# MERLIN/VLBI National Facility

## Biennial Report

## 2003-2004

MERLIN

EUROPEAN VLBI NETWORK

The University of Manchester
Jodrell Bank Observatory

PPARC

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## 2003 - 2004

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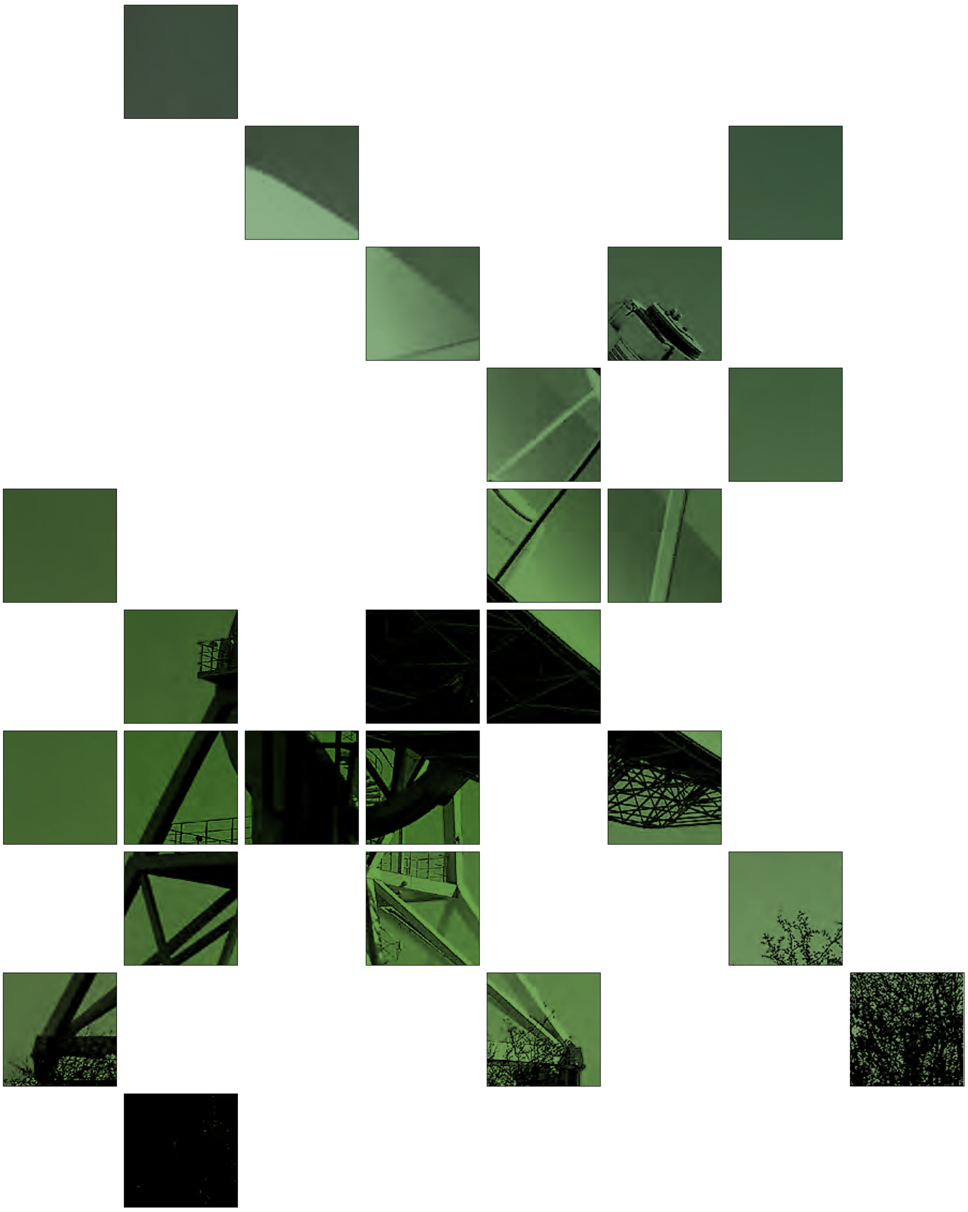

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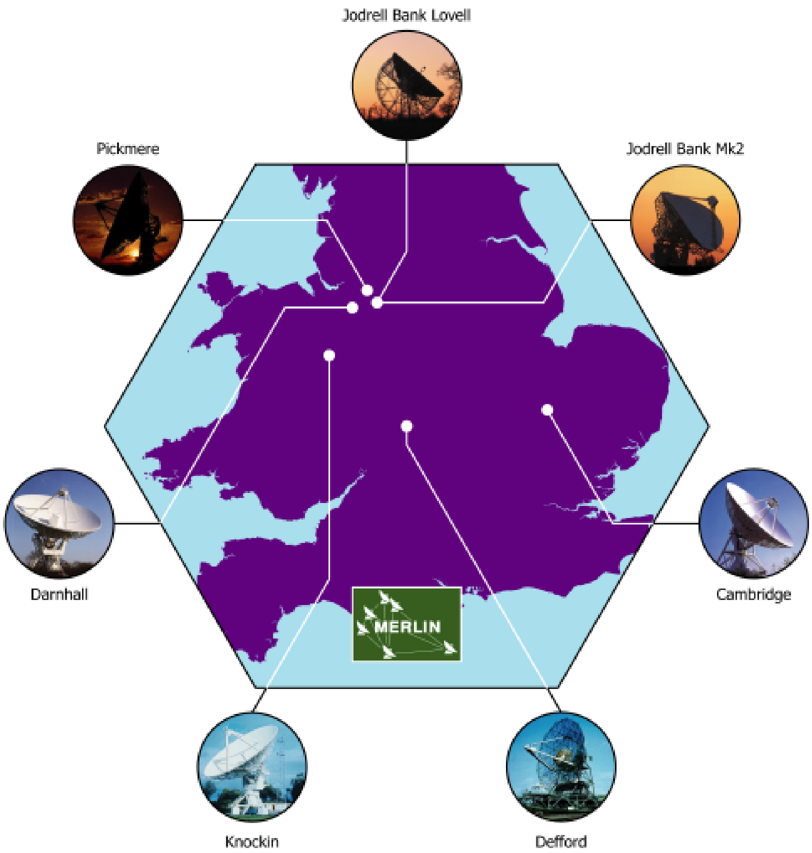
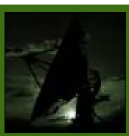
## MERLIN/VLBI NATIONAL FACILITY

The MERLIN/VLBI National Facility, operated by the University of Manchester on behalf of PPARC (Particle Physics & Astronomy Research Council), is the radio astronomy cornerstone of the United Kingdom's astronomy programme. MERLIN (right) is a sensitive 6-element interferometer network (7 when the Lovell telescope is included), with baseline lengths between 11 and 217 km that routinely produces radio images with an angular resolution that matches that of the Hubble Space Telescope (HST). The National Facility is also a regular participant in European and global VLBI (Very Long Baseline Interferometry) observations (below), which achieve the highest resolution of any branch of astronomy. This report covers the activities of the National Facility during the calendar years 2003 and 2004.







# INTRODUCTION

MERLIN (the Multi-Element Radio Linked Interferometer Network) is an array of seven radio telescopes distributed over central England and operated from Jodrell Bank Observatory (JBO) as a National Facility by the University of Manchester on behalf of PPARC (Particle Physics & Astronomy Research Council). The outlying telescopes are connected via microwave links to a central correlator situated at Jodrell Bank. This combination of radio antennas forms the equivalent of a single, integrated radio telescope and is able to image astronomical objects with very high resolution at frequencies from 151 MHz to 24 GHz. MERLIN is the only world-class astronomical facility based entirely within the UK. The key to MERLIN's success is its high angular resolution. With radio telescope separations of up to 217 km, it is the only ground-based facility in the world that routinely matches the resolution of the Hubble Space Telescope (*HST*) and the new generation of 8-m class optical/IR telescopes such as Gemini and the Very Large Telescope (VLT). The capabilities of MERLIN are listed in Table 1. Further details concerning the array are available at http://www.merlin.ac.uk.

