.24). Owing to the detection of more than three non-collinear components in both A and B the expected opposite parities of these images could be verified. A detailed spectral analysis of the components in each of A, B and C has allowed the counterparts of the components of C to be identified in images A and B. In a model by Koopmans, region C is a highly magnified image of a small part of the background source appearing at the north-west end of images A and B. The new spectral analysis is consistent with this basic scenario. The fine structural details discovered in images A and B will provide further constraints for detailed modeling of this system which is now being undertaken.

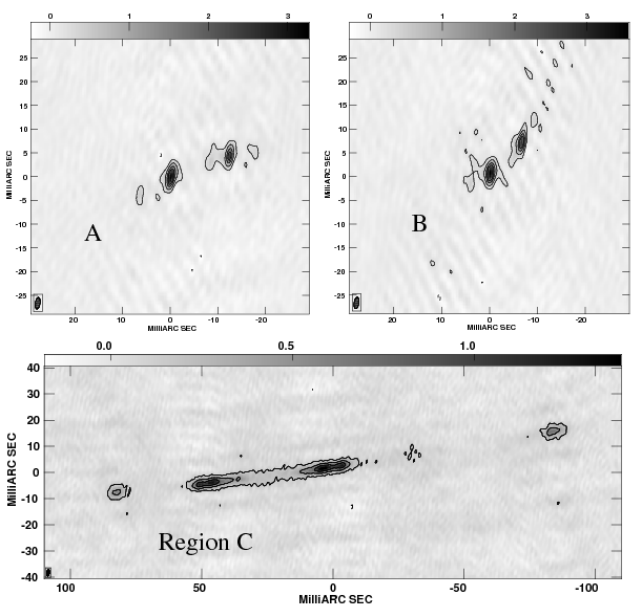


Figure 2.24: Global 5 GHz VLBI maps of gravitational lens 2016+112: image A (left), image B (right), region C (bottom).

2.5. Galactic transients and young stellar objects

The recurrent nova RS Ophiuchi underwent its 6th known outburst since 1898 on 12 February 2006. The phenomenon is believed to result from thermonuclear explosions in hydrogen-rich material accreted onto the surface of a white dwarf from a companion red giant star. O'Brien, Muxlow, Beswick, Garrington and Davis (Jodrell), Bode (Liverpool J.M.U), Porcas (MPI), Eyres (UCLAN) and Evans (Keele U.) made Target of Opportunity VLBI observations with the VLBA on 26 February and 13 March, and with the EVN on 5/6 March at both 1.7 and 5 GHz (Fig. 2.25). The first observation revealed faint radio emission in the form of an approximately circular structure, significantly brighter on its eastern side. The subsequent epochs showed continued expansion at a speed of 0.6 mas/day (equivalent to 1730 km/sec at a distance of 1.6 kpc), but the structure grew more complex, with the appearance of a second component to the east of the ring. Subsequent MERLIN observations showed the appearance of an additional new component to the west, the whole morphology later evolving into an elongated east-west structure. A very similar radio structure was seen in 1.6 GHz VLBI observations made 77 days after the previous outburst in 1985. These observations support the basic model developed following the 1985 outburst, the radio emission resulting from a shock expanding through the wind of the red giant. It is unclear, however, whether the elongated structure results from bipolar ejection or from the shaping of an initially spherical explosion by e.g. an asymmetric red giant wind.

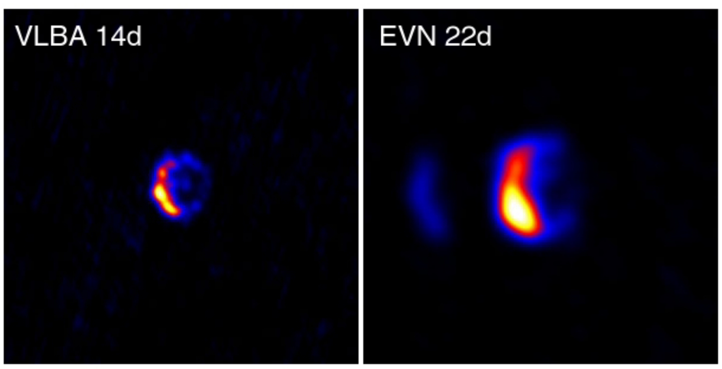


Figure 2.25: VLBA (left) and EVN (right) 5 GHz images of the expansion of RS Ophiuchi 2 and 3 weeks after explosion.

The use of the internet for electronic very-long-baseline interferometry (e-VLBI) data transfer offers a number of advantages over conventional recorded VLBI, including improved reliability due to real time operation and the possibility of a rapid response to new and transient phenomena. Decisions on follow-up observations can be made immediately after the observation rather than delayed by potentially weeks due to problems in shipment of tapes/discs to the correlator. A number of recent test runs have shown that 512 Mbps data rates can be obtained reliably to the 6 European telescopes; Cambridge, Jodrell Mk2, Medicina, Onsala, Torun and Westerbork, currently connected via national and international research networks to the EVN correlator at Joint Institute for VLBI in Europe (JIVE).

Since early 2006, the e-EVN has carried out regular science observations with the array of Cambridge, Jodrell Bank (MkII), Medicina, Onsala, Torun and Westerbork (phased array) telescopes. Campbell, Garrett, Paragi, Reynolds and Szomoru from JIVE took part in some of these science experiments. Observations of GRS1915+105 (led by Rushton, JBO) and Cyg X-3 (led by Tudose, Univ. Amsterdam) were the first attempts to image microquasars in outburst with the e-VLBI technique. Unfortunately, both sources had faded significantly by the observations on 20-21 April 2006. Cyg X-3 soon produced another great outburst which was observed with the e-EVN on 18 May 2006. The VLBI image shows the expanding ejecta on 10 milliarcsecond scales. The extended structure showed significant linear polarization, indicative of relativistic shocks (see Figure 2.26). All the above mentioned experiments were carried out at 128 Mbps. These were the first e-VLBI results that were published in refereed journal papers (Rushton et al. 2007, Tudose et al. 2007).

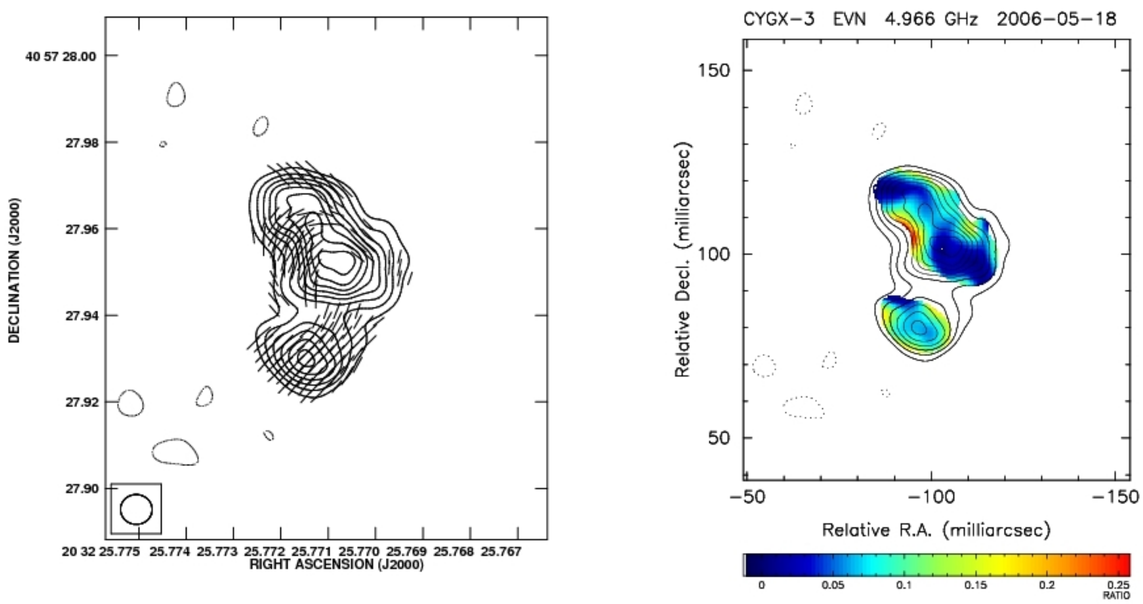


Figure 2.26: e-EVN linear polarization (left) and fractional polarization (right) maps of Cyg X-3 during outburst on 18 May 2006. The e-VLBI observations took place with Cm, Jb2, Mc, On, Tr and Wb14 at 128 Mbps. From these data we were able to produce the first ever VLBI-scale polarization map of a microquasar, which proved the existence of relativistic shocks in the ejecta.

On 2006 April 20/21 the first eVLBI observations of the X-ray Binaries GRS1915+105 and Cygnus X-3 were made with the e-EVN at 4.994 GHz (Fig. 2.27). This demonstrated the technical achievements of producing very high resolution images within hours of the observations rather than the weeks or months this takes with traditional disk recorded VLBI.

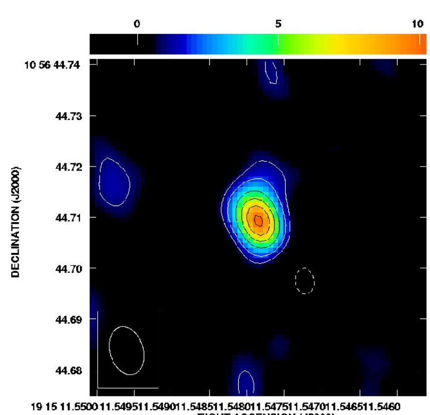


Figure 2.27: e-VLBI image of the X-ray binary GRS1915+105

In order to directly study the role of magnetic fields in the immediate vicinity of proto-stars, Forbrich, Massi, Ros, Brunthaler and Menten (MPI) have used VLBI to attempt the detection of non-thermal centimetric radio emission. This is technically the only possibility to study coronal emission at sub-AU resolution. Observations of the four nearby proto-stars HL Tau, LDN 1551 IRS5, EC~95, and YLW 15 were made,in order to look for compact non-thermal centimetric radio emission. For maximum sensitivity the High Sensitivity Array (HSA) was used where possible. While all four proto-stars were detected in VLA-only data, only one source (YLW15 VLA2) was detected in the VLBI data. The possibility that the non-detections are caused by free-free absorption, possibly depending on source geometry, is considered. For YLW15 VLA2, the prospects for an accurate orbit determination appear to be good.

Van Langevelde (JIVE) worked with Bartkiewicz and Szymczak (both Torun) on 5 cm EVN data, following up methanol maser sources from the Torun blind survey. The data proved to be of excellent quality, allowing high fidelity imaging and astrometry. One of the sources, G23.657-0.127, shows a beautiful ring structure, reminiscent of the circumstellar SiO masers around evolved stars (Fig. 2.28). Such a ring has not been observed in methanol masers before and it offers a unique perspective for the interpretation. There is no clear velocity structure around the ring, which one would expect if this was resulting from a circumstellar disk seen face-on. Instead an interpretation is preferred in which the ring delineates some sort of shock front running into the molecular material around the forming star. Most importantly, in this case there can be no doubt where the central young stellar object is located. After this discovery in 2005, various follow-up observations started in 2006. For example high frequency VLA observations at 22 and 43 GHz were taken in order to detect the central object, but these resulted in marginal detections leaving the status of a central ultra-compact HII region unclear. Together with Brunthaler (now MPIfR) 12 GHz observations were made to measure the expansion of the ring and initial results were obtained. These will also yield a distance from parallax measurements; the distance to this source can currently only be estimated from Galactic rotation, yielding a physical size of the ring of 1000 to 2000 AU.

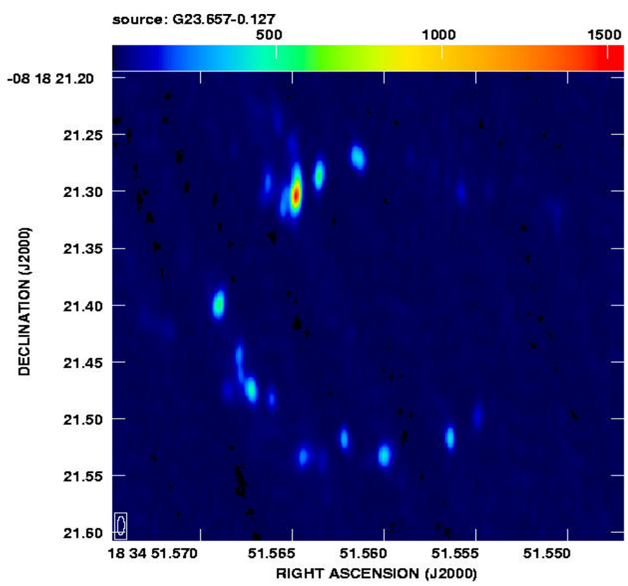


Figure 2.28: Zero moment map of the methanol maser G23.657-0.127

In 2006, Torstensson started an ESTRELA PhD project with van Langevelde based in Leiden. This work initially concentrates on a sample of nearby known methanol masers and is based on previous work with Chris Phillips (ATNF). EVN observations were done in wide field imaging and phase referencing mode. Preliminary results were obtained on the famous Cep A young stellar object. The HW2 source (Fig. 2.29) is supposed to originate from the ionized outflow from a massive young star. Around this object numerous water masers are known, related to shocks between the outflow from the source and the ambient molecular cloud. The water masers were earlier used in work with Vlemmings (JBO) to measure the importance of the magnetic field in this same source. In one case it will be possible to make a direct link between the water and methanol masers. Earlier detailed analysis of the kinematics of the water maser sources has revealed that there exists more than a single origin for these shocks; on very small scales around Cep A, a number of high mass stars are forming. However, the 6.7 GHz masers seem to lie in the equatorial region of HW2, at an offset of 300 - 700 AU from the central source, forming a large-scale, single structure.

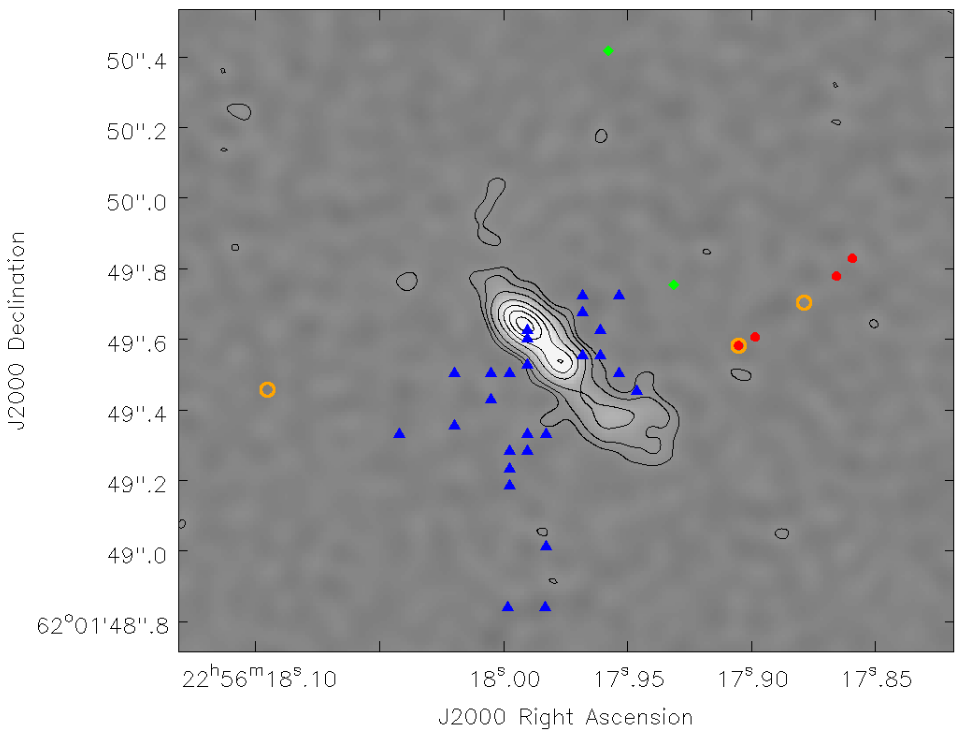


Figure 2.29: The source HW2 in the star forming region Cep A. The gray scales represent the 22 GHz continuum and the blue triangles the locations of H2O masers. The red dots indicate the 6.7 GHz methanol maser positions, the orange circles the 12 GHz methanol masers and the green dots the methanol maser emission at 107 GHz.

This result is the first outcome from an EVN campaign to map out methanol masers in astrometric and wide field imaging mode. To deal with the massive data volumes, we performed calibration in batch mode, exploiting the new capabilities of ParselTongue. Furthermore, a project to find masers over the extended region covered in wide field mode was started in collaboration with Bourke (Galway). The overall goal of the project is to characterize the radio and (sub)mm signature of the young massive star at the origin of the methanol maser. Characterizing the underlying stars with radio and mm observations is part of the project and ideally this should be performed at the highest possible spatial resolution, for example with the eSMA.

Harvey-Smith (JIVE) was the principle investigator in a joint EVN+MERLIN follow-up project to observe the possible circumstellar disc around the massive star-formation centre in W3(OH). She is also undertaking a project to search for methanol masers in nearby galaxies, a survey of methanol and excited OH masers near ultra-compact HII regions using MERLIN, high spectral-resolution maser mapping in possible maser 'disks' using data from the VLBA, the EVN and MERLIN, a multi-line survey of W49 using the eVLA, and methanol and OH maser polarimetry with MERLIN and the EVN.

Massi, Menten and Ros (MPI) together with Boden, Sargent, Akeson, and Carpenter (Caltech), Torres and Latham (CfA), Boboltz and Johnston (USNO) and Ghez (UCLA) have studied the V773 Tau A system using the VLBA+Effelsberg (Fig. 2.30). Interferometric and radial-velocity observations of the double-lined 51-d period binary (A) component of the quadruple pre-main sequence (PMS) system V773 Tau provided preliminary visual and physical orbits of the V773 Tau A subsystem. In addition to the VLBA+EB observations at 8.4 GHz on seven consecutive days (2004 March 11-17), data from the Keck Interferometer, and Digital Speedometers from the Harvard-Smithsonian Center for Astrophysics (CfA) were used to estimate the visual and physical (i.e. three-dimensional) orbits, and determine the component dynamical masses and system distance. Among other parameters, the orbit model used includes an inclination of 66.0 ± 2.4 deg, and allows the component dynamical masses and system distance to be inferred. In particular, component masses of 1.54 ± 0.14 and 1.332 ± 0.097 Msol were found for the Aa (primary) and Ab (secondary) components respectively.

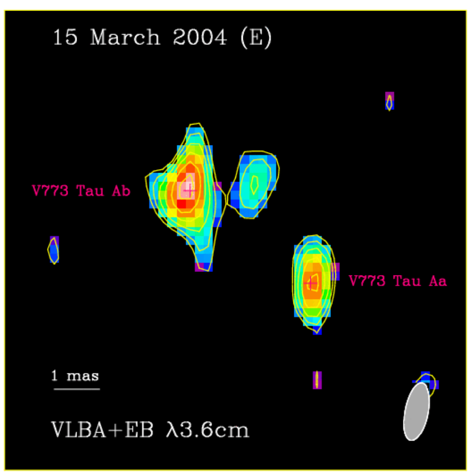


Figure 2.30 Sample phase-reference VLBA+EB image from 2004 March 15 showing the total intensity continuum emission toward V773 Tau A. The lowest contour is of 0.11 mJy/beam. The FWHM beam size is 1.36x0.50 mas at a position angle of -12 deg. The peak flux density is 0.55 mJy/beam. Heavy crosses are shown at the predicted stellar separation. The uncertainties of these positions are about 0.1 mas.

Szymczak and collaborators have discovered a very strong and unusual outburst of the OH 1612MHz maser in the proto-planetary nebula candidate OH17.7-2.0.

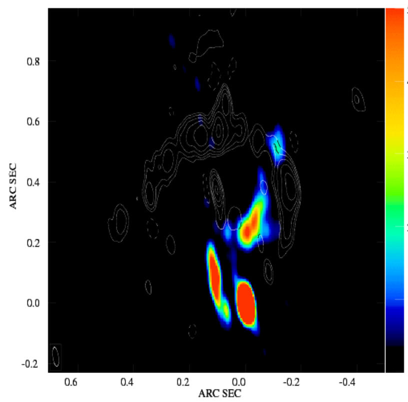


Figure 2.31: *Integrated intensity map of the 1612 MHz maser emission of OH17.7-2.0. Contours show the blue -shifted emission, the red-shifted emission is shown in color.*

The follow-up EVN observations reveal a bipolar morphology of the 1612 MHz maser emission (Fig. 2.31). An offset of about 300 mas is found between the two emission peaks at extreme velocities along an axis at position angle of 8.4 deg. Along the same position angle, a biconical region is seen; the emission comes from the sides of the cones as projected on the sky and likely represents the interaction of a faster post-AGB wind or jet with the outer AGB wind. Low-brightness emission at middle velocities along a plane roughly orthogonal the axis of the cones marks the denser equatorial region or torus-like structure. Compact and unresolved emission in the velocity range of 48.6 - 49.6 km/s is very likely the amplified stellar image. The outbursting emission comes from two very strong unresolved maser components near 73 km/s located at a projected distance of 400mas south of the central star. Their brightness temperatures are 10**11 K. These components arise due to the interaction of a jet-like post-AGB outflow with the remnant outer AGB shell.

Soria-Ruiz, Colomer, Alcolea, Bujarrabal, Desmurs (OAN) and Marvel (AAS) report the first VLBI map of the v=0 J=1-0 maser line of 29SiO in the long period variable star IRC +10011 (Fig. 2.32). This maser emission is found to be composed of multiple spots distributed in an incomplete ring, suggesting that the maser is also amplified tangentially, as already proposed in other SiO circumstellar masers. VLBI maps for the 7 mm 28SiO v=1 and 2 J=1-0 and the 3 mm v=1 J=2-1 lines are produced: the 29SiO masing region appears to be located in a layer between the 28SiO v=1 J=1-0 and 28SiO v=1 J=2-1 lines. The latter is confirmed to form in an outer region of the circumstellar envelope compared to the other 28SiO masers studied.

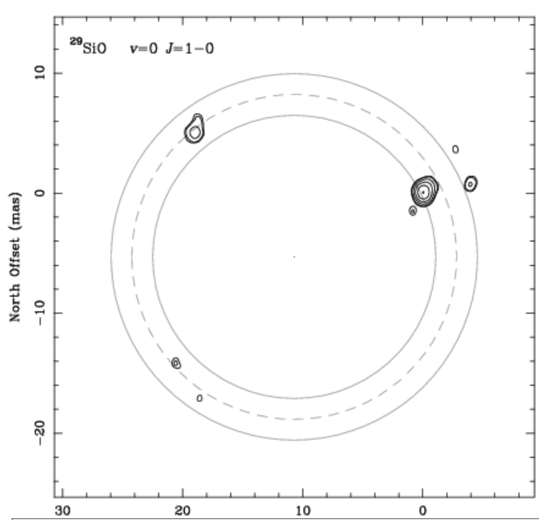


Figure 2.32: Integrated intensity map for the 29SiO v=0 J=1-0 maser emission in IRC+10011. Circles denote the ring fitting the masing regions (dashed:mean radius; continuous: inner and outer radius.

These observationally results will have implications on the SiO maser pumping theory.

