European Consortium for VLBI

and

Joint Institute for VLBI in Europe

Biennial Reports 2001-2002

Foreword by the Chairman of the Consortium

This document presents the science, technical and operational activities of the member institutes and the users of the European VLBI Network (EVN) over the period 2001 – 2002. It also includes the statutory report of the Joint Institute for VLBI in Europe (JIVE).

The EVN is a network of observatories extending well beyond Europe to include two radio telescopes as far away as China. In all, up to 16 telescopes in nine countries are operated as a VLBI array in observing sessions of three to four weeks duration, three times per year. The EVN regularly co-observes with its Associate Members at Arecibo, Puerto Rico and HartRAO in S. Africa and with the US Very Long Baseline Array (VLBA) to form a Global array. It has also operated jointly with a telescope in Space, the Japanese orbiting observatory, HALCA, the space-borne component of the VLBI Space Observatory Programme (VSOP); extending baselines to 30,000 km. NASA's Deep Space Network continues to cooperate in observing runs as an affiliate of the network.

This report is an impressive description of the science highlights produced with the EVN and by its member institutes over this two-year period. It reflects the major level of activity which VLBI generates. On the technical side I am pleased to note the significant enhancements to which the network is committed; the introduction of disk-based recording systems will, I am sure, have a highly positive effect on network efficiency and throughput. We are also seeing the first small steps towards e-VLBI following the brave, and successful, live demonstration of VLBI data transfer over the Géant network at the iGRID2002 event in Amsterdam in September 2002. Finally, it is pleasing to note the tremendous progress made at JIVE as the EVN data processor has become an operational facility.

We should also note that construction has started on two new major partner telescopes for the EVN. The first to be finished will be a new 40-m dish at the OAN in Yebes, Spain. It is hoped that first light will be achieved on the 40-m in 2004/5. The second new antenna is the 64-m Sardinia Radio Telescope to be located north of Cagliari; ground-breaking has occurred and the target date for completion is 2006. The addition of two new large dishes will provide a major leap in sensitivity for the EVN, already the most sensitive VLBI array in the world.

The EVN is the recipient of an Infrastructure Cooperation grant from the European Union's Fifth Framework Program to coordinate improving its performance and reliability through a number of technical and organizational initiatives, especially in the areas of operational reliability and flexibility and of pre- and post-correlation quality control. This RadioNET programme includes activities to foster and organise expert discussions planning the Atacama Large Millimetre Array and the Square Kilometre Array. These and VLBI are important activities towards providing excellent research tools for the community for years to come. In addition, funding was provided for a Trans-National Access programme from FP5 which supports access to the EVN by users from all over Europe. At the time of writing many of the member institutes of the EVN are participating in the generation of a major proposal to the EC's FP6 programme as we hope to build upon the success of past Framework Programmes.

We gratefully acknowledge the substantial financial support of VLBI in Europe by the member observatories and the national funding research councils and foundations.

Very Long Baseline Interferometry in Europe remains an excellent example for a longstanding successful international collaboration between scientific partners at various national observatories. To this end, it is important to note that the EVN is vitally dependent on the financial investment and innovative and skilled contributions at the individual observatories not only during the radio-astronomical observations, but also in new technical developments.

P.J.Diamond, Jodrell Bank Observatory, University of Manchester, UK
(Chairman, 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 Harteebesthoek 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).

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

Radio Astronomy

1) ASTRON (the Netherlands Foundation for Research in Astronomy), Dwingeloo, The Netherlands
2) HartRAO (Hartebeesthoek), S.Africa (Associate Member)
3) Institute of Radio Astronomy (CNR 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), Alcala de Henares, 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

Geodesy

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 research

2.1. Active Galactic Nuclei

AGN remained in the focus of VLBI studies by the EVN scientific community. This section gives a brief overview of some AGN-related studies conducted at the EVN institutes.

Young powerful extragalactic radio sources

A major subject of investigation by several groups who use the EVN is the young radio source population. Early studies have shown in the past 5 – 10 years that this population is found among the so called "CSS-GPS" radio sources (CSS: Compact, steep-spectrum sources; GPS: Giga-Hz peaked-spectrum sources). However it is now clear that "CSS-GPS" contain as well a fraction of core-jet sources, probably Doppler boosted, which need to be filtered out from the true young population. This requires extensive high resolution and multifrequency mapping. Simple theoretical models allow to link their properties to those of the large size more aged radio sources. A crucial test is the comparison of the "observed linear size distribution" with the expectation of the models.

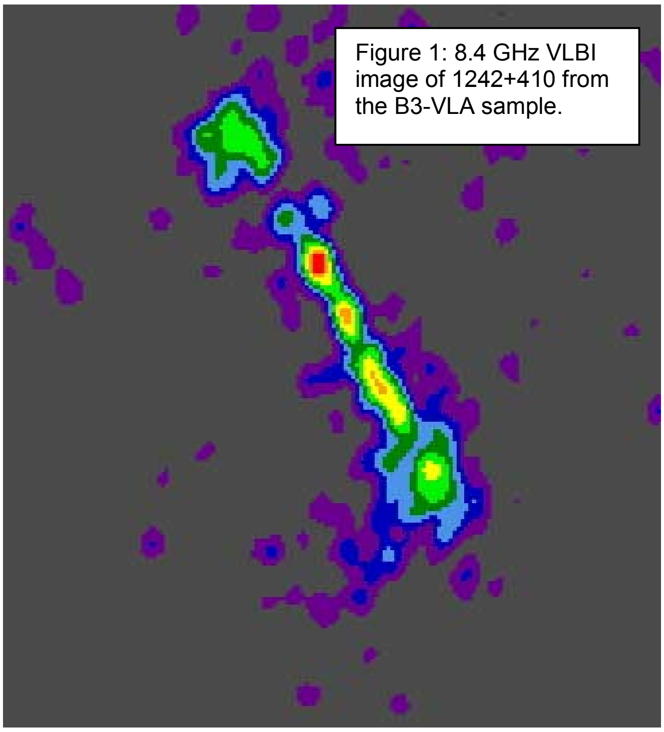


Figure 1: 8.4 GHz VLBI image of 1242+410 from the B3-VLA sample.

In 2000 a new sample of CSS (the B3-VLA sample) of about 80 objects was selected by means of multifrequency VLA observations (Fanti et al., 2001). This sample significantly increases the statistics in the range of sizes from about 0.1 to 20 Kpc. Sources smaller than about 1" have been mapped with MERLIN and EVN (Dallacasa et al. 2002b) or VLBA (Dallacasa et al., 2002a) at 1.6 GHz and later with VLBA at higher frequencies (5 and 8.4 GHz; Dallacasa et al., in preparation: Figure 1). The source structure has been investigated in great detail; in particular, a large fraction of cores was detected and also hot spots were properly mapped. With these observations it has been possible to clean from the sample the intruder core-jet sources (a rather small minority) and the sample is now expected to be composed essentially of truly young and small sources.

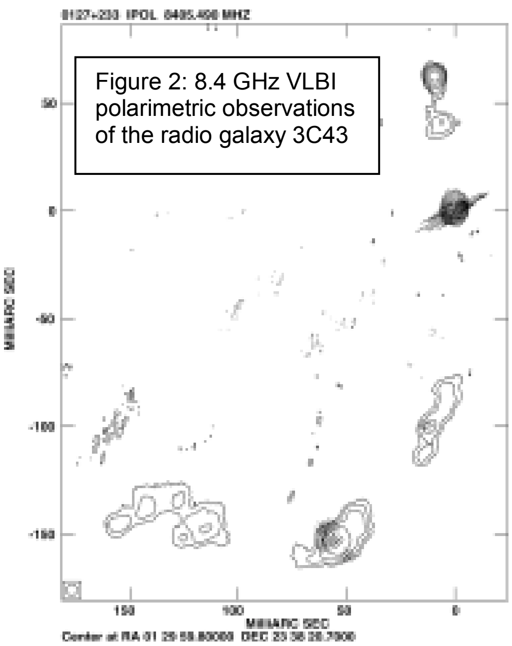


Figure 2: 8.4 GHz VLBI polarimetric observations of the radio galaxy 3C43

A sample of CSS sources, selected on the basis of previous observations of the S4 sample, were observed with the EVN plus MERLIN at 1.6 GHz, with the aim to investigate the evolution of CSSs and their consistency with the unified scheme. These observations will also be useful for identifying CSO (Compact Symmetric Objects) candidates in this sample for further investigations. New CSO cases are an important result, since not many are known (less than 30 in total). For similar reasons, VLBA observations of a sample of candidate CSS/GPS sources from the Peacock and Wall sample were completed and the data analysis is in progress.

The sources were selected among those with poor structure information on the milli-arcsecond scale and the sample consists of 8 candidates. An important by-product of this project is that these observations will complete the structural information and classification of the full Peacock and Wall catalogue of radio sources for which optical information is also complete. This result will allow the study of the statistical properties of the full sample (Mantovani et al. 2001, 2002, 2003).

Stanghellini et al. (2001) completed the mapping of a complete GPS sample using the VLBA at 15 GHz. Stanghellini (2002) has discussed the contamination of core-jet sources among GPS, which is considerably higher than in CSS.

Follow up of all these statistical studies include the combination with other earlier samples, in order (a) to study the linear size distribution and compare it with the models; and (b) to select a few suitable sources to be followed for proper motion studies.

A sample of bright CSS sources in the Southern Hemisphere has also been presented by Tzioumis et al. (2002). Particularly interesting is the case of 1934-638, a very small CSO without any apparent motion of the mini hot spots.

Finally about 10 CSO candidates have been observed with the EVN by Xiang et al. (2002), increasing the number of known sources whose radio emission comes from two nearly symmetric regions on the sub-kpc scale.

Besides the above statistical studies on complete samples, detailed studies of individual sources have also been made. Fanti et al. (2002) have performed a multi-frequency and multi-resolution study of the two classic CSS 3C43 and 3C298. For the latter they obtained, from different arguments, a consistent age of ~< 10^5 years. The interpretation of 3C43 is, instead, more complex.

Mantovani et al. (2001, 2002, and 2003) carried out polarimetric studies of other individual CSS sources, i.e. 0548+165, 1524-136, 3C43 and 3C99. For the first two sources very high rotation measures, most likely due to an external screen, were found, the quasar 3C43 shows a polarised bent jet (Fig 2), while for 3C99 a very inhomogeneous external medium was invoked to account for the large asymmetry. The observations of 1524-136 at 8.4 GHz (Fig 3) also reveal well-defined radio jets on both sides of the active nucleus. The overall radio structure appears highly distorted.

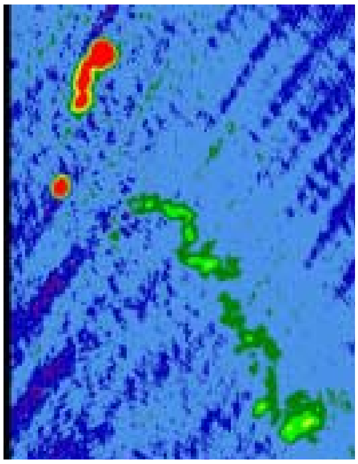


Figure 3: 8.4 GHz VLBI observations of the radio galaxy 1524-136.

Another crucial issue in the study and understanding of this class of sources is the comparison between the spectral and the kinematic ages in CSOs, since their age is perhaps the most critical parameter in understanding the nature of these intrinsically compact sources. If simple assumptions are satisfied, it is possible to relate the curvature of the synchrotron spectrum to the age of the radiating particles, a method known as ``spectral aging''. Synchrotron losses preferentially deplete high-energy electron populations, leading to a steepening in the emission spectrum beyond a time and magnetic field dependent break frequency.

Multi-frequency VLBA+Effelsberg observations allow us to study the trend of the break frequency across the micro-lobes of the CSO B1943+546 (Murgia 2003), whose case is particularly interesting since for this source a kinematic age has been derived from the proper motion of the hotspots. The estimated radiative age is in very good agreement with that derived on the basis of the lobe advance speed. The comparison of the radiative and kinematic ages in CSOs is a unique and fundamental test for the entire synchrotron aging theory.

Polatidis and Owsianik (MPIfR) together with Conway (OSO) have monitored the rates of separation between the hot spots in six Compact Symmetric Objects (CSOs) using multi-epoch VLBI observations spanning between 7 and 20 years. The expansion speeds of 1943+546 and 2352+405 have been measured to be 0.26 and 0.12 c/h respectively. Assuming that the rate of separation mirrors the expansion of the source, the "kinematic" ages are ~1300 and ~3000 years respectively. From a statistical study of results for the ten CSOs for which data exist, the average expansion velocity is ~0.2 c/h and the ages range from 10^2 to a few times 10^3 years. These ages are consistent with ages estimated by other indirect methods such as spectral ageing of the lobes and imply that CSOs are young radio sources.

AGN phenomenon on the parsec--scale

The study of the AGN phenomenon at radio wavelengths and at parsec--scale resolution is a major line of research using the EVN and other instruments. This includes many different classes of radio sources. The common lines of the various sub--topics are the understanding of the AGN phenomenon; the birth and propagation of radio jets, from the central black hole to the outer regions of the hosting galaxy; the role of the local environment and its interaction with the radio emission; the role played by orientation effects on the observed properties.

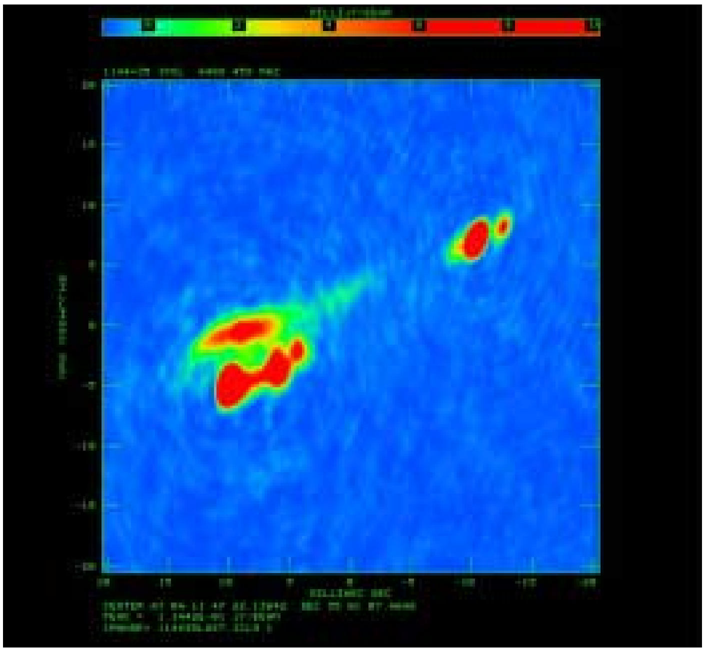


Figure 4: 8.4 GHz VLBI image of the FRII radio galaxy 1144+35.

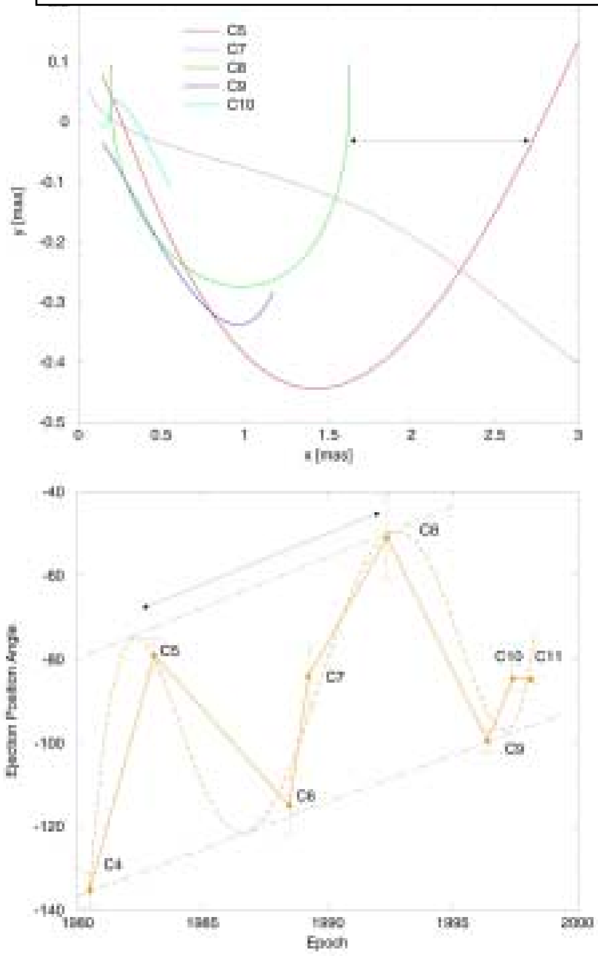
In the past couple of years the study of a complete sample of low--intermediate power radio galaxies was completed, with the achievement of relevant results. In particular, it is now established that both low power (FRI) and high power (FRII) radio galaxies are characterised by relativistic radio jets on the parsec--scale, and superluminal motion is a common feature of both classes of radio galaxies (e.g. Fig 4). For both classes of radio galaxies, the velocity of the relativistic jets and their orientation with respect to the line of sight, as derived on the basis of their observed properties, are consistent with the unification models, which propose that FRI and FRII radio galaxies are the parent population of BL--Lacs and quasars respectively. Moreover, a two-component jet was found in a few low power radio galaxies, i.e. a fast spine surrounded by lower velocity shears, as postulated in some theoretical models.

This study is now being continued on a larger sample of radio galaxies, which includes 96 objects with no selection effects on the core radio power (G. Giovannini, T. Venturi, L. Feretti, in collaboration with G. Taylor (NRAO, Socorro), W. Cotton (NRAO, Charlottesville), L. Lara (IAA, Granada)).

The nuclear regions of a small sample of FRII radio galaxies were studied, with particular attention to their polarization properties. If they are indeed the parent population of quasars, their nuclear regions are expected to be obscured by a thick torus, and this should affect the observed polarization properties and rotation measure. Multifrequency observations designed to study the rotation measure were carried out with the VLBA, and the results indeed shows that these nuclei are seen through a deeper Faraday screen, as expected by unification.

Over the last 20 years, jet components in the quasar 3C 345 have been observed to move along curved trajectories with superluminal velocities. Klare, Zensus, Lobanov, Ros, Krichbaum and Witzel (MPIfR) have obtained new images using VSOP at 5 GHz (4 epochs) and at 1.6 GHz (4 epochs), the VLBA at 43 GHz (9 epochs) and 22 GHz (7 epochs), and the CMVA at 86 GHz (4 epochs) which emphasize the

Figure 5: Trajectories and ejection angles of the mas-scale jet components in 3C345.



com t trajectories show that, while each jet feature follows a unique path, there is still a common trend shared by all of them (Fig 5). Changes of the component ejection angle indicate a periodicity of 8-10 years, implying an underlying periodic process (e.g. orbital motion and precession in a supermassive binary black hole).

Kadler, Ros, Zensus, Lobanov and Falcke (MPIfR) together with Kerp (U. Bonn), Vermeulen (ASTRON), van Langevelde (JIVE), Kellermann (NRAO) and Cohen (Caltech) have observed the double-sided parsec-scale jet in NGC 1052, using the VLBA at 5, 8.4, 22 and 43 GHz (Fig 6). These observations have revealed the presence of a dense circumnuclear absorber obscuring the central engine and covering the bases of jet and counter-jet. The most compact component of the counter-jet has a spectral index larger than 2.5, ruling out synchrotron self-absorption. Brightness temperature variations along the jet have been determined at all four frequencies, from model fitting the visibility data. They show a frequency-independent cut-off at about 3 milliarcseconds along the approaching jet, implying an absorbing column density of ionized material of ~6 times 10**22 per square cm. The observed shift of the apparent core position with frequency also confirms the strong influence of free-free absorption in conjunction with steep pressure gradients at the bases of both jets.

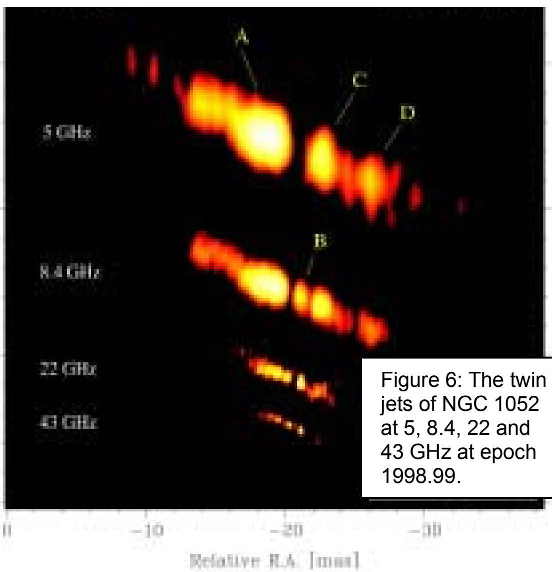


Figure 6: The twin jets of NGC 1052 at 5, 8.4, 22 and 43 GHz at epoch 1998.99.

Roy (MPIfR) Falcke and Krichbaum, together with Colbert (JHU), Mundell (Liverpool JMU), Norris (ATNF), Ulvestad and Wrobel (NRAO) and Wilson (U. Maryland & STScI) have observed a sample of eight nearby Seyfert galaxies at least one nuclear component was observed in 5 galaxies (NGC 1068, NGC 2639, NGC 5506, Mrk 231, and Mrk 348). Such absorption could in principle be caused by synchrotron self absorption, Razin-Tsytovich effect, or free-free absorption. The likelihood of synchrotron self absorption in each source depends on the brightness temperature (varying from 10^6 to 10^9 K between objects), the presence of water masers (NGC 1068, NGC 2639, and NGC 5506) which indicate an edge-on disk, the presence of large X-ray absorbing columns, and the absence of a counter-jet (Mrk 231 and Mrk 348) which is most easily accounted for by absorption in a nuclear disk.

Charlot (Bordeaux), Gabuzda (Cork), Sol (Meudon), Degrange (Palaiseau) and Piron (Montpellier) pursued their collaboration to further interpret multi-frequency VLBA polarization observations and TeV data (from the CAT ground-based

Cerenkov telescope in the French Pyrénées) that they acquired in 1998 on the gamma-ray blazar Mkn 421. Most notably, these observations revealed very obvious changes in the core region of Mkn 421 on time scales of a few weeks, at a time when it showed strong TeV activity. Additionally, it was found that the measured radio flux at 22 GHz from the VLBI core matches perfectly that predicted by high-energy synchrotron self-Compton models, which is an indication that the high-frequency VLBI core is likely to be the radio counterpart of the high-energy emitting region. In contrast, the VLBI core flux at lower radio frequencies (5, 8 and 15 GHz) was found to be larger than the pure radio counterpart of the high-energy emission, as probably caused by additional contribution from more extended radio emission. Such multi-wavelength data constrain the size of the high-energy emitting region as being smaller than the measured VLBI core size of 0.15 mas at 22 GHz (corresponding to ~0.1 pc for standard values of cosmological parameters), thus providing a direct observational evidence that the size of the high-energy emitting region is very small.