MERLIN was developed contemporaneously with the USA's Very Large Array (VLA). It was a concept that emerged from the pioneering experiments in long-baseline interferometry at Jodrell Bank in the 1960s and 1970s. MERLIN was designed to provide sub-arcsecond imaging of astronomical sources at centimetre wavelengths. The original design goals were quickly surpassed, both technically and astronomically, and MERLIN was immediately recognised as a front-rank instrument. A major upgrade in 1990, in which the resolution was increased by nearly a factor of 2 and the sensitivity by almost an order of magnitude, ensured that MERLIN was transformed into a general-purpose instrument capable of attacking a wide range of astrophysical problems. It has thus remained a world-class facility and is recognised as one of the leading strengths of UK astronomy.

A new upgrade is currently underway, aimed at providing a major broadband capability to MERLIN. The capabilities of the upgraded instrument, *e*-MERLIN, and the current status of the upgrade project are discussed elsewhere in this report.

MERLIN is a National Facility open to all users. As with other UK telescopes, the observing year is divided into two observing semesters (February to July and August to January). All observing proposals are peer-reviewed and, if appropriate, allocated observing time by the Panel for the Allocation of Telescope Time (PATT) of PPARC. PATT allocates MERLIN observing time based on the perceived scientific merit of proposals and the actual observing time available in a given semester. In order to maximise the efficiency of operation, flexible scheduling is employed so that observations are not normally scheduled in detail more than a few days in advance. This allows the array to take maximum advantage of prevailing weather/atmospheric conditions or technical limitations. Observers are not normally expected to be present during observations but can visit Jodrell Bank Observatory for data reduction, although increasing numbers of experienced users now retrieve data remotely.

MERLIN often observes simultaneously with the European VLBI Network (EVN), an array of 16 telescopes distributed across Europe, Asia, South Africa and Puerto Rico. In fact, joint MERLIN/EVN observations are one of the most popular modes of observation within the EVN at 1.4 and 5 GHz due to the ability of the joint array to provide images of a wide range of radio structures from the arcsecond scale down to the milliarcsecond scale. The EVN Consortium Board of Directors and its associated Programme Committee and Technical & Operations Group coordinates EVN activities.

VLBI achieves the highest angular resolution of any branch of astronomy, enabling imaging at angular scales as small as 100 microarcseconds. In 1993, the EVN Board of Directors set up the Joint Institute for VLBI in Europe (JIVE) based in Dwingeloo, the Netherlands, as the home of the

*Figure 1: The 76-m Lovell telescope at Jodrell Bank Observatory, a crucial element of both MERLIN and the European VLBI Network (EVN).*

| Band (Wavelength) | K (1.3 cm) | C (5 cm) | C ( 6 cm) | L (18/21 cm) | P (73 cm) | VHF (2 m) |
|---|---|---|---|---|---|---|
| Frequency Range (MHz) | 21 - 24 GHz | 6000-7000 | 4500-5200 | 1300-1430<br>1550-1730 | 406-410 | 150.5-151.5 |
| Number of Telescopes | 5 | 5[a] | 6 (7)[b] | 6 (7)[b] | 6 (7)[b] | 6 (7)[b] |
| Resolution (arcseconds) | 0.008 | 0.04 | 0.04 | 0.15/0.13 | 0.5 | 1.4 |
| RMS Noise Level[c,d] after 12 hours (μJy/beam) | 400 | 100 | 50 (35)[e] | 60 (35)[e] | 700 | 7000 |

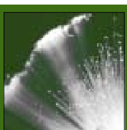
*Table 1: Capabilities of MERLIN. Notes: (a) Five MERLIN antennas were equipped with new C-band receivers by the end of 2004. (b) The Lovell Telescope can be used instead of, or as well as, the Mk2 telescope at Jodrell Bank at the lower frequencies. (c) Subject to a maximum dynamic range. This depends on source structure, declination and u-v coverage, but is typically 10,000:1 (peak:RMS) for full track observations at the higher declinations. (d) Adverse weather conditions can significantly degrade the performance, especially at the highest frequencies. (e) Inclusion of the Lovell Telescope reduces the RMS noise to ~35 μJy/beam.*

| Wavelength | 1.3 cm | 5 cm | 6 cm | 18/21 cm | 49 cm | 92 cm |
|---|---|---|---|---|---|---|
| Number of EVN Telescopes | 10 | 10 | 11 | 11 | 4 | 5 |
| EVN Resolution (mas) | 0.3 | 5 | 1.5 | 5 | 16 | 30 |
| Global Resolution (mas) | 0.25 | - | 1.0 | 3 | 10 | 19 |
| EVN Sensitivity (μJy/beam) | 84 | 52 | 12 | 10 | 300 | 1000 |

*Table 2: Capabilities of the EVN. Note that the EVN also observes at 30 cm, 3.6/13 cm and 7 mm but the National Facility telescopes are not equipped at these wavelengths. The sensitivity estimates are from the EVN User Guide and assume 8 hours on source with 1 Gbit/second data rate (equivalent to 16 x 16 MHz with 2 bit sampling). The 92 cm and 49 cm values are based on these but scaled using estimates of the system performance and available bandwidth at these wavelengths.*

EVN data processor. The EVN has been at the forefront of VLBI developments, transforming its capabilities with new technologies. The EVN was the first astronomy VLBI network to adopt the new disk-based Mk5 recording system, developed at Haystack Observatory. This capability, together with the large radio telescopes at Effelsberg, Jodrell Bank and Westerbork, make the EVN the instrument of choice for high sensitivity VLBI. The VLBI capabilities of the EVN are listed in Table 2.

*Figure 2: The EVN Correlator is operated by the Joint Institute for VLBI in Europe (JIVE), which is hosted by ASTRON in Dwingeloo, the Netherlands.*



# DIRECTOR'S REPORT

Over the period 2003-2004, the MERLIN/VLBI National Facility has continued to provide excellent data to its users, as is demonstrated in the science highlights in this report. However, attention within the National Facility has inevitably focused on the high-profile *e*-MERLIN upgrade project, which is proceeding on schedule and within budget. These developments have been matched by equally impressive developments in the world of broadband and e-VLBI in which National Facility staff and telescopes have played a major and influential role. The workload that these projects generate has meant that the pressure on the staff, emphasised in the previous Biennial Report, has increased and so we will continue the tradition established two years ago of providing a comprehensive, yet succinct, Biennial Report.

Elsewhere in this report, there is a comprehensive update on the current status of the *e*-MERLIN project. The project is on track to be completed in 2007/8. However, users are already seeing the benefits of the upgrade: new broadband C-band receivers have been deployed and used in several user projects. Indeed, one of the science highlights shows the first $CH_3OH$ maser image made with MERLIN. More capabilities will follow within the coming months. Funding for the upgrade project has been provided by the Universities of Manchester and Cambridge, the North West Development Agency, PPARC and, more recently, a welcome contribution from Liverpool John Moores University.

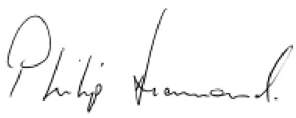
*e*-MERLIN will be, by some measures, the most powerful radio interferometer in the world. It will be competitive with and complementary to the new generation of telescopes (optical, IR, mm and sub-mm) now in operation or under construction. It will also act as a pathfinder for the next generation of radio telescope, the Square Kilometre Array (SKA), providing experience on the operation of a broadband (210 Gbps) fibre-optic network spread over several hundred kilometres and addressing some of the science areas outlined in the SKA science case. The new instrument will have significantly greater sensitivity than at present, allowing new areas of science to be opened up, particularly in the fields of extragalactic astronomy and cosmology, star formation across the universe, stellar evolution and studies of the extreme conditions around black holes.