VLBI measurements of maser lines are the only tool which allows us to access scales as small as a few 10 AU in regions of OB star formation, whose distances are typically of a few kpc. This technique not only allows to resolve the surrounding of the deeply high-mass stars deeply embedded in their molecular, dusty cocoons, but makes it possible

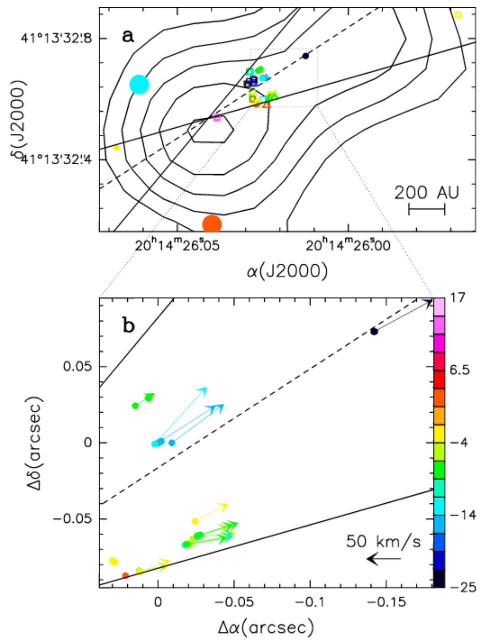


Figure 2.33: Top: Map of the H2O maser spots detected towards IRAS 20216+4104 superimposed on a contour map of the 8.4 GHz continuum emission. Also shown are the two OH maser emission peaks (big circles). The colors denote the LSR velocity of each spot according to the scale in the bottom panel. The solid lines indicate the conical jet known to be powered by the proto-star. Bottom: enlargement of the central region illustrating the locations and absolute proper motions of the H2O maser spots.

also to determine the 3D velocity field of the gas through proper motion measurements of the maser spots. The effectiveness of the method has been clearly illustrated by the experiment conducted by Moscadelli, Cesaroni (OAFi) and Rioja with first multi-epoch, phase-referenced VLBI observations of the H2O maser emission in a high-mass proto-star associated with a disk-jet system, IRAS 20126+4104 (Fig. 2.33). The results confirm that the masers are indeed associated with the jet powered by the star and move along it at speeds as high as 100 km/s, as predicted in a previous paper by the same authors. As shown in another study by Goddi et al. (2006), very likely the H2O maser proper motions are not apparent motions due "Christmas tree" effects, but correspond to real movements of the material where the masers are arising from.

2.6. Solar System science

The reporting period began from a remarkable event – VLBI tracking of the Huygens Probe descent in the atmosphere of Titan, as a part of the ESA-NASA-ASI Cassini-Huygens mission. The atmosphere entry and touch-down took place on 14 January 2005. The Huygens VLBI experiment was led by JIVE (L. Gurvits, S. Pogrebenko, M. Avruch, R. Oerlemans, B. Campbell, A. Brunthaler, H. Bignall and others) and involved more than 50 people from radio astronomy organisations in Australia, China, Europe, Japan and the USA. The JIVE group worked primarily on coordination of observations and analysis of the Huygens Probe VLBI Tracking data. In the months leading up to impact on January 14th 2005, he coordinated the observational setup of the 17 telescopes which took part (including several EVN antennas). The control files include frequency settings and calibrator sources, required several iterations to achieve the proper setups for each station, due to the unusual conditions of the experiment.

Figure 2.34: First Detection of the Huygens Probe at the Green Bank Telescope, by the JPL Radio Science Receiver.

For the observations, S. Pogrebenko and M. Avruch were part of the JIVE/ESA/JPL contingent at the Green Bank Telescope. The Huygens signal was detected by the JPL Radio Science Receiver at about 10:20 UTC, the first proof that the probe had survived entry Fig. 2.34). The probe was observed by the Parkes telescope to land at approximately 12:45 UTC. The probe's batteries far outlasted expectations, so that at 15:00 UTC when the VLBA was scheduled to end observing, the Mauna Kea telescope was reallocated and kept in the array. As Huygens set below the Parkes horizon at 16:00 UTC, and all telescopes performed a final calibration, M. Avruch quickly prepared an extended schedule for several telescopes in Europe that might possibly continue the observation. Some telescopes made an attempt, but unfortunately none detected the probe.

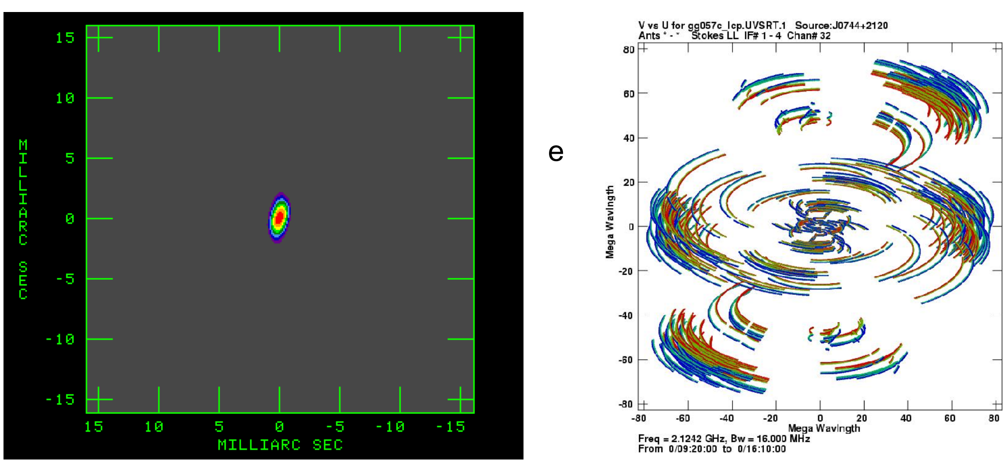


Figure 2.35: Left, Preliminary image of the phase reference source J0744+2120 in the Huygens Tracking experiment, and right (u,v)-coverage by the Huygens VLBI Tracking array on the phase reference source J0744+2120.

The processing of the Huygens experiment at the EVN Mark IV data processor at JIVE included detailed investigation of the so called “Huygens Field” – the patch of sky situated around the position of Titan on 14 January 2005 (Fig. 2.35). Special handling was required due some unusual features of the observation, and a few bugs in correlator control software were uncovered. The data were processed in February and March, and post-processing with AIPS began in April 2005. During the following months, the Huygens VLBI data were processed in full and delivered to ESA.

2.7 Astrometry & Geodesy Research

VLBI contribution is essential to defining and maintaining the International Celestial Reference Frame, providing precise measurements of coordinates of extragalactic radio sources. The quest for increasing accuracy of VLBI geodetic products has lead to a deeper revision of all aspects that might introduce errors in the analysis. The departure of the observed sources from perfect, stable, compact and achromatic celestial targets falls within this category.

A study by Rioja (OAN) and collaborators investigates the impact of the unaccounted frequency-dependent position shifts of source cores in the analysis of dual-band S-X VLBI geodesy observations, and proposes a new method to measure them. The multi-frequency transfer technique developed by Middelberg et al. (2005) increases the high frequency coherence times of VLBI observations, using the observations at a lower frequency. The proposed *source/frequency phase referencing* method endows it with astrometric applications by adding a strategy to estimate the ionospheric contributions. The method was successfully applied to measure the core shift of the quasar 1038+528A at S and X-bands.

Moreover the *source/frequency phase referencing* method opens a new horizon with targets and fields suitable for high-precision astrometric studies with VLBI, especially at high frequencies where severe limitations imposed by the rapid fluctuations in the troposphere prevent the use of standard phase reference techniques. A series of observations with VLBA by Dodson (ISAS, OAN), Rioja (OAN), Porcas (MPIfR) and Dwahan (NRAO) using rapid frequency switching between 43 and 86-GHz has successfully produced astrometrically aligned images of two pairs of quasars at 86-GHz with respect to 43-GHz.

The apparent position of the ``core'' in a parsec-scale radio jet depends on observing frequency, due to external absorption and synchrotron self-absorption. This dependence, while providing a tool to probe physical conditions in the vicinity of the core, poses problems for astrometric studies using compact radio sources.

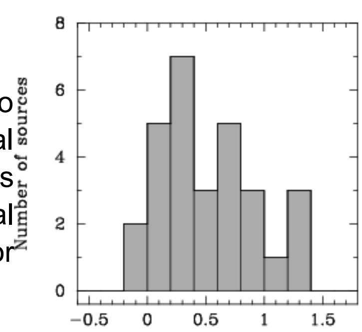


Figure 2.36: The core shift from dual frequency VLBI observations

A search was made by Kovalev, Lobanov, Pushkarev and Zensus (MPI) for the core shift in a sample of 277 radio sources imaged at 2.3 GHz and 8.6 GHz, using VLBI observations made in 2002 and 2003. The core shift (Fig. 2.36) was measured by referencing the core position to optically-thin jet features whose positions are not expected to change with frequency. Twenty nine AGN with bright distinct VLBI jet features were selected, which could be used for differential measurements and allow robust measurements of the shift to be made. In these AGN the magnitude of the measured core shift between 2.3 and 8.6 GHz reaches 1.4 mas, with a median value for the sample of 0.44 mas. An average shift between the radio 8.6 GHz (4 cm) and optical (6000 Å) bands is estimated to be about 0.1 mas, and must be taken into account in order to provide the required accuracy of the radio-optical reference frame connection. This can be accomplished with multi-frequency VLBI measurements, yielding estimates of the core shift, for sources used for the radio reference frame and radio-optical positions alignment.

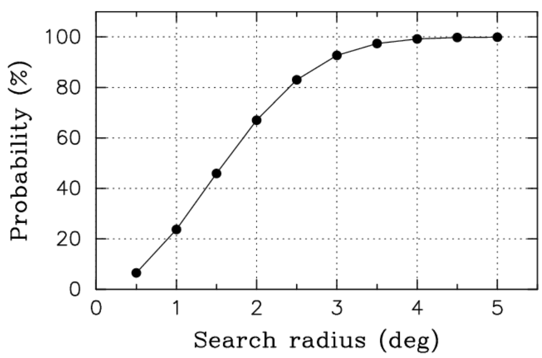


Figure 2.37: The probability of finding a calibrator within a circle of given radius, for declination >-30 deg.

Nine 24-hour VLBA observing sessions at 2.3 GHz and 8.6 GHz were carried out by Kovalev (MPI), Petrov and Gordon (NASA GSFC) and Fomalont (NRAO) in 2004-2005 in order to (i) find new phase-referencing calibrators to make their sky coverage as uniform as possible, and (ii) construct a homogeneous, statistically complete sample of flat-spectrum, compact extragalactic radio sources north of declination -30 deg with integrated VLBA flux densities greater than ~200 mJy at 8.6 GHz (Fig. 2.37). More than 1000 new compact sources were detected. Their positions were derived with mas accuracy from an astrometric analysis of ionosphere-free combinations of group delays determined from the 2.3 GHz and 8.6 GHz frequency bands. The complete sample has been constructed.

Within the ALBUS project, Anderson researched the modelling of radio signals through the ionosphere. The three images in Figure 2.38 show preliminary test results using different ionospheric calibration methods for the EVN. The source J1159-2148 was observed at 1.6 GHz in phase-referencing mode on 2 June 2005. Progressive modelling of the ionosphere shows improvement, as the deep negatives have been eliminated and the results of fringe-fitting are better, but significant ionospheric distortions remain. These tests suggest that ionospheric corrections can significantly improve EVN observations at low frequencies.

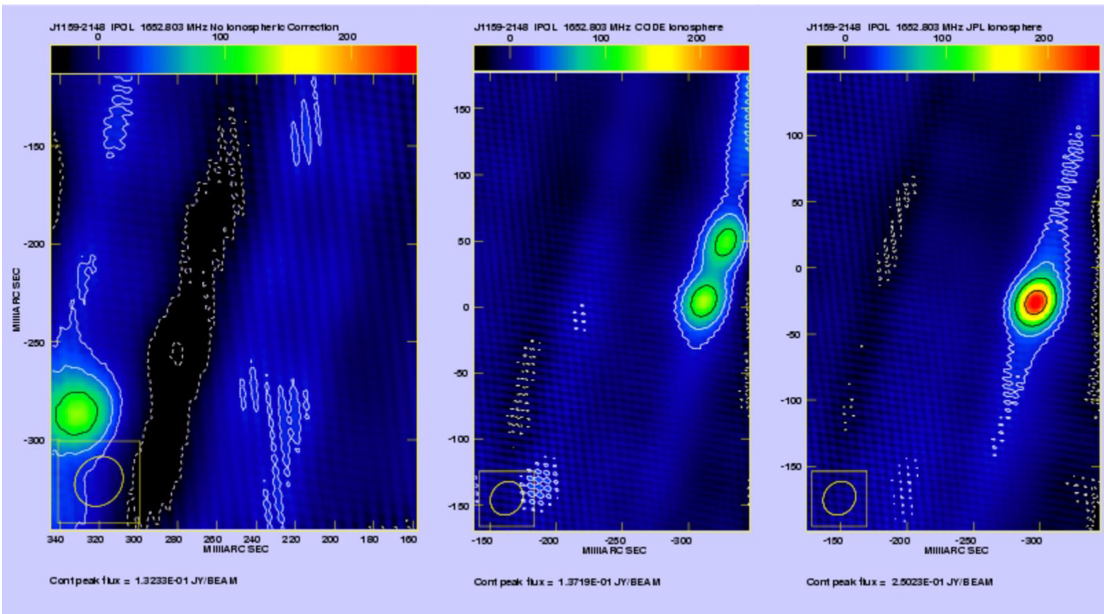


Figure 2.38: Preliminary test results for different ionospheric calibration data sources for the EVN. All three images have the same color flux scale from -0.036 mJy/beam to +0.250 mJy/beam, with contours indicated at factors of 2,4,8,... times 0.012 mJy/beam. The image on the left was produced with no ionospheric corrections applied. The central image was produced using ionospheric corrections from the CODE group. Finally, the right-hand image shows the results using ionospheric calibration data from the JPL group.

Campbell (JIVE) was involved in setting up the charter of the European VLBI Group for Geodesy and Astrometry (EVGA) on 23 April 2005 in Noto. This is a subgroup of the IVS, and comprises all European IVS associated members and is also open to any scientist affiliated with a European institute involved in geodetic and/or astrometric VLBI. Among other items, the EVGA fosters the use of European VLBI resources for deriving high quality reference frames, and promotes and represents European geodetic and astrometric VLBI within the broader international scientific communities.

3. EVN Network Operations

3.1. EVN Program Committee (EVN PC)

The EVN PC is an independent body appointed by the EVN CBD which carries out scientific and technical assessments of all EVN and Global VLBI requests for observing time. A *Call for proposals* is distributed three times a year with proposal deadlines of 1st February, 1st June and 1st October. The EVN PC meets roughly one month after these deadlines to evaluate the proposals. EVN PC members provide reviews of each proposal in advance of the meeting, which are discussed and a final recommendation is formulated to the EVN Scheduler. Summary comments and the detailed comments of each PC member are sent to the PI (with copies to all co-Is) afterwards.

Since 2006, the EVN PC has also been in charge of reviewing requests for observing time during the e-VLBI sessions. Such sessions are organized every 4 to 6 weeks and are generally 24-hour long. For the review and scheduling of e-VLBI proposals, a specific rapid-response procedure was used during 2006. Proposal submission was two weeks prior to each session, leaving one week for review by the EVN PC (carried out by e-mail), while the other week was available for JIVE to prepare the schedule of the observations.

3.1.1 Membership

Table 3.1: Membership of the EVN PC in the period 2005-2006

EVN PC member	Institute
Patrick Charlot (Chair)	Bordeaux Observatory
Javier Alcolea	OAN – Madrid
Simon Garrington	Jodrell Bank Observatory
Dong Rong Jiang	Shanghai Observatory
Michael Lindqvist	Onsala Space Observatory
Andrei Lobanov	MPIfR – Bonn
Tiziana Venturi	IRA - Bologna
Rene Vermeulen	ASTRON – Dwingeloo
Until 2005:	
Huib Jan van Langevelde	JIVE – Dwingeloo
Since 2006:	
Bob Campbell	JIVE – Dwingeloo
Claudio Codella	IRA – Florence
Denise Gabuzda	University College Cork
Josep Martí	University of Jaén
Richard Porcas (Scheduler)	MPIfR – Bonn

The EVN PC comprises 8 *observatory* members (including a representative from the EVN data processor at JIVE) which have particular responsibility for assessing the technical feasibility of proposed observations from their observatory's perspective. In addition, there are 4 *at large* members, chosen from non-EVN institutes, to complement the astronomical experience of the observatory members. Proposals requesting the Bonn correlator or the Arecibo telescope or the MERLIN array are also sent to representatives at these institutes for additional review. The EVN Scheduler is a member of the EVN PC, but he does not carry out a scientific evaluation of the proposals.

Since 2003 the Chairman of the EVN PC has been Patrick Charlot, from Bordeaux Observatory. He was renewed for a second 3-year term at the end of 2005. At the beginning of 2006, a new JIVE representative (Bob Campbell) was appointed to replace Huib Jan van Langevelde. During the period covered by this report, the EVN PC membership was as given in Table 3.1.

3.1.2 Meetings and proposal statistics

In 2005 and 2006, six meetings were held, in Shanghai (15th March 2005), Bonn (27th June 2005), Florence (14th November 2005), Yebes (10th March 2006), Dwingeloo (7th July 2006), and Noto (5th December 2006).

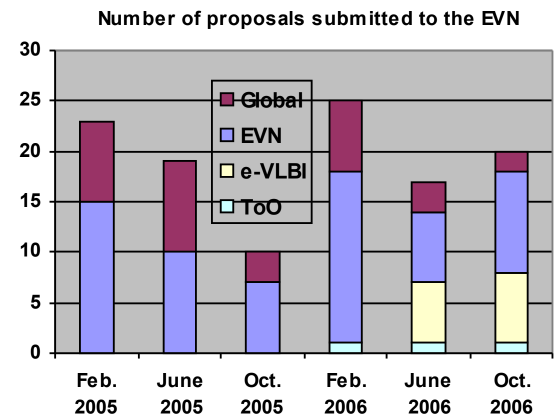


Figure 3.1: Number of proposals submitted for each deadline during the period 2005-2006. The load is indicated separately for each proposal category (ToO, e-VLBI, EVN, Global).

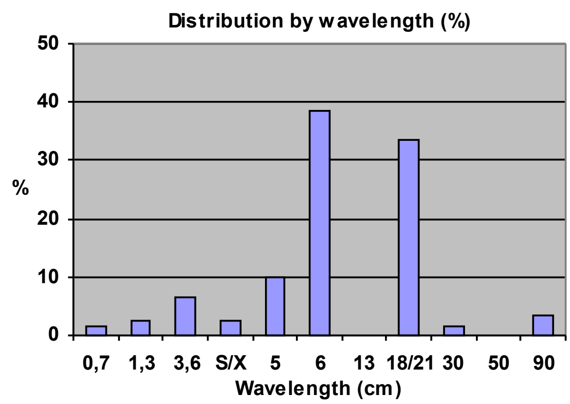


Figure 3.2: Distribution of observing requests for each wavelength during the period 2005-2006.

The number of proposals reviewed at each meeting varied from 10 to 24. If including the additional 3 Target-of-Opportunity (ToO) and 13 e-VLBI proposals received in 2006, the load represents an average of 19 proposals per deadline, which is comparable to that seen during the past two years (average of 18 proposals in 2003-2004). The chart in Fig. 3.1 indicates more specifically the number of e-VLBI, ToO, EVN and Global VLBI observing requests for each deadline. For clarity, the e-VLBI proposals are shown as if they had been submitted by the June and October 2006 deadlines, whereas the actual e-VLBI deadlines were in March, April, October and November 2006. The same applies to the ToO proposals, which were not submitted by specific deadlines since they are by nature unpredictable. Cumulated over the two years, there were 58% of EVN-only proposals, 28% of Global VLBI proposals, 11% of e-VLBI proposals and 3% of ToO proposals. The portion of proposals requesting the MERLIN array, the Arecibo telescope, and DSN antennas over the period covered by this report were 18%, 19%, and 11%, respectively. As usual, the bulk of the proposals requested the prime wavelengths of 6 cm and 18/21 cm where EVN sensitivity is greatest. Each of these two wavelengths contributes to more than one-third of all proposals while the other wavelengths contribute each to less than 10% (Fig. 3.2).

The range of EVN proposals received covers a wide variety of areas, reflecting the growing applications of VLBI as sensitivity increases. These included studies of masers in star forming regions, individual stars and X-ray binaries, scattering in the interstellar medium, supernovae remnants in nearby galaxies, weak Seyfert nuclei, environment of active galaxies through OH and HI absorption lines and megamasers, the "classical" studies of AGN jets, galactic astrometry, and reference frames.

3.1.3 *EVN user community*

The PIs of EVN and Global VLBI proposals are drawn from a large international user community. During 2005 and 2006, the 114 proposals received originated from PIs affiliated with research institutes located in 21 different countries, about 70% of which are in Europe and 30% in the rest of the world (Fig. 3.3). Roughly 60% of the proposals had PIs from non-EVN institutes and 40% of these do not include EVN collaborators either.

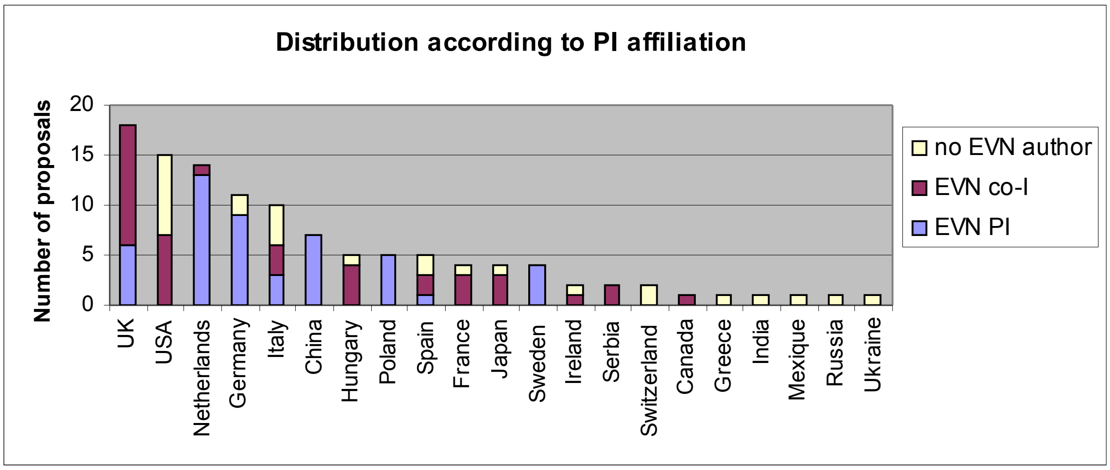


Figure 3.3: distribution of proposal according to PI affiliation

The EVN PC is also a useful channel of communication with the EVN user community. The Call for Proposals, available as a web page, provides important guidance on preparing proposals. New users often contact the EVN PC Chairman or EVN scheduler for specific questions. An EVN users meeting was held in September 2006 during the EVN Symposium in Torun. The agenda covered the whole process of doing VLBI from proposal preparation to scheduling, correlation, and data analysis, providing an overview of the way the EVN works in practice and permitting fruitful exchanges with the user community. The meeting also included two demonstrations, about the new EVN proposal tool Northstar and about using ParselTongue/Python to ease data processing in AIPS.