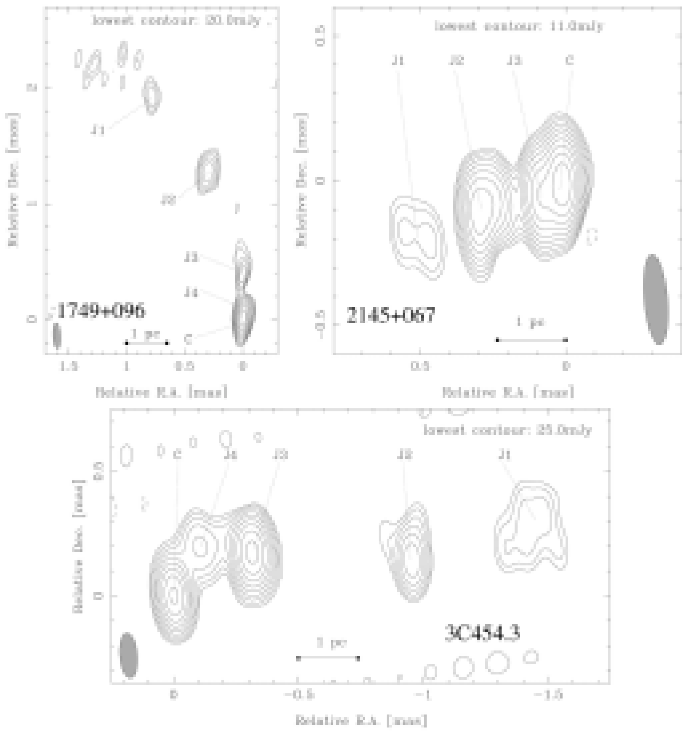


Figure 7: Morphology of the inner jets in 1749+096, 2145+067 and 3C454.3 at 86 GHz.

VLBI surveys of extragalactic radio sources

Lobanov, Krichbaum, Graham, Medici, Kraus, Witzel and Zensus (MPIfR) together with Greve and Grewing (IRAM) have started a large VLBI survey of compact radio sources at 86 GHz. The first three parts of the survey were completed during the CMVA observing sessions in October 2001, April 2002 and October 2002. Over 100 different sources have been observed so far (for several objects two observations were made), and fringes have been detected for 93 % of the observed sources. The complete survey will increase the total number of objects imaged at 86 GHz by a factor of 3-5 (with a baseline sensitivity of ~0.1 Jy and image sensitivity of better than 10 mJy/beam: Fig 7).

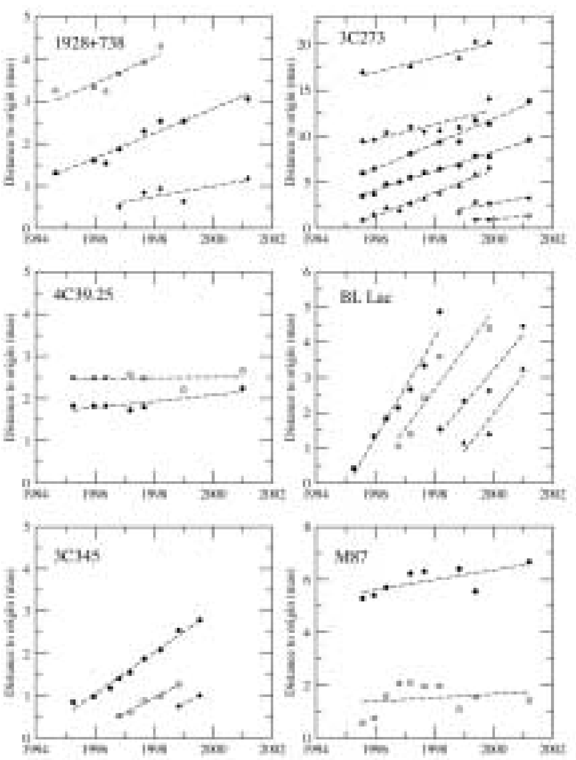


Figure 8: Angular separation r versus time for the main components of selected radio sources from the 2cm Survey. The lines show a least-squares fit to component positions. This plot shows the time sampling and the quality of the kinematical results from the survey.

Ros, Zensus and Kadler (MPIfR) together with Kellermann, Lister and Homan (NRAO), Cohen (Caltech) and Vermeulen (ASTRON) have continued work on the imaging survey at 15 GHz which has been carried out with the VLBA since 1994. The survey is aimed at understanding the nature of relativistic flow and the origin and propagation of relativistic jets (Fig 8). Of particular importance is how blazars differ from other quasars and AGN. The high resolution radio images (more than 1000 have been made so far) often show pronounced bends and twists. An overview of the images can be seen at: http://www.cv.nrao.edu/2cmsurvey

Analysis of a huge VLBA+GBT Deep, Wide-field survey began. The observations (in collaboration with Wrobel & Morganti) were centred on a portion of the NOAO-N Bootes Field. A total of 24 hours of VLBA and GBT-100m data were obtained at 256 Mbps. The data were processed at Socorro using a stripped-down version of the correlator software – this permitted extremely fine sampling to be made (0.5 second integrations and 1024 x 62.5 kHz channels). Two correlator passes were made – one centred on the "blank' target field and one centred on an "in-beam" calibrator (previously detected by Wrobel in a shallow snapshot survey of the region). Each data set was 60 Gbytes in size. Conventional phase-referencing and in-beam calibration techniques were employed on the averaged data set associated with the in-beam calibrator. The derived calibration tables were then copied to the un-averaged data sets and images made of the target field. Two sub-mJy sources were detected within the inner 3 arcmins of the GBT primary beam – the r.m.s. noise in these images (thought to be the deepest VLBI images produced to date) reached a single-figure value of 9 microJy per beam. By tapering the data, an additional 6 sources were detected across the GBT and VLBA primary beam. The results suggest that at observing frequencies between 1-5 GHz the *summed* response of compact sources in the primary beam can be used to self-calibrate any VLBI observation, no matter which region of sky the telescopes are pointing. This technique (dubbed "full-beam" calibration) and its impact on VLBI as a true survey instrument, was presented at the NtiV meeting in South Korea and the Radio Galaxy meeting in Leiden. Associated Preprints were submitted to astro-ph.

Gravitational lenses as seen with VLBI magnifiers

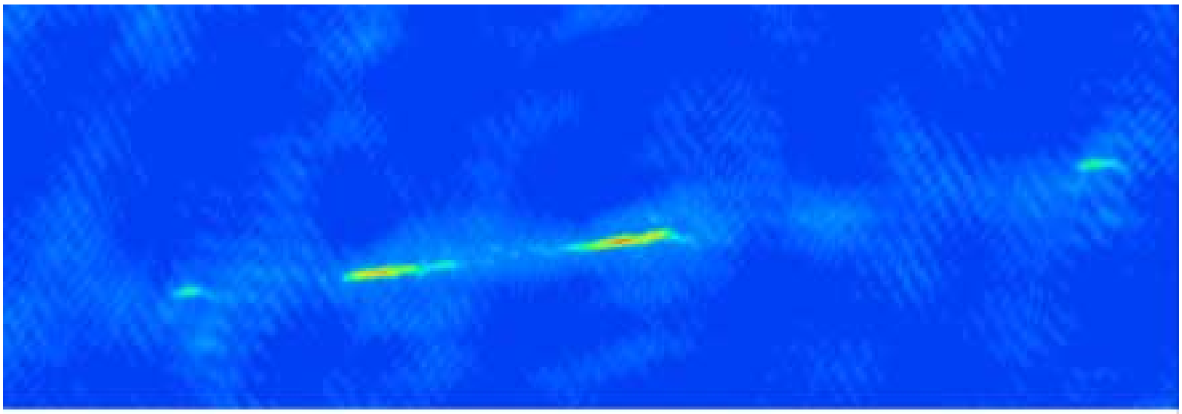


Figure 9: Global 5 GHz map of 2016+112, region C,

Porcas and Patnaik (MPIfR) together with Garrett (JIVE) and Nair (RRI, Bangalore) have studied the enigmatic gravitational lens 2016+112. The radio structure consists of 2 images of a single background radio source and an arc-shaped region ("C") which VLBI observations have shown to comprise at least 4 components. These are thought to be 2 further, or merging, images of the same background source, but the details of the relationship between them is still unclear. Further global VLBI observations at 1.6 and 5 GHz, together with MERLIN observations, have been made in order to make a detailed spectral study of region C. For both observations the Arecibo telescope was added to the array in order to enhance the detection sensitivity on the long baselines. Preliminary results from the 5 GHz observations indicate that region C is extremely thin (apparently unresolved: Fig 9) in the direction tangential to the separation from the lens. This gives some support to the suggestion that C is in a region of extremely high magnification.

2.2. Starburst and other galaxies.

During the period covered by this report we began to glimpse the possibilities presented by the combination of high-data rate recording and the large antennas of the EVN. In addition, a team led by Garrett (JIVE) made progress in understanding and overcoming the 'barrier' which had prevented users of the EVN achieving image noise levels close to the thermal limit. Thus, for the first time VLBI was able to begin to probe into the micro-Jy level and produce images which could not have been contemplated in previous years.

Deep Fields and Starbursts

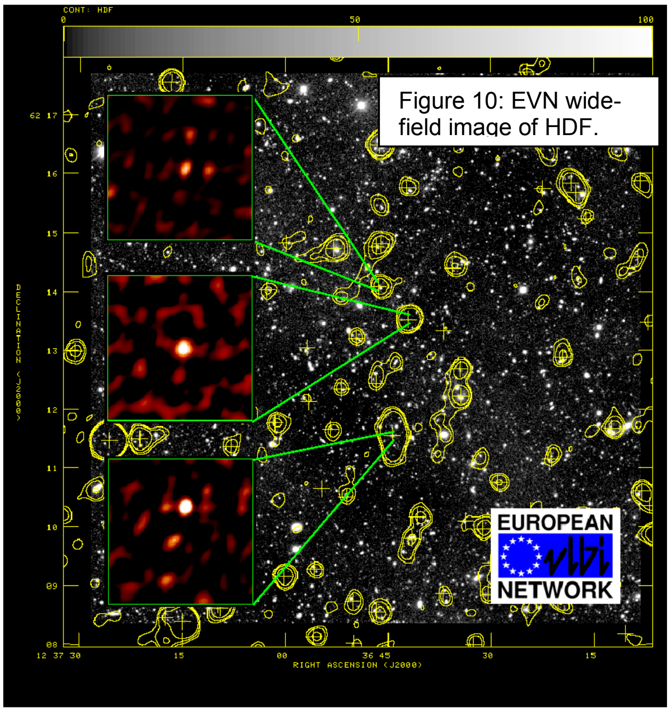


Figure 10: EVN wide-field image of HDF.

Probably the most significant observation of this period was the deep, wide-field EVN image of the Hubble Deep Field (HDF) region at 1.6 GHz. Garrett et al (A&A, 366, 5, 2001) produced an image with an rms noise of ~35 microJy/beam and clearly detected two sources in the HDF field (Fig 10). One of the sources is a low-luminosity FR-I radio galaxy, the other appears to be a dust enshrouded, optically faint, z=4.424 starburst system. The VLBI detections suggest that most of the radio emission from these sources is generated by an embedded AGN.

In related work Garrett (A&A, 384, 19, 2002) confirmed that the FIR/radio correlation continues to high redshift. In addition Garrett, Wrobel and Morganti started analysis of a huge VLBA+GBT Deep, Wide-field survey. The observations were centred on a portion of the NOAO-N Bootes Field. A total of 24 hours of VLBA and GBT-100m data were obtained at 256 Mbps. The data were processed at Socorro using a stripped-down version of the correlator software – this permitted extremely fine sampling to be made (0.5 second integrations and 1024 x 62.5 kHz channels). Two correlator passes were made – one centred on the "blank' target field and one centred on an "in-beam" calibrator (previously detected by Wrobel in a shallow snapshot survey of the region). Each data set was 60 Gbytes in size. Conventional phase-referencing and in-beam calibration techniques were employed on the averaged data set associated with the in-beam calibrator. The derived calibration tables were then copied to the un-averaged data sets and images made of the target field. Two sub-mJy sources were detected within the inner 3 arcmins of the GBT primary beam – the r.m.s. noise in these images (thought to be the deepest VLBI images produced to date) reached a single-figure value of 9 microJy per beam. By tapering the data, an additional 6 sources were detected across the GBT and VLBA primary beam. The results suggest that at observing frequencies between 1-5 GHz the *summed* response of compact sources in the primary beam can be used to self-calibrate any VLBI observation, no matter which region of sky the telescopes are pointing. This technique (dubbed "full-beam" calibration) and its impact on VLBI as a true survey instrument, was presented at the NtiV meeting in South Korea and the Radio Galaxy meeting in Leiden. Associated Preprints were submitted to astro-ph.

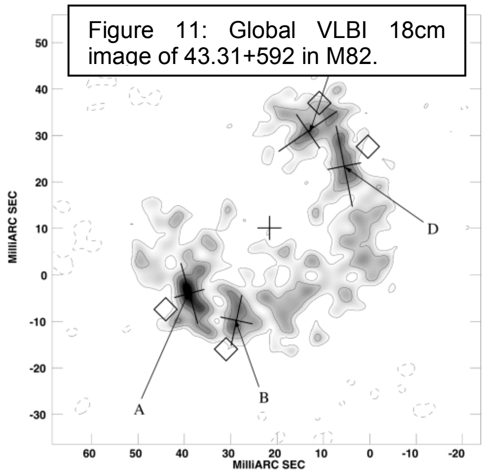


Figure 11: Global VLBI 18cm image of 43.31+592 in M82.

Other work on the nearby starburst galaxy M82 was published during the period of this report (McDonald et al, MNRAS, 322, 100, 2001). This group performed a 20-station global observation of several bright young supernova remnants in the centre of M82. Most significant were the determination of a limit on the deceleration of the youngest SNR and the placing of an upper limit of 2000 km/s on the radio expansion rate of 41.95+575, the most compact source in M82 (Fig 11).

Extragalactic Supernovae

In 1993, in the neighbouring galaxy M81, a bright supernova was spotted by an amateur Spanish astronomer. Since then a European-wide collaboration led by Marcaide of Valencia has used global VLBI to follow the evolution of the radio remnant. The shell-like radio structure has expanded in general accord with models of shock excited emission, showing almost circular symmetry for over 8 years, except for a bright feature at the south-eastern region of the shell which has been observed at every epoch. The expansion can be modelled well with a single slope but a deceleration, fit with two slopes, is better. There are also intriguing hints of structure in the expansion curve.

In follow-up work Perez-Torres, Alberdi and Marcaide (A&A, 394, 71, 2002) presented evidence of synchrotron self-absorption in the type II supernova SN1993J. This conclusion was reached based on a study of the radio light curves. It implies a large initial magnetic field, of about 30 Gauss, and the existence of an (initially) highly-relativistic population of electrons. It was also shown that at early epochs the dominant absorption mechanism is external absorption by thermal electrons, while at late epochs and long wavelengths synchrotron self-absorption dominates. Perez-Torres et al (MNRAS, 335, L23, 2002) made use of publicly available 5 GHz global VLBI archival data of SN1986J taken in February 1999. High resolution radio images were made for this supernova remnant. The images show a distorted shell of radio emission, indicative of a strong deformation of the shock front. Several bright knots delineate a shell-like structure and an absolute minimum of emission, which could be tentatively identified with the centre of the supernova explosion. If this is the case, SN1986J suffered from an asymmetric expansion. The asymmetric structure of the radio supernova is likely to be due to the collision of the ejecta with an anisotropic, clumpy (or filamentary) medium. The supernova shock is currently expanding into the circumstellar medium at the very high speed of 6,300 km/s, with no evidence of strong deceleration for the last 10 years.

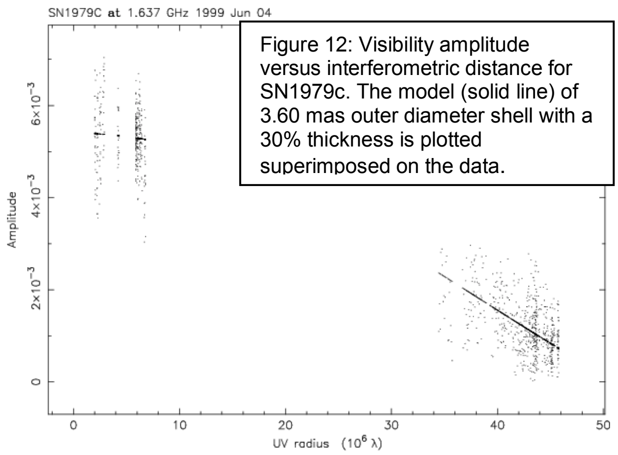


Figure 12: Visibility amplitude versus interferometric distance for SN1979c. The model (solid line) of 3.60 mas outer diameter shell with a 30% thickness is plotted superimposed on the data.

Finally, in work performed on extragalactic supernovae during this period, Marcaide et al (A&A, 384, 408, 2002) observed SN1979C in the galaxy M100 in June 1999, about twenty years after it first exploded (Fig 12). The new data suggest that the supernova shock was initially in free expansion for ~6 years and then experienced a very strong deceleration. The team estimate that about 1.6 solar masses of material have been swept up by the shock wave.

The circum-nuclear environment of galaxies - absorption

It is difficult to study gas in emission in extragalactic environments due to the surface brightness limitations imposed by the nature of VLBI: maser emission offers the only real tool for such studies. However, it is possible to observe atomic, molecular and ionised gas in absorption against compact continuum emission. Over the period covered by this report there has been an increase in the number of studies carried out due to the nature of the science that can be performed and due to the sensitivity of modern VLBI arrays. Some examples of the work performed are given below.

Vermeulen et al (A&A, 401, 113, 2003) have performed a comprehensive study of the elliptical LINER galaxy NGC1052. NGC1052 has an unusually bright (1 to 2Jy) core-dominated arcsecond-scale radio structure, and two lobes spanning only about 3kpc, typical for a CSS radio galaxy. The overall spectrum is fairly flat and has sometimes been classified as gigahertz peaked. At a distance of only 22 Mpc (cz=1474 km/s), 1 milliarcsec ~ 0.1 pc, so detailed scrutiny is possible. VLBI observations have revealed a bi-symmetric sub-parsec-scale morphology, as illustrated in the figure. This is very different from typical one-sided core-jets, and NGC 1052 has become the subject of intensive study. There are now ten observing epochs at 15 GHz; multiple sub-parsec scale features have been traced as they move outward, reasonably linearly, at typically v ~ 0.26c on both sides. Given this symmetry, the jets must be oriented near the plane of the sky. Atomic gas is seen in HI absorption. Spectral line VLBI observations required the inclusion of the most sensitive (largest collecting area) telescopes in the Global Array. Three absorption systems with different characteristics can be distinguished, distributed in front of the approaching as well as the receding jet. The sub-pc scale structure shows that at least two of the systems are situated close to the AGN rather than in the galaxy as a whole. The most prominent absorption, with a peak optical depth of 20--25 %, is at ``high velocity'', receding by 125-200 km/s with respect to the systemic velocity. Under the uncertain assumption that this atomic gas has a spin temperature T_{spin} = 100K, and uniformly fills a path-length of 0.5 pc, it has a column depth of $N_H \sim 10^{21}$ cm^{-2}, and a density of $n_H \sim 1000$ cm^{-3}. This absorber may have a continuous velocity gradient of some 10 km/s/pc across the nucleus, but while it is seen at a distance of 1-1.5 pc on both sides of the centre, there is a deficit in the innermost parsec; this ``central hole'' in atomic gas may be largely ionised.

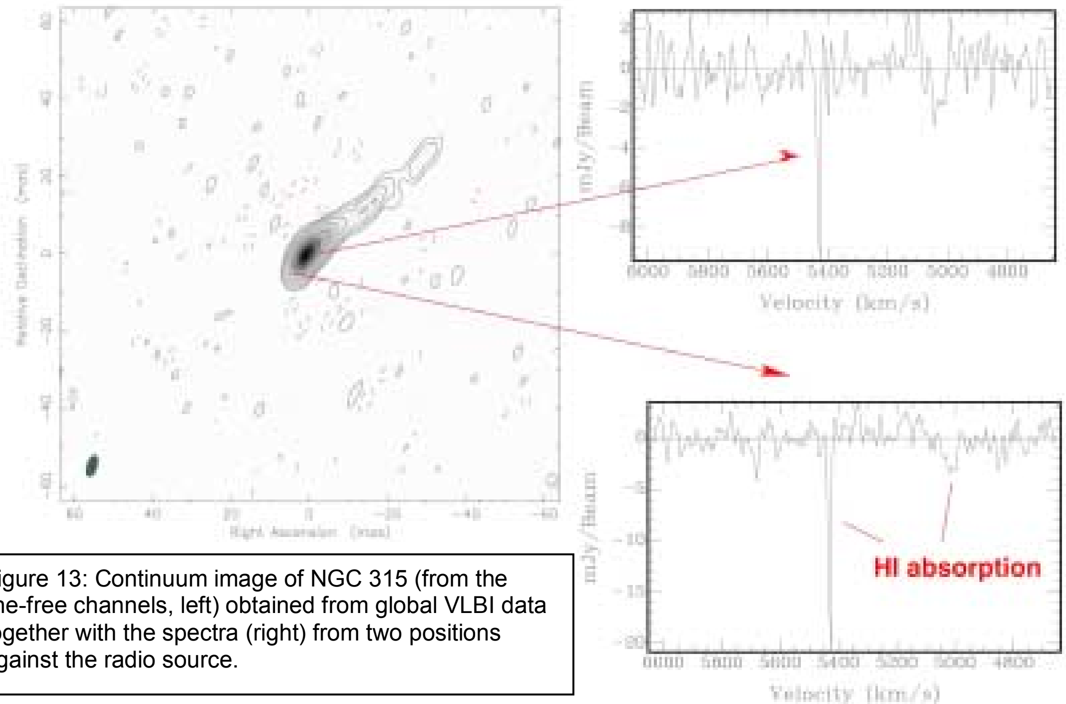
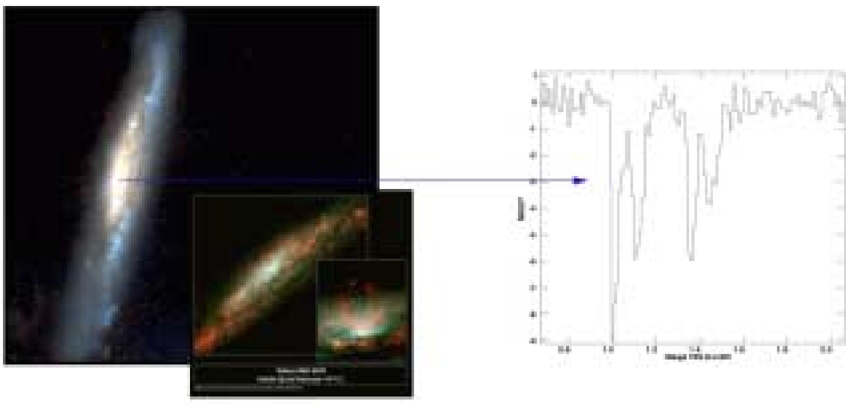


Figure 13: Continuum image of NGC 315 (from the line-free channels, left) obtained from global VLBI data together with the spectra (right) from two positions against the radio source.