Since the time of the last Biennial Report, we have seen the capabilities of the European VLBI Network (EVN) take a major leap forward. Mk5 disk-based recording systems are now installed at all of the EVN stations and are in routine operation; indeed, in 2005, the first all-disk observations have occurred within the EVN. The older tape-based systems have been retained to enable compatibility with the VLBA. The development of e-VLBI has been dramatic and rapid with, as presented in this report, the first science results emerging from the prototype e-EVN. In addition, the use of ftp-VLBI across the network has resulted in an increase in reliability as problems at stations can be diagnosed and rectified rapidly, thereby minimizing the impact on the users.

Generally, therefore, the news is positive. However, funding of operations continues to be of great concern. As mentioned in the previous Biennial Report, the operational funds for the National Facility were cut in 2001/02, as were those of other UK observatories, in order for the UK to join ESO. For MERLIN, this was at a time when a major upgrade was starting and so the impact could be mitigated since science operations were reduced to the minimum possible. However, the National Facility is now looking forward to the operation of *e*-MERLIN, with early science hopefully being delivered in 2007. In order to operate this major and complex telescope the National Facility budget must be increased to a viable level and a case to address this problem has been submitted to PPARC.

*Figure 3: Prof. Philip Diamond, Director of the MERLIN/VLBI National Facility.*

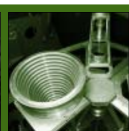
The scientific output of users of MERLIN and the EVN continues to impress. Over the period covered by this report, a period of major construction for *e*-MERLIN, the number of papers published that have used National Facility telescopes is 117, only 6 less than in the previous reporting period, despite the restricted capabilities during the upgrade. In addition, National Facility staff have published another 14 papers using other telescopes. The range of science addressed by the National Facility continues to be broad, as is shown in the scientific highlights section.



P. J. Diamond

Director, MERLIN/VLBI National Facility





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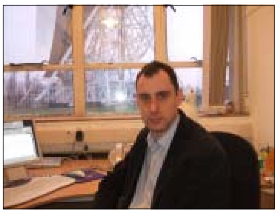
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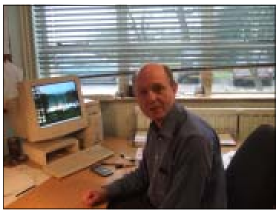
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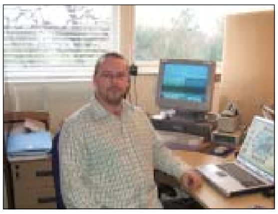
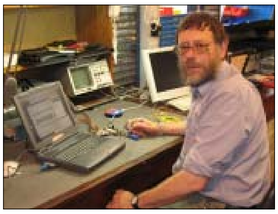

A. G. Gunn


R. G. Noble


R. J. Beswick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A. M. Bayley


R. McCool


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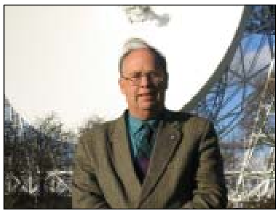
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C. D. Baines


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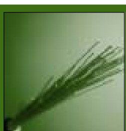


## Overview & Highlights

During 2003 and 2004, astronomers have continued to exploit the strength of the MERLIN/VLBI National Facility instruments to investigate a wide range of astronomical objects; from nearby stars to high redshift galaxies. At the heart of many of these projects is the unique range of angular scales accessible through MERLIN and EVN observations, which has provided the zeroth order impact. However, during this reporting period, two complementary enhancements - the availability of the newly refurbished Lovell telescope for observations at 5 GHz and the deployment of new methanol-band observing capabilities on the majority of the MERLIN telescopes - have considerably added to the range of astronomical phenomena that can be studied by MERLIN. In total, observations using the National Facility instruments have produced 117 refereed publications during 2003 and 2004 (see Appendix E: National Facility Publications). Examples of these scientific results, which demonstrate the diverse and original science programmes that have been undertaken, are presented in this Section. The references indicated by square brackets are to be found in Appendix E. Other references can be found on page 26.

A few years ago PPARC conducted a Long-Term Science Review (LTSR) which identified four major themes of strategic importance: cosmology, including such questions as the origin, large-scale structure and eventual fate of the Universe and the nature and distribution of dark matter; the formation and development of galaxies; star formation and planetary systems; extreme environment astrophysics. As can be seen in the science highlights reported below, many of the key results from the National Facility over this reporting period address the LTSR themes. The results profiled on gravitational lenses (e.g. [29]; [98]), star-formation at high redshift and in nearby galaxies address issues of great importance for cosmology and cold dark matter. The work on neutral gas (e.g. [18]), megamasers (e.g. [75]) and ULIRGs (e.g. [110]) is of direct relevance to the formation and development of galaxies. The new results on methanol masers obtained with the first fruits of the *e*-MERLIN project provide unique information on the processes of star-formation, especially in the high-mass regime (e.g. [38]). Finally, the astrophysics of extreme environments is studied at high spatial resolutions through work with MERLIN on relativistic jets (e.g. [64]), microquasars (e.g. [41]) and supernova remnants (e.g. [62]).

## Gravitational Lenses & Cosmology

The study of gravitational lenses is one of the few ways of learning about the distribution of dark matter in galaxies and the only way that can be used for distant galaxies. The distortion of the image of a distant object by a lens depends upon its mass distribution and, the more complex structure of the object being imaged, the more lines of sight through the lens that are sampled. It turns out that lensed radio sources are some of the best probes of dark matter because they have structure on a wide range of angular scales and radio arrays such as MERLIN and the EVN have the ability to map these structures in great detail. Two of the most suitable systems are CLASS 0631+519 and CLASS 0128+437.

York *et al.* (2005) report the discovery of a new gravitational lens system, CLASS 0631+519. VLA, MERLIN and VLBA observations show it to have a doubly-imaged radio core, a doubly-imaged lobe and a second lobe that is probably quadruply-imaged. The 1.7 GHz MERLIN map, overlaid on the *HST* I-band image, is shown in Figure 4. The VLBA resolves the most magnified image of the flat-spectrum radio core into a number of sub-components spread across approximately 20 milli-arcseconds. Optical and near-infrared imaging with the *HST* shows that there are two galaxies along the line of sight to the lensed source. The nearer galaxy at z=0.0896 is a small blue irregular, while the more distant galaxy at z=0.6196 is an elliptical, which appears to contribute most to the lensing. The host galaxy of the lensed radio source is visible in a NICMOS image as a set of arcs that form an almost complete Einstein ring. A smooth, isothermal, mass model has been used to reproduce the radio features and the optical/IR ring.