3.2 Scheduling and Operations

Reports on individual EVN Sessions

2005 Session 1: Feb 17 - Mar 10

Wavelengths: 1.3cm 3.6/13 cm 6cm 18/21cm(+MERLIN)

A major aspect of this session was the desire for, and realization of, Mk5A disk recording for all projects for which this was possible. Only 3 projects, each requiring the VLBA correlator, were recorded using tape (and thus excluding the participation of Noto). This highlighted the competition for disks, especially since a number of 1Gb/s observations were eligible for scheduling. One of these was scheduled for 24h at 3 antennas (including Arecibo), requiring a total of 30 TB; 2 further observations had to be postponed until Session 2.

Another feature was the availability of EVN+MERLIN at 18/21cm, last available in May 2003, and a number of older project (the oldest proposed in Feb 2002 !) were at last scheduled. As usual, the most difficult scheduling task was the coordination of observing time with antennas which do not reserve the whole EVN block. In this session one astrometric project required time with Ny Alesund, Algonquin Park, Wettzell and Goldstone DSS14, and others required Arecibo, GBT and Robledo DSS63. The ability of Effelsberg and Medicina to rapidly change between 1.3cm and 3.6cm was extremely helpful in finding a solution to this problem.

2005 Session 2: Jun 2 - Jun 14

Wavelengths: 18cm(+MERLIN) 6cm

This was a short session (13 days) mainly because of the limited number of Mk5A disk modules (an estimated 199 TB were required). Only one project (requiring the VLBA correlator) was recorded on tape. The block schedule plan was redesigned to give a better summary of the disk requirements for each telescope and project. (Bob Cambell (JIVE), Walter Alef (MPI) and the Scheduler evolved procedures whereby the disk space available for use in each session is ascertained before the schedule is finalized.) EVN+MERLIN at 18/21cm was again available and all well-rated projects which were eligible for scheduling were observed.

A number of high bit-rate projects were scheduled. The most disk-hungry required 50TB (2 sources with 512Mb/s) and another 30TB (24h at 1Gb/s), carried over from Session 1. This was also a session in which Haystack had offered to support 1Gb/s recording at the GBT (their "UVLBI" project). In the event only 1 project lasting 5h was eligible for scheduling; Haystack thus postponed their support at GBT until Session 3. This single project (which was time critical) was observed in a hybrid mode, recording 1 Gb/s at the 4 EVN antennas, and 512Mb/s at the GBT. Owing to maintenance and engineering work at GBT and Effelsberg, and an "Aeronomy world-days campaign" at Arecibo, these telescopes were not available for the later part of the advertised session window.

2005 Session 3: Oct 18 - Nov 12

Wavelengths: 6cm 1.3cm 18/21cm 90cm

As has become standard now, EVN stations all recorded on MK5A disks for all projects, with some exceptions for global projects being correlated at the VLBA correlator. The VLBA correlator could only take a limited number of "external" MK5A recordings since it had only 9 MK5 playbacks. At least 4 of these were taken by 4 "disk-only" VLBA stations and up to 8 VLBA stations could record disks (leaving only 1 slot for external stations). A maximum of 5 external stations could be accommodated if 6 VLBA stations record on tape. For this session we arrived at a compromise with only Tr, Nt, and On recording disks for the VLBA correlator experiments, and Ar and Ro recording disks for the small amounts of time when they were observing for them.

This session also contained one "UVLBI" project, which required scheduling in 5 separate GST time slots on 3 different days, including Ar and the GBT. Haystack Observatory provided equipment and logistical support at the GBT and disks for Ar and GBT.

The nominal window for this session ended on 10 November but due to GBT and Ar scheduling constraints it would not have been possible to schedule the highest-rated 90cm project without extending the session to 12 November at Wb, Jb and Ar. I thank these observatories for permitting this. This resulted in a large gap between the end of the 18/21 cm part on 6 November, and the start of the 90 cm session on 11 November.

2006 Session 1: Feb 14 - Mar 4

Wavelengths: 6cm 3.6cm 5cm(+MERLIN) 18/21cm

All projects in this session were recorded at all stations using MK5A disks, except for a single project correlated at the VLBA correlator for which Effelsberg used tape. This was probably (hopefully !) the last use of tape at an EVN observatory during an EVN session. It was necessary because of the limited number of MK5A playbacks at the VLBA correlator.

All reasonably rated projects requiring the wavebands offered in this session were scheduled, including a full week of 5cm projects, observing both methanol and excited OH lines. Many 5cm projects also included MERLIN. The session was not disk-limited. One project proposed for 256 Mb/s was scheduled at 1 Gb/s to increase the sensitivity (working towards the goal of having this bit-rate as the EVN default, where appropriate). Two of the 3 EVN-only continuum projects were run at 1 Gb/s.

Arecibo was used for 2 user projects, GBT for 2 projects and the DSN-Robledo 70m dish for one. Four of the 13 user projects were global. The VLBA correlator was used for 1 project.

Following the sixth known outbursts since 1898 of the recurrent nova RS Ophiuchi on 12th February this year, a Target of Opportunity proposal was submitted to the EVN on 16th February to observe at 18 and 6cm wavebands. It proved possible to schedule these observations following the last scheduled project in the session, on March 5th and 6th, thanks to the generous allocation of time by the EVN observatory Directors and the efforts of the observatories' and JIVE support staff.

2006 Session 2: June 1 - June 19

Wavelengths: 30cm 18/20cm 5cm 6cm(+MERLIN)

This session proved difficult to schedule due to the restricted availability of the GBT, Arecibo, Jodrell_LT and the Effelsberg telescope (which was unavailable during daylight hours on work days from 12 June onwards). A further complication was the need to accommodate one highly-rated project requiring simultaneously the UHF receiver in Effelsberg and L-Band receivers elsewhere, including GBT and Arecibo. However, in the end the session proved to be disk-limited, and only projects with ratings ~1.5 could be scheduled (all such eligible projects were).

Five of the 14 scheduled projects were global. One project was correlated at the VLBA correlator. All EVN observatories recorded using MK5A disks.

One "short observation" request was received on 20 April (a request for exploratory observations limited to 4h and minimal disk and telescope resources). This was approved by the EVNPC Chair and it proved possible to accommodate this in a suitable gap in the main schedule.

A second Target of Opportunity proposal to observe RS Ophiuchi was submitted to the EVN on 26 April, requesting observing time either before (preferred) or within Session 2. Due to the willingness of observatories to accommodate this request it proved possible to schedule this at 9 stations on May 15/16, 2 weeks before the start of the session.

2006 Session 3: 23 - 29 November

Wavelengths: 6cm 3.6cm

This session was later than originally planned, due to work to replace the subreflector of the Effelsberg telescope. The session was put as late as possible, subject to a number of observing constraints (many of the telescopes already had IVS commitments). The plan was to schedule just those wavelengths observed from the secondary focus in Effelsberg, as prime focus operation would come up later than secondary. This included user observations at 1.3cm (1), 3.6cm (1) and 6cm (6).

Unfortunately, problems with the azimuth track at Shanghai meant that it could not participate in the session; in addition the Urumqi 1.3cm receiver had broken. These further restrictions reduced the session to just two 6cm observations and one 3.6cm observation (a global). The spare time made available was used to schedule a special 24-hour amplitude calibration investigation, lead by D. Graham.

3.3 Technical Developments and Operations

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.

The TOG was chaired by Walter Alef of MPIfR and met three times during the period of this report: at the Onsala Space Observatory, Sweden on July 1, 2005, at ASTRON, Dwingeloo, The Netherlands on March 24, 2006, and at the Noto VLBI station, Sicily on December 4, 2006. All meetings were supported by RadioNet (funded from the European Community's sixth Framework Programme under RadioNet R113CT 2003 5058187). Reports from the meetings are available on the EVN web-site (www.evlbi.org). The meeting at ASTRON was combined with a one day training workshop. Subjects covered were Mark 5 system checkout, Field System, single dish and amplitude calibration, as well as an introduction to the Digital BBC project.

The major goal of the TOG is to improve and maintain the quality of service of the EVN towards the observers. Of high importance for achieving this goal are an E-mail discussion group and the regular meetings of the TOG which also serve as a forum for information exchange, teaching and planning.

Three members of the TOG were involved in the program committee of the TOW Technical and Operations Workshop) at MIT Haystack, USA, and three TOG members served as lecturers. 17 participants from EVN institutes attended the courses to improve their knowledge of VLBI observing.

The main emphasis of the TOG activities during the period of this report were improving the data quality mostly by reducing data loss, and the quality of the network calibration. Significant achievements to be noted are:

- The disk-based Mark 5 recording system which had fully replaced tape recording in the EVN at the end of 2004 lead to a visible reduction of data loss due to failures of tape drives or bad recordings.

- A total of about 900 TB of disk space were procured by the EVN member institutes for recording VLBI observations at the telescopes.

- Projects with bit-rates of 1024 Mbits/s have become a standard observing mode for EVN continuum observations. It is hoped that by the end of 2007 all continuum observations can by default be observed at this data rate.

- Ftp fringe checks are done regularly for every frequency session: short scans are ftp-ed to JIVE where they are correlated with the KSRC/NICT VLBI software correlator. The process has been automated during the reporting period. Soon after the fringe checks are observed the results are accessible via the Internet and stations are informed via email. A few times problems at stations were detected at the beginning of a session and stations could correct the problems.

- As the data quality has been improved due to disk recording, most efforts were concentrated on improving amplitude calibration. Lectures for training station personnel were given at the TOG at ASTRON. But a big improvement was brought about by the efforts of Dave Graham of MPIfR and to some extent Michael Lindqvist of Onsala, who analyzed the calibration problems of some stations remotely and gave suggestions for improvements, which took effect towards the end of 2006.

- Automatic off-source data flagging could be implemented at all EVN stations.

4. Joint Institute for VLBI in Europe

4.1 ***Production Correlation***

4.1.1 Sessions and Experiments

Session 1/2005 itself had a total of ten user experiments. Among these was the first Gbps user experiment to be correlated and distributed. Three of the experiments were globals.

Session 2/2005 had twelve user experiments, including three more Gbps recordings. In one of these, Green Bank also participated at 512Mbps (by recording with one-bit sampling instead of the two-bit sampling used elsewhere -- the correlator "saw" Green Bank's data as being two-bit sampled, with the magnitude bit always set to "high").

Session 3/2005 also had twelve user experiments, including four more Gbps recordings. Westerbork and Robledo had similar problems in their Mark 5 Gbps recordings, in which the data decodability would come and go on time-scales of several minutes. The net consequence was a loss of about 40% of the data from these telescopes in the Gbps experiments. The underlying cause proved to be interference from nearby video cables. This behaviour continued for a couple subsequent sessions at differing stations; eventually following discussions with the stations and at TOG meetings, this problem seems to be resolved.

Session 1/2006 had a total of fifteen user experiments correlated at JIVE. Among these were two Gbps experiments and three globals. Included in the global experiments were periods of full 16 disk-stations correlation, which was also a first. Spectral-line experiments at 5 cm (methanol or excited hydroxyl masers) formed more than half the total number.

Just days after the end of session 1/2006, there were two target-of-opportunity experiments devoted to the flaring in RS Oph (one each at L- and C-band), recorded on disk by 10-11 station arrays at 512 Mbps. As the star was already beyond the peak of its flare by the time of these observations, there was quite a premium on rapid correlation and distribution of the resulting FITS files. Following coordination with the PIs, JIVE fully correlated the C-band experiment prior to receipt of the Noto disks to provide the fastest results, then correlated the L-band experiment (by then the Noto disks had arrived), and finally re-correlated the C-band experiment with all stations. Table 2.1 summarizes the number of [calendar] days following observation until completion of correlation and distribution of the FITS files:

	Correlation completed	FITS files distributed
C-band (without Noto)	8	10
L-band (all stations)	11	14
C-band (all stations)	15	18

Table 4.1: days following the observation of the target-of-opportunity experiments on RS Oph to completion of correlation and distribution of the FITS files.

Prior to the start of session 2/2006, there was a follow-up target-of-opportunity observation of RS Oph, this time at 1 Gbps. A paper including these observations appeared in Nature in July. The period between sessions 1/2006 and 2/2006 also saw the first e-VLBI observations resulting from the new open calls for e-VLBI proposals.

Session 2/2006 also had fifteen user experiments, including three more Gbps recordings and five globals. This session was the first to be entirely tape-free: all stations sending data to JIVE for correlation recorded exclusively onto Mark 5 disk packs. UHF experiments were included for the first time in two years. Urumqi had to miss one of these because of conflicting Chinese lunar mission requirements.

Session 3/2006 was extraordinarily short, owing to engineering work at Effelsberg and Shanghai. There were only five user experiments, including one at Gbps recording and three globals. This was another disk-only session.

There were a total of eight separate e-VLBI user experiments observed during 2006 in five different e-VLBI "sessions", for which separate open calls-for-proposals were promulgated. All but the first one of these lasted a full 24hr, to provide the opportunity to observe any sidereal-time range.

Tables 4.2 and 4.3 summarize projects observed, correlated, distributed, and released in 2005 and 2006. 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 sub-band/pol to maximize spectral resolution, etc.).

	User Experiments		
	N	Ntwk_hr	Corr_hr
Observed	36	495	634
Correlated	34	600	807
Distributed	46	624	870
Released	39	556	772
	Test & Network Monitoring		
	N	Ntwk_hr	Corr_hr
Observed	21	103	106
Correlated	20	101	104
Distributed	20	101	104
Released	24	110	113

Table 4.2: Summary of projects observed, correlated, distributed, and released in 2005.

	User Experiments		
	N	Ntwk_hr	Corr_hr
Observed	46	554	732
Correlated	48	603	797
Distributed	49	618	812
Released	57	713	963
	Test & Network Monitoring		
	N	Ntwk_hr	Corr_hr
Observed	23	139	163
Correlated	21	110	110
Distributed	19	101	101
Released	17	95	95

Table 4.3: Summary of projects observed, correlated, distributed and released in 2006

With the advent of disk-based recordings, the processing factor -- defined as the actual correlator time required to complete an experiment divided by the product of network hours times the number of passes required -- has decreased noticeably. However, there do seem to be some problems that affect Gbps recordings preferentially, notably interference into the flat cable from the formatter (from nearby video-cables), an increased sensitivity to slow disk(s) in a given Mk5 pack, and the diagonal weights that affect all 16MHz sub band playback through the station units. Efforts to recover the maximum amount of data possible increases the cumulative processing factor for Gbps experiments. For experiments from 2005-6, these cumulative processing factors are: 2.61 for Gbps experiments, 2.33 for experiments with one or more tape-station, and 1.89 for other disk-only experiments.

Figure 4.1 presents the work division among various correlator tasks (production, clock-searching, network/correlator tests) as a number of hours per week, over the past three years (2005-6 highlighted). A six-week running average is shown. Since 25 April 2005, we have been running with two operators while keeping the

1:3 night-shift rotation (thus a three-weekly cycle of 80-80-40 hr/wk), reducing the net hours-per-week to 66.67 over the 6-week smoothing used in the plot.

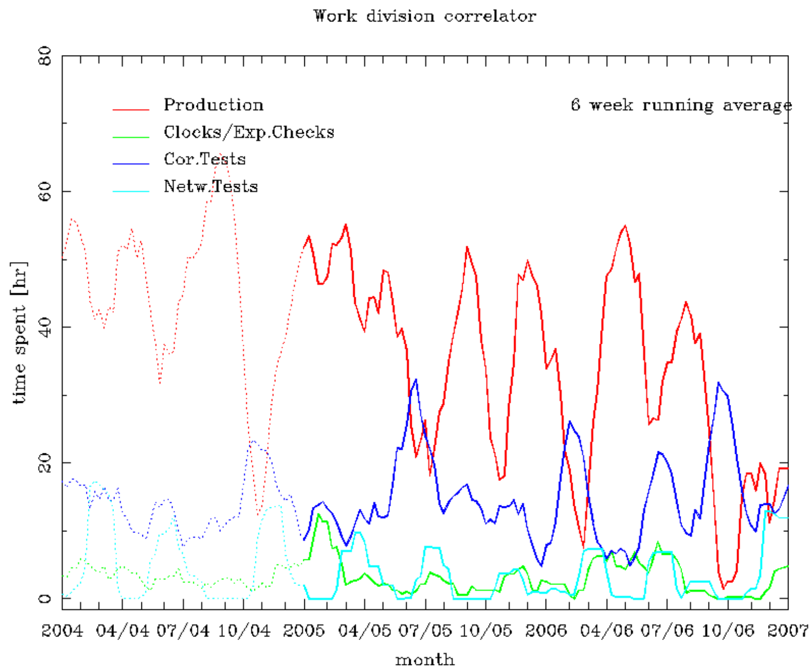


Figure 4.1: Work division among various correlator tasks, in hours per week.

Figure 4.2 presents various measures of correlator efficiency. The red line plots the completed correlator hours during time actively devoted to production correlation. The green line shows completed correlator hours over the total operating time of the correlator -- the red and green lines diverge more in periods when production takes up a smaller fraction of the total time available. The blue line shows completed network hours over total operating time -- the green and blue lines diverge because some experiments require multiple passes. A twelve-week running average is shown to smooth out spurious peaks caused by periods with no remaining production correlation.

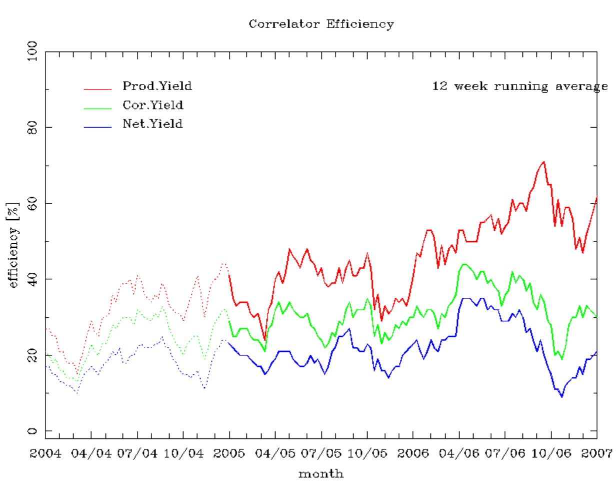
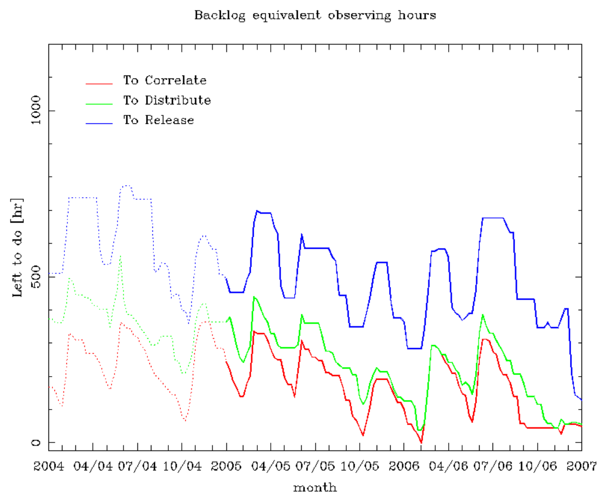


Figure 4.2: Various measures of correlator efficiency.

Figure 4.3 presents the size of the correlator queue at different stages in the processing cycle, showing a snapshot of the status at the end of each week. The red line plots the number of correlator hours that remain to be correlated. The green line plots the number of correlator hours whose data remain to be distributed to the PI. The blue line plots the number of correlator hours associated with recording media that have yet to be released back to the pool (in practice, release occurs prior to the following session, leading to a blocky pattern for the blue line).

Figure 4.3: Size of various correlator queues, measured in correlator hours.



4.1.2 Logistics and Infrastructure

The EVN data processor at JIVE has 16 Mk5A units, all housed inside temperature-controlled cabinets. Ten working tape playback units remain in place, and can still be attached to SUs via a simple swap of input cables.

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 policy that stations should buy two sessions' worth of disks; hence the disk flux should balance over the same 2-session interval. A different rule pertains to NRAO stations, under which we pre-position disk packs to make up the anticipated 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

Table 4.4 charts the net disk flux to support both EVN and VLBA stations (all entries in TB), with positive balance signifying flow away JIVE to stations or from EVN to NRAO.

IN		OUT		BALANCE	NET
3/2003	22.00	2/2004	30.52	+8.52	+8.52
1/2004	63.69	3/2004	86.31	+22.62	+31.14
2/2004	111.52	1/2005	69.89	-41.63	-10.49
3/2004	122.53	2/2005	100.67	-21.86	-32.35
1/2005	140.58	3/2005	142.31	+1.73	-30.62
2/2005	176.99	1/2006	152.93	-24.06	-54.68
3/2005	211.85	2/2006	303.37	+91.52	+36.84
1/2006	191.05	3/2006	133.36	-57.69	-20.85
2/2006	306.63	to recycle in 1/2007			
3/2006	103.68	to recycle in 2/2007			

Table 4.4: balance of disk receipts/shipments from/to EVN stations. The applicable guideline is to recycle disks in time for recording in the 2nd-following session, which is how the pairs are ordered per row, followed by the balance per receipt/shipment pair and the cumulative balance since the beginning of disk recording.

4.1.3 Astronomical Features

Towards the end of 2005, JIVE began to include celestial pole offsets into the CALC8-based a priori correlator model. These amounted to about a 20-25 mas shift of direction of the celestial ephemeris pole added onto the IAU1980 nutation model used by CALC8. In the early autumn of 2006, following careful testing, we shifted over to CALC10 for the a priori correlator model.

In session 2/2006, Jodrell Bank recorded data from both Cambridge and another MERLIN station (Darnhall) onto Cambridge's Mark 5 pack in an experiment for which the 16 MHz MERLIN bandwidth left "unused" channels in the recording. We copied the Cambridge pack onto an empty Mark 5 pack, and through straightforward VEX-file manipulation were able to correlate the data for both stations. Fringes were seen in the sub-bands which contained actual signals on all Cm-* and Da-* baselines. This scheme offers the possibility to record a third MERLIN station routinely in combined EVN+MERLIN experiments, providing a more robust for tying the two arrays together.

4.2 EVN Support

The EVN pipeline has been re-written in ParselTongue (novel VLBI data processing software developed within the framework of the FP6 RadioNet Joint Research Activity ALBUS, led by van Langevelde, JIVE). The new pipeline is considerably easier to use, more robust and has much 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.

The pipeline provides telescopes with feedback on gain corrections for all experiments correlated, both NMEs/fringe-tests and user experiments. These data can identify telescopes/frequency bands with particular problems. These ftp fringe tests continue to provide the opportunity to identify station problems early in the session (stations receive initial reports on the same day as the experiment is observed) and have contributed to an overall increase in the ERI in recent sessions. Figure 4.4 shows fringe plots generated automatically from a fringe test, which are available to the telescopes via the EVN web site.