Morganti et al (in preparation) have, as part of a larger project, studied the neutral hydrogen in the central regions of the radio galaxy NGC315. A global VLBI observation at 1.4 GHz showed that, even at the milliarsec resolution (pc scale at the distance of this galaxy) two HI absorption systems are detected against the nucleus of this galaxy (Fig 13). The narrow absorption -- that is 500 km/s redshifted compared to the systemic velocity -- is extended on a scale larger than 10 pc and the properties are consistent with those of a cloud at large distance from the nucleus, such as tidal debris. A broad absorption line, close to the systemic velocity, is also detected, although at a very faint level. This absorption is likely due to thin disk close to the nucleus, possibly the inner region of the large, dust disk observed by HST near the centre. This result confirms the idea that nuclei of low luminosity (i.e. Fanaroff-Riley type I galaxies) appear basically unobscured, i.e. the standard pc-scale, geometrically thick torus is not present in these objects.



(left: at the Lowell Observatory by Frei et al. 1996)

(right: HST images by Cecil et al. 2001)

Hydroxyl (OH) absorption (1667 MHz and 1665 MHz) spectrum obtained by the EVN

Figure 14: EVN spectrum of hydroxyl absorption at 1665 MHz (right) and 1667 MHz (left) viewed against the active nucleus in NGC 3079.

Hagiwara, Kloeckner & Baan used the EVN to study hydroxyl (OH) absorption features of the 1665 and 1667 MHz transitions towards the active radio nucleus of the LINER galaxy NGC 3079 (D=16 Mpc) at 30 milliarcsec resolution. The OH absorption towards the compact nuclei is confined within a 5 pc region at the nucleus (Fig 14). Both OH transitions are seen doubly peaked, which may indicate that the OH absorbing complexes with different velocities are associated with the radio core itself and a prominent jet component within the nuclear region. The OH absorbing gas is most likely associated with a dense circumnuclear torus obscuring the LINER nucleus. These results will be used to further disentangle the puzzling structure of the nucleus of NGC 3079.

Conway (IAU 205, 2001) reviewed the properties of the atomic and ionised components of the (<1kpc scale) circumnuclear gas in AGN; primarily as traced by high resolution radio observations. In both Seyferts and radio-loud objects there is evidence from HI absorption observations for disks of atomic gas. In the Seyferts the plane of the atomic gas seems to be associated with the galactic plane and the gas generally occurs at large radii (100pc -1kpc). In contrast in the radio-loud objects the atomic gas lies closer to the central engine (10pc - 100pc) and the plane of the gas may be closer to perpendicular to the radio jets. The difference in properties may be due to the presence of a hard X-ray source in the radio loud objects which heats the circumnuclear gas. This effect might also explain

the general lack of molecular masers or molecular absorption in radio loud objects. In several radio loud objects there appears to be a continuous change in properties from molecular gas at HST resolution at 1kpc to atomic gas at 10pc-100pc, to ionised gas at 1pc-10pc. The resulting extended disk may provide the fuel for the nuclear activity. In addition part of the circumnuclear disk may provide the obscuring region required by unified schemes. Finally we discuss come clear cases from VLBI HI absorption observations of jet-cloud interactions and their implications.

The circum-nuclear environment of galaxies - emission

Two major results have emerged from studies of OH megamaser emission in the period covered by the report.

Kloeckner, Baan and Garrett (Nature, 421, 821, 2003) published a detailed EVN study of the structure of the Seyfert 1 galaxy Mrk 231.Hydroxyl (OH) Megamaser galaxies are morphologically peculiar and show high molecular and dust contents within a nuclear environment that is dominated by Starburst activity and/or and Active Galactic Nucleus. So far only the most prominent Megamaser galaxies have been

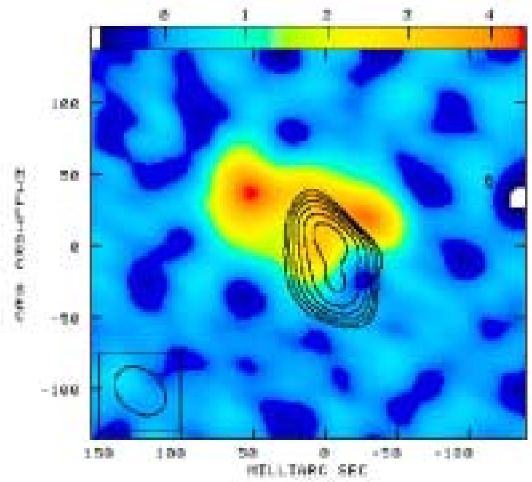


Figure 15: EVN images of the continuum and the OH line emission in Mrk 231.The integrated OH-line emission in pseudo-colour (in mJy per beam) is superimposed on the nuclear continuum emission in contours (peak 39mJy per beam). The synthesized beam is 39 mas x 28 mas, where 1 mas corresponds to a size of 0.83 pc at the distance of Mrk 231 (172 Mpc).

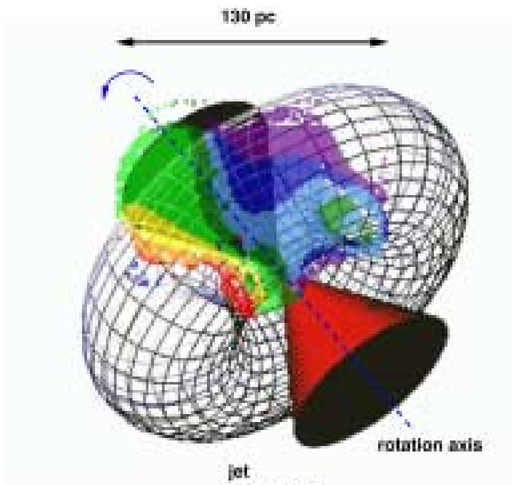
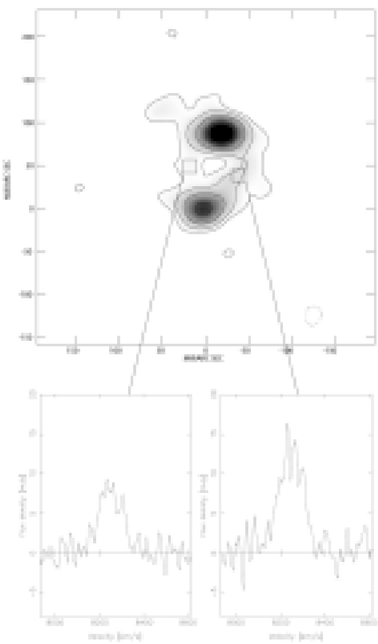


Figure 16: The velocity field of the OH 1667 MHz emission in Mrk 231 is shown in pseudo-colours together with an inferred model of the nuclear torus displayed as a wire diagram and with two symmetric ionization cones. This model takes into account all large-scale characteristics of the nuclear radio emission and the OH emission.

observed at high resolution using very-long-baseline-interferometry. Such observations provided a detailed but rather complex picture of the continuum and the molecular emission in these nuclei (Lonsdale et al. 1999, ApJ 511 178; Pihlström et al. 2001, A&A 377 413). Because at parsec scale resolutions as much as 50 percent of the OH emission has not been detected, the hydroxyl emission is likely to emerge from regions with distinctly different scale sizes. Recent studies of the maser emission of the only Seyfert 1 type nucleus Mrk 231 among the OH Megamasers confirmed such a hierarchical structure. The high brightness emission in this nucleus originates in a region with the characteristics of a rotating, dusty, molecular torus (or thick disk) located between 30 and 100 pc from the central engine. The maser emission from this distinct region shows mostly unsaturated characteristics and supports the earliest model for these maser sources based on the amplification of the radio continuum by foreground molecular gas (Baan 1985, Nature 315 26). The compact emission together with more extended emission emerging from a region surrounding the nucleus show that the OH maser emission in such galaxies uniquely traces the circum-nuclear environment in these active nuclei from tens of parsecs to kilo parsecs (Figs 15 and 16).

At Onsala Space Observatory PhD student Pihlström successfully defended her thesis during November 2001 on the subject of 'Radio Studies of Circumnuclear Gas in AGN' (Pihlström 2001). This included previously published work of EVN observations of HI absorption in NGC4261 and other sources. In addition Pihlström et al (A&A, 377, 413, 2001) published combined MERLIN plus EVN observations of the continuum and OH maser emission in the nearby starburst, Luminous Infra-Red Galaxy IIIZw35 (see Fig 17). These observations revealed a two component continuum structure, diffuse emission plus superimposed compact features. It was argued that the compact components are either individual young supernovae or clusters of supernova remnants. The number of compact sources is consistent with expectations given the star formation rate implied from IR observations (19 solar masses per year). Such a star formation rate is also sufficient to power the diffuse radio emission. The OH megamaser emission consists of two clusters of compact components plus a newly detected diffuse emission component forming a ring (see Figure 17). The maser ring has a radius of 22pc with the compact masers occurring at the tangent points of the ring. Rotation is detected across the diffuse structure and the enclosed mass within 22pc is measured to be 7 x 10^6 solar masses. The maser structure can be explained in terms of multiple cloud overlaps along the long line of sight at the ring tangent points, giving the compact maser features. Work has begun on modelling the masers in this system in more detail (Parra et al in prep 2003), to constrain the OH cloud gain, size, filling factor and physical properties.



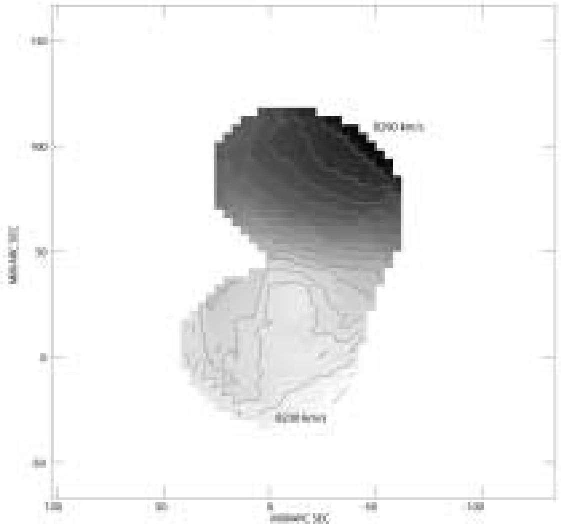


Figure 17: OH Megamaser ring in IIIZw35 (from Pihlström 2001). Left: Integrated 1667MHz maser emission from combined EVN+MERLIN observations, shown in both greyscale and contours. Note the central hole in the maser emission. Resolution is 30mas. Inserts show spectra on the two sides of the ring. Right. Velocity centroid of the OH emission, showing that the ring is rotating. The resolution is 43mas x 35mas.

Hagiwara et al (ApJ, 560, 119, 2001) presented the first results of VLBI observations of the blueshifted water maser emission from the type 2 Seyfert galaxy NGC 5793. These data were combined with new and previous VLBI observations of continuum emission at 1.7, 5.0, 8.4, 15, and 22 GHz. Maser emission had earlier been detected in single-dish observations and found to have both red- and blueshifted features relative to the systemic velocity. Hagiwara et al could image only the blueshifted emission, which is located 3.6 pc southwest of the 22 GHz continuum peak. The blueshifted emission was found to originate in two clusters that are separated by 0.7 mas (0.16 pc). No compact continuum emission was found within 3.6 pc of the maser spot. A compact continuum source showing a marginally inverted spectrum between 1.7 and 5.0 GHz was found 4.2 pc southwest of the maser position The water maser may be part of a maser disk with a binding mass ~10^7 solar masses. If so, it would be rotating in the opposite sense to the highly inclined galactic disk observed in CO emission.

Brunthaler, Falcke and Henkel (MPIfR) together with Reid and Greenhill (CfA) have started a program to measure proper motions for galaxies within the Local Group, expected to range from 20 to 100 micro-as/yr. They use VLBA phase-referencing observations of bright masers in IC10 and M33 to measure the relative position of the masers with respect to background quasars. The H2O masers in IC10 were observed three times over a period of two months to check the accuracy of the relative positions; the rms for the three observations is only 10 micro-arcsec, which is approximately the expected position error due to thermal noise. With this accuracy it is hoped to make a 2-5 sigma detection of the galaxy proper motion within one year. These observations offer the prospect of measuring the geometric distance to M33 using the relative proper motions of two H2O maser sources on opposite sides of M33, combined with other measurements of the inclination and rotation speed of the galaxy.

2.3. Galactic astronomy

In recent years, radio astronomers have made great advances in understanding the processes by which interstellar gas and dust condense to form stars. The end-points of stellar evolution, such as Asymptotic Giant Branch (AGB) stars and X-ray binaries, have also been important targets for radio observations during this reporting period. The excellent sensitivity of the EVN, coupled with its high resolution, has continued to be a significant factor in these studies. In addition, the unique ability of the EVN to observe methanol and OH emission near 5cm has been essential in uncovering some of the physics that govern these objects.

The Sun

VLBI is an under-utilized method of studying the solar corona. Radio waves from radio galaxies and quasars undergo phase and amplitude scintillations due to refractive index variations in the solar wind turbulence. Different VLBI baselines allow the determination of the phase power spectrum at different orientations with respect to the solar wind flow. These can be compared with a theoretically expected power spectrum to derive constraints on the inner and outer scale of the turbulence and on the solar wind speed. Bondi and Mantovani (IRA) in close collaboration with Spangler, Kavars and Kortenkamp (Iowa University) and Alef (MPIfR) have started a project to study the turbulence in the solar corona and in the inner region of the solar wind by means of radio propagation studies. Ad hoc observations using the antennas in Medicina, Noto, Matera and Wettzell have been carried out at 2.3, 6 and 11 cm, observing various sources with heliocentric distances in the range 15 - 70 solar radii (Spangler et al., A&A, 384, 654, 2002).

Stellar continuum emission

VLBI Observations have made significant contributions to the study of young stars and main-sequence stars during the reporting period. Smith (MPIfR), Pestalozzi and Conway (Onsala) have carried out global observations of the infrared/radio object T Tauri S, a member of the complex multiple system of pre-main-sequence solar-like stars. Analysis of the data shows that most of the radio emission is unresolved with sizes <0.4 mas, or 11 times the stellar optical radius. From infrared observations, it is now known that the T Tauri system is itself a close binary of 7AU separation. The VLBI source was found to be 33 mas from the predicted position of the T Tauri Sb star and hence is associated with this M1 class star.

Garrington and Gunn (JBO) and Van Langevelde and Campbell (JIVE) worked on a project to detect the radio star associated with ϑ^1 Orionis A, a member of the dense Trapezium Cluster of young stars. A preliminary analysis of the data from the correlator confirms the MERLIN position and indicates that the radio emission is not associated with the primary star but rather with an IR companion 220 mas north of the primary star. It also shows that the radio emission associated with this star is compact on scales of a few mas (~1AU). The implied brightness temperature is 10^8K, implying strong magnetic fields, unexpected for a pre-main sequence star of this nature. A follow-up project was initiated to measure the proper motion, parallax and orbital motion of this star and hence determine its identity (Garrington et at., EVN Symp., pg. 259, 2002)

Nearby M dwarfs are well suited for VLBI searches for planetary companions since phase-referencing observations with sensitive telescopes are able to detect radio star flux-densities of tenths of mJy as well as the position of the star on the sky with sub-milliarcsecond precision. Alef and Ros (MPIfR) together with Guirado and Marcaide (University of Valencia) and Jones and Preston (JPL) have initiated a long-term program, using Effelsberg and the Bonn MKIII and MKIV VLBI correlators in combination with NASA DSN dishes, to revisit the kinematics of nearby, single M dwarfs. The precision of the astrometry allows a search to be made for possible companions with masses down to 1 Jupiter mass. Analysis is in progress and 3 stars out of 7 have been detected so far (Guirado et al., EVN Symp., pg. 255, 2002).

X-ray binaries and micro-quasars

Of the ~250 currently known X-ray binaries, approximately 50 have detectable radio emission and a dozen or so of these have been found to have radio jets. Extreme examples of the jet sources are GRS 1915+105 and GRS J1655-40, both exhibiting apparent superluminal motion and extreme variability. However, some sources show relatively little variation, such as Cygnus X-1 and LS 5039.

Stirling, Cawthorne & Papageorgiou (University of Central Lancashire) and Spencer (JBO) have continued their study of Cygnus X-1. This source was shown to have a well-collimated outflow during the low-hard state, extending around 10 mas, by Stirling et al. (MNRAS, 327, 1273, 2001). Figure 18 compares the recent global VLBI image taken at 5GHz on 2001 May 31 with an 8GHz VLBA+VLA27 image from Stirling et al. (2001). Assuming the jet is continuous and one-sided, these observations place a lower limit on the jet velocity of >0.6c. As Cygnus X-1 is rather close (~2 kpc) the proper motion of the jet may be more than a mas per hour. In this case, the images would smear discrete ejections into a continuous looking jet (as is seen in GRS1915+105). The global VLBI images are being used to investigate if such large proper motions can be found, and if so, whether the motions are radial.

The EVN data have also been used by Stirling and co-workers to examine the non-linear structure of the jet in Cygnus X-1. At present, it is unclear whether the apparent bends are caused by precession, jitter or interactions with the ambient medium. Alternatively, a more subtle mechanism such as variations in the pitch angle of an underlying helical field may be responsible.

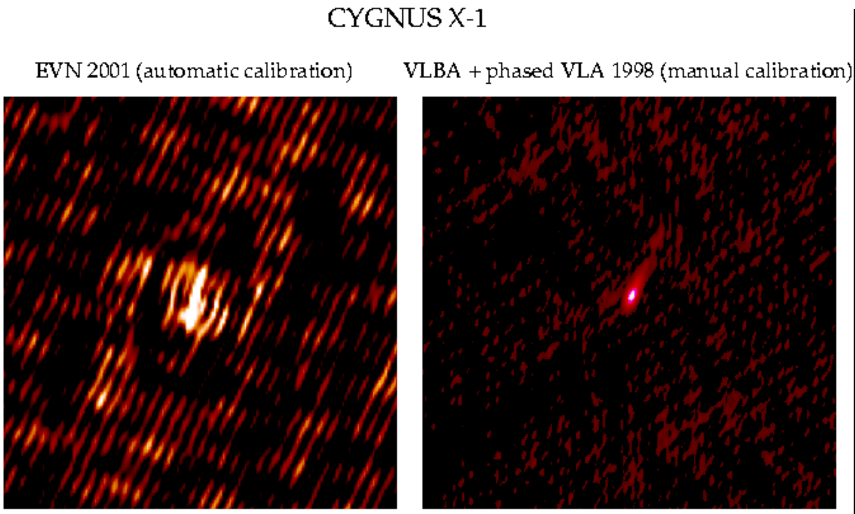


Figure 18: The EVN observed Cygnus X-1 at 5 GHz on 2001 May 31. Image shown is that from the EVN automated reduction pipeline. Compare with an 8 GHz image from VLBA+VLA27 from 1998 which was reduced manually. The automated EVN reduction gives a good detection of a 4 mJy/beam (peak) extended source and yields a structure comparable to the earlier VLBA image, although with a slight change in the jet orientation. The EVN image shows some artifacts since it is the dirty map.

Ribo and Paredes (University of Barcelona) together with Ros and Massi (MPIfR) and Marti (University of Jaen) have initiated a systematic search for new microquasars in the Galaxy. A cross-identification between X-ray and radio catalogs under very restrictive selection criteria for sources with |b|< 5 deg. has yielded a sample of 13 radio-emitting X-ray sources. Follow-up observations of 6 of these sources with the VLA have provided accurate coordinates, which were used to discover optical counterparts for all of them. These six sources have now been observed with the EVN and MERLIN at 5GHz. Five of the six objects have been detected and imaged; one has a two-sided jet, 3 have 1-sided jets, and one is compact. The 1RSX sources J001442.2+580201 (Fig 19) and J013106.4+612035 emerge as promising microquasar candidates (Ribo et al., EVN Symp., pg. 277, 2002). The persistent microquasar LS 5039 has also been studied using the EVN and MERLIN (Paredes, A&A, 393, L99, 2002). These observations confirm the presence of an asymmetric two-sided jet reaching up to ~1000 AU on the longest jet arm. The results suggest well-collimated radio jets, which bend with increasing distance from the core, and/or precession.

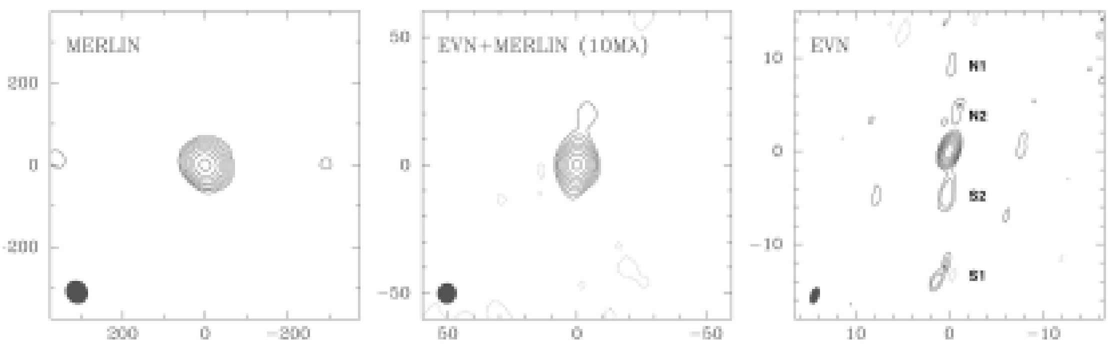


Figure19: Images of 1RXS J001442.2+580201 made using EVN and MERLIN at 18cm. Axis units are milliarcseconds.

Other X-ray binaries have also been studied with the EVN during the reporting period. These include GRS 1915+105 (Giovannini et al., ApSSS, 276, 111, 2001), SS433 (Paragi et al., ApSSS, 276, 131, 2001) and LS 1+61°303 (Massi et al., A&A, 376, 217, 2001).