Earlier VLBA (including Effelsberg) observations of the gravitational lens system CLASS 0128+437 by Biggs *et al.* (2004) at three frequencies - 2.3, 5 and 8.4 GHz -

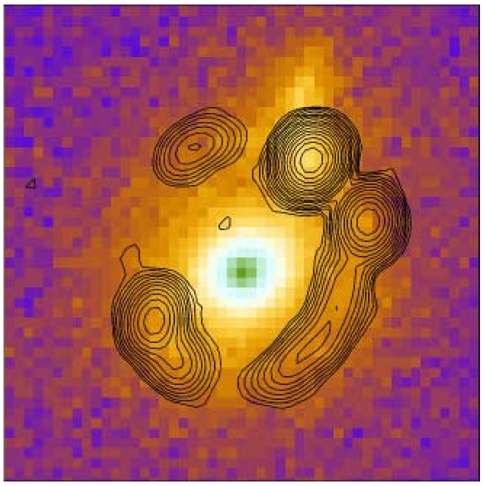
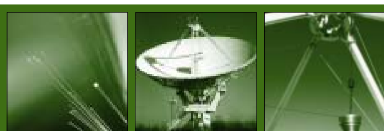


*Figure 4: MERLIN 1.7 GHz image (contours) of the gravitational lens system CLASS 0631+519, overlaid on the HST I-band image (colour). The HST image shows the two galaxies in the lensing system, and the MERLIN image reveals a large amount of detail that can be used to make mass models of the lens.*



have revealed that the lensed source consists of three well-defined subcomponents that are embedded in a more extended jet. As the subcomponents have different spectral indices, it is possible to determine unambiguously which part of each image corresponds to the same source subcomponent. The main finding was that one of the images looked very different from the others, there being no obvious division into separate subcomponents with the image being apparently both broader and smoother. This is believed to be a consequence of scatter-broadening in the interstellar medium of the lensing galaxy. New higher surface brightness sensitivity 1.4 GHz observations with the EVN (Figure 5) show much more extended structure, the subcomponents of which provide an abundance of modelling constraints. In this case, it has proved difficult to obtain a satisfactory model fit, which strongly suggests the presence of substructure in the mass distribution of the lensing galaxy, perhaps of the kind that is predicted by cold dark matter theories of structure formation.

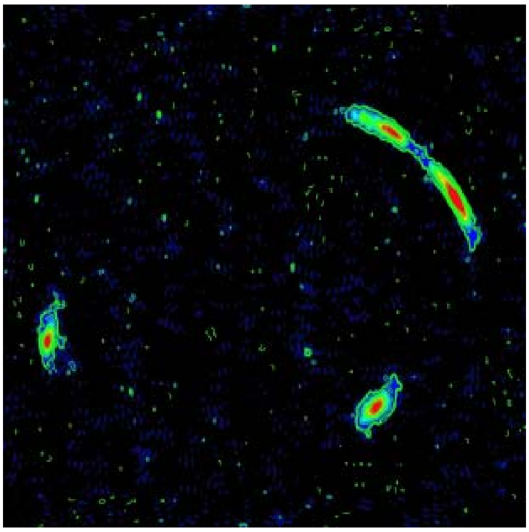


*Figure 5: CLASS 0128+437 is one of the most interesting gravitational lens systems found during the CLASS survey. Model fitting to the 1.4 GHz EVN image (above) has proved difficult, which strongly suggests the presence of substructure in the mass distribution of the lensing galaxy.*

## Star Formation at High Redshift

Deep MERLIN+VLA high-resolution imaging of a sample of 92 radio sources brighter than 40 μJy at 1.4 GHz in a region enclosing the Hubble Deep Field North (Figure 6) has shown that the very weak radio source population is dominated by star-forming galaxies. More than 70% of the radio sources in the sample with flux densities <60 μJy have been identified as starburst systems (Muxlow *et al.* 2005a). Most of the starburst systems with confirmed spectroscopic redshifts ($z$) have been found to lie in the redshift range 0.3<z<2, with implied luminosities and star-formation rates significantly greater than nearby, well-studied, star-forming galaxies (Figure 7). There is an additional tail to this distribution comprised of 'sub-mm' starburst galaxies extending to very high redshifts approaching ~4.

85% of the sample are found to be associated with galaxies brighter than R~25$^{mag}$ and an initial statistical survey of the radio emission at the positions of

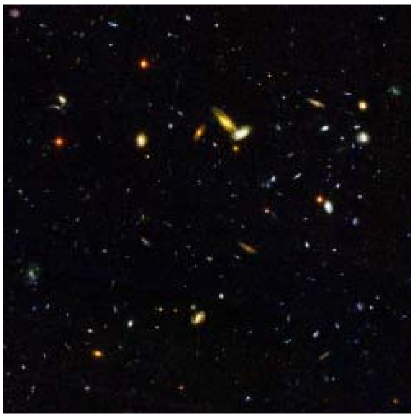


*Figure 6: The HST multi-colour image of the Hubble Deep Field (HDF) North, one of the most distant optical views of the Universe, showing countless distant galaxies.*

every galaxy in the central 3x3 arcminutes of the field shows that this association with optically brighter galaxies is also true for radio source detections of only a few μJy in strength. A full investigation of the statistical properties of the extremely weak radio detections across the whole sample field is now in progress, utilising new ACS data for this region.

*Chandra* has detected X-ray counterparts (Alexander *et al.* 2003) for 50 of the radio sources from the sample with measured redshifts. No correlation has been found between the rest-frame radio and X-ray luminosities. Moreover, 18 of these objects show the hardened X-ray characteristics of obscured AGN (Padovani *et al.* 2004), but the radio emission is only similar to that of an AGN in 4 of these sources, whereas 10 of them appear to be radio starbursts. It appears that the radio and X-ray emission have separate origins within the majority of active galaxies at $z$=1, providing additional evidence that super-starbursts are fuelling massive black holes. Further investigations are underway using Virtual Observatory tools.

## Star Formation in Nearby Galaxies

A deep, 8-day integration with MERLIN at 5 GHz has produced the most sensitive high-resolution image of M82 yet achieved, with an RMS noise level of approximately 17 μJy/beam. This establishes a new baseline image for future deep radio images with *e*-MERLIN and allows detailed comparisons with the original MERLIN 5 GHz image over a timeline of almost ten years (Muxlow *et al.* 2005b). New, deeper, more detailed images of a number of supernova remnants (SNRs) within M82 have resulted in the measurement of expansion velocities for the first time using MERLIN. Figure 8 shows the new results from SNR 43.18+583, which has now been imaged with a signal-to-noise ratio of ~35. Comparisons between the latest deep image and that of the first epoch in 1992 show that the partial shell structure has expanded. Average brightness profiles in circular annuli registered on the dynamical centre of the SNR show that the radius of the shell has moved outwards by 7±0.5 mas in the intervening period. With a derived expansion velocity of 10,500±750 $kms^{-1}$ and assuming linear expansion, the object is thus found to be only 53 years old.

## Supernovae in Nearby Galaxies

Ten nearby starburst galaxies have been observed regularly since late 2003 with MERLIN and the VLA in order to monitor their radio emission and to search for new supernovae. In one of these galaxies, NGC6946, in which seven new supernovae have occurred in recent times, a new, bright (magnitude 12.7) Type-II supernova was discovered on 27 September 2004. The supernova (SN2004et) was located in the outer regions of the galaxy and, although only a single MERLIN baseline (De-Ca) was available for observations due to summer engineering, radio emission at 5 GHz was detected from it early in October 2004. Subsequent monitoring of the supernova, initially on an almost daily basis, resulted in a very well sampled radio light-curve (Figure 9) and a considerably improved position, accurate to within a few tens of milliarcseconds ([17]; Argo *et al.* 2006). Even though the radio emission from SN2004et did not rise above a few mJy, it has been the subject of a major global VLBI observing campaign, which, one hopes will result in the resolution of this source during future epochs.