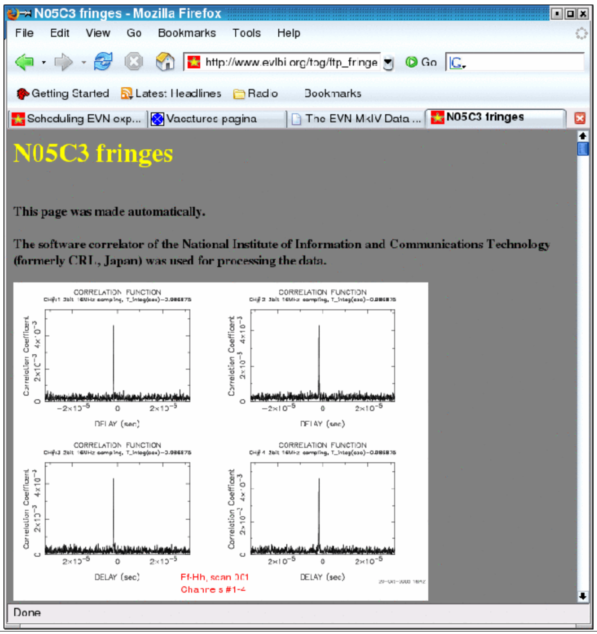


Figure 4.4: Fringes on the baseline Effelsberg - Hartebeesthoek from the session 3/2005 NME ftp fringe-test scan, as seen on the EVN web page.

The NMEs processed in a fully automated way, with minimal support scientist interaction, except in compiling the written reports sent to the stations (first reports were less than 2 hours after the start of the experiment). Web-pages now include autocorrelation spectra for each station, and the correlation vexfile.

The effect of more telescopes participating successfully can be seen in the net improvement of ERI values as a function of time, shown in Figure 4.5 (after discounting uncontrollable losses due to weather). This plot shows the ERI for all user experiments over the past six years, and denotes e-VLBI experiments with solid squares.

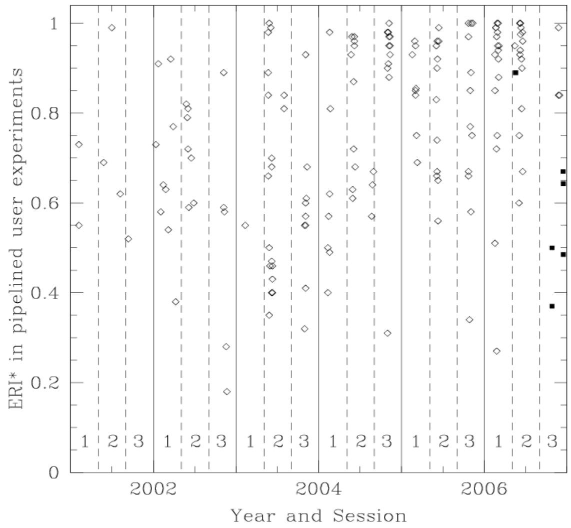


Figure 4.5: Plot of the EVN Reliability Indicator for user experiments up through session 3/2006.

The median ERI for normal EVN/global experiments was never more than 75% in any session up through session 1/2004, but starting from session 2/2004 it has not been below 84%. (Note that for global experiments, the ERI is computed considering only the participating EVN stations.)

Timely delivery of amplitude calibration results can still sometimes be a problem, but the situation overall continues to improve. ANTAB generation at the telescopes seems to be going well. Results are similar to those reported previously, but some improvement is noticed especially at 6 GHz. Torun calibration has improved greatly in the last year (partially due to the repair of a software error in the ANTABFS script which affected VLBA racks).

Following the decision by the EVN Consortium Board of Directors, Gurvits continued to coordinate EVN efforts to assist to the Ventspils International Radio Astronomy Centre (Latvia) and the Institute for Radio Astronomy of Ukraine to upgrade their the telescopes in Irbene (32 m) and Evpatoria (70 m), respectively, to a level that would allow participation in EVN observations. In March 2005, Gurvits (together with Baan and representatives of the European Space Agency) visited the Institute of Radio Astronomy of Ukraine (RIAN, Kharkov), the National Academy of Sciences and the National Ukrainian Space Agency for in-situ assessment of the readiness of the 70-m radio telescope in Evpatoria for test VLBI observations with EVN. In the second half of 2005 JIVE began assisting RIAN in the upgrade process itself.

In the second half of 2006, there were initial fringe tests to these two aspiring EVN stations. Both tests used the DBBCs being developed in Noto, recorded onto PC-EVN, and were translated into Mk4 format on Mark 5 disk packs for correlation at JIVE. Each used a network of three stations, and observed about an hour per day over two consecutive days: 3-4 August for Evpatoria and 13-14 November for Irbene. Good fringes were seen in baselines to Evpatoria in the the expected sub-bands/polarizations (they recorded only LCP). The Irbene tests were observed at 12 GHz, which was the only receiver available at Irbene. This covers methanol maser emission, but is not a standard EVN observing band. The Irbene autocorrelation showed the correct trace in frequency and shape for the methanol maser emission in the band; separate receiver/observing problems at the other two participating stations precluded seeing fringes to a continuum source.

The results of these initial fringe tests are encouraging developments for the future participation of these stations in the EVN.

4.3 PI Support

The EVN Archive at JIVE is up and running. This provides web access to the station feedback, standard plots, pipeline results, and FITS files. More than half of the PIs use the Archive to access their distributed FITS files, rather than having a DAT or DVD sent to them. Public access to source-specific information 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. We have also increased the storage available on the archive machine. The total size of the FITS files in the archive at the end of 2006 was about 3.08 TB; Figure 4.6 shows the growth of the EVN archive size over time. Provisions have been made to store a copy of all the user data outside the main Dwingeloo building.

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, and to check over schedules posted to VLBEER prior to stations downloading them.

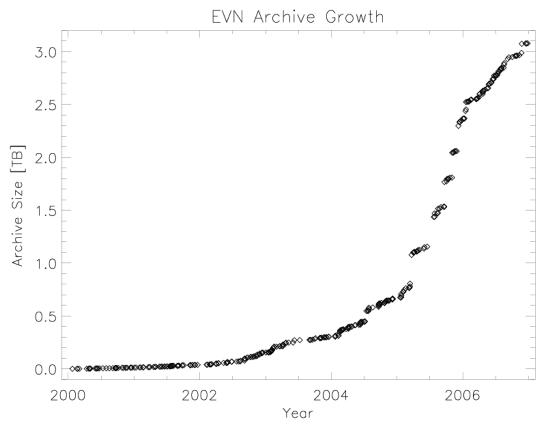


Figure 4.6: Size of FITS files in the EVN archive as a function of time.

Support for disk-only and Gbps schedules have made their way into the newer versions of SCHED.

Significant work has gone into creating support for EVN/Global VLBI proposals in the NorthStar web-based proposal tool. SCHED catalogues have been updated so that all EVN stations, and more recently VLBA ones, have disks as their default recording medium. Roll-out of the proposal tool for use by users is planned for the first proposal deadline (1 Feb) of 2007.

JIVE hosted 27 data-reduction visits in 2005 and 20 in 2006. In addition, through the period of the report, there were five post-graduate students who were co-supervised by members of JIVE staff, and who visited frequently.

4.4 Meetings, organised and hosted by JIVE

4.4.1 EVN-NREN, e-VLBI workshops

During 2005 two EVN-NREN meetings were held, both at Schiphol Airport. While the first meeting (in the last week of January) was still somewhat modest in scope and concentrated on overall progress and ways to move forward, circumstances had changed considerably when the second meeting took place in October. EXPReS and GÉANT2 had been funded, which meant that e-VLBI was set to become a major development effort for JIVE and the EVN, and that DANTE would be able to provide the needed network resources. As a result the meeting focused on the developments needed for EXPReS and on the detailed plans for the new GÉANT2 and SURFNET6 networks (topologies, capabilities like light-path switching, bandwidth on demand).

The 4th e-VLBI Workshop was hosted in July of 2005 by the Australia Telescope National Facility in Sydney, with 60 participants.

In September 2007 the 5th e-VLBI workshop returned to its original venue, Haystack Observatory. The meeting featured workshops on networking by Internet2 experts and covered a broad range of topics. The meeting was well attended with again 60 participants, reflecting the high level of interest e-VLBI continues to generate.

4.4.2 Next Generation Correlators

JIVE hosted the 3rd RadioNet Engineering Forum Workshop “Next Generation Correlators for Radio Astronomy and Geodesy” in Groningen in June of 2006 The aim of the workshop was to review the current state-of-the-art in the field of correlator development, in an attempt to identify those technologies (including software, hardware and hybrid approaches) that might best address the requirements of future radio instruments, including the SKA and related SKA pathfinder projects. The meeting brought together nearly 70 engineers and scientists from all over the world, and was generally regarded as very successful with ample opportunity for discussions and informal exchanges of ideas.

4.4.3 European Astro-G/VSOP-2 kick-off meeting

Following approval of the next generation Space VLBI project Astro-G/VSOP-2 by the Japanese Aerospace Exploration Agency (JAXA), the European VLBI community has begun organizing itself for active involvement in this exciting mission. The launch of Astro-G (Fig. 4.7) is planned for 2012, leaving not that much time for intensive preparatory activities in Japan and elsewhere.

The European participation in Astro-G/VSOP-2 is seen as a natural continuation of the extensive involvement of the European radio astronomers in the Japan-led first dedicated Space VLBI mission, VSOP/HALCA. JIVE coordinates the European effort in support to the Astro-G/VSOP-2. On 15 June 2006, JIVE hosted the European kick-off meeting of the Astro-G/VSOP-2 project. The meeting was attended by Prof. H. Hirabayashi (JAXA/ISAS) and more than 20 participants from a number of European institutes. The main task of the meeting was to work out the plan of actions toward establishing a European segment of the Astro-G/VSOP-2 mission and explore various funding opportunities.

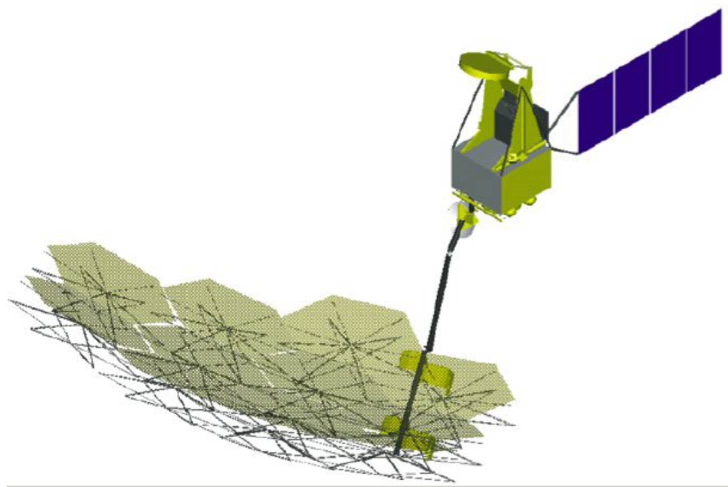


Fig. 4.7: The schematic design of the Astro-G/VSOP-2 spacecraft. The effective aperture of the main reflector is 9 m (courtesy JAXA).

4.5 Data Processor Maintenance

4.5.1 Data Playback Units

As in previous years, capstan motors were the main cause of DPU failures at the EVN correlator at JIVE. In 2005, some failed motors were sent to Metrum UK and fixed, although two of them were returned "no fault found". Metrum offered to upgrade the existing motors to a new and much improved design, at a price of £1695 per motor. Such an investment was found not to be justifiable in view of the rapidly decreasing use of tapes. Other problems, such as broken reel brakes and tape path readjustments, were handled in-house.

The use of the DPUs decreased further during 2006. While the February EVN session still saw a few experiments with one or two tapes, the June session was completely tape-free. With EVN operations about to become disk-only, some of the DPUs were offered for sale to Metrum.

4.5.2 Station Units

The process to clean TRM boards of corrosion continued. In all, a total of 30 TRMs were sent to Azteco where they were cleaned and coated with a protective material. This treatment seems to have halted the degradation, but whether the reliability of the boards has improved remains unclear.

4.5.3 Mark5 Units

Apart from one failed power supply, the Mark5A units performed reliably. Some minor hardware problems occurred, such as the failure of an onboard LAN interface and a power supply, but these were repaired in-house. One of the JIVE units was sent to Westerbork before the October EVN session because of intermittent recording problems with the Westerbork Mark5. However, subsequent tests at JIVE of this unit could not reproduce these problems. All 16 Mark5As are now mounted in cabinets, and at the end of 2006 the total number of operational DPUs had been reduced to 10.

4.6 Data Processor Developments and Upgrades

4.6.1 Mark5

A long-standing problem with 1 Gbps playback at the EVN correlator was finally solved in June of 2005. At 1 Gbps, servoing on the Mark5 units tends to be less effective than at lower data rates, which makes the initial placement of the read pointer in the data stream quite critical. When the placement is not exact, it can take many seconds before synchronization is achieved. In the case of short scans, this can cause a large amount of data to be lost.

While the correlators at Haystack, Bonn and JIVE seemingly used the same method of calculating start bytes, only the EVN correlator experienced problems with synchronization at 1 Gbps. Finally, Olnon and Szomoru decided to visit the MPIfR in Bonn to investigate their synchronization method in detail. They soon realized that the only real difference was to be found in the number of ROT clock broadcasts; the Bonn correlator broadcasts the ROT clock once, while the EVN correlator continues broadcasting the ROT at regular intervals. After receiving one ROT, the Mark5 units will, using their system clock, count down until the start time of the scan, and start playback at the calculated start byte. The repeated ROT broadcast threw off this method and caused playback to start slightly late. Once identified, this problem was easily fixed by making the Mark5s ignore all but the first ROT broadcast.

4.6.2 Archive

Until 2005, the JIVE data archive was kept on a 1.9TB raid array. As this space was rapidly filling up two additional raid arrays were purchased at the end of 2004. The original plan was to locate one of these at JIVE and the other, as backup archive, at the headquarters of the WSRT. Instead of using one of the raid arrays as mirror, regular incremental tape backups are now made and sent to Westerbork for storage. Both new raid arrays were added to the archive machine in Dwingeloo, bringing the total capacity to 5.7TB. As not all slots are in use, this capacity still can be increased to 9TB. Replacing the 250MB disks now in use by 400GB disks would bring the total capacity to more than 13TB, which should be sufficient for at least a few years.

4.6.3 Re-circulation

Re-circulation, which enables one to optimize the use of a correlator through time-sharing its computing resources, was shown to work as a proof-of-concept. Some logistical issues still remain before turning this into a full operational capability of the EVN correlator.

4.6.4 Replacement of correlator control platform

Two heavy-duty Solaris servers were purchased to replace the ageing HP correlator control computer. These machines, equipped with redundant power supplies and dual AMD processors, are meant to be fully and instantly interchangeable, and provide powerful operational and code development platforms. Both local and third party software packages were successfully ported to Solaris, while taking the opportunity to fix and update existing code. This has led to considerable improvements and increased robustness of the control system.

4.6.5 Mark5A to B upgrade

The Station Units are currently the main cause of operational instability, which has been particularly problematic during e-VLBI operations. Spare parts are few, and replacements are unavailable. Upgrading the Mark5A units currently in use at JIVE to Mark5B will allow JIVE to phase out the Station Units. As a preparation for such an upgrade, Mark5B I/O cards, Correlator Interface Boards were purchased from Conduant and Haystack Observatory, and new serial links were manufactured by ASTRON and MPIfR. The upgrade, which is expected to take place in 2007, will also involve a sizeable software effort, as a large part of the control code will have to be re-written.

4.7 Technical R&D Projects

4.7.1 PCInt

Software

A large part of JCCS, the correlator control code, was ported to the Linux operating system. This development was started a year earlier and consequently had to be merged with developments in JCCS that had taken place during that year.

Early in the second half of 2005 the PCInt data path was validated at 1/8s integration time. Another necessary step before the architecture could be validated was 'sorting and normalizing'. First fringes were detected. Work was started to integrate the PCInt code with the off-line AIPS++/CASA task, j2ms2, to enable it to read PCInt-generated data files into a measurement set.

PCInt Hardware

The InfiniBand problem, which made it impossible to use it ever since the purchase of the cluster, was finally solved. The problem turned out to be in the firmware of the switch. As the vendor could not fix this in-house the switch had to be sent to the manufacturer for a firmware upgrade. The switch was returned in the beginning of December but some performance issues remain.

4.7.2 Data Reduction, Software Correlator

Many developments took place within the Huygens VLBI project, in terms of software, hardware and networking efforts. In order to facilitate the conversion between different data formats and speed up data reduction itself, high speed connectivity was established between a number of Mark5 units, several general purpose computers and the PCInt cluster. Various software modules were written to convert data between different formats such as VSI-PCEVN, Mk5 and the internal software correlator format. This work was done in close collaboration with our colleagues Mujunen and Ritakari from Metsahovi Observatory.

This effort has resulted in a software correlator which is now used as the basis for future software correlator developments at JIVE.

To support the EXPReS efforts at JIVE, a dual-core dual Opteron machine with a 5TB raid array was purchased. This machine has been used intensively for data transfer and protocol tests (from Metsahovi, Medicina, Bonn, Jodrell Bank and Sydney), as a development and operational platform for the JIVE software correlator and for software format conversion, for example during a geodetic K-band experiment with the Australian LBA. It was also used to support Smart-1 observations with EVN telescopes (Medicina, Metsahovi and Westerbork) and TIGO (Chile), as preparation of the actual observations during its planned crash on the lunar surface.

4.8 e-VLBI

4.8.1 New personnel

On the first of March 2006, the EXPReS project formally got underway. For SA1, the service activity aimed at establishing a production e-VLBI facility, a total of five new staff positions were advertised. Suitable candidates for all these positions were found.

4.8.2 Tests

e-VLBI testing, which until 2005 had been mostly ad-hoc, was set on a solid basis by scheduling tests at about six-weekly-intervals.

Tests during the first few months of 2005 either failed or were only partly successful. After some discussions with the Mark5 developers at Haystack Observatory it was found that these problems were caused by an incompatibility of a new version of the Mark5A control code with older versions of the Linux kernel. Most units at JIVE were subsequently upgraded to a new kernel. After this, a series of successful tests showed that a data rate of 128 Mbps from all European stations could usually be reached, and occasionally 256 Mbps. Connectivity to Arecibo remains limited, and although 64 Mbps has been reached occasionally, 32 Mbps failed several times as well.

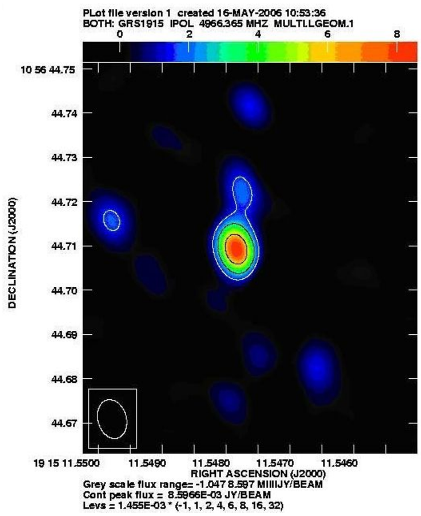


Figure 4.8: e-VLBI image of GRS1915 from the April observing run (20 April 2006)

With the start of the EXPReS project in March 2006, a full-scale real-time VLBI service had to be provided for the astronomical community. As a first step an open call for e-VLBI proposals was issued. Six science runs were conducted during 2006, one of which was granted time as a target-of-opportunity (e.g. Fig. 4.8 and 4.9). Operational developments continued throughout the year. The overall robustness increased greatly, and although some data still are lost during correlation job re-starts, a careful strategy of carrying these out during regularly scheduled fringe-finder scans minimized data loss on the targets. The production data-rate increased from 128 Mbps to 256 Mbps, and we were able to produce fringes at 512 Mbps from most telescopes.

The two main disadvantages of the current e-EVN, low sensitivity and low resolution, will disappear when Effelsberg, the most sensitive telescope of the EVN, and Shanghai, providing the longest baselines, are added in 2007; sensitivity will further increase when 512 Mbps becomes the operational data rate.

4.8.3 Development

Networks

Bwctl, a tool developed by Internet2 to test network throughput, was installed at JIVE and all stations. It was hoped that with additional bwctl boxes along the way it might be possible to quickly pinpoint bottlenecks. However, most NRENs could not grant access to equipment at their PoPs, and as a result the bwctl points are few and far apart. GÉANT did provide a very useful Internet weather map tool, which shows the usage and capacity of their network throughout Europe.

During 2005, modifications were made to the GÉANT network to allow the use of jumbo frames. The use of large packet sizes (larger than the standard MTU size of 1500 bytes) can greatly reduce the CPU load on the end systems, allowing higher data rates.

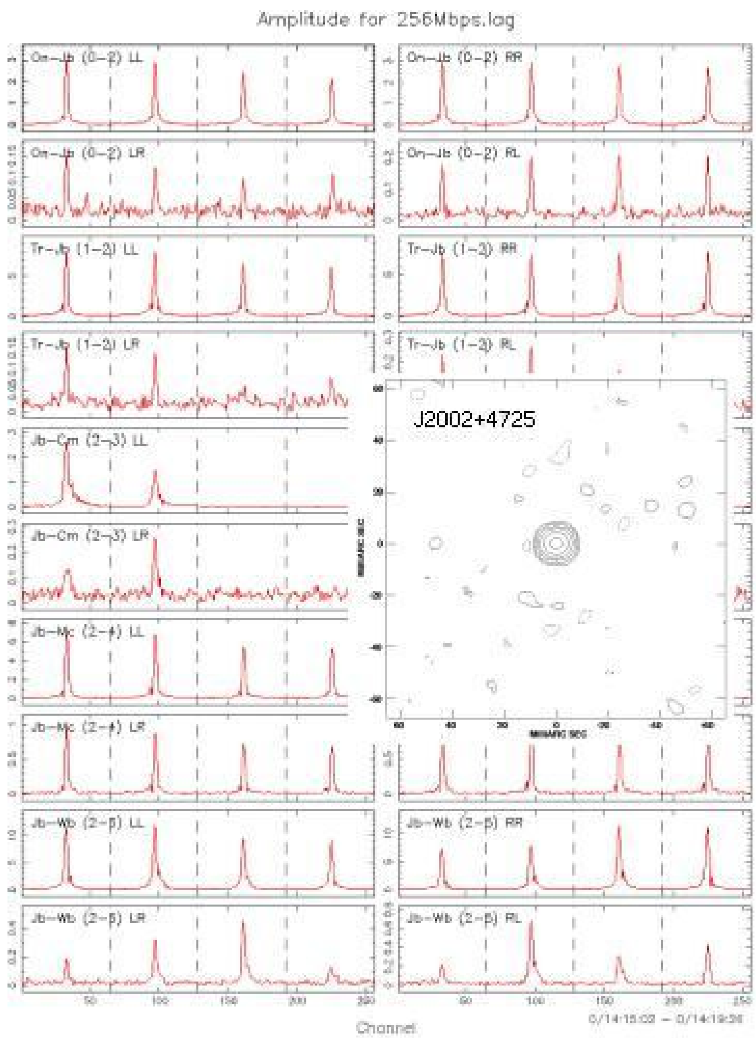


Figure 4.9.: first 256 Mbps fringes to 6 European telescopes (18 May 2006)

Software

Many improvements and modifications were made to the correlator control code at JIVE. Running time-critical observations continuously for many hours puts quite new demands on the correlator, which after all has not been designed for real-time operations. Bugs had to be fixed that would never occur during normal operations. As a side effect of these fixes existing code was tightened, resulting in an increased robustness of the system.