Masers in star-forming regions, proto-stars and HII regions

There is increasing evidence that 6.7GHz and 12GHz methanol masers in star-formation regions are associated with the earliest stages of massive star formation - including possibly the protostellar stage when most energy is derived from gravitational collapse rather than nuclear burning. Supporting this conclusion, Minier, Conway and Booth (A&A, 2001, 369, 278) have compared methanol maser positions with other early tracers of massive star formations such as hot molecular cores, outflows and ultra-compact HII regions. Most of the sources coincided within 2000 AU with the earliest signposts of activity (hot molecular cores and outflows, see Figure 20) indicating that the methanol maser phase occurs very early on - when methanol is first evaporated from grains in the outer part of the protostellar disk. A second paper by Minier, Booth & Conway (A&A, 2002, 383, 614), describes the detailed spatial structure of the masers themselves, including the discovery of very large halos of maser emission which surround the previously detected compact masers. An interstellar scattering explanation is ruled out by comparing 6GHz EVN and 12GHz VLBA observations. Minier, Booth & Conway (2002) conclude that the observed core-halo structures could be caused by maser saturation (although other mechanisms could not be ruled out). Whatever the origin of the diffuse emission, the observations show that the methanol structures extend out to 1000AU in radius from the star/protostar - as expected in a protostellar disk model. Combined with velocity gradients previously measured in these sources the inferred central binding masses equals that expected for a massive star (5-10 solar masses).

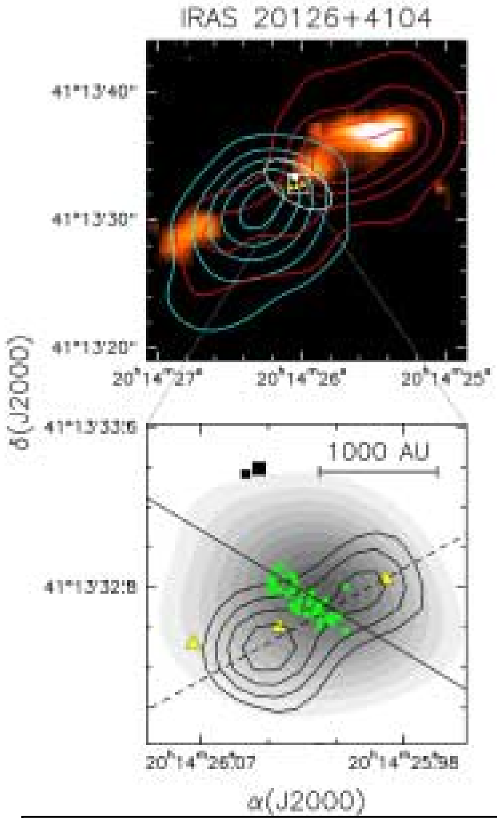


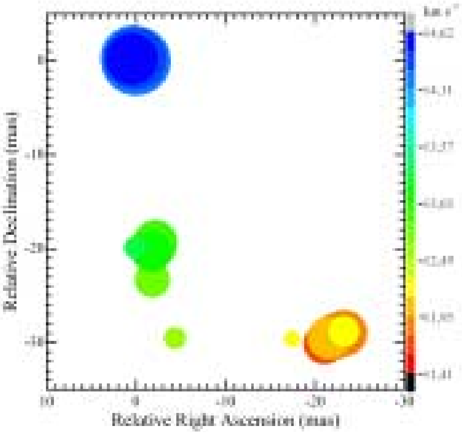
Figure 20: Different tracers of the massive protostar IRAS 20126+4104. Top: ontours represent the HCO+ outflow; greyscale represents the H_2. Bottom: hot-core region, greyscale is the 3mm continuum emission, contours show the radio continuum emission at 3.6cm The yellow triangles are H_2O masers along the jet direction. A probable disk traced by CH_3CN thermal line emission (green dots). The positions of the 6.7GHz methanol masers mapped by the EVN are shown by the black squares.

Pestalozzi (Onsala) has been using the Onsala 25m telescope to conduct a blind galactic plane survey searching for new 6.7GHz methanol masers, which are then followed up by EVN and MERLIN observations. Complementary single dish millimetre continuum and spectral line observations have also been made. In the newly detected star-forming region G41.34-0.14, observations have been made using the EVN and MERLIN arrays. The EVN observations (Pestalozzi et al., EVN Symp., pg. 209, 2002) show two compact maser spots, but the MERLIN observations reveal diffuse emission in between with intermediate velocity. A plausible model is that the high brightness compact masers occur at the tangent points of a disk where velocity coherent path lengths are long but the diffuse masers more faithfully trace the body of the circumstellar disk. Combined EVN + MERLIN observations are being conducted of a large sample of methanol sources to try to determine what in general the geometry of the diffuse emission component is.

Baudry (Bordeaux) and co-workers have been working on the physical conditions prevailing in the OH gas around compact HII regions embedding invisible massive stars. To extend the VLBI work undertaken in W3(OH) and ON1 by Diamond (JBO) and Desmurs (OAN), Baudry and Desmurs used the 6030 and 6035

MHz transitions of OH to map 3 new HII sources with 6 EVN antennas and Arecibo. Preliminary analysis of these weak sources show that Arecibo had several difficulties and the experiment should be repeated in 2003 as the Arecibo dish is indispensable in this project. During the reporting period these researchers have completed both ground- and excited-state VLBI observations of OH in ON1 which exhibits a structure somewhat similar, although less rich, to that observed in W3(OH). These data include the highly excited transition of OH at 13.4 GHz which was surveyed with Effelsberg (Desmurs et al., A&A, 394, 975, 2002) in a selected sample of compact HII regions.

Szymczak (Torun) and co-workers have continued studies of the physical properties of the environments of massive recently-formed stars using the 5cm methanol and 6cm hydroxyl lines. Following a 32m antenna survey, several interesting targets were selected for astrometric measurements with a single MERLIN baseline and some of them were proposed for EVN observations. Those experiments are aimed at determining the brightness distribution of methanol emission at high angular resolution and the kinematics of the maser regions (Szymczak et al., A&A, 392, 277, 2002).



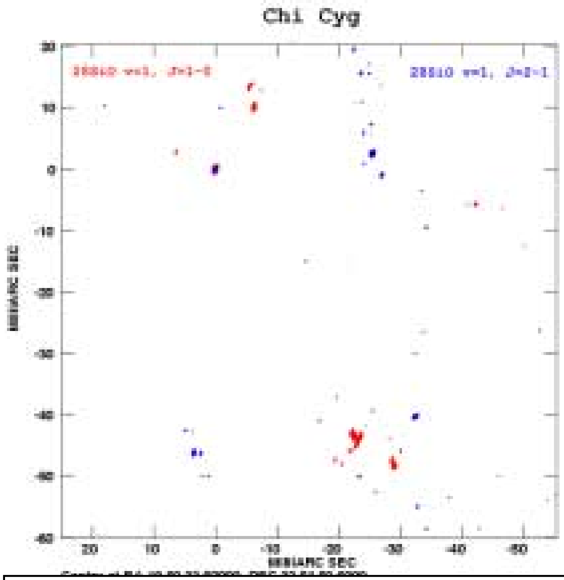
Data on excited OH masers at 4.7 GHz in the Cep A star forming region have also been processed by Szymczak and co-workers. Excited maser emission was found to emerge from three centres of activity at the edge of the HII region. There is a clear gradient in the radial velocity of the maser components with blue- and red-shifted emission in the N-E and S-W side, respectively (see Figure 21). The position angle of the elongation of the maser structure appears to be consistent with the overall continuum emission. OH ground state data taken with MERLIN shows coincidence of the 1720MHz and 4765MHz emission within about 50mas. This finding strongly constrains the current models of maser emission.

Figure 21: Distribution of the 4765MHz OH maser spots in Cep A star-forming region as observed in May 1999. The origin of map is RA(J2000) = 22:56:17.6176, Dec(J2000) = 62:01:44.567. The size of symbols is proportional to the logarithm of the brightness of components; the largest symbol corresponds to 1.55Jy/beam. The velocities were measured with regard to the local standard of rest.

Masers in main-sequence star, evolved stars and HII regions.

Vlemmings (Leiden), Diamond (JBO) and van Langevelde (JIVE) have continued to work on the circular polarization in water masers in AGB stars. The interpretation was extended to include non-LTE excitation modelling between the magnetic sub-levels. This model seems to indicate that the magnetic fields at the location of the water maser are strong, also implying that at closer distances to the star, the polarization of SiO masers should be interpreted as strong magnetic fields. These fields are strong enough to have an influence on the formation of stellar winds and the evolution of planetary nebulae (Vlemmings et al., A&A, 394, 589, 2002).

Imai (JIVE/NOAJ), Diamond (JBO), Sasao (NOAJ) and Obara and Omodaka (Kagoshima University) have been working on exploration of the evolved star, W43A, which demonstrates the ignition of a jet from a star on the asymptotic-giant-branch. Imai et al. (Nature, 417, 829, 2002) report the detection of a collimated and precessing jet of molecular gas that is traced by water-vapour maser spots. These are located approximately 500 AU from the central star. The observations suggest that the jet is formed in the immediate vicinity of the star and that elongated planetary nebulae are formed by jets during a short period (~1000 years) as the star makes its transition through the proto-planetary nebula phase. More extensive research using VLBA observations is continuing. Imai and co-workers have also presented VLBI observations of the water masers in the massive star-forming region W51A (Imai et al., PASJ, 54, 741, 2002).



Several projects to study SiO masers in the circumstellar envelopes of late-type stars are being developed by Alcolea, Bujarrabal, Colomer, Desmurs, Soria-Ruiz (OAN) and collaborators in others institutes (Marvel, AAS; Diamond, JBO; Boboltz, USNO; and Kemball, NRAO). Observations of ^{28}SiO J=1-0 and J=2-1 (around 43 and 86 GHz respectively) for v=1 and v=2, and ^{29}SiO J=1-0 for v=0 were performed for several AGB stars using the VLBA. First results for TX Cam, IRC+10011 and □ Cyg have been presented by Soria-Ruiz et al. (Proceedings of the 5th Scientific Meeting of the Spanish Astronomical Society, in press, 2002). The most surprising result is that the emission at 7mm and 3mm seems to have a very different and non coincident distribution (see Figure 22), in contrast with the predictions of the current theoretical models for these circumstellar masers.

Figure 22: Maps of the SiO J=1-0, v=1 at 43 GHz (in red) and J=2-1 v=1 (in blue) SiO lines towards Chi Cyg. They show the very different spatial distributions between these SiO transitions, in contradiction with current theoretical models.

2.4. VLBI Astrometry

Brunthaler, Falcke and Henkel (MPIfR) together with Reid and Greenhill (CfA) have started a program to measure proper motions for galaxies within the Local Group, expected to range from 20 to 100 micro-as/yr. They use VLBA phase-referencing observations of bright masers in IC10 and M33 to measure the relative position of the masers with respect to background quasars. The H2O masers in IC10 were observed three times over a period of two months to check the accuracy of the relative positions; the rms for the three observations is only 10 micro-as, which is approximately the expected position error due to thermal noise. With this accuracy it is hoped to make a 2-5 sigma detection of the galaxy proper motion within one year. These observations offer the prospect of measuring the geometric distance to M33 using the relative proper motions of two H2O maser sources on opposite sides of M33, combined with other measurements of the inclination and rotation speed of the galaxy.

Porcas (MPIfR) has investigated the use of weak sources from the NRAO-VLA NVSS survey for astrometric registration of VLBI images at different frequencies (in preparation for high-resolution, multi-frequency studies of gravitational lens systems). This involved selection of suitably compact sources stronger than 15 mJy, a spectral "filter" by comparison with the WENNS survey, a MERLIN filter observation at 5 GHz and EVN 5 GHz observations of 8 suitable candidates. All showed very compact structures on the longest baselines from Effelsberg to Shanghai. Three were selected for use in subsequent phase-reference VLBI observations of the gravitational lens system B0218+357, made in 2002.

Charlot and Baudry together with colleagues at NASA/GSFC, USNO and JPL have initiated an EVN observing program to densify the International Celestial Reference Frame (ICRF), the newly-adopted celestial reference frame of the IAU. The ICRF, which is the most accurate VLBI celestial frame available to date, includes a total of 667 extragalactic sources distributed over the entire sky. The goal of this project is to add 150 new sources at specific sky locations to fill currently "empty" regions in the northern sky and improve the overall source distribution (Figure 23). For this project, several external telescopes, among which Algonquin Park (Canada), Goldstone/DSS13 (California) and Ny-Alesund (Spitsbergen) have joined the EVN, as to build a geometrically-strong and sensitive network of 10-12 telescopes observing at S/X band. The first two experiments, each of which observing 50 new sources along with 10 ICRF sources with highly-accurate coordinates, have been carried out in May 2000 and June 2002. Initial analysis of these data indicates that milliarcsecond-accurate coordinates should be obtained for most of the newly observed sources. The third experiment, dedicated to observing the last 50 selected new sources, is scheduled for 2003.

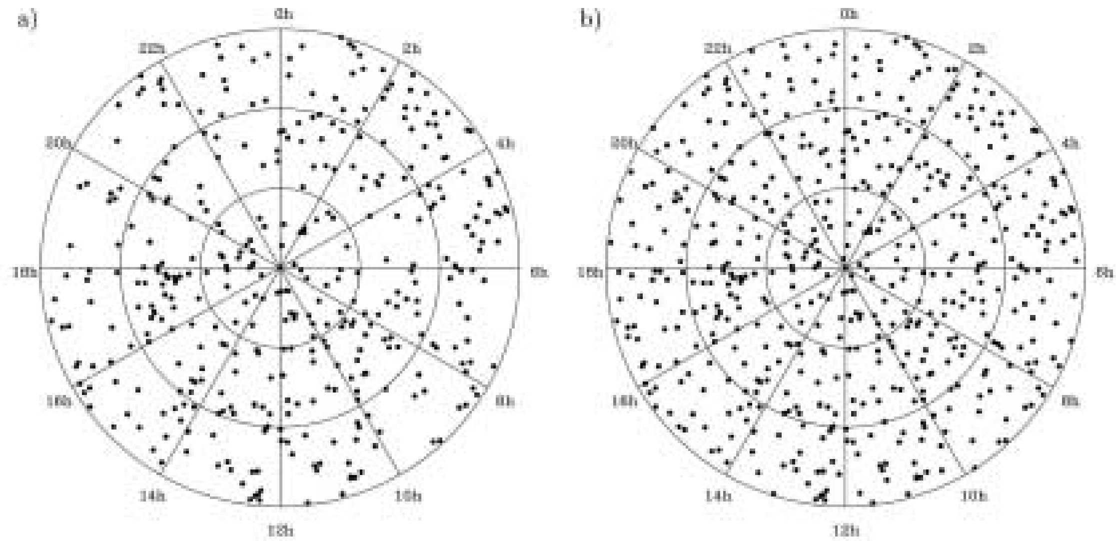


Figure 23: a) current and b) projected distribution of ICRF sources in the northern sky.

Charlot is also collaborating with colleagues at JPL, NASA/GSFC, USNO and NRAO to extend the ICRF at higher radio frequencies (24 and 43 GHz). The major motivations for initiating this large effort include: improving state-of-the-art astrometry, extending the list of calibrators at 24 and 43 GHz to enhance VLBI phase-referencing at high frequencies, studying source structures and their variations with respect to frequency and time, and preparing for deep space navigation at higher frequencies (Jacobs et al. 2002). Three initial experiments, each 24 hours long, have been carried out in May, August and December 2002 using the VLBA at 24 and 43 GHz. A specific contribution to this project has been concerned with the evaluation of the astrometric impact of source structure at these higher frequencies. Initial results indicate that on average the emission structures at 24 and 43 GHz are more compact than their 8 GHz counterparts, hence providing better fiducial points to build highly-accurate reference frames. However, these data also show that the observed structures might be more extended at 43 GHz than at 24 GHz, as would be the case if the 43 GHz observations start to resolve the core of the sources. Additional experiments to come should confirm these findings.

Charlot (Bordeaux) together with Sovers (JPL) and Fey (USNO) also works towards applying source structure modelling in astrometric data analysis. A milestone was reached at the end of 2001 when the first-ever VLBI data analysis with massive source structure modelling was carried out (Sovers et al. 2002). This analysis involved a total of 800 maps (as available from the USNO data base), which were used to derive structure corrections for 207000 delay and delay rate pairs for 155 sources observed during 10 experiments conducted between January 1997 to August 1998 with the VLBA plus other VLBI stations in North America, Europe, Asia and the Pacific. Overall, the 30-ps weighted rms delay residuals were found to decrease by 8 ps in quadrature upon introducing source maps to model the structural delays, with improvements as large as 40 ps for some sources with extended or rapidly varying structures. The temporal stability of the source coordinates was also improved substantially for such extended sources (Figure 24). This work further demonstrated that identification of a true fiducial feature within each extended source is crucial to properly and accurately model structural delays, as otherwise the results may be worse than with no structure corrections. Such statement was illustrated by a specific study on the source 2200+420 (Charlot 2002).

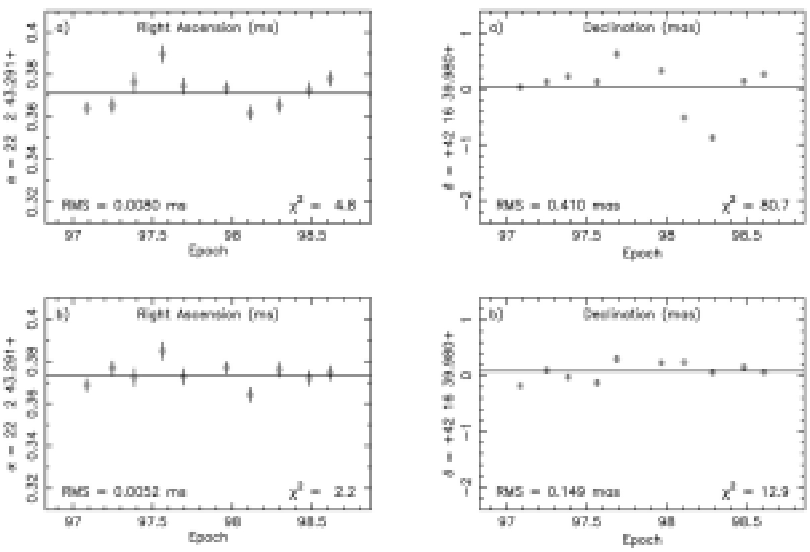


Figure 24: Plots showing the temporal stability of source coordinates for 2200+420. The top plots show the stability achieved without correction for source structure. The bottom plots show the same data but corrected for the effects of the structure.

Results were obtained on a project to measure the proper motion and parallax for Mira variables by astrometry of their circumstellar OH masers. It was found that useful measurements of parallax and proper motion could be obtained for all 4 target stars (e.g. Fig 25). This work was part of the thesis of Wouter Vlemmings in Leiden, supervised by van Langevelde (JIVE), Habing (Leiden), Diamond (JBO), Schilizzi (JIVE/Leiden). Two of the stars have masers with bright blue-shifted components and in these cases it could be shown through comparison with optical astrometry, that these are very likely amplified stellar images. Two other stars have bright red-shifted emission, which was also shown to be persistent enough to yield significant results. The measurements line up quite well with the established Period-Luminosity relation for Mira variables.

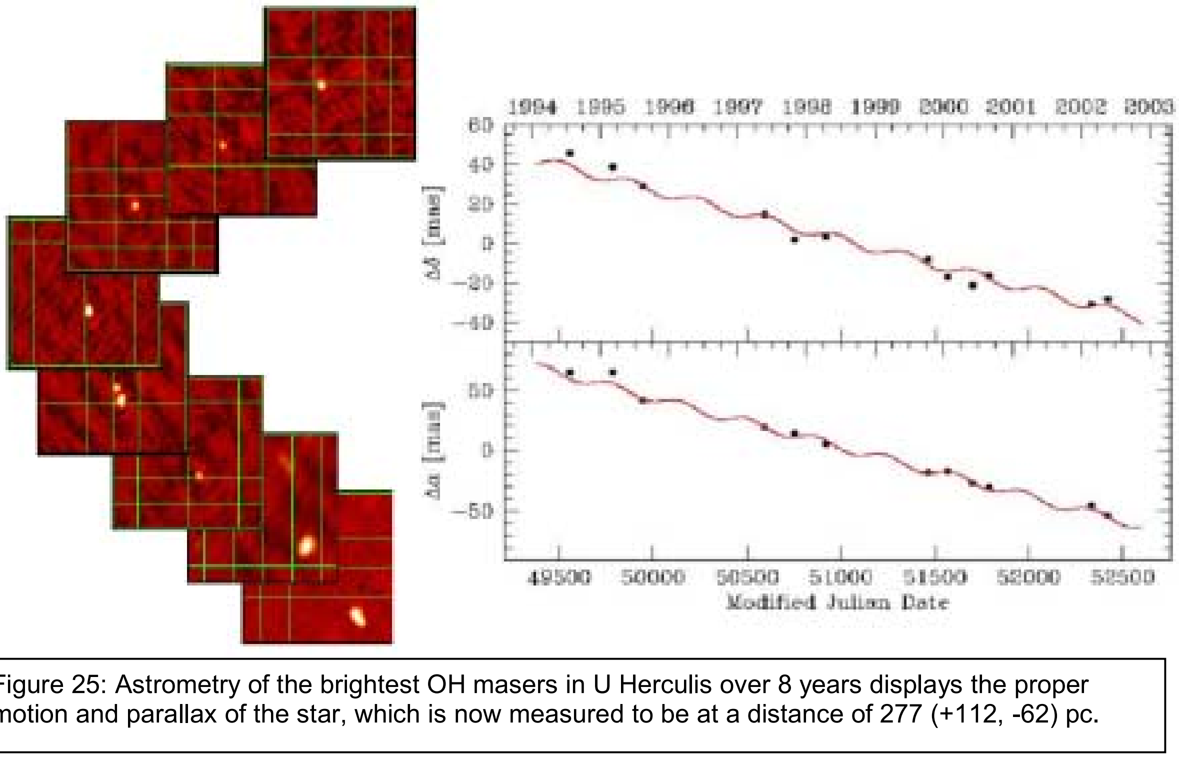


Figure 25: Astrometry of the brightest OH masers in U Herculis over 8 years displays the proper motion and parallax of the star, which is now measured to be at a distance of 277 (+112, -62) pc.

Another interesting project by Vlemmings, Diamond and van Langevelde was the astrometry of the water maser in U Her with MERLIN. The prevailing theories indicated that these masers should show a ring around the position of the star. This was tested for the first time, and instead the brightest maser spot lined up accurately with the optical star. This seems to indicate that the radio continuum can also be amplified by the H_2O maser, as was found for OH masers before.

Van Langevelde & Campbell worked on a project with Garrington to detect the radio star associated with ϑ^1 Orionis A. A quick analysis of the data from the correlator confirms the MERLIN position, which indicated that the radio emission is not associated with the primary star but rather with an IR companion 220 mas north of the primary star. It also shows that the radio emission associated with this star is compact on scales of a few mas (~1AU). The implied brightness temperature is 100 MK, implying strong magnetic fields, unexpected for a pre-main sequence star of this nature. A project was initiated to measure the proper motion, parallax and orbital motion of this star.