NGC2403 is a nearby galaxy within the M81/82 group that has harboured two optical supernovae in the last 50 years (SN1954j and SN2002kg, with magnitudes of 16 and 19 respectively). On 31 July 2004, a third was discovered: SN2004dj. At a magnitude of 11.2, it is the brightest optical supernova for over a decade. During the summer of 2004, the VLA was in D-configuration and was unable to unambiguously separate the SN2004dj radio emission from the

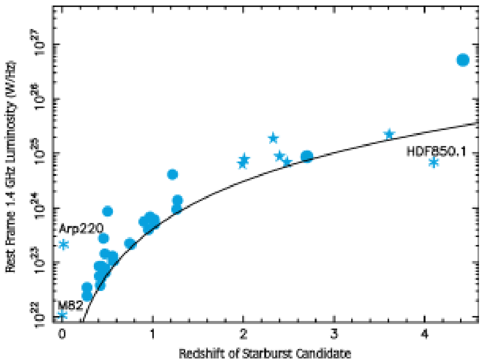



*Figure 7: Distribution of the radio luminosity against redshift for starburst galaxies with measured redshifts in the μJy radio source sample surrounding the HDF (North). Those starburst systems identified as 'sub-mm' sources are identified with five-sided star symbols, triangles mark two high redshift systems with possible embedded AGN and asterisks show named starburst systems for comparison. The plotted line marks the detection threshold of 40 μJy for sources assuming a spectral index (α, $S=v^{\alpha}$ ) of α=0.7 ($\Omega_V$=0.7, $\Omega_M$= 0.3, $H_0$ =65 km $s^{-1}$ $Mpc^{-1}$ ).*

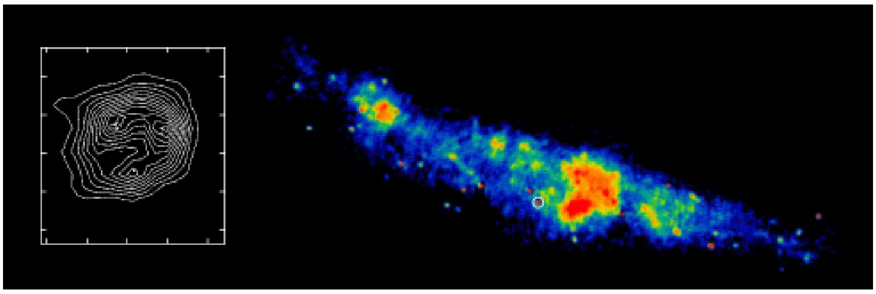


*Figure 8: A deep integration with MERLIN at 5 GHz of M82 achieved an RMS noise level of approximately 17 μJy/beam. The inset contour map shows MERLIN 5 GHz observations of the supernova remnant SNR 43.18+583 within M82 (circled).*

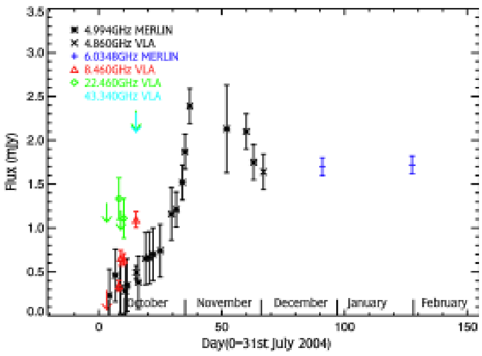



*Figure 9: A 'light' curve of the radio emission from SN2004et in NGC6946, using MERLIN and the VLA at various frequencies.*

extended emission of the host galaxy. However, MERLIN 'downtime' observations, using a sub-set of antennas, were able to detect SN2004dj at 5 GHz, measure its flux density and produce the most accurate position so far recorded for this source. Continued monitoring resulted in a well-sampled early radio light curve for this Type II-P supernova. The observations, which were carefully phase-referenced, using three independent calibrators, resulted in a positional accuracy of better than 0".050. With the exception of the unusual and very close SN1987a, these observations represent the *first* detailed radio light curve for the emission from a Type II-P supernova (Beswick *et al.* 2005).

## Cold Neutral and Molecular Gas Absorption in NGC 3079

NGC3079 is a well-studied, nearby (16 Mpc) edge-on galaxy containing a LINER/Seyfert 2 nucleus. In the optical, this exquisite edge-on spiral is partially obscured by a dense dust lane covering the western side of the optical disk. *HST* narrow-band H$\alpha$ and *Chandra* X-ray observations have shown a number of out-flowing filaments that form a spectacular 'super-bubble' perpendicular to the galactic disk. This super-bubble is thought to be driven by a combination of strong stellar winds and supernova explosions in massive nuclear star-forming regions. As well as this super-bubble of hot X-ray emitting gas, *Chandra* also detects a highly obscured active galactic nucleus (AGN). The sub-arcsecond angular resolution of MERLIN has been used to make a detailed study of neutral and molecular gas within this galaxy.

Extensive HI, OH (1665 and 1667-MHz) and $H_2CO$ (4829-MHz) absorption has been imaged against the central kiloparsec of NGC3079 (Figure 10). In this region, at least five velocity components are required to characterise the HI and OH absorption structure. By separating and imaging these components, it has been possible to trace the nuclear and galactic disks, as well as the outflows, which are possibly part of the base of the 'super-bubble'. Complementing these HI and OH absorption results, the inclusion of the recently refurbished Lovell Telescope within the MERLIN array has enabled one of the first MERLIN detections of extragalactic formaldehyde ($H_2CO$) via absorption. To date, $H_2CO$ 6-cm emission (or absorption), has only been detected in 20 extragalactic sources. The $H_2CO$ absorption detected with MERLIN is being used to trace the intermediate-density, cool gas close to the nucleus itself (Strong *et al.*, Beswick *et al.*, in preparation).

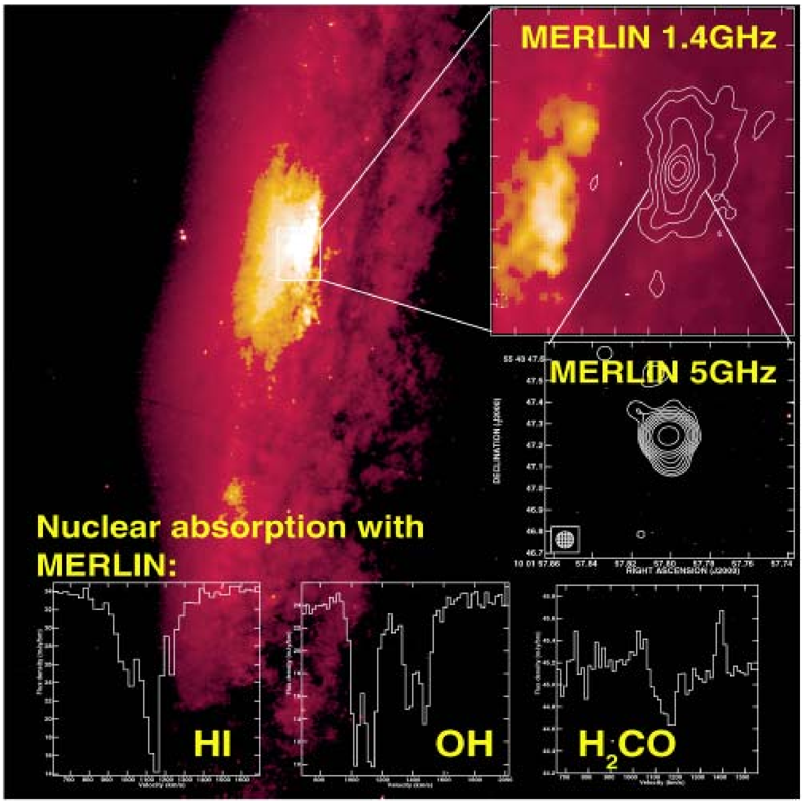



*Figure 10: MERLIN 1.4, 1.6 and 4.8 GHz observations of HI, OH and $H_2CO$ absorption against the nucleus of NGC3079, overlain on an HST image.*

## HI Absorption in Arp 193

The nearby luminous infrared galaxy Arp 193 ($L_{IR}$ = $4 \times 10^{11}$ $L_\odot$) is over an order of magnitude more luminous than M82. Arp 193, which has large optical tidal-tail features, significantly non-circular gas motions and is rich in young stars, is probably the result of the collision of two gas-rich galaxies.