Instead of having the operators at the stations start and stop transfers, set record modes and data rates, either by hand or through field system commands, all Mark5 commands are now sent to the stations by the correlator control computer (Fig. 4.10). Further modifications were made to the control code to enable true real-time operations, and to make it possible to start observations at any point within a schedule, without needing to actually edit this schedule. These changes have improved the reliability and greatly simplified e-VLBI operations both at JIVE and at the stations.

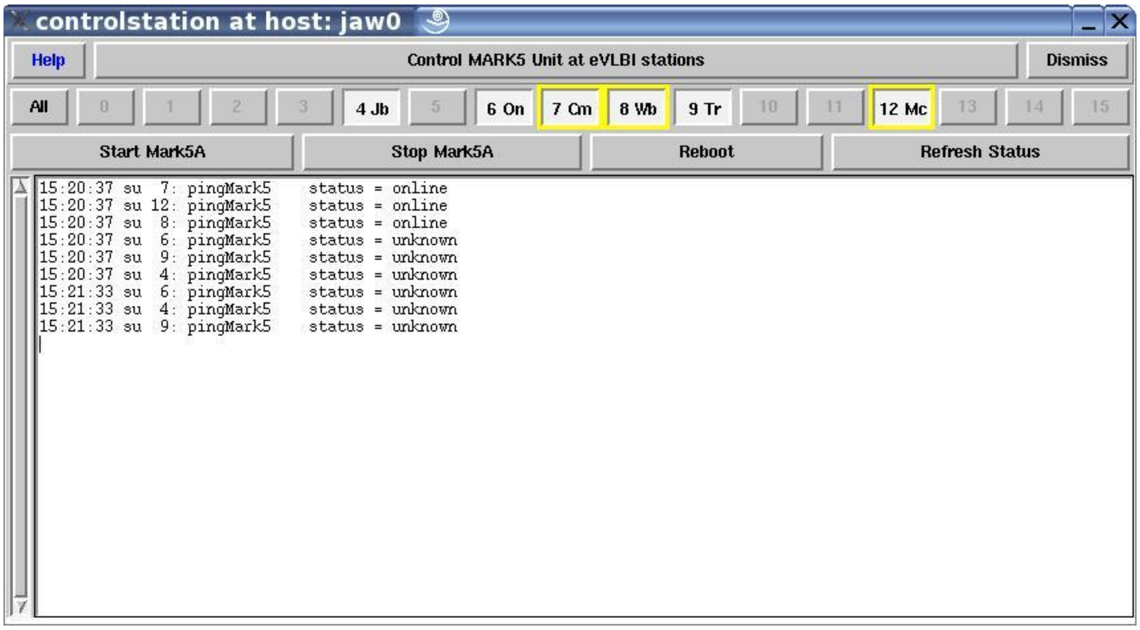


Figure 4.10: Graphical interface to Mark5A units at stations

Several stand-alone software modules were implemented and tested. A real operational improvement was achieved by enabling remote control of the Mark5A units at the stations. This ability is particularly important when doing 24 hour observations.

Another very useful tool that became available were the integrating fringe display (Fig. 4.11), enabling one to detect fringes of weak sources, essential during real-time and/or target-of-opportunity observations, and the data status monitor, (Fig. 4.12) providing an instant overview of the status of the correlation process. The output of these monitoring programs is also made available via a web page, providing feedback to the operators at the stations.

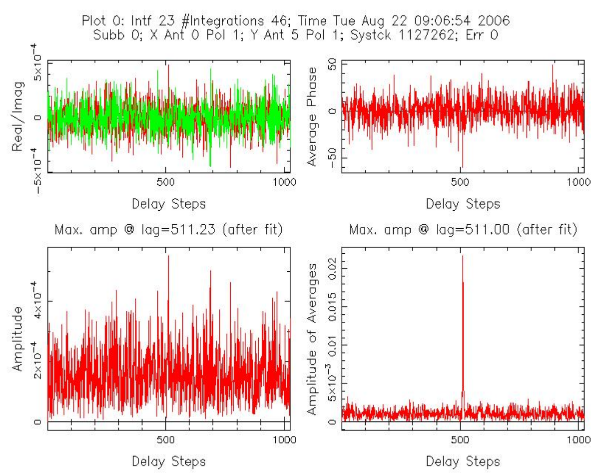


Figure 4.11: Fringe display of weak source: without (left) and with integration (right)

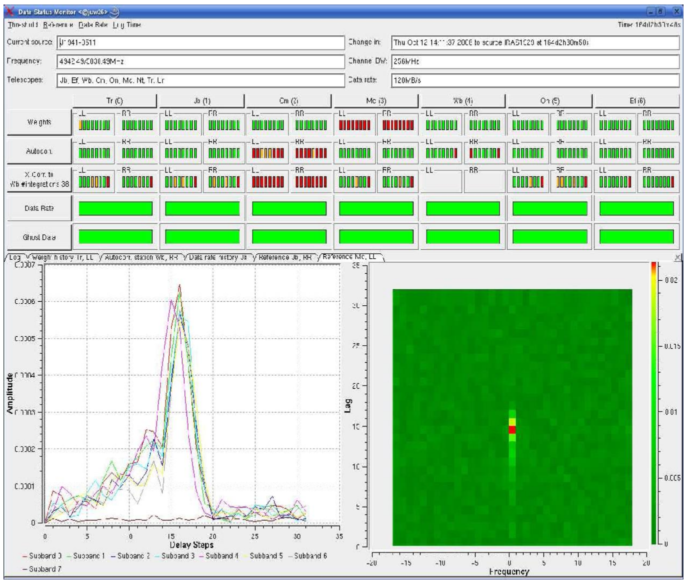


Figure 4.12: One of the views of the data status monitor

Expansion of e-VLBI network

Several new telescopes were added to the expanding list of Gb-enabled sites. Although the physical labour of digging trenches and installing fibres was completed last year, Medicina was finally connected to GARR and GÉANT in 2006, and now participates in all e-VLBI sessions. Metsahovi was connected at 10 Gbps, but had not yet produced fringes by the end of 2006.

4.9 Logistics Software

Various improvements were made to the software that makes the archive accessible to the users. In particular, new source selection tools were introduced, for example a connection was made that allows pipeline images to be overlaid directly on images from on-line optical databases such as available through Aladin (Figure 4.13).

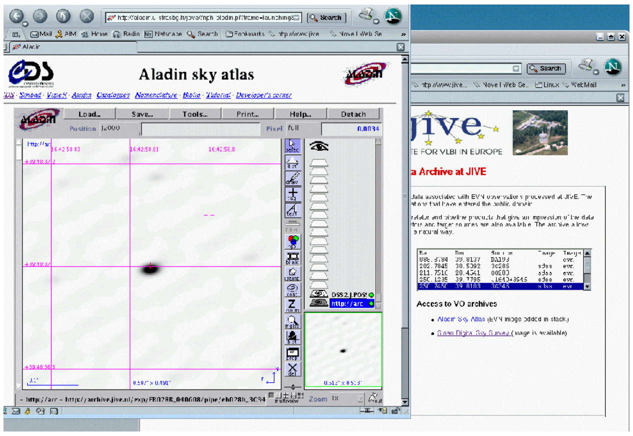


Figure 4.13: Screenshot of the archive tool that plots the pipeline image of 3C345 on POS plates through Aladin.

The EVN has worked towards adopting the Northstar proposal tool, which was developed at ASTRON in the context of RadioNet Synergy (Fig. 4.14). JIVE has taken the responsibility to maintain the EVN specific part of Northstar. Work in this area progressed to a first demo version by the end of 2006 in collaboration with ASTRON.

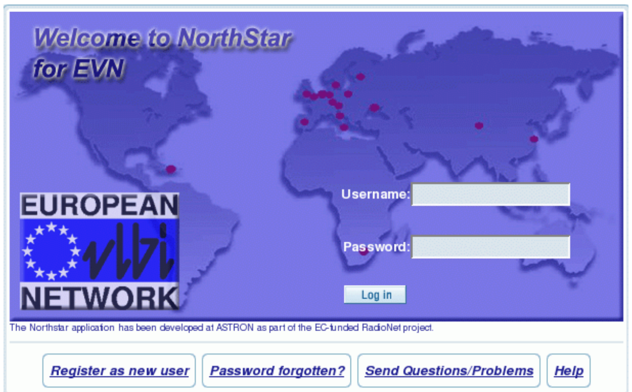


Figure 4.14: Login screen of the Northstar proposal tool for the EVN

4.10 ALBUS

ALBUS (Advanced Long Baseline User Software) is the Joint Research Activity in RadioNet that concentrates on making new algorithms available to the user community. In this project JIVE has the overall management responsibility and also carries out 4 of the original work packages. Moreover, JIVE has taken the lead on ParselTongue, which is now probably the most visible one amongst the ALBUS projects.

Calibration transfer

The first part of this work package provided the direct transfer of system temperature calibration and off-source flagging information from the telescopes to the data product. The EVN pipeline (developed in ParselTongue) has been enhanced to allow it to use these calibration data and attaches them to the data product, meaning that the old-style external calibration files are no longer required for user processing.

The correlator software has been upgraded to allow phase-cal measurements to take place continuously. The output from the measurements is attached to the data product and can now flow through all the stages of JIVE's internal data handling. The usefulness of the resulting product for phase calibration has been demonstrated using software written in ParselTongue (Fig. 4.15). There is also a related effort to improve the accountability of the correlator model in the output data. This allows one to extract the component parts of the model which can then be replaced by, for example, external troposphere models.

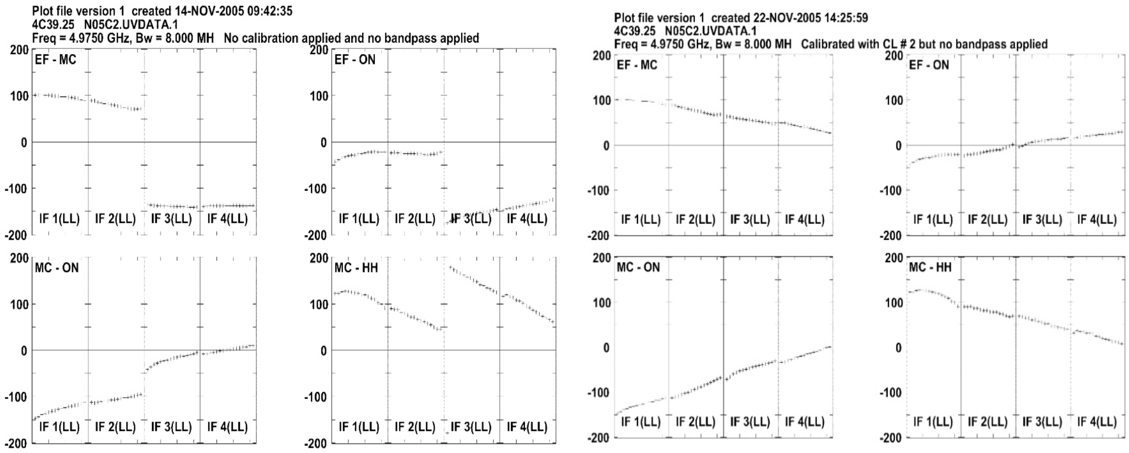


Figure 4.15: Phase response on several baselines before (left) and after (right) applying the phase tone detections made at the EVN Mrk4 data processor

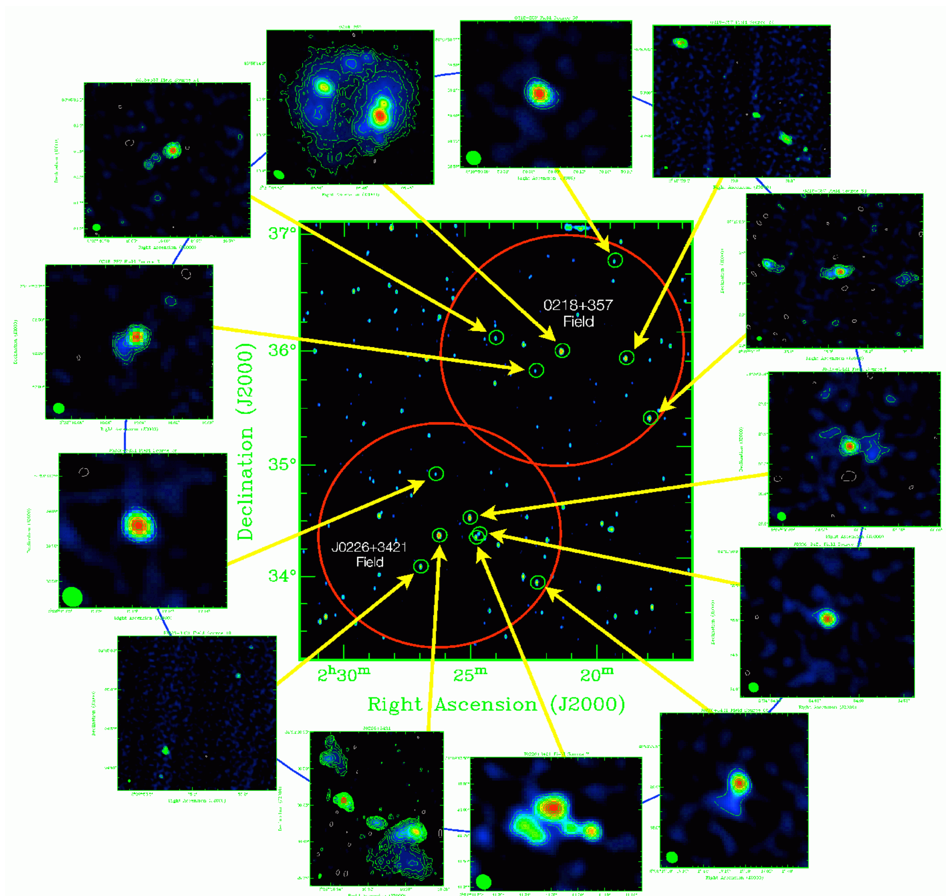


Figure 4.16: Thirteen sources detected using wide-field VLBI at 90 cm in 3.1 degree2 fields around the AGN J0226+3421 and the gravitational lens 0218+357. The central image is a low resolution WENSS image of the surveyed regions (Lenc et al., 2006).

Ionospheric calibration

Different strategies for calibration of the ionosphere are exercised in this project. The estimates of the ionospheric conditions include purely theoretical models, conventional GPS estimates, local GPS data and global empirical models. One hurdle was to develop methods to add these estimates to AIPS data sets. In 2005 this worked focused on processing EVN test data taken in various conditions. But more recently the algorithms were deployed to assist in the reduction of a 320 MHz science project (Figure 4.16). The goal of this project was to perform wide-field imaging at low frequencies. The ionospheric delay errors at these low frequencies are typically the largest sources of calibration errors and the ionosphere changes substantially over the field of view.

Wide-field Imaging

Some initial work on wide-field imaging for ALBUS started in 2006 and focused on software development to facilitate data reduction for a 320 MHz dataset (above). Software to simplify processing tasks was written in ParselTongue to automate many of the repeated AIPS tasks necessary to calibrate the observations for a particular direction in the sky and then shift the phase reference centre. Unfortunately, the processing steps necessary to perform this use routines which require that copies of the full dataset be written out to disk many times. This means that processing the data is extremely slow. A new routine to incorporate the same functionality into a single routine needs to be developed within AIPS to significantly speed up the processing.

5 VLBI Operations support at member institutes

5.1 ASTRON, Westerbork Synthesis Radio Telescope, The Netherlands

Regular sessions

Session 1 of 2005 was marked by extreme snowfall (for the region), which left more than 50 cm of snow on the ground and trapped the telescope operator inside the observatory for the night. The snow caused the telescope dishes to be so unbalanced that they could not be moved. For some time later, the system temperature was increased and the effective area reduced because of the wet snow on the dishes. During this session there were occasional problems with the tape recording system, but most of the observations were being done with the Mark5A disk recording system, and ran well.

Session 2 of 2005 was smooth except for the tape unit vacuum motor, which continued to give problems despite an attempted repair. Session 3 of 2005 was conducted with a Mark5A unit borrowed from JIVE to replace the regular one, which was later diagnosed with a power supply voltage drop. Crosstalk with the video cable led to problems, but only at the highest data rate (1 Gbit/s); the session otherwise ran well. There was a total of 817 hours of VLBI observing in 2005.

Session 1 of 2006 ran well, and saw a new 5cm (methanol line and excited OH) receiver successfully taken into service for Single Dish VLBI. Sessions 2 and 3 of 2006 also ran with only minor problems, although before session 3 the power supply for the VLBI rack failed. Once this was repaired some other parts gave initial problems. There was a total of 767 hours of VLBI observing in 2006, of which 180 hours with Single Dish.

eVLBI

In 2005 a wide-band noise system was initially used for occasional eVLBI bandwidth tests with JIVE. Westerbork was then heavily involved in the first eVLBI observations in Europe, and in the regular sequence of eVLBI test and science observations which were scheduled after February 2006.

Special observations

During the summer of 2006 Westerbork did test observations with the Evpatoria radio telescope (in the Crimea), and initial tests of the observing mode for the SMART probe impact onto the moon, although the final 'descent' was not observable in Westerbork.

Tape operations

Switching between disk and tape was a risky operation all through 2005 because of the fragility of the connectors. During the third session a swap led to one of the pins on the flat-cable connector breaking; fortunately it could be repaired quickly. In 2006 tape recording was finally taken out of service.

Meeting hosted

In March 2006 Westerbork hosted the EVN Technical and Operations Group (TOG) meeting.

5.2 Institute of Radio Astronomy - INAF, Italy

5.2.1 Medicina Station

1) Mark5 and Disks
Following the decision taken by the EVN CBD at the November 2004 meeting the EVN stations ask to achieve as a goal enough disks space to sustain 10 days of observations at 1 Gb/sec, which corresponds to a total of 100 Tb. The station bought up to 60 Tb of disks by May 2005, 83 Tb by November 2005, 93 Tb by May 2006. The goal of purchasing disks/frame for 100 Tb was finally achieved by the end of 2006. Disks/frame with a capacity of 9 Tb were also bought in order to support geodetic network observations.

At the beginning of 2005 the old tape recorder showed many problems. The quality of the recorded data was considered too poor. Consequently, it is was decided to close its life cycle. Starting from that point on, any VLBI session was made by recording on hard disks. Data were recorded using a Mark5A terminal. The Mark5A recording system has the following configuration:
- Mark5 O.S. kernel was updated from 2.4.18 to 2.4.32
- Mark5 software version installed: 2.7x (2005.147)
- Mark5 firmware version: 0xb8,0x19

2) Field System

The Field System version installed to run most of the observing session in the period 2005-2006 was the 9.7.7 release.

3) e-VLBI:
IRA and the Emilia-Romagna regional government signed an agreement under which the government will financially support the installation and connection of a fibre optic link at 1Gb/sec between the Medicina Station and Bologna. The digging started at the beginning of 2005. At present the last mile is completed and the antenna control room is already reached by the optic link. The backbone between the Medicina Station and the pop in Bologna was deployed and it was foreseen that it should be finished within the end of the year. In fact, by the link was made available and the Medicina 32-m antenna successfully participated EVN e-VLBI test experiments during 2006. Fringes were soon found.

4) Back-end
The upgrade of the polarimetric system has been completed and a software package for making raster scan observations is under test. Recent tests with the

polarimeter showed that the cross-talk (D-term) for the 5 GHz receiver is of the order of ~1%, much less than the ~10% found in previous VLBI projects. The reasons for such a difference are still not fully understood.

5) Frequency agility:

- The Medicina 32-m dish is now fully capable of changing all receivers in a fast and automatic way. Up to 9 receivers can now be placed in the secondary focus Cassegrain cabin. A receiver can be automatically selected by tilting the sub-reflector to the axial focus of the receiver itself. The switch between primary and Cassegrain receivers also implies to shift Aside, off-axis, the sub-reflector, operation which is done also automatically. All the operations are under computer control and are made in a very user friendly mode via a graphic interface.

6) Mechanical hardware problems

The EL cog presents points of stress and wear. The plan was to replace it with a new one by Summer 2006. The changing was timed to avoid to affect the EVN sessions. At last, financial problems did not allow the change of the EL cog, which was postponed to 2007.

7) Events

Three events related to the station activities happened in the period of the present report, namely the:
- 2nd RadioNet Engineering Forum Workshop "New Trends in Receiver Developments" held at the Medicina Station Visitor Centre “Marcello Ceccarelli”, Monday, 30 May 2005
- Second Summer School in Spectrum Management for Radio Astronomy, held in Castel San Pietro Terme, Italy, 6-10 June 2005.
- On 15 October 2005 official opening cerimony of the visitor centre "Marcello Ceccarelli".

5.2.2 Noto Station

1) Front-ends
The cooled multi-feed SXL receiver was complete and mounted on the antenna receivers' environment in 2005. The installation of the full system required to idle the antenna for sometime.

A relative long period of pointing and calibrations observations was used to allow regular observations with the borrowed 86 GHz receiver. By the end of 2006 the receiver was not fully operative for preliminary VLBI tests.
A 'task force' has been set up to operate with the 86 GHz receiver. A calibration and pointing campaign is needed. There is a plan for a three weeks calibration

campaign in January 2007. The main aim is to measure the efficiency of the telescope and the pointing parameters.

The new VHF-UHF receiver, covering the range 250-600 MHz, and 600-1000 MHz was successfully used during EVN observations.

2) Mechanical structure of the telescope
The AZ rail showed a major problem in the grout, which seems to be severely damaged for about 1m. Further investigation were done in order to check on how much the grout is damaged.

The AZ driving system was affected by a serious fault during the EVN session in June 2005. A new engine and a new encoder were needed. As soon as they were mounted, further problems affected the servo-system in the communication with the Antenna Control Unit. The antenna could be driven only manually. Remote contacts with VERTEX did not allow to solve the problem. A VERTEX expert came to visit to the Noto Station to find the reason of the fault.
Because of that failures the Noto 32-m dish cloud not participate to the last 2 EVN Sessions in 2005.

Finally, the failures on servo and the problem of anomalous small oscillations of the antenna, were solved. New motors and encoders were installed, together to new hardware and software facilities in order to frequently monitor the telescope performances.

To improve the quality of the data provided by the station, the following actions have been taken:
i) periodically check of the data quality with CHCHK, in particular RFI signal and pcal;
ii) provide detailed wx and RFI comments for each experiment;
iii) the information about the frequency agility of the telescope have been communicated to C. Reynolds
iv) Last MK5 and FS release have been installed.

The observing activity continued without major problems in both VLBI and single-dish type of observations. Fringes have been found in all the later experiments, reaching again the normal fully operational status. Moreover, the upgraded driving system improved the performances of the antenna, adding also new scanning features. Problems related to the antenna oscillations have been solved with the introduction of software filtering in the driving process, which avoid self-resonance conditions in the antenna structure.

A student started working for the upgrading of the antenna driving software, which is web-oriented, and allows remote operations for both the antenna driving and he data acquisition system.