2.5. VLBI Geodesy

General remarks and the key role of geodetic VLBI

The Very Long Baseline Interferometry (VLBI) technique has been employed in geodesy for nearly 40 years. Covering intercontinental baselines with highest accuracy, monitoring Earth rotation at the state of the art and providing the quasar positions as the best approach to an inertial reference frame, VLBI significantly contributed to the tremendous progress made in geodesy over the last decades. VLBI was a primary tool for understanding the global phenomena changing the “Solid Earth”. Today VLBI continuously monitors Earth rotation and its variations and also crustal movements in order to maintain global reference frames, coordinated within the International VLBI Service for Geodesy and Astrometry (IVS) – a Service of the IAG and IAU. Science and applications set the requirements for the realization and maintenance of global reference frames at VLBI’s technical limitations. VLBI, as the unique technique for providing a celestial reference frame and for deriving the full set of Earth rotation parameters, plays the fundamental role of generating the basis for many applications and research in the geosciences.

VLBI today is the key technique for monitoring and realizing global reference frames. The importance of global reference frames has increased as space and satellite technologies, e.g. satellite navigations systems, are employed for many applications in research in particular in geosciences and in all kinds of surveying and navigation. For the description of satellite orbits a “quasi” inertial system is required, which does not rotate with the Earth – a celestial reference frame (CRF). Such a system is realized by positions of radio sources and is internationally available as the International Celestial Reference Frame (ICRF). Point positioning on the surface of the earth needs an Earth fixed system – a terrestrial system (TRF). The terrestrial reference frame is realized through stations for which the positions and velocities are determined and known. The most recent realization (the adopted international realization) is the ITRF2000. Both TRF and CRF systems are needed and the relation between both must be known to an accuracy as best we can, in order to meet the broad spectrum of applications. The relation between the CRF and TRF is described by the Earth Orientation Parameters, which fix the Earth rotation axis with respect to the CRF (d□, d□ and by the polar motion parameters x_p and y_p which fix the Earth’s crust. The rotation is described by the parameter DUT1 as the difference between the time scale provided by the Earth rotation itself (Universal Time UT1) and the time scale generated by atomic clocks (Universal Time Coordinated UTC).

As all the parameters are changing with time and no model is precise enough for prediction, the parameters have to be derived continuously from observations. Among the geodetic space techniques (Satellite/Lunar Laser Ranging and GPS etc.), VLBI plays a unique role, as it is the only technique which is capable of realizing and maintaining the CRF, of providing the complete set of Earth orientation parameters and in particular of observing DUT1. Due to superior accuracy in the determination of long baselines VLBI dominates in the determination of the ITRF scale. Because subdaily variations in Earth rotation occur, it is important to observe regularly with adequate resolution in time and accuracy. Regular and more dense observations will become a demand with the request for mm-precise reference frames, consistent for decades, that will be set by the IAG within its upcoming project International Global Geodetic Observing System (IGGOS).

International VLBI Service for Geodesy and Astrometry

The International VLBI Service for Geodesy and Astrometry (IVS) is a Service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU) and a member of the

Federation of Astronomical and Geophysical Data Analysis Services (FAGS). The charter and the basis for international collaboration is given by the Terms of Reference (ToR) accepted by IAG and IAU and by the proposals provided by individual agencies in response to the call for participation.

IVS is an international collaboration of organizations that operate or support Very Long Baseline Interferometry (VLBI) components. The goals are

- to provide a service to support geodetic, geophysical and astrometric research and operational activities,
- to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique,
- to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

Six IVS Analysis Centres provide a timely, reliable, continuous solution for the entire set of five Earth Orientation Parameters (EOPs) - two polar motion coordinates, Universal Time 1 determined by the rotation of the Earth minus Coordinated Universal Time (UT1-UTC), two celestial pole coordinates. The IVS Analysis Coordinator makes a combined solution – the official IVS product – as timely input for the IERS and its combination with the GPS, SLR/LLR and DORIS solutions. It turns out that the IVS combined solution gains 20% in accuracy over the single VLBI solutions.

Evolving observing programs

To meet its product goals, beginning with the 2002 observing year IVS designed an observing program coordinated with the international community. The 2002 observing program included the following sessions:

- EOP: Two rapid turnaround sessions each week, initially with 6 stations, increasing to 8 as soon as station and recording media resources are available. These networks were designed with the goal of having comparable x_p and y_p results. One-baseline 1-hr INTENSIVE sessions four times per week, with at least one parallel session.
- TRF: Monthly TRF sessions with 8 stations including a core network of 4 to 5 stations and using all other stations three to four times per year. The number of stations may be increased if the correlator can support the increase data load.
- CRF: Bi-monthly RDV sessions using the Very Long Baseline Array (VLBA) and 10 geodetic stations, plus quarterly astrometric sessions to observe mostly southern sky sources.
- Monthly R&D sessions to investigate instrumental effects, research the network offset problem, and study ways for technique and product improvement.
- Annual, or semi-annual if resources are available, 14-day continuous sessions to demonstrate the best results that VLBI can offer, aiming for the highest sustained accuracy.

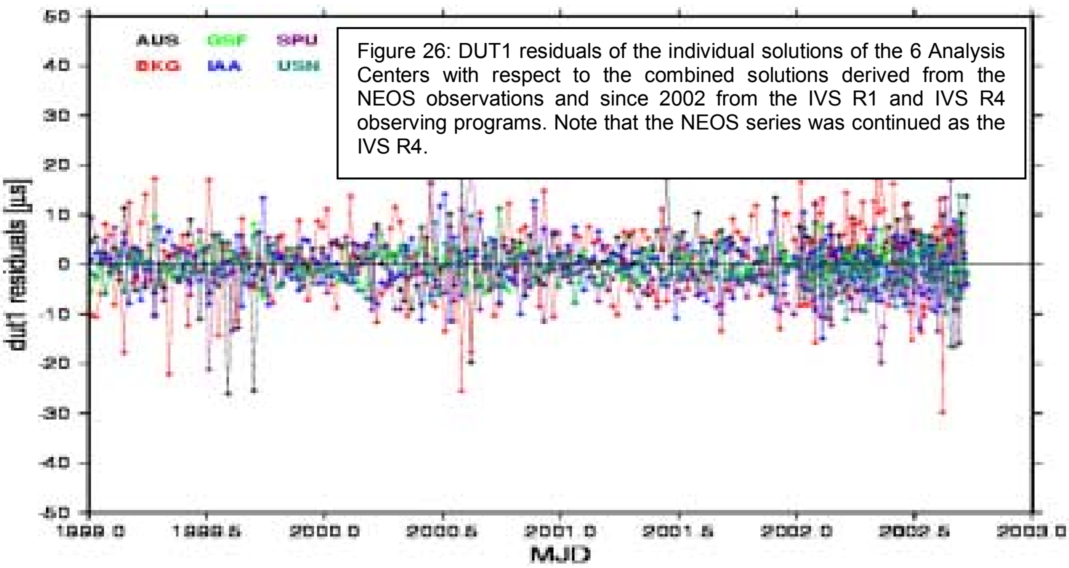


Figure 26: DUT1 residuals of the individual solutions of the 6 Analysis Centers with respect to the combined solutions derived from the NEOS observations and since 2002 from the IVS R1 and IVS R4 observing programs. Note that the NEOS series was continued as the IVS R4.

Figure 26 shows the residuals of the individual Analysis Centers with respect to the combined solution as an example for the parameter DUT1 (UT1-UTC).

The VLBI observations from the rapid turnaround observing sessions R1 and R4 allow determination of tropospheric parameters, in particular the wet zenith path delay. An IVS Pilot Project was established by the IVS Directing Board at its 7th Meeting in order to investigate this product and also to set up the capability to provide the zenith wet path delay as an official IVS product. The University of Vienna is combining the solutions of five Analysis Centers. Figure 27 shows the zenith wet delays for an R4 observation in the GPS Week 1180. The results are comparable to those which were provided by the IGS (International GPS Service) or seem to be slightly better.

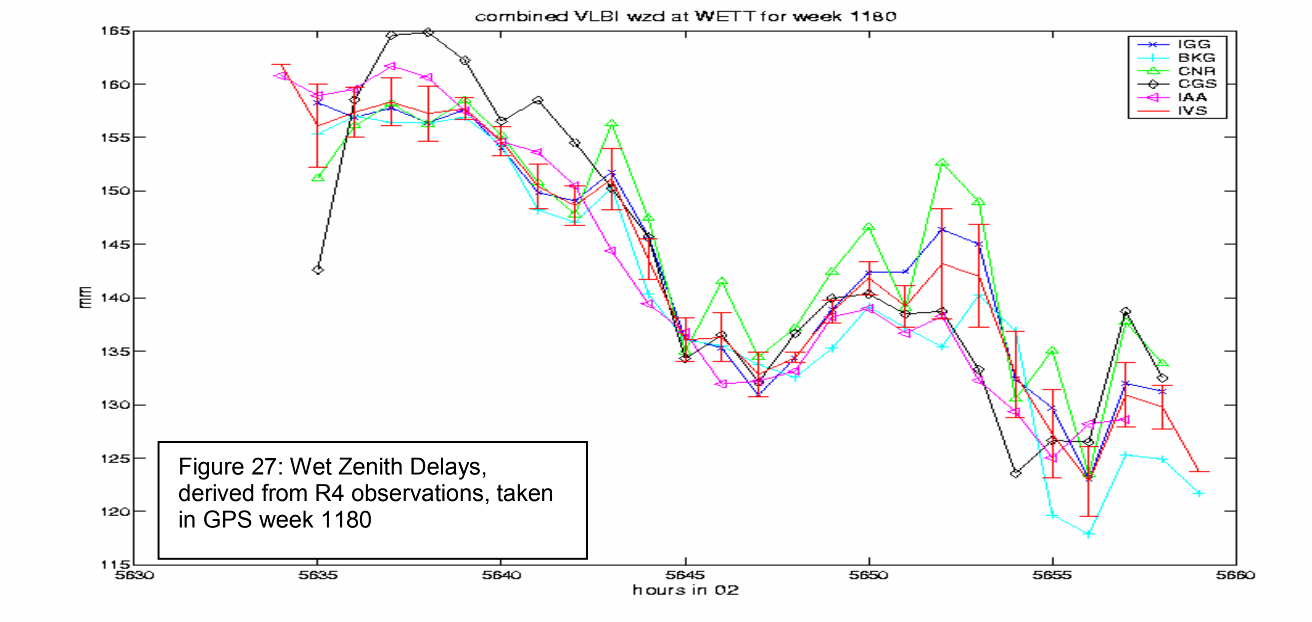


Figure 27: Wet Zenith Delays, derived from R4 observations, taken in GPS week 1180

3. EVN Network Operations

3.1. EVN Program Committee (EVNPC)

The EVNPC is an independent body appointed by the CBD to consider requests for observing time on the EVN. The PC distributes a Call for Proposals three times per year with submission deadlines of Feb 1, June 1 and October 1. During the period covered by this report the PC was chaired by Simon Garrington of Jodrell Bank Observatory, University of Manchester, its membership is given below:

PC Member	Institute	Replaced by (in April 2002)	Institute
John Conway	OSO		
Simon Garrington (Chair)	JBO		
Dong-rong Jiang	Shanghai		
Richard Porcas	MPIfR	Andrei Lobanov	MPIfR
Richard Strom	ASTRON		
Marian Szymczak	Torun	Marco Bondi	IRA
Grazia Umana	IRA	Javier Alcolea	OAN
Andreas Eckart	Köln		
Arto Heikkilä	Halmstad		
Patrick Charlot	Obs. de Bordeaux		
Luca Moscadelli	Cagliari		
Huib Jan van Langevelde	JIVE		

3.2. Proposal, Observing and Publication Statistics

It is instructive to provide an overview of the EVN operation through a few statistical measures. The following focuses on the number of proposals, their broad subject areas and the performance of the array.

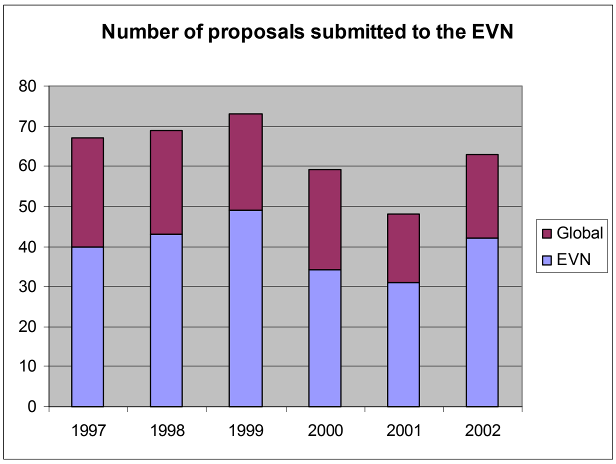


Figure 28: EVN Proposal statistics

The above figure illustrates the number of proposals received by the EVN in the calendar years from 1997 to 2002. As can be seen, the mean over this period is about 63 proposals per year. This statement does not indicate the pressure on the array but an estimate of that can be obtained through the over-subscription rate which averages about a constant 2.3 over the same period; similar to or even higher than that of other radio interferometers.

The pie-chart shows crudely a breakdown of the broad subject areas of interest to astronomers who propose to use the EVN. As can be seen, extragalactic studies are dominant. However, closer inspection suggests that an increasing number of proposals are requesting time for observations of different types of extragalactic sources than the traditional AGN/jet objects, such as starburst galaxies, OH megamasers and deep field observations.

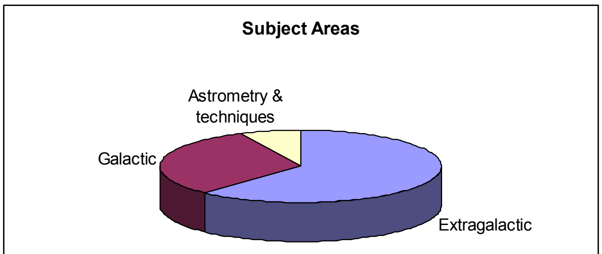


Figure 29: Proposal subject areas

During the period covered by this report we have attempted to quantify the performance of the EVN. An EVN Reliability Index (ERI) has been defined as the ratio of the number of visibilities delivered to the user to the number of visibilities expected based on the block schedule.

The plot below shows the ERI for the period 1997 – 2003. For the first half of this period the reliability index was obtained from the Network Monitoring Experiments (NME); in the second half the results of the pipeline run on the user data was used. As can be seen the average ERI over this period was ~0.8, which is acceptable although not desirable. What is not acceptable are the occasional excursions to lower values of the ERI. These are a result of technical problems at some telescopes and are being addressed by local staff and the EVN Technical and Operations Group (TOG).

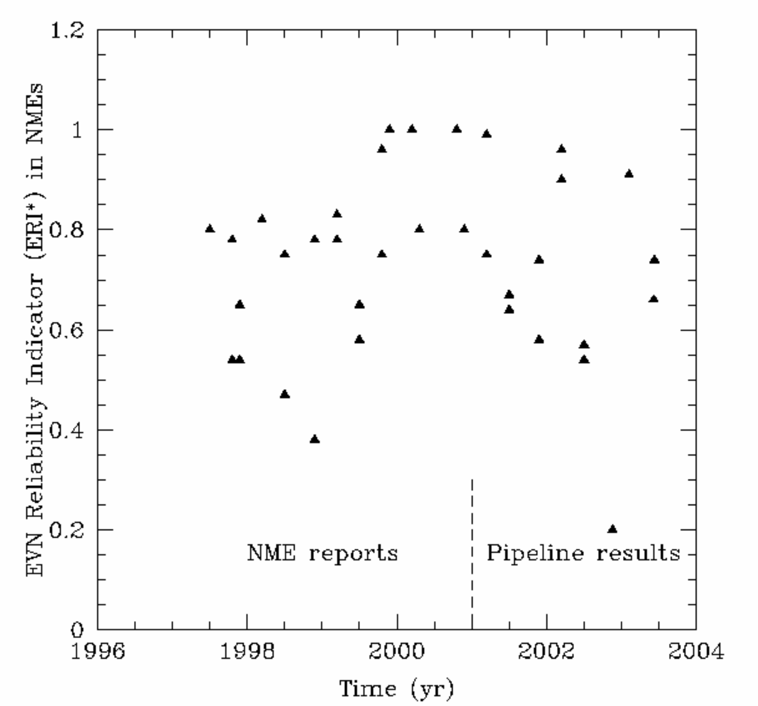


Figure 30: EVN Reliabilty Index

3.3. Correlator reports

3.3.1. Operations of the EVN Data Processor at JIVE

3.3.1.1. Science Operations

The correlator throughput was frustrated in 2001 and early 2002 by the so-called byte-slip problem and -- to a lesser degree-- playback problems. The playback improved gradually, but the use of sampler statistics for detecting byte-slips, initially only resulted in more re-correlations. After suspect hardware was swapped out, and especially when the byte-slip was cured in the middle of 2002, the throughput picked up.

In 2002 33 user's projects were completed, distributed and later released, as were 17 network monitoring experiments and tests. This entailed approximately 520 network hours. The numbers are quite similar for 2001, when the byte-slip problem could not be addressed as rigorously.

A lot of attention went into the management of tapes. With thin tape only operations these are a scarce resource. Careful planning and close monitoring was required to allow up to 200 tapes to be released for each session.

The checking of data and distribution of FITS files to the PIs became the bottleneck by the end of 2002. This led to new data inspection tools that are run by the operators during correlation and identify malfunctioning hardware. Furthermore, quick release of data can be accomplished by relying on a standard set of plots, which can be produced in an automatic way, to show that the data quality is good. Release of projects is now automatic for most projects, i.e. does not require consent of the PI.

The output data path has switched over to use the aips++ Measurement Set version 2. This allows proper flagging of data in specific polarizations. We now write IDI Fits to accommodate the splitting of large projects into multiple files. A few changes to classic AIPS, allowing proper processing of JIVE data, were communicated to NRAO.

A very important improvement of the EVN data product was the update of telescope positions. Software was developed at JIVE to ensure correlation is always performed with the latest coordinates.

Almost the entire archive of EVN data correlated at JIVE is now available on-line for internal use (e.g. pipeline). A tool has been developed that allows products of different types (standard plots, FITS files, calibration files) to be made available through a common web interface.

3.3.1.2. Technical Developments

Continuous effort is needed to enhance the playback performance of the tape drives. The tape units were outfitted with new hardened parts and re-aligned in the process. More improvements came when the position of the only head in our drives was changed to the position of the second head, giving a more symmetric path for forward and reverse playback. Furthermore, the positive effects of thin tape only operation could be noticed.

In 2002 correlator staff at JIVE became involved in testing new disk-based recording systems. The first fringes with the PC-EVN disk system were produced at JIVE and later Mk5 fringes were obtained. A project was started to incorporate disk systems into the correlator software in order to take full advantage of the operational characteristics of disks. The first tests of this software were successfully performed by the end of 2002. Moving to disk-based recording will require some logistical changes but will then improve the operational efficiency greatly.

Successful eVLBI tests have been performed with the new fibre connection into JIVE, correlating data from Westerbork to Jodrell Bank in near real-time fashion.

3.3.1.3 Correlator Capabilities

A decision was made to process 512 Mb/s recordings with one head by processing the data in two passes. Software changes were made to accommodate this mode of operation and by 2002 NMEs were routinely processed in this way. Also software was developed to process observations that use more than 16 telescopes simultaneously in several passes.

Tests were done to see whether it was possible to use speed-up correlation, in which the data is processed (2 times) faster than it was recorded. Fringes could be obtained in this mode, but additional timing issues to get this mode operational proved hard too fix. After considerable testing, the capability to deal with oversampling was made operational. In this mode high spectral resolution is achieved by observing narrow bands at super Nyquist rate. Enhancements have been made to the code that deals with mode changes in the observing schedule. Spectral line projects benefited the most from these changes.

The autocorrelations - and to a lesser extent the cross-products - produced by the EVN data processor still suffer from non-robust treatment of the station sampler statistics. This problem was investigated by setting up an environment for statistical simulations. A cure for this problem was found which is being implemented. Due to the so-called byte-slip problem, occasionally correlation functions developed a secondary peak, offset by 8 lags from the actual peak, in the middle of a scan. It was discovered that the inspection of the autocorrelation amplitude, was a good diagnostic tool for tracing these slips. When discovered the scans needed to be re-correlated. Metrum UK was contracted to find a cure for this problem, which led to a successful new version of the embedded software in the summer of 2002. Furthermore, a problem with faulty boards was addressed in the same way.

Other new capabilities related mainly to the data throughput, which was enhanced to allow a minimum dump time of 1 second for the entire correlator by the end of 2001. In the process the software was ported to a new compiler which shook out quite a lot of bugs. This allowed a new workstation to be dedicated to capturing the output data. Tweaking the TCP parameters of the correlator read-out initially doubled the maximum data rate. A large development effort went into the implementation of parallel read-out and more compact data blocks. Sub-second integration times were implemented for correlator configurations that require fewer spectral points.

Further enhancements of the correlator data rate, especially required for recirculation, will come from the PCInt project. New hardware has purchased to be added to the correlator. Software development started to make these systems configurable and replace the current data path.

3.3.2. MPIfR correlator operations

The two major functions of the Bonn MK4 VLBI correlator are the correlation of mm-VLBI observations and of geodetic observations. In addition, a few EVN observations are correlated, either because they are MPIfR projects or because they need some of the features which the Bonn correlator offers. These include "hands-on" correlation, phase-cal extraction, geodetic export path, or availability of the correlator model in the exported data.

3.3.2.1. Improvements achieved in 2001-2002

Most planned features of the correlator had already been implemented in 2000 so the software development was mostly bug fixes. Important new features are:

- use of sampler statistics for correcting 2-bit data
- barrel rolling also for MK4-formatted data
- sub-netting and parallel correlation of more than one experiment
- correlation of data at twice the recording speed (still somewhat buggy)
- MK5 support
- correlation with LO offsets
- support of switchable equalizers

The most important bug-fixes were related to the station-units:

- a byte slip in the track recovery modules was fixed (found by JIVE)
- a setup problem in the station-unit interface module which reduced the correlator throughput by up to 20% was fixed.

Switchable equalizer boards for the playback units were developed in Bonn. They allow smooth correlation of observations recorded at different tape speeds.

2 MK5P units were delivered in September 2002 and have been in use for geodetic production correlation since October. Two MK5A units arrived in December 2002. 250 120-GBytes disks and 101 empty MK5 8-pack modules were purchased at the end of 2002 for supporting mm-VLBI and EVN observations with MK5. In total, these disks have the same storage capacity as about 55 thin tapes.

The setup of the correlator was modified to allow easy switching between MK5 and MK4 playback units in a completely flexible way. This was achieved by connecting the MK5 units to the inputs which are designated for a second playback head from the MK4 units (which are not installed at the Bonn correlator). The limitation of this setup is that, for data rates of 1 Gbit per second, two additional data cables have to be disconnected from the MK4s and plugged into the MK5 units.