MERLIN HI absorption measurements (Figure 11) have revealed the atomic gas distribution and dynamics within the centre of Arp 193 with an angular resolution equivalent to less than 100 parsecs ([31]). Comparisons of these HI data with CO emission observations indicate significant differences in the projected velocity distribution of the atomic and molecular gas. Assuming



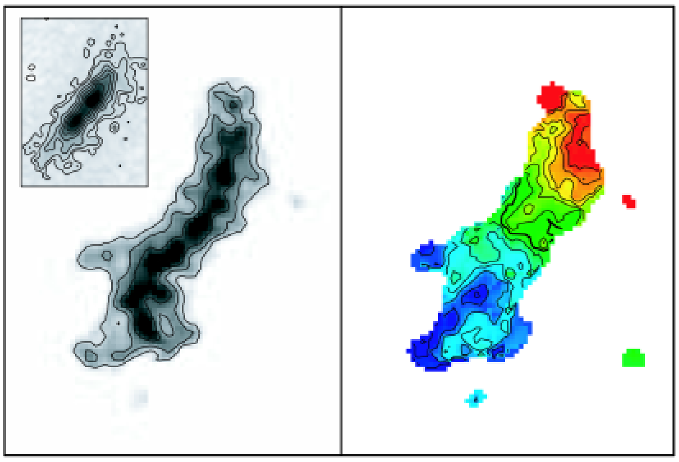


*Figure 11: MERLIN images of Arp 193. The left-hand panel shows the velocity integrated HI absorption profile and the right-hand panel the HI absorption velocity field. The inset image is the 1.4GHz continuum MERLIN image of the galaxy.*

a constant spin temperature and a constant CO flux to $H_2$ mass conversion factor, it would appear that the interstellar medium becomes progressively more $H_2$ rich toward the centre of the sources. The difference in the molecular and atomic gas distributions implies that these two cold gas tracers are situated in different regions as well as having different dynamical structures.

## OH Megamasers in Arp 220

Arp 220 is the nearest of the Ultra-Luminous Infrared Galaxies (ULIRGs) with an $L_{fir}=1.4\times10^{12} L_{\odot}$ and provides one of the best examples of the starburst phenomenon. This was dramatically demonstrated by the VLBI discovery of several tens of compact mJy radio sources within the centre of Arp 220, which have been interpreted as radio supernovae (Smith *et al.* 1998). Arp 220 is also one of the brightest OH megamaser galaxies. MERLIN observations of the radio continuum and OH megamaser emission from Arp 220 have revealed the true spatial distribution of these two components ([110]). Toward the eastern radio nucleus of Arp 220, the 1665/1667 MHz megamaser emission and the nuclear radio continuum emission are spatially coincident, whereas toward the western nucleus the OH maser emission is situated in two clumps, north and south of the radio continuum source (Figure 12).

The OH maser emission in the eastern nucleus traces a shallow velocity gradient of 0.32 $kms^{-1}pc^{-1}$. This is consistent in direction but approximately one third of the magnitude of the velocity gradient derived from MERLIN HI absorption observations (Mundell, Ferruit & Pedlar 2001), implying that the OH gas is not spatially coincident with the HI disk. The velocity structure in the western region is far less ordered globally than in the east. However, the detailed velocity structure of the masers in this region does reveal some smaller coherent structures. In particular, in the north-western maser region, velocity gradients are present that are not consistent with simple rotation, whereas in the south-western maser region there is a steep velocity gradient (18.67 $kms^{-1}pc^{-1}$) that could indicate the site of a low mass ($\sim1.7\times10^7$ $M_{\odot}$) AGN.

## Megamasers and the Unified Scheme

Mrk 231 and Mrk 273 are classified as Seyfert types 1 and 2 respectively, suggesting that material orbiting a central AGN is almost edge-on in the former and face-on in the latter. Both systems have undergone mergers and are now ULIRGs with nuclear starbursts. Megamaser observations using MERLIN and the EVN ([74]; [75]; Yates *et al.* 2000) give a complete picture of the OH emission from the central few 100 pc and show that it is unsaturated, low-gain and radiatively pumped in both sources (Figures 13 and 14). Their appearance and kinematics are consistent with their Seyfert classifications, although Mrk 273 shows higher ratios between the maser and continuum flux densities and between the 1667 and 1665 MHz maser line brightnesses, consistent with a greater maser amplification depth in an edge-on disc. This means that the supposed quadratic relationship between maser and continuum luminosity is subject to orientation effects and is nearly linear in edge-on systems.

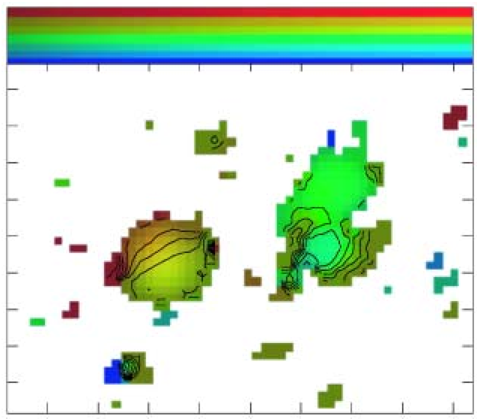
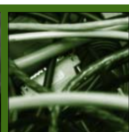


*Figure 12: The moment map of Arp 220 from MERLIN OH 1667 MHz observations. The intensity represents the flux density and the colours the velocity field, the reddest being the most redshifted.*



## High-sensitivity Observations of Markarian 273

High-sensitivity MERLIN+EVN observations of the northern (N) and south-eastern (SE) components of Markarian 273 have been made by Bondi *et al.* ([26]) at 5 GHz (Figure 14). These observations, which included the resurfaced Lovell telescope operating at 5 GHz for the first time, showed that the northern component was split into two main components aligned almost East (N2) - West (N1) with extended emission surrounding these two peaks. The eastern component, N2, has a complex morphology which, from a comparison of these observations with the (VLBA+VLA) observations at 1.4 GHz by Carilli & Taylor (2000), has an integrated spectral index which is almost flat (0.15). Such a spectral index could arise from a superposition of several components with peaked spectra and/or free-free absorption, indicative of matter fragmentation and condensations. This is consistent with findings in the NIR that identify N2 as a compact region with the strongest star formation. Although the western component, N1, has often been considered to be an AGN nucleus, these measurements show that it has a very steep spectral index (1.2). Thus, unless flux density variability has occurred between the two epochs of observation, this result is difficult to reconcile with the AGN hypothesis.

## Cold Gas and Jets in 3C293

The study of the physical properties of the dust and gas at the centres of active galaxies is of great observational interest. Its significance is inextricably linked to the activity observed in these sources since it is the gas and the dust that is ultimately the fuel for the activity. The dust distribution can be studied using optical and infrared imaging, whereas the atomic gas can be studied using the 21-cm line of neutral hydrogen (HI). As well as giving clues to the formation of active galaxies, dust and gas may obscure a direct view to the active galactic nuclei (AGN) and thus affect our ability to view the central optical continuum and broad, emission-line region. The radio galaxy 3C293 is a nearby (D=180 Mpc) moderate sized two-sided Fanaroff-Riley type-II radio source.

As has been demonstrated by earlier MERLIN results (Beswick, Pedlar & Holloway 2002), extensive HI absorption is known to exist against its inner radio structure on almost all scales. This has recently been investigated across a much wider range of angular scales by using a combination of MERLIN, VLA (including the VLBA Pie Town antenna) and Global VLBI ([18]). The combination of these three imaging arrays has enabled both the radio continuum and HI absorbing gas to be imaged on scales ranging from a few tens of mas to many arcsecs (Figure 15). Parallel to these radio studies, *HST* observations have also discovered and characterised infrared and optical synchrotron emission coincident with the positions of the radio knots imaged with MERLIN (Floyd *et al.*, submitted) along the inner jet of 3C293 (Figure 16).