Lack of funds did not allow to do any maintenance work on the grout of the azimuth rail before the end of 2006. The performance of the rail is continuously slowly degrading with time.

3) Acquisition Terminal and Digital Technology

A large number of disk packs has been bought to reach the required total amount of 100 Tb to sustain the EVN Sessions.

A travel version of the Digital Base Band Converters (DBBC) has been realised and two experiments have been performed in the EVN aspiring stations of Evpatoria (Ukraine) and Irbene (Latvia), using the Metsahovi VSIB recording system. Three complete DBBC units are under construction for Wettzell, Tigo and O'Higgins. In such system, the tuning configurations and the multi-channel solutions, possibly required in future by geodetic observations, are made possible. The delivery for such units was planned by the end of 2006 and the first quarter of 2007.

At the same time it is also started the production of two complete DBBC units for the Noto and Medicina dishes. Several systematic observations have been done between Noto and Medicina for testing the DBBC. The recording was done making use of an EVN-PC kindly borrowed from Metsahovi. Geodetic observations with DBBC-VSIB recording in parallel with the MK4-MK5 are planned almost regularly in 2007.

INAF approved the first phase of a proposal to set a spin-off company with the aim to produce the DBBC back-ends, and parts related to the same technology adopted for such system.

5.2.3 Sardinia Radio Telescope

1) Front-end
The specifications for the receivers have been defined as follows:
a) bandwidth of ~35%; b)IF bandwidth 2 GHz.
The following receivers have been planned (one for each focal points):
310-420 MHz, 1.3-1.8 GHz, 5.7-7.7 GHz, 18.9-26.5 GHz.

Three receivers are under construction:
- a co-axial 300MHz-420MHz and 1300MHz-1800MHz receiver for the primary focus
- a 5.8GHz-7.8GHz receiver for the beam wave guide focus
- a multi-feed 22GHz receiver for the Gregorian focus of the telescope.

2) Observing time
It is anticipated that the telescope will spend observing time as follows: 30-40% VLBI; 30-40% Single dish; 10-20% Space Science.

3) Fibre Optic connection

A proposal for fund to connect SRT with the GARR/GEANT backbone is under examination. The Regione Sardegna Government expressed interest in the project.

Construction
The foundation has been almost completed.
The steel structure is almost completed in the factory; rail, wheels
and cog are available.
The panels are under construction. Expected accuracy is 65 micro-m rms.
The expected accuracy for the secondary mirror is 50 micro-m rms.

4) Status of the construction activities

Sardinia Radio Telescope (SRT), is a new general purpose, fully steerable antenna of the National Institute for Astrophysics.
It is under construction in the Gerrei territory, about 40 km (one hour car driving time) from Cagliari, the Sardinian capital region. For sake of simplicity, the construction phase of this observational facility can be seen as composed by 3 macro-activities:

- Basement Construction.
Activity fully accomplished. The Az track already positioned.

- Erection of the mechanical structure.
Being a "wheel & track" radio telescope, this activity has been started with the welding procedures of the azimuth track. The Az track is made by seven macro-segments, which has to be welded together: indeed, six of them were already assembled, so that this working phase is almost completed.
The alidade, which will be sent from Egypt to Cagliari late January, where it has been made, will be assembled starting next February 2007.

Part of the panel of the main mirror are ready as well as 400 actuators, which will allow the active surface of the main mirror. The panels of the secondary mirror are also ready.

- Civil and Technological infrastructures.
Awaiting for the final setup of the erection areas, now these infrastructures too will be started. This will provide the actual Station, i.e. the buildings which will host offices, technical departments, laboratories, and so on Local activities.
INAF has established a provisional area for logistics and science department. Monitoring of the RFI and meteo conditions, GPS survey, video and photographic documentation is up and running. A couple of webcams will allow everybody to watch what is going on at yard. Check the SRT home page at www.ca.astro.it for more information. Furthermore, the INAF- Cagliari Astronomical Observatory is deeply involved in edutainment activities, which will allow to strengthen the link between local people and astronomical sciences.

5) Events

The workshop 'Science with SRT' has been held in Bologna on 10-11 May, 2005. The INAF President, Prof. Piero Benvenuti and the INAF Director of the Dipartimento Progetti, Dr. Gianpaolo Vettolani, joined the meeting. The proceeding of the workshop have been published.

5.3 Jodrell Bank Observatory, UK

During the period 2005-2006, the MERLIN/VLBI National Facility, based at Jodrell Bank Observatory (JBO), participated in all six EVN observing sessions. These involved the 25-m Mk2 telescope at 1.3, 5 and 6 cm, the 76-m Lovell telescope at 6cm, 18/21 cm and 90cm, the 32-m Cambridge telescope at 1.3, 5, 6 and 18/21 cm, and the Darnhall telescope at 5 cm. National Facility telescopes were scheduled to observe 98 VLBI projects, for a total of 1500 telescope hours. 32 of these experiments were joint EVN+MERLIN observations. During this two year period a total of approximately 69 telescope hours (4.6%) were lost due to technical problems at the time of observation, astronomer/operator error or weather. This is comparable to the average data loss value over the previous reporting period.

By the start of this reporting period, most observations (apart from those to be correlated at Socorro) were being recorded on the Mk5 data recorders. Some initial problems with the new technology were reported to the developers and were eventually resolved. The Mk5 systems continued to operate reliably. Most of the data loss during this period was caused by a power supply failure on the VLBA rack during the October 2005 session, a problem with disk directory structure on a Mk5 system during the February 2006 session, and because of high winds. It should be emphasised that data loss due to high winds are frequent during the months of March and October. Two of the experiments during the February 2006 session were Target-of-Opportunity programmes on the recent nova outburst of RS Oph. One of these was used to test the process of recording two MERLIN antennas (Cambridge and Darnhall) simultaneously on a single Mk5 recorder, utilising unused bandwidth, and essentially supplying an additional EVN antenna for minimal increase in resources. The test was very successful and this will become a standard observing setup for future experiments.

5.4 Max-Planck-Institute for Radio Astronomy, Germany

Antonis Polatidis acts as Friend of VLBI at the Effelsberg telescope and supervises absentee observing for EVN and other VLBI observations. Where necessary, technical assistance for machine control of observing schedules is provided by Dave Graham.

Andrei Lobanov is the MPIfR representative on the EVN Program Committee and attended its meetings.

Richard Porcas is the EVN Scheduler and attends meetings of the EVN Program Committee and the EVN Consortium Board of Directors in this capacity. Assistance with EVN Proposal administration was provided by Ute Runkel, and

Walter Alef took care of the receipt of emailed proposals. (These tasks are now performed via the web-based EVN Proposal Tool.)
Andrei Lobanov and Richard Porcas are members of the eVLBI Science Advisory Group.

Walter Alef organizes the distribution of tapes and disks prior to observing sessions, in conjunction with the Scheduler, JIVE, the observatories and NRAO.

Walter Alef is Chairman of the EVN Technical and Operations Group (TOG). Dave Graham and Antonis Polatidis are also members. All 3 attend the TOG meetings.

Walter Alef is scientific supervisor of the MPIfR/BKG MK4 correlator in Bonn, and oversees the correlation of EVN experiments processed there. These include projects of an astrometric or geodetic nature (which can take advantage of the associated post-correlation software) and projects with "local" PIs (e.g. Bonn or Cologne) who wish to have a "hands on" approach to correlation.

Antonis Polatidis is responsible for maintaining the "EVN Status Tables" on the EVN Home Pages and Richard Porcas maintains the "Instructions for EVN Observers".

Walter Alef helped organize the VLBI "Technical and Operations Workshops".

Thomas Krichbaum, Dave Graham, Walter Alef and Richard Porcas jointly organize the European part of the Global 3mm VLBI Network. Richard Porcas is Scheduler, Thomas Krichbaum is Schedule Coordinator and Walter Alef and Dave Graham coordinate the technical and correlation aspects.

MPIfR correlator operations

The Bonn MK IV VLBI correlator is jointly operated by the MPIfR, the German Federal Agency for Cartography and Geodesy (BKG), and the Geodetic Institute of the University of Bonn. Is is used for the correlation of observations of the global mm-VLBI array (GMVA) which observes twice per year at 86 GHz with up to 13 antennas. In addition about 40% of the worldwide geodetic VLBI observations under the IVS umbrella are processed at Bonn. A few EVN experiments are correlated as well, either because they are MPIfR projects or as they need some of the features the Bonn correlator offers, like hands-on correlation, phase-cal extraction, geodetic export path, or availability of the correlator model in the exported data.

1) Improvements achieved in 2005-2006

In collaboration with the BKG a project was initiated to upgrade the correlator to 12 stations and Mark 5B units. A Mark 5B playback unit can completely replace the combination of Mark 5A and station unit, which should increase the robustness of the MK IV correlator significantly. MPIfR and MIT Haystack have been collaborating on extending the capabilities of the MK IV correlator, namely:

- Upgrade and modify the software to allow the correlator to be supported on a Linux-based computer.

- Enhancements to support direct correlation of Mark 5B data.

- Support for 12 to 16 stations.

- Support the correlation of data rates up to 2 Gbps.

For the upgrade new serial links were designed and produced, also for the correlators at Haystack, Washington and JIVE. Four Mark 5B units and eight upgrades for the existing Mark 5A recorders were procured. MIT Haystack designed and manufactured correlator interface boards for connecting Mark 5B units to the correlator. In the course of 2006 two tape units were decommissioned to make space for the additional Mark 5 units. In the final stage all playback units will be mounted in 3 racks. At the end of 2006 the first Mark 5B unit was connected to the correlator.

In the reporting period the correlator was regularly reconfigured to operate with any combination of 9 tape drives and 8 Mark 5A disk playback units; for 2-head recordings a few cable connections had to be changed.

During the time covered by this report, recording with tape was nearly everywhere phased-out of operation. As a result the robustness and the throughput of the correlator nearly doubled. It is expected that the last tape recordings will be correlated in 2007.

About 135 TB in 35 disk-packs have been assembled and tested at Bonn for supporting GMVA operations.

2) Operation

The number of observations correlated stayed at a high level in 2005 and 2006. The total percentage of correlation time over total time was about 35% which is lower than in 2003/2004 due to the increased throughput. About 35% of the correlation time was used for astronomical correlation, 65% for geodetic projects. This corresponds to 47 astronomical projects and 113 geodetic experiments.

3) Software Correlator

In autumn 2006 the DiFX software correlator developed by Deller and others at Swinburne, Australia, was installed on a small cluster. It has been adapted to scan-based correlation, as used at the MPIfR MK IV correlator. The results of a first test were presented at the "18th European VLBI for Geodesy and Astrometry (EVGA) Working Meeting" in Vienna in spring 2007.

The most important plans for the near future are:

- verify the DiFX software correlator for geodetic VLBI correlation (a comparison of DiFX for astronomical data was already successfully done against the VLBA and the Australian VLBI correlators)

- Apply for money for a medium sized cluster for software correlation

- Develop DiFX into a production system which can be run in parallel with the hardware correlator.

5.5 Metsähovi Radio Observatory, Finland

VLBI Observational Activities

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).

VLBI Sessions in 2005

In 2005 Metsähovi took part in four geodetic VLBI experiments in collaboration with the Finnish Geodetic Institute (FGI). Two regular EVN VLBI sessions were conducted in February and in October. The Global mm-VLBI Array (GMVA) observed also two sessions, in April and in October.

Huygens Probe

Metsähovi participated in measuring the trajectory of the Huygens probe when it dropped through Titan's atmosphere. The experiment was one of the biggest VLBI experiments ever, seventeen observing stations in total, and the accuracy of the results was remarkable. An accuracy of 1000 meters was achieved at the distance of a thousand million kilometers.

The equipment that was used in Australia to measure the trajectory of the probe had been developed in Metsähovi, and Ari Mujunen developed the conversion software to change the results to a format suitable for the JIVE correlator.

VLBI Sessions in 2006

No EVN 22 GHz nor 43 GHz sessions. Eight 24 h geodetic schedules were run in six receiver change sessions.

Two 3 mm/86 GHz mm-VLBI sessions of GMVA (Global mm-VLBI Array) were conducted in April and in May.

ESA Smart-1

In May 2006, Metsähovi was one of the stations to participate in accurate VLBI tracking of the trajectory of ESA's electronic propulsion SMART-1 moon mission spacecraft using the geodetic S/X receiver. VLBI was used also to track the S/C final descent and intentional crash landing on the Moon on 03-Sep-2006.

5.6 National Astronomical Observatory, Spain

Nothing to report, as no observations have been done in 2005-2006 with the antennas in Yebes.

5.7 Onsala Space Observatory, Sweden

The Onsala telescopes continued during 2005 and 2006 to play a full role within the global observing program for astronomical VLBI. In total 10 astronomical VLBI-sessions (6 EVN sessions and 4 global mm-VLBI sessions) were conducted. In addition, the Onsala 20m telescope has been used for some 27 geodesy VLBI experiments in 2005 and 35 during 2006. Onsala also participated in the continuous geodetic VLBI campaign CONT05 in September 2005.

Onsala is regularly involved in e-VLBI sessions in the EVN. This has been made possible by the advent of the disk-based Mk5 terminals and the construction of a 1 Gbps optic fiber link from Onsala to Chalmers in 2003. The record obtained during 2006 to JIVE is 512 Mbps. Onsala is a partner in the FP6 project EXPReS.

5.8 Shanghai Astronomical Observatory, P.R. China

Sheshan Station observations

During the period 2005-2006, Shanghai 25m telescope participated in five EVN observing sessions at L, C and K bands. Most L and C band observations run successfully. In addition, the Shanghai telescope has attended 30 geodesic experiments coordinated by the IVS at S/X bands. Besides the international VLBI observations, the Shanghai telescope was involved into the Chinese Chang'E project, more than 70 testing experiments have been done with Chinese VLBI network (consist of Shanghai, Beijing, Yunnan, Urumqi telescopes and correlator in Shanghai).

Instrument improvement and technique update

Antenna

The antenna drive system was replaced in 2005 August, and the antenna control software was then updated. With the new drive system, the slewing speed has been improved to 60 degree/minute in the Azimuth direction and 36 degree/minute in the Elevation direction. The new drive system reduced the data lost due to antenna control.

We have adjusted the antenna surface using the microwave holography in 2005 November. The surface accuracy improved from 1.20 mm (r.m.s.) to 0.55 mm.

The antenna track was inspected in 2005 August. At some intersections, the rails showed big gap and displacement. In the period August--December, the rail track and the base were repaired.

One of axletree of the antenna was repaired in July of 2007.

Receivers

In September 2005, Shanghai telescope was equipped with a cryogenic dual polarization L band receiver at the primary focus. It was first used in the EVN 2005 November session, and works well in subsequent experiments.

In December 2005, Shanghai telescope was installed with a new S/X feed, and a new set of cryogenic S/X receiver. The S/X receiver works at 2150—2450MHz with a LO frequency 1600MHz, 8200-8600 MHz with LO frequency 9100 MHz and at 8600-9000 MHz with LO frequency 8100 MHz, respectively.

Terminals

Six BBCs and one IF distributor of the Shanghai telescope were borrowed to be installed in Miyun radio telescope (in northwest suburb of Beijing), which is another tracking station involved in the Chinese Chang'E lunar project. Since then, the Shanghai telescope had eight BBCs and one IF distributor in use.

In 2007, we borrow several BBCs from NASA allowing the Shanghai telescope to work with 8 BBCs again.

e-VLBI

A fiber link has been paved from the Sheshan station to Shanghai host institute in 2006. A number of e-VLBI tests have been carried out. An e-VLBI experiment together with Australian VLBI station and European VLBI station was made in August of 2007. It is a great successful e-VLBI experiment.

An e-VLBI system of Chinese VLBI network with 34 Mbps was built, with will be used for Chang’E project.

Laboratory and Dormitory Building

A new building has been constructed at the site of the Shanghai telescope in 2006. It consists of laboratories, meeting room, canteen as well as dormitories.

5.9 Arecibo National Astronomy and Ionosphere Centre, Arecibo Observatory, Puerto Rico

Connectivity

Detailed design work is under way for the upgrade to Arecibo's network connectivity, following approval of a proposal submitted in March 2007 to the AO and the University of Puerto Rico (UPR) by telecoms provider Centennial Puerto Rico. The upgrade will boost peak capacity of the current trans-Caribbean link shared between AO and UPR from 155Mbps to 1Gbps using Gigabit Ethernet, with the goal of achieving a 512Mbps e-VLBI capability at AO by year-end. Further upgrades are expected to be feasible in the Spring of 2008 using 10Gbps WDM switching technology over Centennial's new submarine fiber to the St Croix landing station.

Tests

Formatter-only tests were conducted between Mark5 recorders at JIVE and Ar on August 20th 07 and September 10 07, to explore the possibility of higher transfer rates for eVLBI using UDP, a connectionless datagram protocol, instead of TCP, a connection-oriented reliable transfer protocol used in previous runs. The tests used a new version of the StreamStor code provided with the Mark5A software distribution from MIT Haystack, together with development versions of the Mark5A program provided by JIVE. Tests were conducted from 0400 to 1130 AST with notifications to the UPR network administrators of the traffic levels to be expected on the shared 155Mbps outbound link.

Although JIVE judged the link adequate for a traffic level of up to 70 Mbps using the Iperf diagnostic with small UDP packets (losses were below .001%), sending buffer sizes needed to be carefully tuned to approximate a steady data stream before the sustained Mark5A transfer rate finally reached 64Mbps during the run on September 10.

Equipment

A Long-Haul (70km) fiber gigabit ethernet interface was acquired for the Arecibo Observatory edge router in preparation for the connectivity upgrade described above. Also under consideration is an upgrade to the AO Mark5 recorder PC to use a modern mainboard with built-in gigabit network interface.

e-VLBI - First Continuum Science Results & Current Status

As part of the continuing development of e-VLBI, a continuum science demonstration was organized on 12 March 2005 by the e-VLBI science group led by John Conway. The idea was to build on the very successful spectral line e-VLBI science demo (see EVN Newsletter No. 10). Telescopes involved included Arecibo, WSRT phased-array, Onsala, Torun, Jodrell Bank and Cambridge. The target source was SN2001em, a supernova that was recently shown to have a rising radio and x-ray luminosity (Stockdale et al., IAUC 8282), 2 years after the initial explosion. Granot & Ramirez-Ruiz, (ApJ 609, L9) have proposed a "GRB jet" explanation for the enhanced radio & X-ray emission at late times, in this scenario the emission from a relativistic but substantially off-axis jet only becomes visible as it turns sub-relativistic - a hypothesis that might be tested with high resolution radio observations of the source.

The e-VLBI observations of SN2001em were conducted at 18 cm using a sustained data rate of 64 Mbps. These data rates were achieved throughout most of the run, even via the 155 Mbps link to Arecibo. Unfortunately, due to poor weather conditions in the UK the radio telescopes at Jodrell Bank and Cambridge were "winded-off" but the remaining telescopes performed flawlessly. In the morning various technical tests were conducted before Arecibo joined the array. The tests included long scans on well known calibrators with the EVN correlator performing well. Just after lunchtime, the observations switched to the faint supernova, since this is a sub-mJy source phase-referencing was employed, involving rapid source switching and short scans. Enhancements made to the correlator control software that had worked well for long and continuous single source scans (on calibrators), were found to be less optimal for rapid source switching observations. e-VLBI fringes disappeared as soon as the SN2001em experiment began and the next hour was spent frantically trying to identify and then correct the problem. By the time a quick fix had been made the visibility of the source was becoming less than optimal but about 45 minutes of reasonable data were obtained. Although phase-referencing failed there is a tentative detection of the source with self-calibration, the presence of Arecibo in the array (and appropriate data re-weighting) playing a crucial role in this process (Garrett et al. in prep).

All-in-all, a great deal was learned from this science demo, in particular, further technical tests should include more realistic scheduling scenarios. We are confident that the lessons learned from this demo will greatly increase the efficiency rate of future observations.

A few days after the e-VLBI science demo was run, a large and ambitious e-VLBI proposal was submitted to the EC, as part of the Research Infrastructures Grid programme. The proposal coordinated by JIVE, aims to make e-VLBI a production grade astronomical instrument, transparently combining the e-EVN telescopes and e-MERLIN together into a powerful interferometer, sensitive to scales ranging from the arcsecond to milliarcsecond scale, with sub-microJy sensitivity. The proposal also includes network provision for telescopes that are not yet connected to the pan-European research network, GEANT. A significant R&D aspect is also present within the proposal, looking forward to data rates of 10-30 Gbps per telescope and the next generation correlator that will be required to process these data. An evaluation hearing takes place in May and we expect to find out if the proposal will be funded or not shortly thereafter. Fingers crossed.

Finally, Steve Parsley, head of Technical Operations and R&D at JIVE, will leave Dwingeloo in July, taking up a new position at Cardiff University as project manager of a new CMB experiment, destined for the Antarctica. We wish Steve all the best in his future position. Steve has played a major role in pushing forward e-VLBI in Europe, from an interesting concept to a practical reality. He has also been instrumental in raising the profile of e-VLBI within the wider networking community, often taking the lead in the various e-VLBI demos that have appeared at TERENA and iGRID meetings around the world. As Steve leaves, a new student is joining the e-VLBI team at JIVE, Julianne Sansa is a PhD student at the University of Groningen (Kapteyn Institute) and part of her thesis will investigate various networking aspects of e-VLBI, including the use of different transport protocols. Julianne will be co-supervised by several staff members at the Kapteyn and JIVE, including Arpad Szomoru. Until a successor to Steve Parsley is chosen, Arpad will also serve as the main point of contact for all matters concerning e-VLBI at JIVE.

5.10 Hartebeesthoek Radio Astronomy Observatory, South Africa

The 26m antenna at Hartebeesthoek participated in most of the EVN observing sessions and about 40-45% of proposals requested this long Europe – South Africa, N-S baseline. The observatory also participates in the observing programmes of the International VLBI Service, IVS, for Geodesy and Astrometry, as well as the Australia Telescope - Long Baseline Array and the Asia Pacific Telescope array. VLBI frequencies supported are 1.6 GHz, 5 GHz, 6.7 GHz, plus S- and X-bands. The Mk V disk recording system is used for all EVN observations.

6 VLBI technical activities at member institutes.

6.1 ASTRON, Westerbork Synthesis Radio Telescope, The Netherlands

Hardware

In mid-2005 the Westerbork reference time and LO distribution chain was upgraded for all the backend systems.

A new Field system PC was taken into production in Westerbork in August 2005.

Progress was made on the new fully digital tied array (TADUmax) hardware, but only after a number of significant setbacks, including delays and fabrication errors with the output boards. In May 2006 the analogue tied-array hardware was moved to make space for TADUmax, but was kept in use. Initial tests showed the need for a re-design of the TADUmax firmware, which led to further postponement of its use. Fortunately, the FPGAs in the hardware do support the new design of the firmware.

In 2006 a Mark5A-5B upgrade kit as well as a higher specification motherboard and power supply were bought for Westerbork. These will be installed to interface to the TADUmax hardware, since its output is the VSI specification that a Mark5B expects.

Software

In 2005 software development was carried out to achieve simplified and more robust operations for Single Dish VLBI at Westerbork, which was put to good use in 2006 for 5cm operations. Improved scripts were produced to check on Westerbork telescope pointing. Further scripts were also developed to verify the frequencies used in the observations; these scripts allow handling of the complicated series of mixing steps needed in the current Westerbork tied array configuration.