An export path to AIPS has been available since early 2001. Its core is the AIPS task MK4IN which reads un-averaged cross-spectrum data. It can be generated from the raw correlator data with the standard MK4 fringe-fitting program `fourfit'. The cross-spectrum data has all phase and amplitude corrections such as phase-cal and sampler statistics applied. At the same time the initial baseline-based fringe-fit solutions from `fourfit' are exported as well. From these, antenna-based solutions can be calculated with the AIPS task BLAPP, which has been modified to accommodate MK4 data. Another feature of MK4IN is that it exports the correlator model to a CL-table, thus enabling the determination of total delays, phases, and phase-rates, as needed by some high-precision applications.

3.3.2.2 Operations

The number of observations correlated stayed at a high level in 2001 and 2002, and it was slightly higher than in 2000. In 2001 19 astronomical and 46 geodetic projects were correlated while in 2002 the numbers were 18 and 47. The number of stations per observation gradually increased and thus, even though the efficiency of the correlator could be increased, the total percentage of correlation time over total time went up from 41% in 2001 to 48% in 2002. This could only be managed by hiring more student operators. The time spent on maintenance and repairs was an additional 3% and 6% in the two years.

3.4. Technical and Operations Group (TOG)

The TOG is made up of the personnel at the EVN stations who provide the technical and operational expertise, they are the engine-room of the EVN. The TOG was chaired by Mike Garrett of JIVE and met twice during the period of this report: in Bonn on 25 June 2001 and in Bologna on 27 September 2003. Reports from both meeting are available on the EVN web-site (www.evlbi.org).

The goals of TOG meetings are to:
- (i) facilitate knowledge sharing across the network and direct access to significant VLBI technical/operational expertise
- (ii) provide an opportunity for people to volunteer their own expertise on behalf of network projects (the harvest is rich but the labourers are few!),
- (iii) enforce self-assessment (both at the local and network level) i.e. just what has been achieved since the last meeting, what problems remain, how can they best be remedied etc,
- (iv) generate a “plan of action” for technical and operational developments (including improved reliability) on both short (months) and long term (years) time scales.

The main emphasis of TOG activities continued to be the reliability and performance of individual telescopes and the Network as a whole. Significant achievements to be noted over the period of this report are:
- the completion of the MkIV formatter upgrade;
- the further development of the Field System in collaboration with Ed Himwich of NVI;
- the completion of the installation of 2-heads at all stations;
- the development of automatic amplitude calibration software;
- the understanding of systematics within the EVN led to the production of images at the EVN’s thermal noise limit;
- the purchase and installation of MkIV decoders;
- the development of efficient calibration experiments within the block schedule;
- the introduction of disk-based recording systems, both PC-EVN and Mk5, at some stations;
- the first tests using fibre-based VLBI, i.e. e-VLBI.

4. VLBI operations support at member institutes

4.1. ASTRON, the Netherlands

Westerbork has taken part in all European VLBI sessions in the period 2001-2002. For most of these observations the 14 telescopes of the Westerbork synthesis telescope have been used as a tied-array system with an effective surface area of 94m diameter. Very few VLBI observations were done with a single 25m telescope.

One such single-dish observation was a part of a campaign by Patrick Charlot (Bordeaux) to improve the absolute positions of the EVN telescopes. This experiment provided an order of magnitude reduction in the positional error of the WSRT telescope involved (RT7). Since the relative positions of all telescopes in the array are known to within 0.2mm, the absolute position of the tied-array is now also known to within 20cm. This was later improved upon by Bob Campbell (JIVE) to give an absolute positional accuracy of the Westerbork tied-array of 2cm. This gives a major improvement in the phase connection when making phase-reference observations of weak sources.

Westerbork also made continual upgrades in the Field System software, as this was needed to test both tape recordings with 2 head-stacks (for high bandwidth tape recordings) and the hard-disk based (Mk5 and PC-EVN) recording systems in collaboration with JIVE. A 'warm spare' computer for VLBI sessions was also made available.

There were also many changes made in the online Telescope Management System (TMS) at Westerbork. These were needed for commissioning of the new tied-array (TADUmin) hardware, but were also made to improve the operational reliability and stability. One of the most useful was a routine to check the VLBI logging and to automatically trigger an alarm for the operator if severe errors occur.

The Mark4 formatter was upgraded with new PROMs (to correct for a bug) and the synthesizer board was also replaced. There were also several replacements of mechanically worn out hardware in the tape recorder.

4.2. Hartebeesthoek Radio Astronomy Observatory, South Africa

After many years of supporting EVN experiments on request, HartRAO became an Associate Member of the EVN in November 2001. HartRAO is now available for each EVN session subject to the following criteria:

- The target sources are South of 30 degrees North
- For survey experiments with a number of sources, the HartRAO telescope should be scheduled for at least 50% of the experiment.

HartRAO can now support dual polarization at 18, 13, 6, 5/4.5 and 3.5 cm as well as simultaneous 13/3.5 cm (S/X-band) wavelengths with both Mark IV and S2 recording systems.

4.3. Institute of Radio Astronomy, Italy

Both the Medicina and Noto 32-m dishes are part of the European Consortium for VLBI (EVN), acknowledged as a European Large Scale Facility. Most of the time they operate with the other antennas of the Consortium in the interferometric network at the highest level of efficiency. The Institute offers single-dish observing time to external observers, on the basis of a scientific request, evaluated by the Institute.

A Network Server is maintained, which allows remote access to Principal Investigators, friends of VLBI at the VLBI stations and personnel at the correlators. Observing schedules and log files for all EVN/Global VLBI experiments for all EVN stations are collected on this common area. The server can be accessed via web or anonymous ftp to vlbeer.ira.cnr.it for the EVN and Global operational data.

In 2002 the VLBI antenna in Medicina observed for a total of 323 days (24/24 hours) in the following capacities:

a) Single Dish programs: 211 days. In particular: single dish flux density monitoring for a sample of extragalactic radio sources (92 days); spectral line observations, i.e. H2O, OH masers (63 days); calibrations and receiver tests (56 days).
b) Astronomical VLBI observations carried out with the standard EVN frequencies and geodetic VLBI observations (for a total of 112 days). In particular: 4 EVN/global sessions (62 days); 25 geodynamic sessions, i.e. CORE, VLBA, EUROPE (50 days).

The remaining days were used for maintenance, receiver changes, and general checks on the instrumentation.

In 2002 ,the Noto 32-m telescope has been used for a total of 97 days in the following scientific projects:

a) Single dish: 50 days - flux density monitoring of a sample of radio sources; spectral line observations;
b) VLBI Observation, 47 days:

- 40 days in 4 sessions of the European VLBI Network,
- 3 days for observations of the geo network (CORE, EUROPE),
- 4 days for observations of space VLBI (VSOP) ad hoc observations

From August 2002 to the end of the year, the observing activities of the Noto telescope were halted to allow the upgrade of the primary mirror (installation of the adaptive optics panels).

4.4. Jodrell Bank Observatory, UK

The major upgrade of the 76-m Lovell telescope at Jodrell Bank Observatory (JBO) is now complete. During 2001 the drive system and azimuth track were completely replaced and work begun on replacing the 340 surface panels. In the summer of 2003 the new surface panels will be adjusted using a combination of laser ranging and holographic techniques to provide a surface accuracy of between 1 and 2 millimetres. The refurbished telescope is expected to perform well at least up to the EVN prime observing frequency of 5 GHz. The major development at JBO during this reporting period was the securing of funding for e-MERLIN, a £8.0M investment that will completely transform MERLIN's capabilities. A dramatic increase in sensitivity will be achieved by the installation of broad-band optical fibre links between the MERLIN telescopes and the construction of a new wide-band correlator. The instrument is expected to be operational by 2007. Work has been progressing to ensure that VLBI operations fit within the design and implementation of the e-MERLIN system.

During the period 2001-2002, JBO participated in all six EVN observing sessions. These involved the 25-m Mk2 telescope at 1.3, 5, 6 and 18/21 cm, the 76-m Lovell telescope at 18/21 cm and the 32-m Cambridge telescope at 1.3, 5, 6 and 18/21 cm. Five of these observing sessions included at least two joint EVN+MERLIN observations, during which MERLIN provides short baselines allowing source structure to be mapped on scales from a few milliarcseconds to several arcseconds. JBO telescopes were scheduled to observe 98 VLBI projects for a total of 1848 telescope hours. 22 of these experiments were joint EVN+MERLIN observations. A total of 482 telescope hours (26%) were lost due to known technical problems at the time of observation. Further data were lost when other problems became apparent during correlation. This high rate of failure was due primarily to serious problems during the February and November 2002 sessions. During February 2002 the MERLIN microwave link failed due to the ingress of water into an underground section of the waveguide at one of the repeater sites. This was the first time such a problem had arisen in the 20-year history of MERLIN. At the same time a problem with the inserts between the headstacks and the carriers on the VLBA recorder developed. This resulted in none of the scheduled 18cm observations being carried out for Cambridge in February 2002. The weather was also very bad during this session and more than 7% of the scheduled observing time was lost due to high winds. The entire November 2002 session at L-band was lost for the Lovell telescope because the LO had been wrongly connected prior to the telescope being recommissioned following the replacement of the surface. Also in November 2002, the Mk2 K-band receiver appeared to have lock problems and no fringes were found at the correlator. A failed capacitor in the power supply unit of the Mk4 recorder during May 2002 also caused significant loss of data. It is worth pointing out that only 4% of observing time was lost during the whole of 2001.

4.5. Joint Institute for VLBI in Europe, the Netherlands

The EVN Support Group at JIVE continued to monitor the performance of the EVN and support EVN operations in general, providing support to EVN users in particular. JIVE staff involved in these activities included I. Avruch, A. Biggs, R. Campbell, D. Gabuzda, M. Garrett, H.J. van Langevelde, Z.Paragi, C. Phillips, C. Reynolds and L. Sjouwerman.

4.5.1. Network Monitoring, Reliability and Performance

Network Monitoring Experiments (NMEs) were scheduled and correlated for all six sessions in 2001-2002. The associated reports (both formal written reports and short messages to EVNtech e-mail exploder) were distributed in a timely manner (well in advance of the following session). The NMEs continue to be an essential element in monitoring the reliability and performance of the network. Feedback from the NMEs was considerably enhanced by the development of an automatic data analysis pipeline. This pipeline operates within AIPS and provides a very detailed analysis of each NME, generating all the usual diagnostic plots available within the AIPS analysis package (see http://www.evlbi.org/tog/pipeline.html). With the pipeline in place an EVN Reliability Indicator (ERI) was introduced – essentially the ratio of the number of good visibilities used to create the final image, compared to the number of visibilities that were expected from the original block schedule.

The Infrastructure Cooperation Network, RadioNET (European Commission contract HPRI-CT-1999-40003), is providing funds to the EVN observatories for coordinated improvements to VLBI observing setups and practice. The aim is sustained reliable operation for the EVN such that no more than 10% of the expected data are lost due to operational problems. This level of reliability had been reached by the second half of 2002.

In addition to the NMEs, regular Fringe Test Tapes (FTT, another short test experiment ran several days in advance of the session proper) were scheduled and correlated at JIVE. Feedback to the telescopes was generated within about 1 week of the observations being made.

4.5.2. Network Calibration

C.Reynolds produced ANTAB calibration data for all six EVN observing sessions in 2001-2002. The number of errors in the format of the tables has decreased over the reporting period, but errors do still occur for non-standard set-ups. The effort to improve the quality of EVN calibration remained in the focus of JIVE network support activities.

4.5.3. Data Correlation Support in Socorro

The year of 2001 was the last year that JIVE provided support for the correlation of EVN and Global VLBI projects at the NRAO processor in Socorro. From session 2001-2 onwards the vast majority of EVN projects were correlated at JIVE, including 15 global VLBI experiments processed over the reporting period

4.5.4. General Network Support

In April 2001 the EVN (via JIVE) contracted NVI to implement a Field System (FS) development programme. A subset of the main developments included: off-source flagging, improved TSYS monitoring, an antenna calibration package, and 2-head recording capability within the FS.

Efforts within the support group also centred on trying to understand some of the systematic effects that limit the EVN's sensitivity. A specially designed NME was conducted in phase-reference mode and pipelined automatically. The compact target – a relatively faint 10 mJy source - was easily detected by the EVN at 6 cm (purely via the telescope corrections derived from the calibrator) and after self-calibration it was possible to reach the thermal noise level expected from theoretical considerations. A noise level of 32 microJy/beam was achieved from a 4 hour observing run (Fig 31). In principle, longer integrations (with in-beam phase referencing for example) could generate VLBI images of faint targets with similar sensitivities to connected arrays such as the VLA and WSRT.

The format of NME experiments evolved over this period. From session 2001-2 onwards the observations were made in phase-reference mode after feedback from EVN users analysing data at JIVE suggested problems in this area. In particular, reports that the inclusion of the WSRT actually degraded phase-referenced maps of weak targets were followed up in some detail via the NME and other test experiments. An offset in the position of the tied array (w.r.t the Westerbork antenna RT7) was later identified as the main source of error. The offset had been in common use for many years but only showed up as a limiting factor once the position of RT7 was better determined.

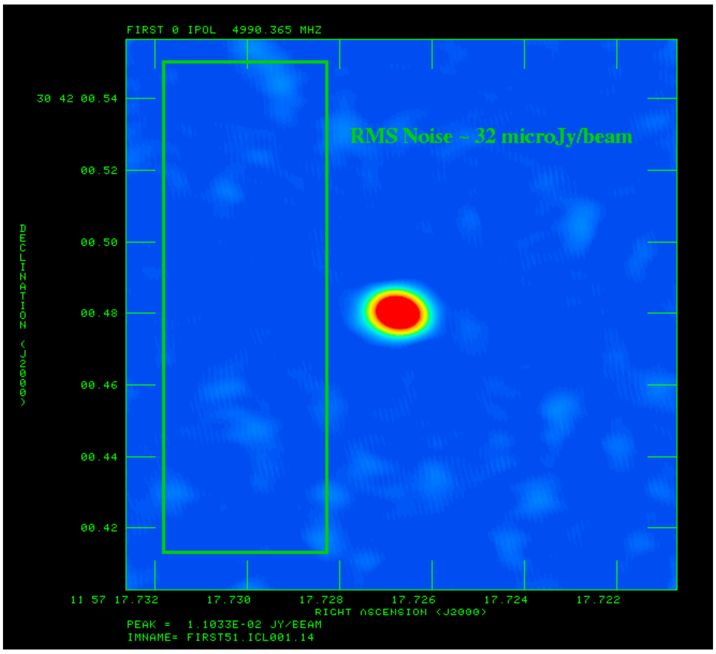


Figure 31. An EVN image of a 10 mJy source obtained in the NME at 6 cm. The off-source noise of the image, 32 microJy/beam, is close to the theoretical thermal noise limit.

4.5.5. Support for individual investigators

During the period 2001-2002 JIVE staff supported PIs in scheduling of 37 EVN experiments. Assistance was also provided for the preparation of several EVN and Global VLBI proposals. JIVE staff maintained and updated the SCHED software and associated catalogues for MkIV observations and EVN telescopes.

Visitors to JIVE (for the purposes of data analysis) included: G. Balodis (VIRAC), P. Barthel (U Groningen), S. Beck (U Tel Aviv), K. Berzins (VIRAC), A. Caccianiga (U Lisbon), P. T. Cawthorne (U Central Lancashire), Charlot (Bordeaux Observatory), V. Chernetskii (Moscow State U), P. Diamond (Jodrell Bank Observatory), S. Dougherty (NRC/DRAO), K. Exter (Queens's U, Belfast), I. Fejes (FÖMI SGO), M. Filho (U Groningen), W. Flemmings (U Leiden), E. Fomalont (NRAO), S. Frey (FÖMI SGO), M. Giroletti (U Bologna), N. Gizani (U Madeira), X. Hong (Shanghai Observatory), S. Kopeikin (U of Missouri), A. Labiano (STScI), A. Lobanov (MPIfR), X. Liu (Urumqi Observatory), J. Lovell (ATNF), M. Marcha (U Lisbon), A. Marecki (U Torun), M. Marcha (U Lisbon), M. Messineo (U Leiden), L. Mosoni (Eotvos University), R. Nan (Beijing Observatory), A. Papageorgiou (U Central Lancashire), Z. Paragi (FÖMI SGO), M. Pestalozzi (OSO), Y. Pihlström (Onsala Space Observatory), A. Polatidis (Onsala Space Observatory), M. Rioja (OAN), L. Sjouwerman (NRAO), D. Smits (U Cappe Town), I. Snellen (Royal Observatory Edinburgh). H. Sol (Paris-Meudon Observatory), H. Spoon (JPL), A. Stirling (U Central Lancashire), A. Tarchi (U Bonn), W. Tschager (U Leiden), W. Wang (Shanghai Observatory), H. Zhang (Beijing Normal U), W. Zhen (Shanghai Observatory).

In addition, JIVE staff supervised three summer students: S. Fodor (Whittier College, CA, USA), P. Kharb (RRI, Bangalore, India), K. Berzins (VIRAC, Riga, Latvia, F. Stefanachi (University of Bologna, Italy), G.Coldwell (Cordoba Observatory, Argentina).

4.6. Max-Planck-Institute for Radio Astronomy, Germany

Alex Kraus acted 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.

Richard Porcas (to Feb 2002) and Andrei Lobanov (from June 2002) served on the EVN Program Committee and attended its meetings.

Rolf Schwartz served as EVN Scheduler until Feb 2002. Richard Porcas took over as EVN scheduler from Feb 2002. Both attended meetings of the EVN Program Committee and the EVN Consortium Board of Directors in this capacity. Assistance with EVN Proposal administration is provided by Ute Runkel, and Walter Alef takes care of the receipt of emailed proposals.

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

Walter Alef, Dave Graham and Alex Kraus are members of the EVN Technical and Operations Group (TOG) and attend its meetings. Walter Alef heads the group responsible for overseeing the change from tape - to disk-based recording in the EVN ("T2D"). Walter Alef has now (Jan 2003) taken over as Chair of the TOG.

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 the creation of schedules for the Fringe Test experiments run just before the start of each observing session. Antonis is also responsible for maintaining the "EVN Status Tables" on the EVN Home Pages and Richard Porcas maintains the "Instructions for EVN Observers".

Walter Alef helped organise the VLBI "Technical and Operations Workshop" held in Haystack in March 2001. Thomas Krichbaum and Alex Kraus also attended .

Alex Kraus took an active role in running the "Amplitude Calibration Workshop" held in Medicina in September 2002.

4.7. National Astronomical Observatory, Spain

The 14m radio telescope of OAN at Yebes (CAY, Guadalajara, Spain) has participated in the EVN sessions at S/X frequencies in May 2001 and February and May 2002. Regular geodetic VLBI campaigns for the EUROPE and CORE projects have also been performed (6 sessions in 2001, and 6 sessions in 2002).

Several enhancements in the hardware and software of the antenna control system and VLBI equipment are described in Section 5.8.

4.8. Onsala Space Observatory, Sweden

The Onsala telescopes have played a full role in all of the EVN sessions in 2001 and 2002. In addition the Onsala 20m has been used for approximately 15 days per year in Geodetic VLBI observations. The Onsala 20m has also participated successfully in three CMVA (Coordinated Millimetre VLBI Array) wavelength 3mm sessions during 2001/2002. The SEST telescope in Chile has also been used in some of these sessions, also participating in test observations at a wavelength of 2mm.

4.9. Shanghai Astronomical Observatory, P.R. China

The Shanghai station at Seshan participated in EVN VLBI experiments of each three sessions of 2001 and 2002 respectively, the VLBI experiments of NASA, VSOP, APSG, and some ad hoc VLBI observation with Russian antennas. The operating time (including test) of the telescope was about 1000 hours in 2001 and about 1400 hours in 2002, while the VLBI recording time was about 560 and 830 hours for 2001 and 2002, respectively. The successful observations were about 95% for 2001 and 96% for 2002.

In general the performance of the observation systems of Shanghai has been improved dramatically at all bands over the last few years. The Field System works well with the 9.5.17 version at Shanghai station since EVN session 3/2002. The 'ONOFF' command has been successful executed in Field System.

The MKIV recording system works well for EVN and IVS observations, and S2 recording system works well for VSOP observation during last two years. Two head stacks recording system has been tested successfully and good fringes have been found to Seshan station in 2002.

Seshan station made a series of measuring for the gain curves, K/Jy, SEFD et al at the L, C, X/S bands during last two years. The calibration source T-cal values were calibrated with the cool/hot load at the C, L, X/S bands. And checked the calibration source T-cal values at C and L band during EVN session 3/2002. The results are better at C-band than that at L-band. The polynomial terms gain curves and K/Jy were upgraded at C, L, X/S bands in 2002.

The right channel receiver of the L band was broken during the EVN session 2/2002. So, only LCP was available at that session. The RCP of L band has been recovered and dual polarization was available during the EVN session 3/2002. But the stability of the RCP was not quite good. Interference signals appeared sometimes around 1640 and 1680 MHz at right channel of L-band. It looks like that was resulted by the feed itself via a series of tests.

The C-band receiver system has worked at the state of the room temperature since the EVN session 3/2002. Because of the cooling power support module of was broken. The stability of the receiver system is very good now.

The wide-band (8.2-9.0GHz) X-band receiver system was used for geodetic experiments since the beginning of 2001. And the fringes are obtained for all experiments. The two top X-band channels had low sensitivity in fringing because of the frequency limit of the feed.

Fringes to SH at 1.3 cm (GM043C session 1/2001) were found in Socorro (from Lorant Sjouwerman) in March 2001. Unfortunately, we did not find the fringe to SH for 1.3cm band in session 3 of 2002 (N02K1). The reason is unclear. It may due to the weak fringe finder on long baselines at 22 GHz or/and due to the poor accuracy of the main plane of the antenna. The antenna sensitivity is not good at the 22 GHz now. There is a plan to adjust the main plane of the antenna at Shanghai station in 2003. We expected the performance of the antenna be improved at the K-band.

4.10. Toruń Centre for Astronomy, Poland

The Department of Radio Astronomy, Torun Centre for Astronomy is a division of Physics, Astronomy and Informatics Faculty at the Nicolaus Copernicus University in Torun. The personnel of the Centre consists of 19 research positions, 20 engineers and technicians and 20 supporting and administration staff. There are 18 Ph.D. students and above 60 undergraduates studying astronomy as a chosen subject. The Radio Astronomy Department with 30 employee operates two parabolic radio telescopes – 15m and 32m. The major instrument, the 32m precise antenna, is equipped with ultra low noise receivers covering bands from 20 cm down to 1 cm and with a modern back ends used to process and record scientific data. Three basic units of the auxiliary equipment are in continuous use. The pulsar broad band 64 channel machine PSPM2, an autocorrelation 16k channel spectrometer and VLBI MkIV recording terminal. In addition a polarimeter and OCRA prototype receiver for 30 GHz plus a sophisticated total power back-ends are soon in full operation. The 32m telescope is used most of the time, with the major concentration on pulsar timing (1/3 time allocation), studies of interstellar and stellar molecules (about 1/3 of telescope time) and VLBI studies of distant quasar, active galaxies as well as galactic compact objects carried out mainly within the European VLBI Network. In the reported period the telescope was used for astronomy at a level of 87% of total time. The fraction of time devoted to VLBI observations, tests and VLBI related maintenance approaches a level of 1/3 of the total observing time. Participation in VLBI observations and data analysis are the most significant activities at theTorun Centre for Astronomy. During the last two years Torun station observed in all requested EVN and global experiments carried out in the L and C bands. Total number of the observing hours in VLBI mode in 2001 and 2002 has reached 1500 for more than 120 individual projects. The improved quick feedback form the JIVE correlator allows prompt identification of technical problems before or even during the sessions resulting in the immediate action at the station. It occurred at least once that the LO signal path was not locked to H-maser and a faulty amplifier was urgently replaced. The subsequent experiment produced good strong fringes. Effective communication, fast reaction and good local coordination led to quick and efficient improvements of the performance. It is due to the ICN coordination that such actions are now possible.