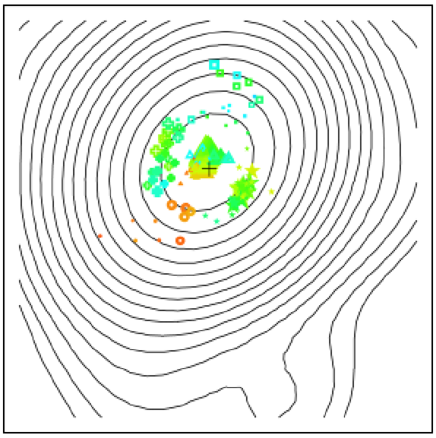


*Figure 13: The 1.6 GHz MERLIN image (contours) of OH megamaser emission from Mrk 231. Overlain are the 1665 MHz and 1667 MHz maser components shown by solid and hollow symbols respectively, the different symbols referring to the different emission regions. The symbol size is proportional to the component flux density.*

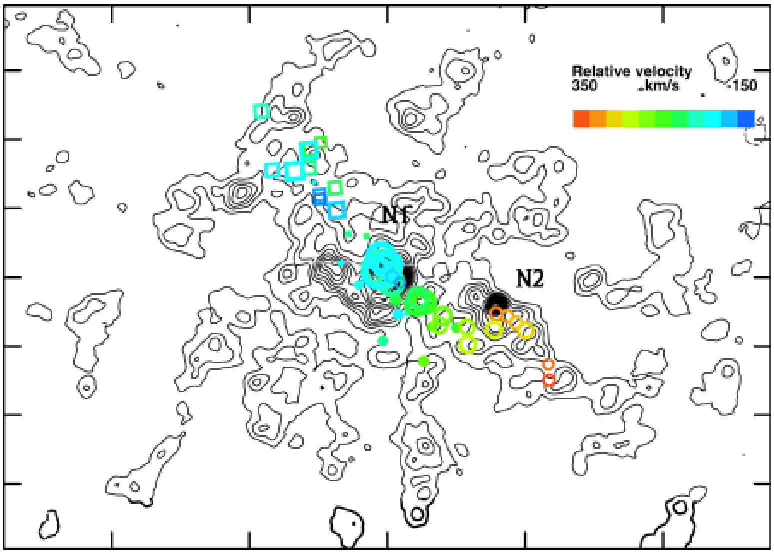



*Figure 14: MERLIN+EVN image of the northern component of Mrk 273 at 5 GHz. Overlain are the 1.6 GHz maser components colour-coded for velocity.*

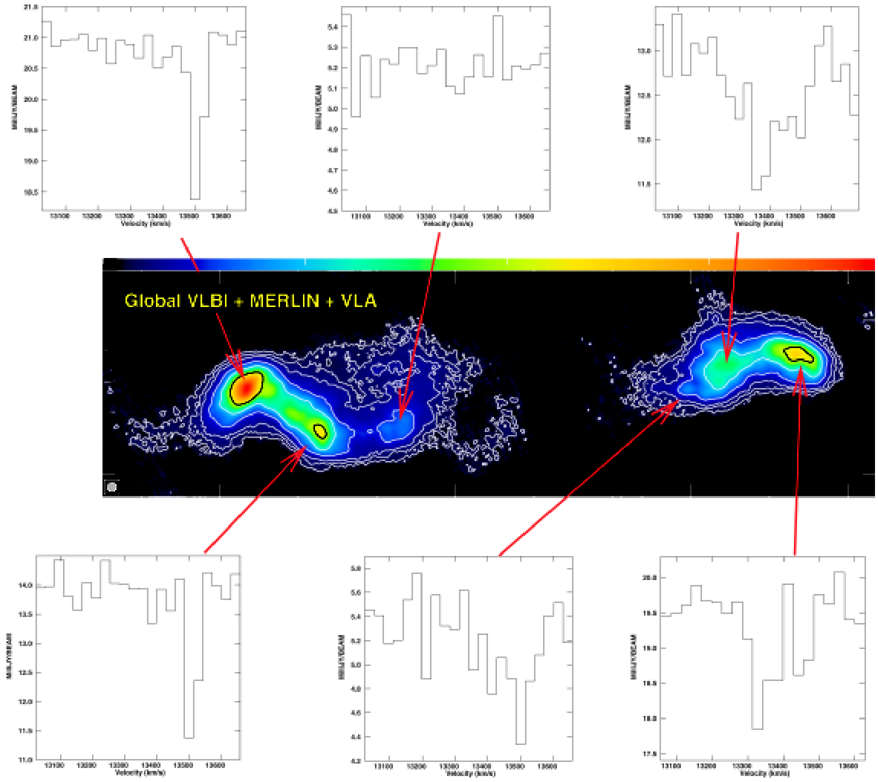



*Figure 15: Combined global VLBI, MERLIN and VLA observations of H*I *absorption against the inner radio jet of 3C293. The insets show the absorption profiles at various positions in the radio galaxy.*

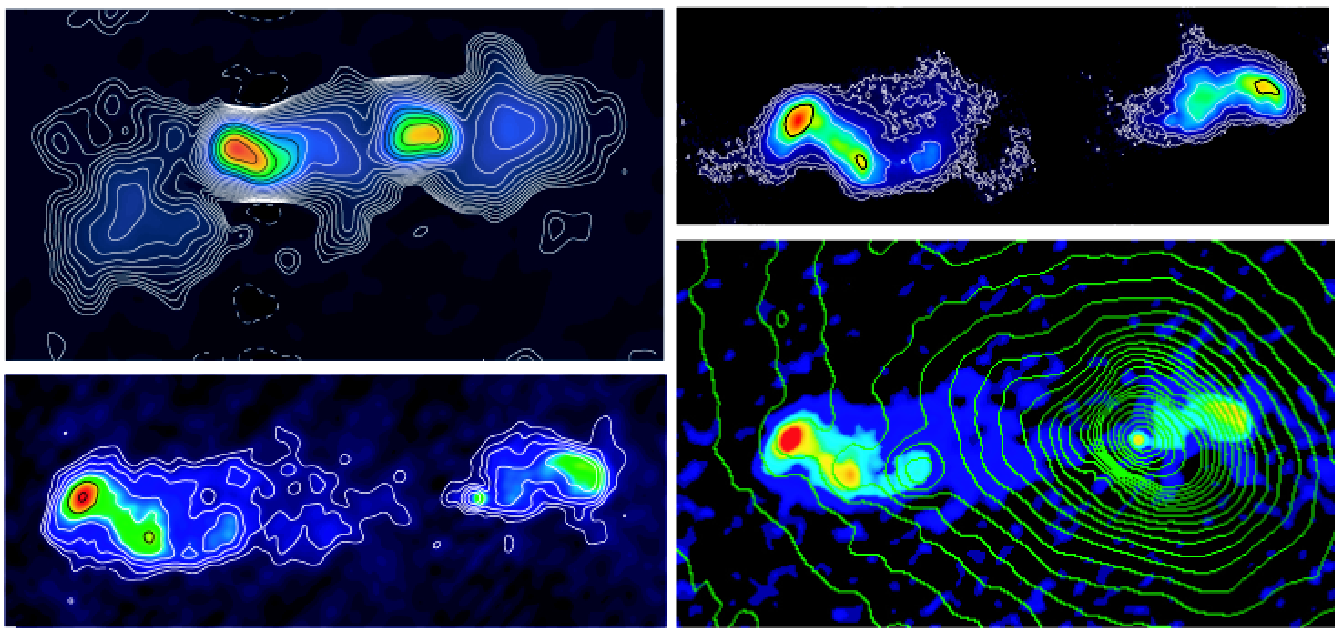


*Figure 16: Multi-scale, multi-frequency views of the inner jets of 3C293. The top left panel shows the 1.35 GHz MERLIN image, top right is the global VLBI, MERLIN and VLA combined 1.35 GHz image, bottom left is the MERLIN MFS 4.5 GHz image and the bottom right panel shows the HST K-band (contours) overlain on the MERLIN 4.5 GHz image.*