In 2006 software upgrades were carried out to improve the off-source and tracking reporting of the Westerbork array. There were also regular modifications in operational software for VLBI, to follow upgrades in the general TMS Westerbork array control software.

Disk packs

The total stock of disk packs purchased by ASTRON rose to 87 Tbyte at the end of 2005, and 99 Tbyte at the end of 2006, mostly in the form of 2 Tbyte packs.

6.2 Hartebeesthoek Radio Astronomy Observatory, South Africa

The 26m telescope resurfacing project was completed during 2004 and holographic measurements of the dish profile are nearing completion towards the end of 2006. Thus, the performance at the highest EVN frequency 22 GHz, is not yet known but it is anticipated that the antenna will be available fort 22 GHz measurements in the no too distant future. A room temperature 22 GHz receiver has been assembled for initial tests. Weather conditions at the site are typically humid in the southern hemisphere summer months but very dry in the winter period so observing sessions using HartRAO with the northern hemisphere observatories at 22 GHz must be carefully planned.

Observations with the Mk VA recorder have gone well and plans are well ahead to convert to the Mk VB in the near future.

An interesting new development at the Hartebeesthoek site is the start (November 2006) of the construction of a 15m prototype antenna for the South African SKA pathfinder, the Karoo Array Telescope. The reflector will be moulded out of a composite (glass fibre) material with an aluminium reflecting layer, laid down on the mould before pouring the composite.

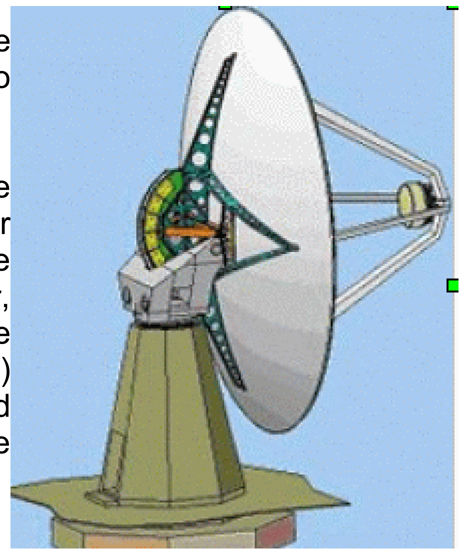


Fig. 6.1: CAD model of the South African SKA path finder prototype antenna structure design.

It is anticipated that this antenna, after assessment and testing, will be left at the observatory and may ultimately be available for VLBI and other radio astronomy measurements, on a continuous basis.

6.3 Institute of Radio Astronomy – INAF, Italy

6.3.1 Medicina Station

In the period 2005-2006 subsequent purchasing of MK5 disks carried the station capacity at 100TB. The maintenance of the VLBI system, particularly that one relative to the upgrade of the MK5 firmware and FS software is continued smoothly. This biennial report has seen VLBI in Medicina to switch to disk only recording, closing the tape recording era, and implementing the fiber optic link for participating at e-VLBI. Details about that will be given in the final part of this report. It has been completed the frequency agility at the telescope (see Fig. 6.1) so now each receivers can be online for observation within 4 minutes in the worst case.

A new receiver in the band 4.3-5.8GHz is available for VLBI and single-dish observation. It shows a high upgrade in term of polarization leakage: the D-terms

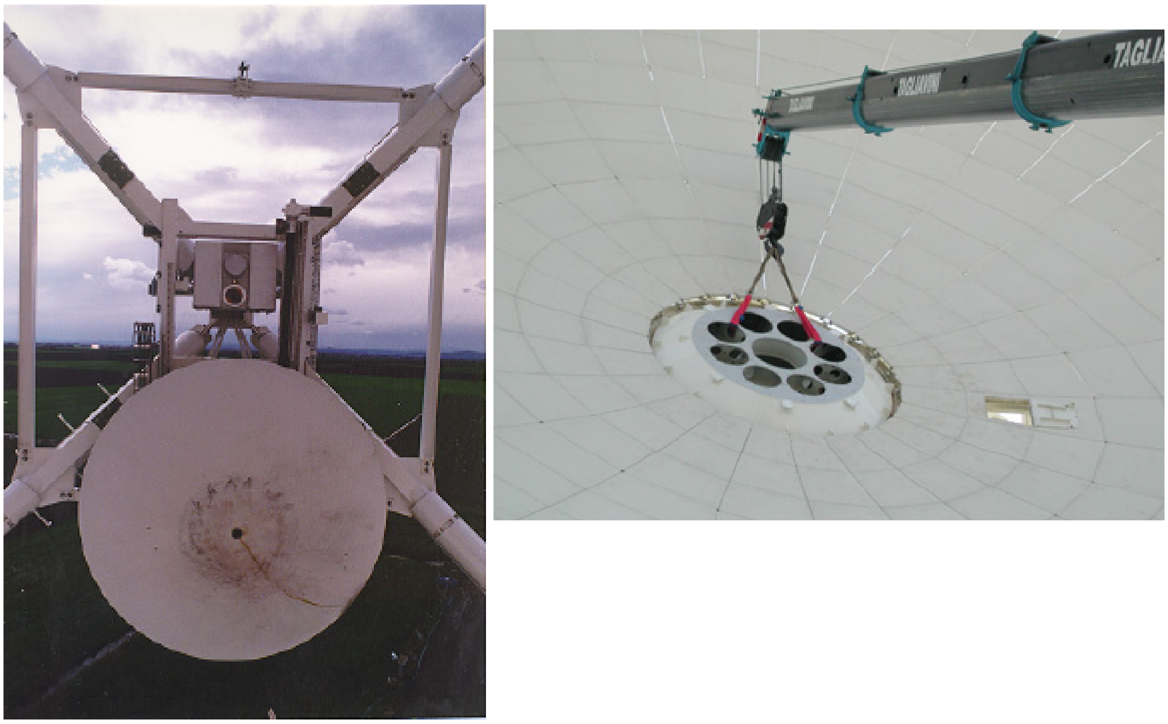


Fig. 6.2: Agility in secondary focus (left), and in primary focus up to 9 RXs can be mounted (right)

are now 1-3% when before they were 10-16%. The Tsys is almost a factor of two better with respect the old receiver.
A 7-beam multifeed system has been constructed and it is going to be mounted on the Medicina antenna for first tests. The receiver is 18-26GHz sky bandwidth issuing a total of 14 left and right circular polarization outputs 2GHz wide each one. The 18-26GHz low noise amplifiers are in InP MMIC technology (Fig.6.2).

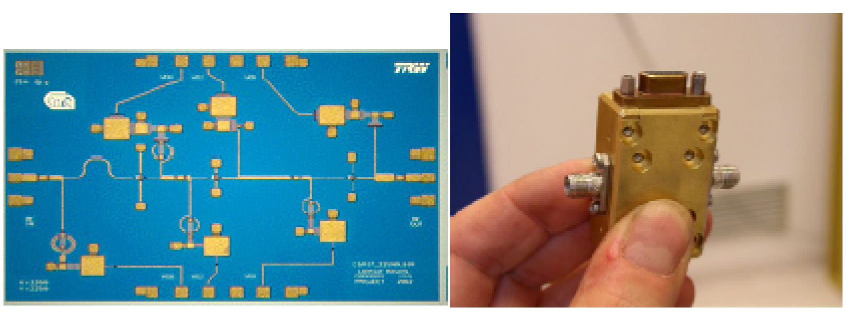


Fig. 6.3: MMIC-LNA, 3.2 x 2.25mm Packaged MMIC-LNA

The system has been provided by a mechanical derotator for maintaining fixed the field of view. The central feed will be used as an upgraded 22GHz receiver of the old one currently in use. It will then be used on Sardinia Radio Telescope.

In the same framework of this project Low Noise Amplifiers, made with the same technology, were also provided in the 4-8GHz, 8-12GHz, 26-40GHz, 33-50GHz, 70-90GHz, 90-115GHz frequency bands. The diced amplifiers have been tested, diced and delivered.
Receivers in the band 5.7-7.7GHz and a dual-frequency 305-425MHz/1.3-1.8GHz are also under design for the Sardinia Radiotelescope.
e-VLBI and EXPReS status. Starting from January 2006 the Medicina radioastronomical station is connected to Garr/Geant network via an optical link. The connection is part of "Lepida", the Emilia-Romagna Regional network for e-government. In the “Lepida” project the connection between Medicina station and the network backbone of the Garr in Bologna is a "dark fiber" on a path length of 40 Km. This project is not yet completed for a bureaucratic problem in the crossing of a railroad. Lepida provides an alternative solution with respect to the backup ring, on a path length of 120 Km, where a 1 Gbit/sec repeater is present.
The repeater is an old equipment that does not support jumbo frames (frames of 4000-9000 bits) and in the first test with Jive we got a low transmission speed in the range of 200-400 Mbit/sec. In May 2006 Medicina was able to participate to the first test at 256 Mbit/sec but only after a fine tuning of the routers of the trans-european network path.

Fig. 6.4: Laying the fiber optic cable at Medicina and Test results Medicina-JIVE link

6.3.2 Noto Station

1) Back-end
The DBBC project for the realization of a digital base band converter system was fully operative and two prototypes were produced. In a parallel project, the ``mDBBC'' were produced for the Chinese Lunar Program in a collaboration between the two stations of Noto and Shanghai. Fringes were obtained with this digital system.
A 16 channel prototype was also under construction, and made available by Summer 2005. The plan was to use it for testing the methodology and eventually to serve as a basis for mass production.

Several configurations have been developed including 0.5, 1, 2, 4 MHz bwd, to be improved, but is working; 0.25, 8, 16 MHz is near to completion; 0.125, 0.0625, 0.03125, 32 MHz is ready in simulation; tunable base band with 1 Hz resolution is ready today; tuning range in Nyquist blocks of 64 MHz is ready; tuning range in Nyquist blocks of 128 MHz is close to completion; tuning range in Nyquist blocks of 256, 512 MHz ready in simulation.
Good performance in conversion and tuning have been measured from 0 up to 2.5 GHz with selected AD converters (much more than expected). Today with an appropriate Nyquist zone pre-selection, L and S band can be directly down-converted and recorded with modified MK4 formatter (Noto and EVN spare).

A travel version of the DBBC has been realised and two experiments have been performed at the stations of Evpatoria (Ukraine) and Irbene (Latvia), which aspire to join the EVN as soon as they can, using the Metsahovi VSIB recording system. Three complete DBBC units are under construction for Wettzell, Tigo and O'Higgins. In such system tuning configurations are possible, so as multi-channel solutions as the geodetic community is oriented to use. Delivery for such units is planned between the end of 2006 and the first quarter of 2007. It also started the realization of two complete units for Noto and Medicina. Several systematic observations have been done between Noto and Medicina for the DBBC testing. The recording was realized with a EVN-PC offered by Metsahovi. Geodetic observations with DBBC-VSIB recording in parallel with the MK4-MK5 are planned almost regularly in 2007.

Finally, INAF approved the first phase of a proposal to set a spin-off company with the aim to produce the DBBC back-ends, and related technology.

2) Receivers
The digital version of the new L band Effelsberg receiver is under construction in collaboration with MPIfR. Part of the DBBC technology is adopted making use of a different firmware implementation. Data recording is realized with VSIB boards. However, to improved the data rate, a new recording board is worth to be developed in collaboration with Metsahovi.

6.4 Jodrell Bank Observatory, UK

Both the VLBA and MkIV tape recorders were decommissioned during this reporting period. The Jodrell Bank home station (Lovell, Mk2 etc.) and Cambridge are now 'Mk5-only' VLBI stations. The two Mk5 recording systems continue to operate well and have undoubtedly contributed to recent good performance figures. The Cambridge remote recording system is working highly predictably, with the occasional non-standard or broadband experiment not being observable.

Our eVLBI (internet-based VLBI data transmission and correlation) operation has been developed substantially, in conjunction with JIVE and the other EVN stations, and with our local network providers. We have tested changes to the dedicated light-path networks and are able to sustain line-rate (nominally 960 mbps) data transmission rates. VLBI real-time fringes are consistently achieved at 512 mbps with improved correlator automation. There has been substantial co-operation from local and European network organizations. Recently, we have obtained fringes at up to 900 mbps using software modifications developed for the Fabric project, using a form of data-packet dropping (as VLBI data rates would be constrained at 1024 mbps rather than 960).

RF mixers and synthesisers have now been installed to support recording of two more MERLIN stations simultaneously on one disk-pack. One unit (Cambridge and Darnhall) was tested during the February 2006 session for Target-of-Opportunity observations of the nova RS Oph. We can extend this to two-station recording on two terminals, thus supplying four antennas to the EVN.

Some investigations have been made of the Mk2 gain-curve, initially implying that the measured curve is accurate. However, we wish to compare with an independent means of measuring the gain-elevation curve, but as yet, have not secured telescope time to proceed with this. The form of the Lovell gain-curve at 6cm is also being investigated. The Cambridge calibration issue has been revisited, and we have a plan to supply simple Tsys over one 16MHz band.

6.5 Max-Planck-Institute for Radio Astronomy, Germany

Sub-reflector of the 100m-telescope

In fall 2006, the sub-reflector of the 100m telescope was replaced by a new one. The new system has a much higher surface accuracy than the old one (60 micron compared to 800 micron), resulting in a significantly higher sensitivity for observations from the secondary focus (up to more than 40%).

Additionally, the new sub-reflector is equipped with an active surface (with 96 elements) allowing compensation for small-scale deformations of the main reflector which are not corrected by homology. This leads to considerably flatter gain curves in the secondary focus.

Together with the sub-reflector the old worn focus drive was replaced by a hexapod. While the old drive permitted only movements in two linear and one rotational axes, the new hexapod system enables us to move the sub-reflector in all three linear and three rotational axes.

Finally, the new system is equipped with a mechanism allowing to switch between secondary and prime focus receivers without manual interactions. Together with the planned new receiver boxes with up to three receivers for the prime focus, this will lead to a much better frequency agility in the future.

VLBI record terminals

In December 2006 the VLBA terminal was converted from tape to Mark 5A disk recording allowing full 512Mbit/s capability.

DBBC AD board

MPIfR is a partner in the development of the EVN project to develop Digital Baseband Converters (DBBC), which is led by Tuccari of the Noto station. Wunderlich of MPIfR developed the analog to digital converter board for the DBBC project.

Technical specifications:
- Analog input: 0-2.2 GHz
- Max Sampling Clock single board: 1.5 GHz
- Max Instantaneous Bandwidth in in Real Mode: 750 MHz
- Max Instantaneous Bandwidth Complex Mode: 1.5 GHz
- Output Data: 2 x 8-bit@ 1/4 SClk DDR

Serial Links

The MK IV correlators are connected to the so-called station units with coaxial cables. Those cables are connected to the output and input boards with high-speed serial-link boards. As part of the correlator extension projects at Bonn, Haystack and Washington, Wunderlich developed new high-speed serial-links, as the chips used on the old boards were no longer available.
A second batch of the new serial-link boards was manufactured for JIVE for their Mark 5B correlator upgrade project.

IF switchbox

Graham developed and built a computer-controlled IF-switchbox to replace the manual patching of MK IV between the 2 (or 3) IF-distributors and the 14 baseband-converters. It has been in operation at Effelsberg since the middle of 2005 increasing the flexibility and reliability of the Effelsberg MK IV terminal.

High data-rate test recordings

At the end of 2006 for VLBI observations at 1 mm wavelength with a recording bitrate of 2 Gbps an upgraded Mark 5B recorder was installed at the Pico Veleta mm-telescope in Spain in collaboration with Haystack and IRAM. Previous observations were done at 512 Mbps. It is planned to record up to 4 Gbps as soon as digital Baseband Converters become available.

eVLBI

A proposal to connect the Effelsberg telescope with the institute in Bonn was successful. Up to 2 M€ were granted for building a dedicated fiber connection to the German academic research network DFN. The planning stage was completed by the end of 2006. The project should be completed in 2007. Some financial support is provided by the EU project EXPReS.

Data transfer tests between some selected VLBI stations and the correlator were performed. The aim is to provide geodetic observables like earth orientation as quickly as possible in support of e.g. the GPS satellite system. In these tests the recorded VLBI-data of those antennas is sent via Internet rather than physically on a disk-pack. Realtime and near realtime transfers were investigated with various software and ethernet protocols.

Tropospheric Corrections

System tests of the water vapour radiometer (WVR) at the 100-m-telescope in Effelsberg have been largely completed and the system has entered the production stage. The WVR data has been used to apply phase correction to mm-VLBI experiments. On many scans a substantial increase in coherence could be achieved. However, in the presence of thick clouds the corrections are unable to improve the signals. Investigations for better cloud separation algorithms have been started.

Work on GPS-based tropospheric corrections has been initiated. Tropospheric delays are collected for a number of GPS stations in the close vicinity of the telescope. Software was developed to use GPS-based delays for phase-referencing experiments. WVR- and GPS-based delays can now be publicly inspected & downloaded from http://tropo.mpifr-bonn.mpg.de/

6.6 Metsähovi Radio Observatory, Finland

VLBI Instrumentation

1.3cm K-band LCP+RCP receiver continues to be available, as does 0.7cm. 0.7cm was still in receiver laboratory pending some wiring in 2005. During the year 2006 the repair of the 43 GHz dual channel VLBI receiver was started. First the room temperature part of the system was tested. This part consists of a 40-45 GHz mixer/tripler assembly, two phase locked local oscillators and two IF-sections. The first LO(1) frequency is set to 11.62 GHz and after the tripler the Q-band LO is at 34.86 GHz. The first IF-band is amplified 46 dB and limited by a bandpass filter to 8.0-9.5 GHz. The second LO is set to 7.62 GHz to down convert the signal to the standard 0.5-1.0 GHz VLBI band. Both of these LOs are YIG-oscillators with voltage coarse tuning and the FM-coil is exploited for the phase locking. The LO(1) can be tuned via ADAM/NuDAM module network and LO(2) is set manually to the desired fixed frequency. The phase locking scheme uses 100 MHz frequency standard followed by a comb generator and the PLL IF-frequency is 20 MHz. Thus the LO frequency is N x 100 MHz + 20 MHz and the harmonic numbers are N = 116 and 76, respectively. The phase lock status can be monitored via the above mentioned module and both of the LO's are operating without failures.

The receiver was tested with a coherent signal at 43.23 GHz center frequency which can be generated by Rohde & Schwarz synthesizer multiplied by a Spacek quadrupler. These tests indicate that the room temperature part of the receiver works correctly according to the block diagram and theoretically calculated signal levels and frequencies were measured.

The new MMIC-based LNAs developed at Ylinen Electronics were installed to the cryogenic front end. The cooling capacity of the CTI model 22 refrigerator (1 W at 20 K) is quite not enough to cool the LNA's adequately. The ambient temperature reaches only down to 50 K but this is considered to be acceptable with some sacrifice to the sensitivity. However the LNA's did fail to operate probably due to an electrical static discharge. The MMIC devices are more sensitive to bias transients than the separate HEMT transistors and the operation points (voltages) are significantly lower. The LNA's were sent to DA-Design Oy (Pekka Sjöman) to be repaired and the bias circuitry and especially the grounding problems are investigated thoroughly.

13/3.6cm standard S/X (not wideband X with the third IF3) geo-RCP-only receiver is available. It is owned by Finnish Geodetic Institute (FGI) and using it for astronomy requires arrangements, thus prospective PIs need to contact Metsähovi directly. The 2/8 GHz Geo-VLBI receiver has proven to be reliable. Only some cleaning and tightening of the SMA-connectors has been done and the feed horn was protected with an extra tape to avoid moisture penetration into the feed system.

The single-headstack VLBA recorder (the upper tracks of which had been failing for years, no reason/explanation ever found for this) has been detached from the rack and put into storage, so no tape recordings can be made at Metsähovi anymore.

The Mark5A unit on loan from JIVE had to be returned in February 2005, but the Finnish Geodetic Institute (FGI) purchased a replacement unit which arrived in March 2005. It is being used in all VLBI experiments. It has developed a strange behaviour, some disk packs work only in slot B. If they are inserted in slot A some of the disks are not recognized and the Mark5 program locks so that the disk pack cannot be powered down---only a complete reboot helps. The test programs provided with the Mark5 do not help, since they lock too. The unit was finally sent to Conduant Corporation in December for warranty repairs.

All the 14 BBCs can achieve lock at their geodetic standard frequencies but BBC09--14 have all sorts of other troubles. For astronomy it is best to favor 8 BBC modes.

A repair kit has been designed for the gigabit counter in the VLBA BBC. It has not been tested yet, but it only replaces the GaAs counter with the same device in a different package.

In April 2006 Jan Wagner repaired the bank of failing BBC baseband converters by replacing dividers in the LO synthesizer. In August 2006, correlation plots from geodetic VLBI experiments revealed a filter board signal leakage problem in most of the BBCs. The filter boards were subsequently modified and fixed by Jan Wagner and Guifre Molera.

In year 2005 Metsähovi continued to develop and improve the VSI-standard data acquisition system. A considerable improvement was made when the first nForce4-based motherboards arrived in June.

The possibility to speed up the data acquisition to 4 Gbps was studied, but the project was postponed since suitable microcircuits were not yet available. We also made a brief study of the technologies used by the SETI institute in the Allen Telescope Array. This technology uses common and inexpensive components designed for cellular phone base stations and gives essentially the same (or better) functionality as the old BBCs. The geodetic ``VLBI 2010'' plan seems to be based on this technology. For details see www.seti.org and http://astron.berkeley.edu/ral/ata/memos/ .

3 and 2 mm SIS Receivers

The new mm-wave SIS receiver designed and constructed at Institute of Applied Physics (hereafter called IAP), Russian Academy of Sciences, Nizhny Novgorod, Russia was used twice for 3 mm VLBI sessions in 2005. The first session was on 11 to 18 of April and the second on 13 to 19 October. During the April session the receiver operated in a dual channel mode with high sensitivity (noise temperature about 50 K). Unfortunately during the October session the left polarization channel showed higher noise temperature and finally died completely. Also due to the mechanical stickiness of the quasioptics resulted a failure to the calibration of the receiver. The reason for the mechanical fault was found later and has been now corrected. The reason for the second mixer failure however remained unexplained.

The mm-wave SIS receiver was used twice for 3 mm VLBI observation sessions in 2006. For the April session the receiver was tuned carefully in the laboratory and it showed high sensitivity (noise temperatures ~ 80 K) for both polarization channels. However after installing the receiver up on the telescope the sensitivity was degraded to 130 K for the B-channel (LCP) and to 240 K for the A-channel (RCP), respectively. Another drawback was observed, i.e. the sensitivities were dependent of the elevation angle. This might indicate that there was some loose contact inside the dewar which cannot be anymore repaired during the session.

For the October session the IAP personnel did not succeed to restore the sensitivity of the receiver even in the laboratory. For the channel B 180 K was measured and the RCP-channel was almost dead. On the telescope again the noise temperature of the working channel increased to 300 K. With such a receiver the session could not be performed successfully.