Since 2001 we have the two-headstack tape recorder. The second headstack was successfully tested during February and May 2002 session. We were reported from JIVE correlator that the quality of the recordings with this second headstack was not yet satisfactory. Further steps were undertaken to improve recording quality. The malfunctioning BBCs, which cased problems and which in fact limited the recording bandwidth are being serviced. The work is going on and thanks to the OSO help, there is a hope to operate with full bandwidth in 2003.

4.11. Urumqi Astronomical Observatory, P.R. China

In 2001-2002, The Urumqi 25m radio telescope conducted 3 session VLBI observations each year for the EVN; about a dozen experiments for the NASA and APSG projects; several test experiments for Shanghai correlator and irregular observations with MKII recorder for Russian LFVN and VLBI radar experiments.

4.12. Bundesamt für Kartographie und Geodäsie (BKG) - Wettzell, Germany

The 20m Radio telescope Wettzell (RTW) is strongly involved in the newly established IVS observing program. RTW contributes regularly in the rapid turn around sessions, which were set up for determination of the Earth Orientation Parameters. One of the objectives is to obtain the latency as short as possible between the observations and the provision of the products. Moreover RTW is also involved in the IVS sessions established for the maintenance of the terrestrial and the celestial reference frame , which are scheduled monthly or bimonthly. RTW participates also in the research programs R&D and RDV. Daily observations of one hour, in order to derive DUT1, the Intensives, were performed via the baseline Wettzell – Kokee Park (Hawaii) and Wettzell – Tsukuba (Japan). Only 4 experiments were carried out to support radio astronomy projects.

While in the of year 2000 the number of observations (24h per days) were close to 100 days, in 2001 the amount of observations increased up to 121 and in 2002 up to 139 days. This is an increase of more than 20% per year. Considering the age of the antenna and the mechanical stress for the antenna in particular due to fast changes in pointing to various sources, the observing time per year approaches close to its limits. Any prohibition of mechanical damages will need more precaution and increased maintenance.

For data acquisition in general the MK4 and the MK5P resp. Mk5A system is employed. In particular the K4 system is used for the hourly observations with Tsukuba (Intensive K4).

Additional, auxiliary observations were carried out, in order to measure antenna height variations due to the thermal expansion. It appears more or less as a seasonal effect and reaches height variations of the order of 3mm. Continuous observations were performed with a water vapour radiometer. The objective is to provide time series of the zenith wet path delay, mainly for comparison with the tropospheric parameter, which are estimated from VLBI observations.

5. VLBI technical activity at member institutes

5.1. ASTRON, The Netherlands

Several major and some minor technical upgrades have taken place at Westerbork during 2001 and 2002.

On the reference telescope of the tied-array (RT7) a new phase calibration unit was installed. This was closely based on the geodetic design, but it has an on-board microprocessor for temperature control, switching on/off, and for setting the attenuation. A small local field system program was written to control it. This proved invaluable in debugging various problems with the new tied-array.

During this period 512Mbit/s tape recordings using both head-stacks were commissioned, using test observations between Jodrell Bank and Westerbork, and then made operational for normal observing sessions. Tests were also made of the disk-based recording using both the Mark5P and PC-EVN systems in collaboration with JIVE. Both of these disk recordings were 'piggy-backed' onto tape recordings by taking the input signal for the second recording head. These tests proved very successful.

A Mark4 decoder was installed, so that the Mark4 tape recording quality could be checked.

Westerbork also changed entirely the tied-array hardware and software, so that there is now almost no system in common between the old and the new tied-array hardware placed between the receivers and the connection to the VLBI rack. The old hardware could provide a maximum of 8 bands of 8MHz bandwidth each. The new (TADUmin) tied-array system works with a standard channel bandwidth of 16MHz and uses different fringe rotation schemes, analogue to digital conversion, delay compensation and adding hardware, and a different means to produce circular polarization from the input linear polarizations. New online control software was needed, as well as modifications to the offline calibration and specification software. The new channel bandwidth configuration of the WSRT allows for recordings of 16MHz channels and simplifies the setup of observations using 8MHz of lower and upper sideband. Also the new filters and equalizers give a better bandpass. The new polarization system, which in principle allows for better polarization purity, had several initial problems in its calibration and use. The new IF section entailed using new local oscillator settings. The new mixing scheme, which is slightly harder to configure, does provide more operational flexibility than the old one.

TADUmin was taken into full operational use in the November 2002 EVN VLBI session, although it is still undergoing online software and some minor hardware improvements. Initially only 4 bands of 16MHz were tested and used. It now works reliably.

5.2. Hartebeesthoek Radio Astronomy Observatory, South Africa

The most important activity over the past two years has been the progressive upgrading of the surface of the 26-m telescope. This work has been carried out in-house with 2-3 additional contract staff members. An adjustable "bed-of-bolts" jig equipped with a high precision measuring system enables the surface sheets to be formed with an rms accuracy of better than 100 microns. The existing outer portion of the panel frames is re-used after replacing the ribs with more rigid members. The new frames are attached to the surface skin on the bed-of-bolts with epoxy resin, which acts as a filler and bonding agent. After curing of the epoxy, screws are also inserted through the skin into the frames. Ninety percent of the completed panels have a measured rms accuracy <150 microns.

Manual panel adjusters are being fitted at each mounting point to allow the panels to be adjusted from within the surface. The final adjustments will be made using satellite holography at 11 GHz. The aim of the upgrade is to achieve good efficiency at 22 GHz.

A new hydrogen maser, EFOS-28, is on order from Observatoire Cantonal, Neuchatel, and is due to be delivered in June 2003. This will replace EFOS-6 as the primary frequency and time standard at HartRAO, EFOS-6 will be retained as a backup system and consideration is being given to having it upgraded to extend its useful lifetime. EFOS-6 has been in near-continuous operation since 1985.

In common with other EVN stations, HartRAO will upgrade to the Mark V disc recording system. Because HartRAO has a significant commitment to the IVS geodetic VLBI programme, the acquisition of the Mark V recorder will be co-ordinated with the IVS implementation plan for Mark V. The purchase is scheduled for the second half of 2003 and a sufficient number of disc packs will be ordered to meet the minimum initial requirements for HartRAO Mark V operations.

5.3. Institute of Radio Astronomy, Italy

The Institute is deeply involved in the development and exploitation of new techniques for maintaining the existing national instrumentation at the best levels. At the same time the Institute contributes to the major radioastronomyprojects now carried out in international consortia both for ground and space facilities. IRA, together with former CAISMI, covers almost entirely the area of technology research for radio astronomy instrumentation in Italy. Such activity has recently improved thanks to cooperation established by IRA and CAISMI with University Departments of Electronics and Telecommunications in Florence, Rome and Messina and with other CNR Institutes in Bologna, Turin and Rome.

Fig 32: Mk5 Prototype

During year 2001-2, various technical studies and projects have been completed, both to improve the performances of existing telescopes, and as participation in national and international collaborations.

5.3.1. Medicina Radio Station

5.3.1.1.Development of the VLBI antenna

Planned upgrade of the radio telescope consists in the change of the vertex room design for frequency flexibility. The electronics parts of the 5 and 7 GHz receivers are ready. LNAs design is in progress. The feed system has been completed and mostly measured. The research about the possibility to correct non-systematic pointing errors by using electronic level meters and temperature sensors has continued. The rail has been substituted as provided in the project of the new antenna rail support system completed in 2000. The new MK4 decoder and display unit is now installed at the station. The capability of two head recording to enhance the recording rate up to1Gbit/sec has been installed on the MK4 recorder. First tests at 512Mbit/sec were successful. IRA decided to buy the prototype of a MK5 system, the new VLBI terminal (Fig 32). This equipment has been used for a first ad hoc test experiment on September 17, 2002 successfully correlated in Bonn. Further tests were planned and processed by the JIVE correlator. The equipment uses 120GB disks at the moment. The feasibility project to replace the coaxial link between the antenna receivers and the MK4 VLBI terminal by optical fibres was investigated.

Fig 33: 5-element 22 GHz focal plane array built as part of the FP5 FARADAY programme

5.3.1.2. Cassini Mission

The construction of a dual frequency (X and Ka) uncooled receiver for Cassini Radio Science experiments has been started in 2001 in Medicina and successfully completed in 2002 when on the Noto radio telescope, with the new active surface tuning, Cassini spacecraft carrier was well detected at both frequencies. The Ka receiver was also used for the aforementioned efficiency measurements of the new surface.

5.3.1.3. LNAs development and FARADAY EC project

A collaboration is going on between Medicina and Arcetri with MECSA (an University Consortium of Electronic and Telecommunication Departments, including Rome and Florence Universities). The aim is to realize state-of-art LNAs. In the 2002 the specification of a 22 GHz LNA and tests on InP and GaAs transistors were done. The realization of a 1.4-1.8GHz LNA was completed by realizing a new design to proceed further with higher frequencies. A bonding machine, together with a milling machine for producing printed circuits, has been acquired for Medicina. The training of new people and the increasing the microwave measurements capability continued. At the end of 2001 the EC founded project FARADAY started with the aim to develop a 5 element focal plane array at 22 GHz with MMIC LNAs. The program is carried out by Medicina and Arcetri labs (Fig 33.).

5.3.1.4. Fibre optic applications

The use of this technology is increasing in radio astronomy. The possibility in the near future to connect VLBI correlators and observing stations via optical fibres pushes towards a real time correlation and similarly those institutions having arrays and antennas want to cable optically the interconnections. IRA opened a window also on this subject, both for eVLBI and for Italian antennas (Medicina, Noto, and next SRT). We are trying to acquire experience in this field by developing applications on the Northern Cross and on the 32m parabola. Some testing has been done on:

1. tight and loose fibre cables in order to appreciate the phase stability coefficient vs. temperature: this is important since the Northern Cross interferometer will be upgraded with such technology;

2. inexpensive analogue Tx/Rx FO modules in order to adapt their real dynamic range to be sufficiently high to avoid saturation under interferences. This is important in case we replace the RF/IF coaxial receivers' cables with fibres on the 32m parabola.

5.3.2. Noto Radio Station

In 2001-2 with an ad hoc budget of about 1 MEuros, Noto 32-m radio telescope went through an important upgrade consisting of:

i) improved surface accuracy and new active system for panel control,

ii) new improved driving servo system. Also the data acquisition has been upgraded as the new MKV recorder has been evaluated and two such units have been acquired for Noto and Medicina. The EVN environment for high-density recording has been analyzed.

5.3.2.1. The active surface for Noto antenna

In 2001-2 part of the Medicina staff was mainly focused on the final development of the active surface system for the Noto antenna. The upgrade of the primary mirror of the parabolic antenna has been completed. Mounting and aligning both actuators and panels were successful. All the mechanical and electronics parts related to the aligning tools were designed and made in house. First results on gravitational corrections are reported as presented at the last URSI General Assembly.

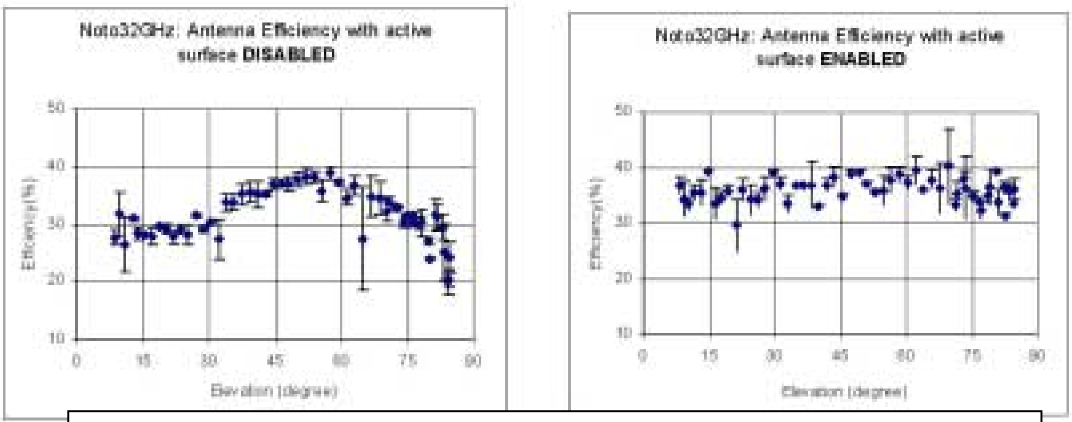


Figure 34: Plots of the efficiency of the Noto telescope at 32 GHz with the active surface control disabled (left) and enabled (right).

was based on new 100 micron accuracy panels with actuators which provide the full control of the surface to any environmental deformation. The servo system was completed by the end of September 2002. With such improvements the radio telescope should be able to operate with top efficiency up to 30 GHz (Fig

34) and with good efficiency up to about 100 GHz, thus allowing a better EVN operation at high frequency

5.3.2.2. Receiver upgrade

A new dewar has been built to cool the prime focus L and S/X band feed built by CSELT and the entire set of front-end amplifiers (Fig 35). The project of an UHF receiver has been done. This system will allows a better use of the telescope for Geodynamics and low frequency operations

Figure 35: the new prime focus L and S/X band system for Noto.

5.3.2.3. Microwave technologies

The first L band amplifier has been completed according to the Yebes design. Moreover a new amplifier has been designed to operate in S band, and the realisation in under way. Research activity on the fields microwave filters, superconductivity, LNA and MMIC devices has continued.

5.3.2.4. Digital technology

A FIR filtering digital system has been developed and the study of a fully digital SSB converter has been activated in the context of EVN developments. on RFI protection. Software has been designed to control the RFI. A tool of data analysis (Matlab) has been developed to give a characterisation of the detected RFI signals.

5.3.3. Radio Astronomy Techniques at CAISMI

The research activities done in the 2001 were focused on programs already scheduled in previous years and based on activities oriented toward international and national millimetric and submillimetric projects. Main activity areas can be summarized as follows:

- development of the capability in the design, implementation and characterization of microwave passive components such as feed horns, OMT, etc. for millimetre and submillimeter wavelength regions;
- design and construction of cryogenic radio receivers: in 2001 CAISMI has produced the feasibility study of a dual polarization broadband receiver for the 40-50 GHz band in collaboration with IRA and the initial construction of a five beam receiver for the 18-26 GHz band. These receivers will be installed at the secondary focus of the VLBI antennas of Medicina and Noto. The mm/submm activity includes the construction of receivers for the 85-110 GHz and 330-350 GHz frequency bands using SIS devices as mixers. This activity was conducted in collaboration with Köln University, the University of Milano and IEN of Turin. The receivers will be used at focus of MITO 2 meter telescope located on the Alps at 3500m sl CNR site Testa Grigia;
- design and construction of high resolution autocorrelators and wideband acoustic optical

spectrometers.

5.3.4. Sardinia Radio Telescope

The engineering design of the Sardinia Radio Telescope (SRT) was begun in March 1999. In 2001, the following milestones were achieved:

1). Defining the technical requirements for the industrial contracts for the mechanical structure and all the servo systems of the Radio Telescope. This activity started in March with a meeting IRA - ASI - VERTEX. It was clear that the cost of the whole SRT Project is larger than expected, as suggested by the feasibility study performed in 1995. Before starting the industrial tender for the contract competitions, a careful analysis of the Italian industrial capabilities has been performed to check:

- the possibility of a cost reduction with new technologies or new marketing methods.
- the possibility to obtain further funding for the project.

For the first item, the design and development activity carried out in the Institute of Radio Astronomy, in particular for the Noto Radio telescope, will produce important money saving in the producing the active surface of the primary mirror. Furthermore a careful marketing analysis has shown that a number of Italian firms are able to build the mechanical structure satisfactorily and within the requested time. The Institute is publishing the industrial tender for a European competition. For the second item, the Institute has requested funds inside the FIRB competition for two projects: active primary mirror surface (actuators and panels) and design and building the Beam-Wave guide mirrors.

2). The Institute has continued the e study of: the mechanical Finite Elements Models (FEM), for deriving the corrections to be applied to the radio telescope surface; thermal gradients measurement and control system, concerning pointing and surface efficiency; wind measurement and correction system.

5.4. Jodrell Bank Observatory, UK

The VIV upgrade of the VLBA (Cambridge) recorder, which now has two headstacks, new read-write electronics and a MkIV formatter, was completed in 2001. Both heads can be used for recording, with a total data rate of 512 Mb/s, and fringe tests have confirmed the success of the upgrade. The Mk4 recorder was also upgraded for dual-head recording and 512 Mb/s tests were successful. A new decoder has been installed, improving the ability to check recording quality on-site. After major difficulties with recording heads coming loose on the VLBA recorder, the carrier on the first head was replaced. It was necessary to re-lap the heads, using an ultrasonic humidifier to raise the room humidity above 35%. A failed power unit on the Mk4 recorder, which caused problems during the May 2002 session, was repaired. New TAC CNS GPS units are now installed and are running TAC32 Plus software.

Considerable work has been done to integrate the control of the back-end synthesisers, filters and calibration units into the VLBI Field System and to generally strengthen the local diagnostics. The telescope control interface has been rewritten to include continuous checking of parameters, including telescope pointing as well as the back-end synthesisers and filters. A program to automate the switching of IF, LO and calibration signals between single-dish, MERLIN and VLBI observations has been completed. This has made the switch over between observing modes much easier. Significant effort has also been expended in investigating calibration issues at JBO, namely in the implementation of the standard Field System calibration routines which initially caused conflicts in the local antenna control software. This work is ongoing but should be completed by summer 2003.

JBO has been active in the recent development of the PC-EVN disk-based VLBI recording system. In a special test observation, data were recorded on tape at JBO and on disk (in parallel with tape) at Westerbork. Later tape-tape and tape-disk correlation at JIVE yielded identical fringes at 256 Mb/s data rate. JBO was also involved in one of the first e-VLBI demonstrations. On 24th October 2002, PC-EVN hard-disk units were used to record data at JBO and Westerbork in the first disk-disk trial of the system. The unit at JBO was built using a locally purchased PC with interface boards and software supplied by Metsahovi. Four passes of MkIV data were recorded, comprising 32 tracks at 8 Mb/s giving an aggregate data rate of 256 Mb/s. The data were then transferred within a few hours over an international network to

JIVE and correlation produced normal fringes. At present work is beginning in order to replace the VLBA recorder with a Mk5 disk-based unit.

5.5. Joint Institute for VLBI in Europe, the Netherlands

5.5.1 Post Correlator Integrator (PCInt)

At the end of February additional personnel from NFRA joined the PCInt software development team and design of the information infrastructure began. A development server and a 24-port switch were acquired and the prototype system was placed in its own sub-domain of the NFRA network. Preliminary versions of software components confirmed that all design goals could be realised using the chosen hardware. Later in the year the suppliers announced a new model of the SBC featuring more on-board memory, faster CPU and two 100Mbit/s ethernet interfaces. Following some testing nine were ordered by JIVE for the production system.

As the PCInt software developed all of the original ideas, even at the highest abstraction level, were realised without compromise. This will ensure flexibility, stability and expandability in the future. By the end of November a prototype system could be started and simulated data could be saved to disk. Work continues to consolidate this version as an alpha version of the system.

5.5.2 Hard-disk, tape replacement systems

During 2002 the Metsahovi and JIVE teams continued to develop PCEVN, a hard-disk based recording system based on commodity PC components. The project progressed largely according to plan and the various hardware interfaces needed for testing were soon available in quantity. In June the interface to the correlator was engineered and in July first fringes using PCEVN were demonstrated using data recorded at Jodrell Bank and Westerbork.

In September 2002 the first international eVLBI fringes using fibre-optic networks was demonstrated using the PCEVN system. PCEVN's use of normal, Linux files simplified the process and enabled the use of a specialized UDP application as well as normal FTP.

The viability of constructing a working PCEVN system using mostly locally acquired, commodity components was demonstrated in October when Jodrell Bank built the first DIY PCEVN unit. This was used in the same month in the second successful PCEVN/eVLBI fringe test.

In parallel with PCEVN developments, JIVE began preparations to accommodate the American Mark5 system. Two Mark5P units were delivered to JIVE in July and September. Some effort was made to achieve software compatibility in PCEVN with Mark5; the interface to the correlator was tested and fringes were obtained. In November the EVN directors decided to favour Mark 5 for general deployment. JIVE continues to offer correlator support to PCEVN developments at Metsahovi but disk-based developments are now focused on the Mark5 platform.

5.5.3 Fibre optic Developments

In January 2002 contacts in the GRID and high performance networking communities suggested that connected VLBI should be offered as a high bandwidth application at iGRID2002 in September 2002. iGRID is a biennial event which showcases application advancements and middleware innovations enabled by globally connected, high-performance networks. The proposal was accepted by the organisers and a project to stage the demonstration was launched which included personnel from JIVE, Jodrell Bank and The University of Manchester Physics Department. VLBI suited very well the theme of iGRID2002: "Applications with Insatiable Appetites for Bandwidth".

In August 2002 work began on the installation of a SURFnet fibre optic link connecting the ASTRON/JIVE facility in Dwingeloo to the Amsterdam Internet Exchange at SARA. A suitable connection point owned by Global Crossing was available at a location approximately 20 km from Dwingeloo. Two teams of contractors, working in both directions, completed the work in less than a month. By the end of the second week in September the entire fibre optic link was in place and tested, and DWDM equipment was installed and set to work providing multiple Gigabit Ethernet capacity.

The new connection contains 24 fibres. Initially two fibres are lit with three wavelengths to give three, 1Gigabit Ethernet lines. One of these is reserved for general ASTRON/JIVE "production" traffic. The other two are dedicated entirely to JIVE for eVLBI experiments. The installation can be upgraded to sixteen 1GE lines by adding boards and a further 16 can be added with an extra chassis. Much higher data rates are possible with different terminal equipment; each fibre can carry hundreds of wavelengths and each wavelength can carry tens of gigabits per second. The infrastructure is thus in place to provide virtually unlimited capacity to the Dwingeloo site placing the JIVE Data Processor, logically, at the heart of an important global networking hub. Also, by fortunate coincidence, iGRID2002 was hosted at SARA in Amsterdam so it was relatively easy for SURFnet to arrange a connection from the newly installed Dwingeloo fibre directly into the demonstration hall.

The VLBI demonstration was entitled "vlbiGRID" and used data recorded in an earlier PCEVN test to simulate connected VLBI. Data on disk were taken to the Regional Computer Centre in Manchester, England. From there the data were transmitted via Net North West Metropolitan Network, SuperJANET4, GÉANT and SURFnet to the iGRID2002 network and, via the new link, to the correlator in Dwingeloo. Using UDP data rates exceeding 500Mb/s were achieved, with acceptable packet loss, without any special provision on the networks involved.

Following the success of this demonstration a Proof of Concept project was proposed to connect a number of telescopes to JIVE via various National Research and Education Networks (NRENs) and GÉANT over the next two years. This has the support of GÉANT, and several NRENs including SURFnet. An initial meeting between JIVE, GÉANT and SURFnet took place in December and a meeting involving technical personnel from telescopes and NRENs is planned for January 2003.

5.6. Max-Planck-Institute for Radio Astronomy, Germany

MPIfR staff plays an active role in EVN technical developments. D. Graham, W. Alef, A. Kraus and M. Wunderlich are active members of the EVN TOG and attend their meetings.

MPIfR made a major financial contribution to the MK5 development at Haystack. Since the delivery of the first 2 units in summer of 2002 M. Wunderlich, R. Maertens and W. Alef were involved in the further development of the system and helped working out the logistics for MK5 observations.

D. Graham and A. Freihold from MPIfR completed the MK4 formatter upgrade project in early 2001. Upgrade kits were assembled and sent to the EVN stations free of charge.

Following earlier attempts to detect VLBI fringes at wavelengths shorter than 3 mm, two successful VLBI observations at 2mm wavelength were made in 2001 and 2002. In April 2001 the two quasars 3C 273 and 3C 279 were detected at SNR ~ 10 on the 3100 km baseline between the 30 m telescope on Pico Veleta (Spain) and the 14 m telescope in Mets"ahovi (Finland). This indicated that at least the brightest known AGN were compact enough for VLBI at wavelengths shorter than 3 mm. A second experiment, performed in April 2002, in which also the 12 m telescope on Kitt Peak, the 10 m Heinrich-Hertz telescope on Mt. Graham and the SEST telescope in Chile participated, resulted in the detection of relatively strong (SNR <~ 75) correlated signals on several AGN. With fringe detections on the 8500 km long VLBI baseline between Arizona and Spain a new world record in angular resolution was set (~ 20 uas).

A significant enhancement of the sensitivity of mm-VLBI was achieved in autumn of 2002 when, in a collaboration with IRAM, first fringes were found with the phased IRAM Plateau de Bure interferometer. A further enhancement will come when the VLBI recording bit-rate can be brought up to 1 Gbit/s with MK5 (being foreseen for early 2003).

A water vapour radiometer has been constructed, primarily for phase correction of 86 GHz VLBI experiments, which will also be useful during high-frequency EVN observations for atmospheric opacity correction. We are currently conducting commissioning tests in Bonn, and the opacity measurements will eventually be included in the amplitude calibration data for distribution to EVN users.

A dual-frequency GPS receiver has been installed at Effelsberg for measurement of the zenith tropospheric delay for inclusion in the VLBI correlator model and for tying the VLBI reference point into the local geodetic network. Data from the receiver are being archived daily and will be used during a test EVN phase-referencing experiment to see how much improvement one obtains by using the GPS-measured troposphere. This is work in collaboration with the Geodetic Institute at the University of Bonn

Walter Alef and Alan Roy act for MPIfR in EVN's e-VLBI project. Financing of a 1 Gbit/s fibre connection between the telescope at Effelsberg, the institute in Bonn, the University of Bonn network, and the gateway of the German Research Network (DFN) to the European Geant backbone via the Ministry for Education and Research is actively pursued since summer of 2002.

5.7. Metsähovi Radio Observatory, Finland

5.7.1. Technical support for VLBI operations

After feedback from Bonn correlator regarding tape playback quality it was decided that Metsähovi will not use thick tapes in the future. It is known that some of the recorder tracks are corrupted. In autumn Jouko Ritakari and Ari Mujunen investigated the recorder for finding out if the recording quality can be improved. The head stack was found to be slightly (app. 20 micrometers) but not dangerously (app. 30 micrometers) worn out. Thin tape vacuum level was increased to 9in to improve tape-to-head contact and this seems to have helped with recording quality. The second head installation is still pending. New cooling fans were installed to the BBC rack in April. In September 2002 the BBCs were blow-cleaned, guiding walls were added to the BBC rack, and even more efficient cooling fans were installed to both BBC and MK IV formatter racks.

A new 2 and 3~mm SIS receiver has been ordered from Nizhny Novgorod, Russia. With this receiver at 84--115.5~GHz simultaneous circular dual-polarization measurements should be possible, at 129--160~GHz only right or left hand polarization can be chosen at a time. The receiver will operate in a SSB mode for both bands. The receiver has a broadband (1~GHz bandwidth centred at 3,95~GHz) continuum output and standard VLBI outputs at 500--1000 MHz.

Attempts to repair the right channel LNA for the 43~GHz VLBI receiver (originally designed at National Radio Astronomy Observatory, USA) were unsuccessful. The fourth stage seems to have a catastrophic failure and also the fifth stage showed instability problems. In order to repair the dual channel receiver to be operational and reliable in the future completely new LNAs were ordered from Ylinen Electronics. These are based on the MMIC techniques with two cascaded INP-HEMT chips (each chip contains 4 HEMT stages). The frequency response is broadband from 40 to 46~GHz. At the centre frequency of 43~GHz the gain and the noise temperature are (at cryogenic temperatures) 45~dB and 20~K, respectively. The receiver will be assembled with these new amplifiers and the corresponding power supplies in 2003.

The 22~GHz and 86~GHz receivers are functioning normally.

Geodetic Observatory has ordered a new receiver from the TTI Norte, Santander, Spain which will be used at Metsähovi for geodetic VLBI observations. The receiver operates at two different bands i.e.~8.150--8.650~MHz (X-band, BW=500~MHz) and 2.210--2.350~MHz (S-band, BW=140~MHz). The right hand circular polarization can be observed for both bands. The system temperature of this receiver is around 80~K when the LNAs are cooled to 15~K and the bulky feed system and polarizers are at room temperature. The receiver was delivered to Metsähovi in December by the TTI Norte personnel. Some mechanical changes to the receiver and a new, larger subreflector is also needed before the actual observations are possible.

Metsähovi received two new Russian Kvarz H-masers in April. The installation took less than a week. The Russian H-maser, Kvarz-69, replaced the old EFOS-9 H-maser as the station frequency reference. The other Russian H-maser, Kvarz-70, is used to monitor the performance of the Kvarz-69 and, if necessary, to tune it by using automatic frequency control.

5.7.2. Development of Next Generation VLBI Recording Systems

During the year 2001 it became obvious that the speed and capacity of normal personal computers and hard disks would quickly surpass the tape-based recorders normally used in VLBI. MRO started a project to develop a commercial-off-the-shelf VLBI data acquisition system.

The development was based on the following assumptions:

- MRO will only develop minimal data acquisition hardware.
  Commercial companies take care of the personal computer development.
- Data is treated as normal files in Linux filesystem,not as special VLBI data.
- The system must be low-cost and scalable. Because the cost of one data acquisition system is low, several units can be used to achieve high data rates.
- The system must support common VLBI standards: Mk4, VLBA,VSI-based gigabit VLBI, and S2.

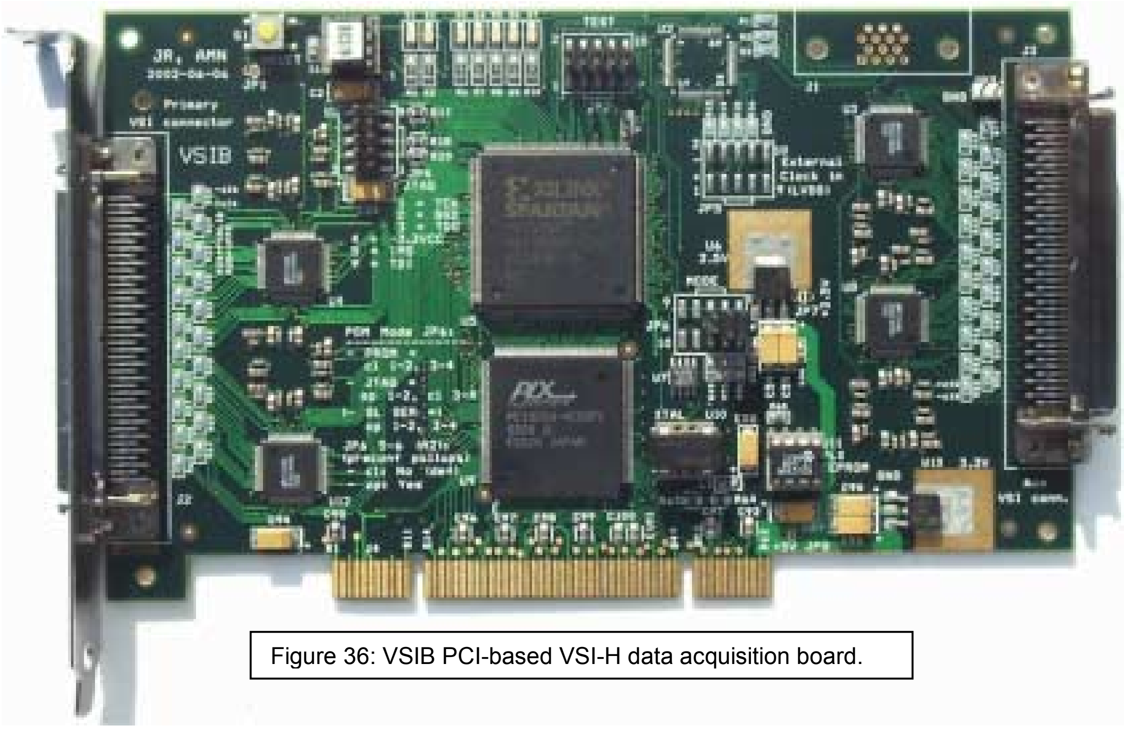


Figure 36: VSIB PCI-based VSI-H data acquisition board.

The data acquisition system would consist of two hardware modules: An VSI-H standard compliant data acquisition board for a personal computer and a multi-standard to VSI-H converter module.

Figure 37: The two-PC prototype used to record gigabit VLBI data

The PCB design of the prototype data acquisition and converter boards was completed in January, the boards were assembled and tested in February-March and the design was adopted for mass-production in April. One final production-quality VSIB data acquisition board is shown in Figure 37.

The operation of the data acquisition system was demonstrated at JIVE, Netherlands in July 2002. A series of 93 data acquisition and converter boards were produced at the start of August using the automated SMT production line of the HUT Laboratory of Electronics Production Technology.

The MRO data acquisition system was successfully tested in the Jodrell Bank Observatory - JIVE iGRID eVLBI demonstration in September 2002.

On 16th October 2002, Metsähovi and Kashima Space Research Center performed the world's first intercontinental gigabit eVLBI experiment using the MRO developed data acquisition system at Metsähovi and the Japanese PC-VSI2000-DIM data acquisition system at Kashima. The prototype equipment is shown in Fig. 36.

5.8. National Astronomical Observatory, Spain

5.8.1. The 40-m radio telescope

The construction of the new 40 meter radio telescope in Yebes is progressing on schedule. The concrete pedestal is erected, and the telescope backstructure (see Figure 38), bearings, gearboxes, and panels are being fabricated. The telescope is expected to be finished in 2003, and operations will start in 2004. More information can be found at the URL http://www.oan.es/cay/40m/.

5.8.2. Software development

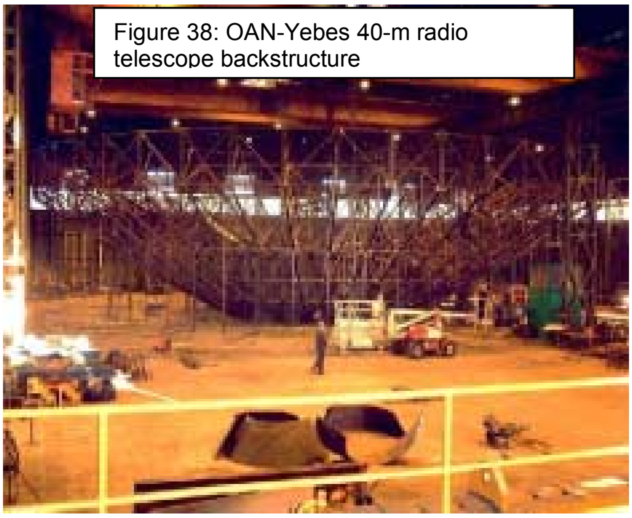


Figure 38: OAN-Yebes 40-m radio telescope backstructure

The operating system for the FS PC has been updated from Debian 2.0 to Debian 3.0, which provides enhanced security tools. This installation was not standard since neither the EVN nor the geodetic VLBI communities have given any information on how to perform this step and there is no new version provided by GSFC. The old version included both the OS and the FS, while the approach we have followed in Yebes is to have an OS (Linux Debian) which can be constantly updated and once running, compile and install new versions of the FS on that system.

In order to ease this transition for other observatories we have written a memo in English(IT OAN 2002-6), available from our web server in which we describe step by step how to install and configure a Debian 3.0 system on the FS PC. We also describe how to install and configure special devices such as a multiport serial card or the GPIB board. The memo also describes how to install the latest FS version and keep all the previous files (logs, procedures and schedules). The memo is available in the following link: http://www.oan.es/informes/archive/fs-linux-eng.pdf

In our case, the FS does not have direct communication with the antenna control and therefore we need to synchronize the observations "by hand". The antenna observation schedule is therefore generated by a program which reads the snap file and computes the start, stop and tracking times for all sources in a session, and later transferred to the antenna control computer. This conversion program, which we developed in 1998, was heavily modified in 2002 to improve phase-referencing observations with our 14-m dish. This work is summarized in the technical report IT-OAN 2002-1 (http://www.oan.es/informes/archive/hp-vlba.pdf)

5.8.3. Hardware development

In 2001 we installed a MK4 decoder and a MAT communication box that connects the decoder with the FS PC. The decoder was placed in the same small rack where the MK4 formatter was, and used the same power supplies. Both, the MK4 formatter and MK4 decoder, were on the top of the original VLBA rack. This work is described in the technical report: IT-OAN 2001-11 (http://www.oan.es/informes/archive/mk4-decoder.pdf)

In 2002 we removed the old VLBA formatter (which did not work properly) from the VLBA rack. In the same location where the VLBA formatter was, we placed the MK4 decoder and the MK4 formatter. These two modules were connected to the power supplies in the VLBA rack which previously were used by the VLBA formatter. We also attached the MAT box supplied by the EVN to communicate between the FS and the MK4 decoder and formatter to the VLBA rack.

The station timing unit was modified to add a new output connector from which we can extract an 80Hz signal which allows us to make continuous calibration as done with the VLBA antennas. This work is summarized in the technical report: IT OAN 2002-9 (http://www.oan.es/informes/archive/recableado-vlba4.pdf)

5.8.4. Other equipment

The Observatory has accomplished some tasks to monitor in real time some parameters of the S/X receiver, in particular, voltage and current in the different stages of the amplifiers, temperature and pressure in the cryostat box, and temperatures in different places near the 14M dish (like the maser room, the receiver platform and the control room).

To achieve that goal we installed a digital multimeter and cables connecting this equipment located in the receiver platform with the control room where a dedicated PC collects all data. The multimeter takes data from several channels and sends this information to a PC where the data are processed, archived and sent to a local web page so that the astronomers and engineers can see them. This work is documented in the technical reports: IT OAN 2002-3 (http://www.oan.es/informes/archive/parametros.pdf) and IT OAN 2002-10 (*http://www.oan.es/informes/archive/monitor-14m.pdf*).

5.9. Shanghai Astronomical Observatory, P.R. China

The MK4 2-Head recording of Seshan station is available from the beginning of 2001. A fringe test for 512M/s data rate had been conducted successfully in 2001.

The Field System has been upgraded to the 9.5.17 version at the Shanghai station by the time of the EVN session 3 in 2002.

The X-band (8 GHz) system has been upgraded to a wider band (8.2-9.0 GHz). This X-band receiver system is in use for geodetic experiments since the beginning of 2001

Quick frequency switching at the Seshan radio telescope has basically been finished by the end of 2002. It covers C-, K , and S/X-bands. The feeds and receivers of C- and K-bands have been moved to a new place, and the S/X feeds are still in the original place.

The sensitivity at 22 GHz is limited by the accuracy of the main plane of the antenna. Preparations for adjustment of the main plane of the antenna in 2003 are underway.

With support by ASTRON and JIVE, Shanghai VLBI station was working on new C- and L-band dual-polarization cooling receiver systems. It is expected that the new C- and L band receivers will be available in June of 2004 and 2005, respectively.

5.10. Toruń Centre for Astronomy, Poland

Further steps were undertaken to improve the reliability of Torun VLBI station. Two more CTI 1020R helium compressors were purchased and installed in 2002. The action allows us to keep the key receivers in the cooled state permanently and to switch between them in matter of seconds. This is very important for the network operation flexibility since requested change of observing frequency will not result in lose of data. New improved IF distribution module was designed, built and installed. It has replaced the older one who had been found to show excessively high channel cross-talk. The new IF distribution has in between-channel isolation better than 50 dB, it also provides ability to remotely regulate gain levels and the slope of frequency response in order to eliminate frequency-dependent losses in coaxial cables. The above improvements have great impact on reliability and sustained operation of Torun telescope in EVN network as these allow fast change of the receivers and easy, reliable automated operation. In effect the most common man made errors in the process of VLBI operation have been significantly reduces.

Some simple observational tests were made at 86 GHz and 110 GHz with receivers borrowed from Sweden. These were used to improve pointing, tracking and to measure aperture efficiency. Further tests aiming towards high frequency operation were performed at 12 GHz with single channel uncooled receiver. The primary goal for this complementary to VLBI activities project is to do the antenna holography. In addition to major task a methanol 2.5 cm line has been surveyed among known strong 5 cm maser sources. The holography project will continue. The first results on surface error distribution are encouraging. Further observations and measurements are scheduled for summer 2003. The holographic measurements are done using Eutelsat W2 satellite 11.7 GHz beacon. Two-channel receiver uses BBC units to convert beacon's signal to acoustic range. The correlation of both channels recorded on PC is done off line. The measured RMS error of the antenna surface is about 1 mm, what is about 3 times higher than the designer's specification. Thus the final goal is to reset the surface panels to significantly improve aperture efficiency of high (10-30 GHz) frequency operations. The work can lead to increased sensitivity by about 50% at 22 GHz and to achieve the planned cut-off limit at 50 GHz. This work is very important development for planned extension of frequency operation range of the EVN. There are not so many telescopes in the network capable to observe at 22 GHz and higher frequency bands. Thus Torun 32m can add significantly its value. The current work at 30 GHz (project OCRA) leads also to pointing / tracking improvements and to optimization of a secondary mirror motion.

Construction of the 22 GHz receiver has continued. The two-feed three-channel system has already been installed in the dewar, but we have not yet purchased (due to financial problems) the image filters and mixers.

There has been considerable improvement made in 2001 and 2002 on data formatting and recording terminal. The MkIV formatter has been put into operation and two headstack recording has been introduced. Several BBC's were repaired, broken LO synthesizer in one of them was replaced with the new one delivered by Jodrell Bank. Remotely controlled attenuators were added on A and C inputs of the terminal. Now four more BBC's are inspected and will be installed soon in the rack. Currently used field system computer looks to be too obsolete for new FS versions and needs to be replaced in 2003. Such change will further ease the terminal operation. In December 2002 a programmable attenuators were installed at the IF inputs of VLBA rack. The all above mentioned work have been carried out by local staff and is financed from the local (University and Science Foundation) sources. The work made for EVN rewards the observatory in general reliability and high quality performance of all scientific activities.

5.10.1. Improvements of services and management

A significant activity is done in respect of better management and organization. The local Friend of VLBI – Dr. K.Borkowski, who's salary is paid directly from the ICN project, has been totally involved into coordination of all instrumental test measurements, organization of test and EVN observations as well as into the analysis of station activity. He is responsible for all activities related to time measurements and H-maser maintenance. This is particularly important task since the atomic clock and the GPS based time service are fundamental for the high quality sustained EVN operation.

A lot of new organizational changes were introduced. An improved log-book, with extensive check list, puts high demands on telescope operators. Regular, weekly meetings of the staff and monthly reviews of current problems and the progress are being held. In the effect the quality and reliability of Torun station improves from session to session. Also the state of the art measuring and testing equipment, essential for VLBI observations, is used much better way since new organizational scheme has been introduced.

5.11. Urumqi Astronomical Observatory, P.R. China

In 2001-2002, the dual-polarization 18cm receiver system was upgraded to a cooling system in July 2002, the Tsys goes down to 20K. The 1.3cm receiver was fixed in 2002, it gives fringes in recent EVN experiment. The 6cm and S/X band system upgrade are undergoing, some problems in the current systems were solved, performance has been improved. The antenna maintenance has been made. One of H-masers has been repaired, but still has some problems. Some problems with MKIV head position have been investigated and fixed, but parity error is still high sometimes in some tracks. Double head recording has been successful. Field System was upgraded accordingly to FS9.5.17, and the new settings for continuous Tsys measurement were tested. We have problem with ON-OFF program in FS.

5.12. Bundesamt für Kartographie und Geodäsie, Wettzell, Germany

The development of the digital data recording system in the last months supported the transition of the newly installed MK4 system towards the MK5 system. The RTW was involved early in the test of the MK5 digital data recorders. The daily “Intensive” observations of 1 hour with Kokee Park were an ideal test series for the new technique. The amount of data could be recorded with only one hard disk, which has to be send to the correlator as fast as possible. This enables the tests of MK5P resp. MK5A and the robustness of the disks for transportation. At the beginning of the test the data were recorder with both recording devices, namely with Mk4 on tapes and with Mk5P on hard disks. Recognizing the real improvement in particular for the correlation and realizing the reliability of the MK5, the disks and the transport, the Intensives with Kokee park were performed only by recording with MK5 on disks.

First test to establish e-VLBI feasibilities have been carried out. A data file was transmitted from the University Regensburg, where RTW has access to the next high speed Internet connection, to Haystack, in order to test the capacity of the link and to search for bottle necks which reduce the transmission speed dramatically. At first it turned out that via the 155Mbps link only a transmission speed of 5 Mbps could be obtained. After improving the internal throughput of the computer and adopting some parameters, a reliable transmission speed of 40 Mbps could be achieved. For further applications and tests a 34Mbps link is requested for the RTW which will be installed soon. The main goal will be the data transmission of the “Intensives” to the correlator. It is expected that the transmission will be done within a few hours, which is a real gain compared to the delay caused by transportation of the hard disk via a courier.

6. EVN and JIVE publications – 2001-2002

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;

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