Due to the fact that the SIS receiver is a very complex system to be used on the telescope the IAP personnel (Dr. V. Vdovin) suggested that the receiver should be upgraded. This would include new developed SIS structures, upgraded cryostat, quasioptical systems and control system. In order to realize this modernization of the whole cryoelectronic receiver complex a new contract was negotiated with IAP personnel as Supplier and Machinoimport as Seller. However the contract can be finally signed when the Intergovernmental Agreement between the Governments of the Russian Federation and the Finland Republic (as the partial compensation of the ex-USSR debt to Finland) has been signed. This finally happened in August, 2006 and Metsähovi Radio Observatory was included in the list for delivery of radioastronomic receivers from IAP with a total value of the Contract as one million US dollars. The severe problems during the October session have led the original plan to simply upgrade the old SIS receiver with new components. The InP HFET technology at 3 mm frequencies now competes with SIS mixers and the choice between these two is determined rather by other requirements than only the noise performance. The most severe drawbacks of SIS mixers are the cooling requirement to 4 K, receiver cannot be tested at all at room temperature, the observed unreliability of the system and need for expert services for the start-up, tuning and shut down. Negotiations with IAP personnel have been started with help of Pekka Sjöman (DA-Design Oy) to change the receiver structure to be based on the MMIC technology cooled to 20 K ambient temperature.
The 2 mm receiver was not tested during 2006. The plan for the future is that when the 3 mm part is changed to the new dewar, this old 4 K system is used only for 2 mm receiver.

Hydrogen Masers

The performance of both Kvarz CH1-75 H maser frequency standards (``Kvarz69'', ``Kvarz70'') continued to be very good. Their performance is monitored with the ``Clodi'' 10-channel clock difference counter and its associated Linux software. ``Clodi'' is able to measure and store the difference between one ``master'' channel (typically the station H maser 1pps) and ten other 1pps channels simultaneously and all channels for every second. Although the measurement resolution of each channel is a relatively low 10 ns, integrating the frequent measurements occurring every second delivers an accurate picture of the long-term drift trends of the associated clocks.

The automated software to extract station H maser vs HP58503A Timing GPS Receiver clock difference to model H maser long-term drift for the VLBI correlators was revamped to properly use all of ``Clodi'' data, integrate it and reformat it to the EVN GPS offset file specifications, and then automatically transfer it using FTP to the EVN shared server vlbeer.ira.inaf.it.

eVLBI

J. Ritakari programmed a realtime version of the Tsunami file transfer protocol in December 2004. In January 2005 the program was successfully tested, streaming 512 Mbit/s over Internet proved to be possible. The protocol is capable of transferring realtime data error-free between two microcomputers. An interesting detail in the new protocol was the low CPU usage, both the sending and receiving computer had enough power to make backup copies on hard disks ``on the fly''.

In March 2005 T. Lindfors programmed a VSI-standard filename parsing for the Tsunami protocol and later a version for distributed data transfer and correlation was developed.

Metsähovi has ordered a dark fiber connection to the Funet hub, bypassing the TKK network. Delivery time is approximately 2-3 months, that is, January 2006. Since the connection is dark fiber, we can install 10~Gbps Ethernet equipment that is increasingly competitive in price.

Metsähovi took part in an EU FP6 Integrated Infrastructure Initiative project proposal ``EXPReS'', ``A Production Astronomy e-VLBI Infrastructure'', coordinated by Joint Institute for VLBI in Europe (JIVE). The main participation area of Metsähovi in this proposal would be the Join Research Activity ``FABRIC'', ``Future Arrays of Broadband Radio-telescope on Internet Computing'' where Metsähovi would develop further high-speed COTS-based data acquisition technology it has pioneered since 2002.

During 2006, 10 Gbps Internet connectivity to CSC/Funet was established in Metsähovi. Metsähovi was the first radio observatory in the world to have a 10G connection. The 10G connectivity was acquired for EU EXPReS SA2, in order to create an e-VLBI test bed at Metsähovi, and a dark fiber was ordered already at the end of 2005. The required contracts were worked out by J. Ritakari and A. Mujunen.

For local networking, an Extreme Networks Summit X450 24-port switch with an optional 10 GBASE-ZR extended range (up to 80 km) fiber module was bought. The switch was configured by T. Lindfors and J. Wagner for a new e-VLBI test network on the Internet.

G. Molera and J. Wagner built several e-VLBI test bed PCs, and installed a preconfigured Metsähovi e-VLBI Debian system image created and maintained by J. Wagner. Initial 10G fiber commissioning tests resulted in overflooding the by that time bottlenecked 2.5G link capacity at CSC, as a result of which Ritakari was invited to give presentations at FUNET.

During summer 2006, in cooperation with several other European stations, real-time e-VLBI on the Metsähovi 10G fiber was tested using the further improved Tsunami protocol. Tests successfully achieved aggregate rates up to 1.5 Gbit/second. Participating stations included Jodrell Bank, Onsala, Bonn, Jive and Torun. Test accounts to the Metsähovi e-VLBI PCs were handed out to several interested people in other European and Japanese observatories.

In October 2006, a larger scale e-VLBI test and transfer demonstration was carried out for the EU EXPReS Month 7 Demo. Real-time streaming several VLBI experiments over the Internet to JIVE and Metsähovi from Jodrell Bank, Onsala and Metsähovi was a full success. Rates of 256 and 512 Mbit/second were easily maintained.

After a real-time Tsunami modification by Wagner and Ritakari, another world first was achieved in December 2006. Antenna data was streamed at real-time 896 Mbit/second over a 1G network connection bottleneck, both locally and over the Internet to Jodrell Bank. The higher rate allows 1.32 times better VLBI sensitivity.

For the EU EXPReS project and real-time e-VLBI data acquisition, Wagner carried out several software development tasks. The earlier Linux 2.4 kernel driver for the VSIB data acquisition board, programmed by Mujunen, was ported to the new Linux 2.6 kernel. Some additional small VSIB software tools, such as a real-time spectrum display, were developed. Molera carried out several long-term stress tests for the new kernel module, which at the same time tested the noise immunity of the VSI cabling in the VLBI computer rack.

The Tsunami UDP transfer protocol, modified in 2005 by Ritakari and Lindfors for real-time e-VLBI with the VSIB board, was further developed by Wagner. A new open-source project for Tsunami was opened on SourceForge by Wagner. Tsunami needed several stability improvements and a number of new features to be usable for production use in real-time e-VLBI observations. In winter 2006, Wagner developed additional FieldSystem schedule interoperability scripts for real-time Tsunami that had been desired by other European observatories.

Aspiring EVN stations in Ukraine and Latvia were equipped with the Metsähovi PCEVN system. Hardware setup was aided and initial fringe checking tests were run at the stations under consultation of Mujunen, Wagner and several other participants.

In later autumn 2006, the capabilities of the IBM Cell Broadband Engine, tentatively to be used in a Metsähovi software correlator, were researched by Jouko Ritakari and Ari Mujunen. Jan Wagner began testing and evaluating the Linux based Cell software development kit and the included Cell simulator.

6.7 National Astronomical Observatory, Spain

The construction of the new 40 meter radio telescope in Yebes is completed (see figure 6.4). The Nasmyth and other mirrors have been installed, and work on the servo system is progressing Commissioning will start with a 12 GHz receiver for holographic measurements (in primary focus) and a cryogenic Ku-band (18-26GHz) receiver, which are already operational.

The telescope was dedicated on April 26th 2005, in a celebration with Their Royal Highnesses the Prince and Princess of Asturias (see figure 6.5).

The Kvartz CH1-75 H-maser has been moved from the old 14-m building to the40-m tower, together with the GPS antenna and receiver. Also the new meteorological station has been moved, to allow the construction of a new gravimeter facility at Yebes.

More information can be found at the URL http://www.oan.es .

Figure 6.5: OAN-Yebes 40-m radio telescope.

Figure 6.6: Dedication of the OAN-Yebes 40-m radio telescope on April 26th 2005.

EXPReS project

The OAN telescopes are located in the town of Yebes, 75 km NE of Madrid (Spain). Several commercial options have been investigated for the last-mile connection to deliver the data of the new40-meter radiotelescope, under commissioning, to the GÉANT national node at RedIRIS, the GÉANT node infrastructure in the city of Alcobendas (north of Madrid and distant 94 km to Yebes via Madrid). Negotiations with RedIRIS are finished, being already possible to install the needed equipment at their premises. Colomer leads the efforts at the local and European level, being coordinator of EXPReS SA2.

Polarization VLBI with Nasmyth and E-W mount types

Dodson continues to work on the conformation of the new code developed for Nasmyth and Ewmount types, for use in polarized VLBI imaging. The main driver for the project is to enable polarization solutions for the new Yebes 40m antenna. This, to allow many simultaneous multi-band feeds, uses the Nasmyth focus. The new code to correct the feed motion of this type has been implemented, along with similar code for the E-W mount type. The E-W mount is used by the Hobart telescope in the LBA. As the Yebes antenna has not completed commissioning the Nasmyth tests have been run using the Pico Veleta antenna, as part of the GMVA. The EW-mount tests are more advanced as there is more data available. Images from the LBA have been produced, of continuum and spectral sources, and the latter will be published shortly. As part of the investigation, comparison is done of the total linear polarization as a function of velocity of the methanol maser source G339.88-1.26 from ATCA data (made available by Dr Ellingsen, Uni. Tasmania) and the LBA observations from experiment V148B (Fig. 6.6). The good agreement of these two datasets gives confidence as the work towards the final complete demonstration continues. Finally, a continuum image from the LBA is presented, which we believe is the first polarization image made with it, showing the Southern compact object J0743-67 (Fig. 6.7).

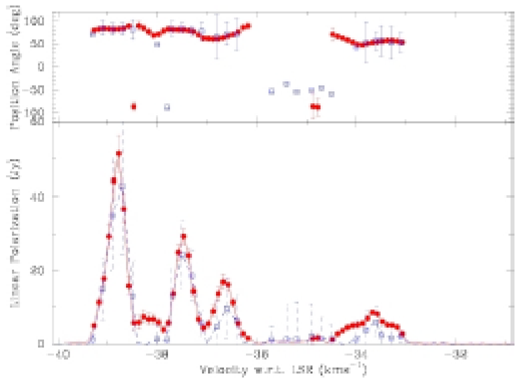


Figure 6.7: Polarization angle and fraction for G339-1.26, as observed by the LBA experiment V148B (blue open squares) and the ATCA (Ellingsen, priv. comm., red closed circles). The spectra is scalar summed across the image (Stokes I, Q and U), and shows good agreement between the VLBI and the connected array results. The errors are the absolute errors based on the confidence in the polarization calibration (2 % and 0.4 % respectively), not the relative errors. Where errors are not shown they could not be calculated.

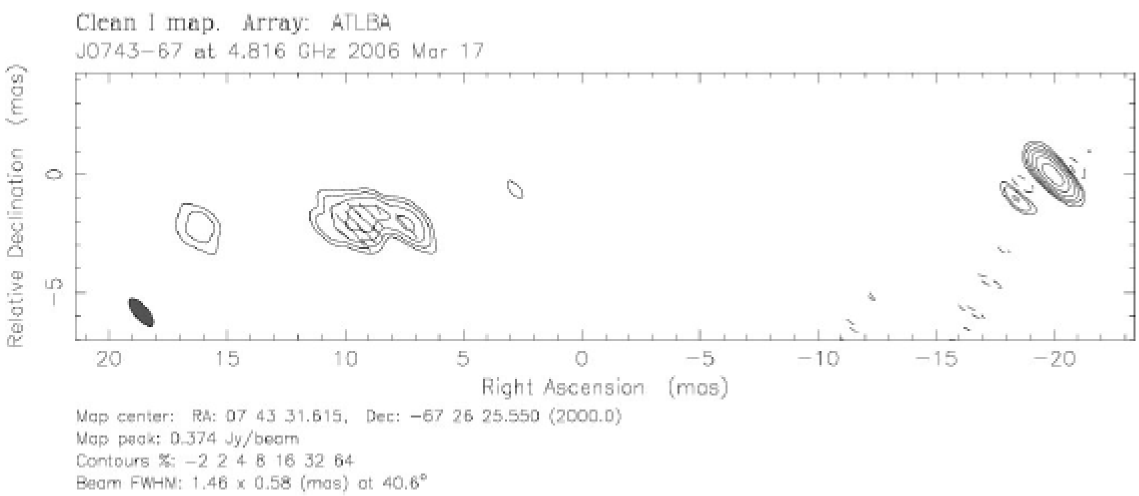


Figure 6.8: Image of J0743-67 from experiment V182A. The polarization vectors are shown overlaid. Absolute polarization angles can not be derived so the direction is arbitrary. The core (to the West) is unpolarized (< 1%) and the jet (to the East) is smoothly polarized with a polarized fraction of approximately 16%.

6.8 Onsala Space Observatory, Sweden

The installation of the new control system on the 20m telescope has been completed. This has solved the problem with occasional antenna stops during slewing.
The 22/43 GHz system on the 20m telescope has been upgraded to dual polarization.
The radome of the 20m telescope was painted during the summer of 2006.

The 25m telescope L-band SEFD performance has been improved by installing new HEMTs. Typically, the SEFD is around 320 Jy between 18 and 21 cm (both polarizations).

In September 2005 Onsala installed equipment for coarse wavelength division multiplexing (CWDM, Transmode WDM), separating the Mark5 network traffic from the rest of the observatory network traffic. This allows Onsala to use the 1 Gbps link with MTU sizes up to 4470 with the Mark5 while the observatory network uses a MTU size of 1500.
Onsala reached the EVN goal of 100 TB (105 TB) of Mark 5 disk storage by the end of 2006. A PC-EVN system has been purchased as part of the EXPReS-project.

An act on "Protection of Research Sensitive to Disturbance (SFS 2006:450)" has been passed in Sweden during 2006. It will entitle the observatory further protection against Radio Frequency Interference.

6.9 Shanghai Astronomical Observatory, P.R. China

VLBI Laboratory at SHAO

The real time hardware correlator

Figure 6.9 shows a diagram of 5 stations real time correlator for Chinese lunar project (CE-1). In this project uses 4 VLBI stations to make orbiting tracking for lunar satellite. The data rate of correlator is 16Mbps / station in real time mode, and 256Mbps / station for post processing. The wide bandwidth data will be writing to disk array and playback by correlator. The correlator used FPGA technologies for playback interface (include deformator and track recover function), FFT, MAC and the control logic. The virtex II from XILINX is power enough to acceptance the station electronics and baseline electronics. The data streams are controled by playback interface. The FFT and MAC logics of one channel of 5 stations could be configured in one FPGA chip (the OEM board of XILINX). Compare with old hardware correlator, this design could reduce many connect cables and will increase the system reliability. The models calculate and the system monitor are executed by a PC, which named CCC. The model parameter will be send to FFT chip and PBI chip via Master control board (also based on OEM board of XILINX). The fringe search and PCAL function are carried into execution with C program language in two work stations. The main specification of this correlator are:
Number of station : 5
Number of channel : 8 channel / station
Max. data rate : 256 Mbps / station
Data Input: Mk4 data stream via network or MK5 Disk array
Data Output : Disk file in self definition format (FITS format in plan)

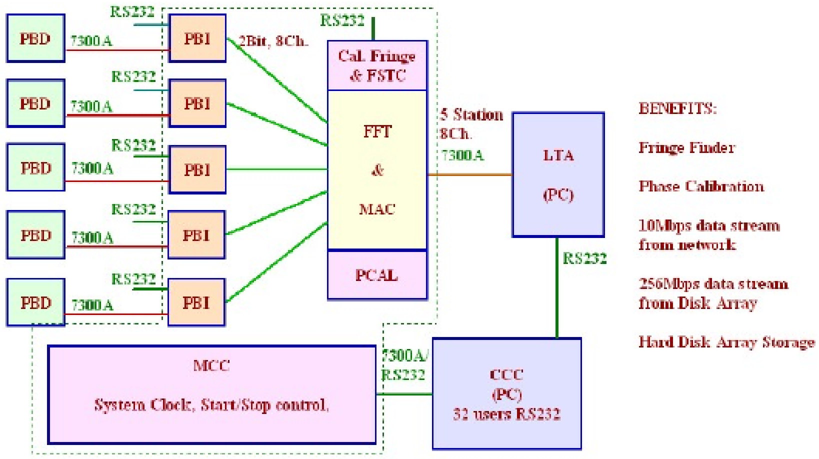
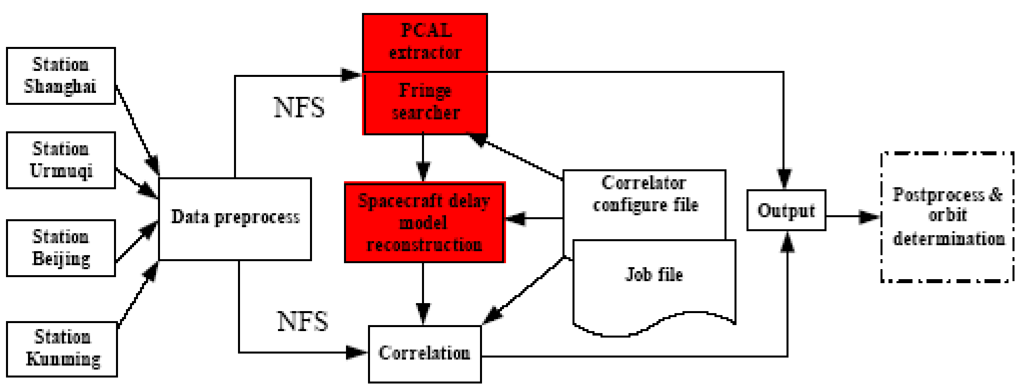


Figure 6.9: Diagram of correlator (Chines Lunar Project)

Software correlator

The 4 stations CVN software correlator was especially designed for the Chang E project with near real-time correlation, fast fringe search and PCAL detection abilities. It consists of 5 modules: preprocess correlation, correlation module fringe searcher (FS), satellite delay model reconstruction (SDMR), PCAL calibration (Fig. 6.10).



ar Project)

Figure 6.10: Block diagram of CVN software correlator

The correlation module is the kernel. It adopts the FX structure and the parallel computation algorithm to fulfill the operations of decode, ISTC (Integral Sample Time Correction), Fringe stopping, FFT, FSTC (Fractional Sample Time Correction), MAC (Multiply And Accumulate).

The platform of a correlation module is a high performance commercial SMP (Symmetric Multiple Processor) PC server with 4 dual core AMD CPUs. FS, PCAL extractor and SDMR are running on another SMP server. The Operation System (OS)is a Redhat Linux enterprise version. Pthreads technology was used to realize the parallelization computation. More SMP servers can accelerate the wide band data correlation speed.

The PCAL extractor module extracts the amplitude and phase of every PCAL signal. This correlator will join in the tracking observation of the first Chinese lunar probe CE-1 in 2007.

The DBBC

For new Chinese VLBI station we need VLBI terminal. But it is difficult to build analog BBCs. Since this year, Shanghai Astronomical Observatory has been started to develop Digital Broadband BBC to replace the current analog BBCs. This DBBC is full flexibility of channel placement as analog BBC.

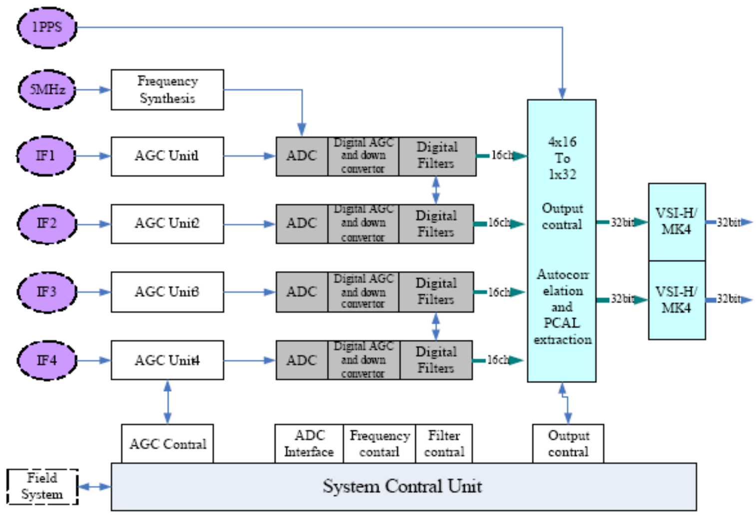


Figure 6.11: The design of DBBC

The basic component of DBBC (see Fig. 6.11) is a PCI board which is developed by SHAO. There are 1Gsps ADC and 4 FPGA chips (XC4VLX160) in this board. Four PCI boards consist of digital part of the DBBC. For compatible with analog BBC, there is a phase stable AGC part in DBBC. The dynamical range of AGC could be reached to 70 dB. The PCI board are testing in labor now. First observation test with these DBBC will be done before end this year. The main specification of this DBBC are:
Bandwidth : 4 x 512MHz
Output bandwidth : 16, 8, 4, 2, 0.5 MHz selectable
Output interface : MK4 and VSI
Full compatible with analog BBC, include FS commands
Data Analysis Functions autocorrelation PCAL extraction and graphical display

6.10 Toruń Centre for Astronomy, Poland

Two years ago we started to participate successfully in e-VLBI tests soon after we had got two 1 Gbps links to the Observatory. The spare pair of fibers was used for trans-european transfer rate tests by GEANT2 people. Toruń station has become the reliable e-EVN partner.

The Mark5A terminal has been upgraded - new mainboard was installed and 512 Mbps effective stable transfer rate was achieved in e-VLBI tests.

32 m telescope azimuthal encoder mount was rebuilt and some modifications in the antenna control system were done. As a result settling times are now several times shorter than before the change.
The work on a new telescope control system based on. Real Time Linux has continued. It might be ready for implementation by end of 2007.

Significant rearrangement and rebuilt have been made in the receivers cabin.

Participation in EVN activities especially in TOG.

Toruń has joined other observatories to help Irbene (Latvia) station to bring them into EVN.

6.11 Urumqui Astronomical Observatory, P.R. China

The antenna control system was upgraded in September 2005. The main surface of the antenna was adjusted and the precision of the surface is 0.4mm (rms). We also finished painting the whole antenna.
New S/X band receivers were installed in November 2005. A new time and frequency system was established at Nanshan station. A new Hydrogen Maser MHM2010 has been used since October 2005 and it works well. We also upgraded the GPS time receiver.

A new FS computer is in use at Nanshan and the Field System has been upgraded to version 9.9.0. The P-cal control system has been updated and the parameters of S/X band receivers are sampled from the FS terminal. A data sampling station for weather monitoring was installed in September. A K5 terminal from Japan was installed at the
station, now Mark 5, K5 and Mark II recording systems are available at Nanshan VLBI station. The antenna pointing was measured and modeled with 22 parameters in FS, and it is improved and reached 18”(rms). The station is also equipped with a new UPS and a power generator. The performance of the observing system has been improved over the last two years.

Additional 1-MHz filters for MarkIV VC were purchased in 2006. A band of 34 MHz network is available for e-vlbi. New 92 cm and 49 cm receivers on the main focus have been built in 2006. A new 1.3 cm dual polarization cryogenic receiver is under construction.

7. EVN Publications including external PIs - 2005-2006

This list includes:

- publications based on results obtained with the EVN facilities;
- VLBI publications by authors affiliated with EVN institutes;
- other publications by JIVE staff;

7.1 Refereed Journals

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