## Massive Star Formation in the Milky Way

Methanol ($CH_3OH$) and OH, important tracers of massive star formation, both have radio frequency spectral lines between 6 and 7 GHz. By the end of 2004, five of the MERLIN antennas had been equipped with wide-band C-band receivers, making it the only instrument capable of providing high-resolution astrometry and which is also sensitive to extended

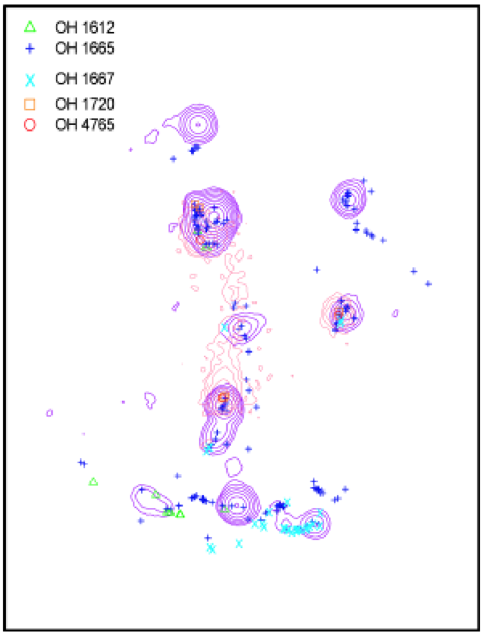



*Figure 17: W3(OH) methanol masers along the zone of interaction around a pre-main-sequence star. The excited OH elongated filament (red) is overlain with the positions of ground state masers (symbols) and methanol filaments (purple).*

structure in this frequency range. This has made it possible to measure accurate positions for about 200 methanol sources, revealing that the masers do not always coincide with known IR cores. However, they appear to provide the earliest detectable indications of massive star formation.

Multi-transition studies of W3(OH) have revealed $CH_3OH$ masers with sizes up to 114 AU. These maser clumps have core-halo structures arising from dense condensations surrounded by diffuse gas (Minier, Booth & Conway 2002). In contrast to this, the OH maser emission at 4765 MHz (Harvey-Smith & Cohen 2005) is seen as an extraordinary 2200-AU filament, apparently tracing a large-scale shock produced by a rotating disc (Figure 17). MERLIN and EVN observations of polarized OH emission at 6031 and 6035 MHz ([38]; Desmurs *et al.* 1998) show a strong magnetic field of up to 1.5 T in this region. Models for the physical conditions and magnetic structures which are being developed (e.g. Gray 2003; Gray & Bewley 2004; [53]), are particularly well-constrained wherever co-propagation of multi-frequency OH masers is detected (e.g. [100]). The differences between the $CH_3OH$ and OH maser structures in W3(OH) seem to show that $CH_3OH$ sublimes off grains before the conditions for OH masing are met.

## First Measurements of Magnetic Fields in Supernova Remnants

Hoffman *et al.* (2005) have imaged the OH 1720 MHz masers in the Galactic supernova remnant W28 using MERLIN and the VLBA. These masers, which have compact cores with transverse sizes of ~60 AU and diffuse emission surrounding the cores extending to over 300 AU, are typical for OH 1720 MHz masers in SNR (e.g. [62]). The Zeeman splitting of the OH 1720-MHz maser emission indicates a magnetic field of ~75 nT. The masers originate from post-shock gas, whereas collisionally-broadened CO emission is found on the rim of the shock front (Figure 18). From the linear and circular polarization measurements, the magnetic field is seen to be well-ordered and aligned with the shock front and its direction is consistent with polarized synchrotron emission from the shock (Dickel & Milne 1976).

## Significant Magnetic Fields in Evolved Stars

The first measurements of the location and strength of magnetic fields in proto-planetary nebulae (PPNe) have been reported from MERLIN observations of OH17.7-2.0 and IRAS 20406+2953 ([9]; [10]). The field strengths are in the range 0.2-0.5 μT at least a few hundred AU from the star. In both cases the masers lie in the equatorial regions of quasi-spherical shells and display ordered linear polarization, which can be modelled by a stretched dipole field (OH17.7-2.0; see Figure 19) or a toroidal field (IRAS 20406+2953). Both sources also show signs of interaction between the

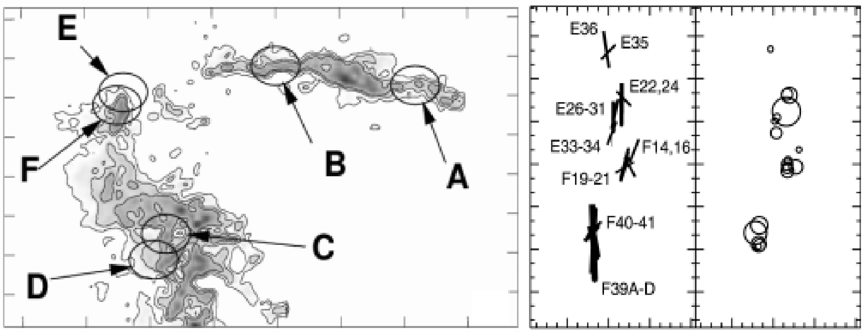
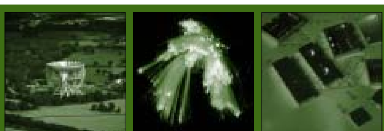



*Figure 18: (left) The positions of 1720-MHz masers overlain on a greyscale of CO emission from the Galactic SNR W28. (right) Polarisation vectors of W28 masers measured by MERLIN.*



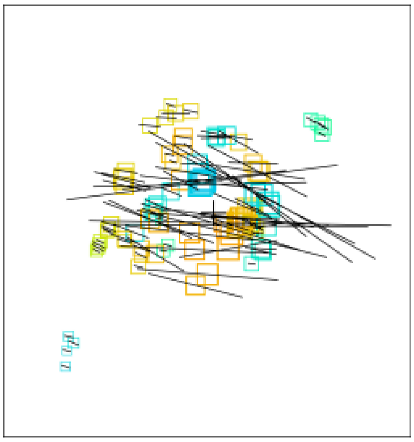


*Figure 19: 1612-MHz maser emission around OH17.7-2.0, showing the linear polarization vectors. The colour scale indicates the velocity range, from 47-75 kms$^{-1}$.*

steadily expanding partial shells traced by the masers and a faster, hotter wind seen in the NIR or radio continuum.

The outermost 1612-MHz masers around the red supergiant NML Cyg (Figure 20) have an almost spherical distribution with tangential polarization vectors. Closer to the star, the 1612 and 1665 MHz maser distributions show that the wind has recently become more bipolar with the polarization vectors following the direction of elongation ([39]). Polarimetric observations of the water and OH masers in two more red supergiants (RSGs), S Per and VX Sgr, have been made using MERLIN (Szymczak, Cohen & Richards 2001) and the VLBA (Vlemmings, van Langevelde & Diamond 2005) and the magnetic fields in the two partially overlapping OH and $H_2O$ maser regions have been determined. It has been found that, if the magnetic field in the $H_2O$ maser region is calculated from an extrapolation of the field in the OH region, this value is a factor of ~50 times less than that actually determined from the $H_2O$ masers. This factor is similar to the density ratio between $H_2O$ and OH mainline maser clumps in the overlap zone (Richards, Yates & Cohen 1999). Where the $H_2O$ masers have an axis of symmetry, as for the OH masers, this is also aligned with the magnetic field (e.g. Richards, Yates & Cohen 1996; [97]), which suggests that the magnetic field is frozen in to the wind close to the star. It would appear that both low- and high-mass objects evolve from near-spherical Mira/RSG winds to become elongated PPNe and post-RSG shells. The energy density of the magnetic fields is sufficient to contribute to the shaping of the nebulae in all cases. Objects with multi-epoch monitoring show no signs of rotation in their envelopes, apparently ruling out dynamically significant companions or even rapid stellar rotation during the slow wind phase. Thus, the origin of the magnetic field is still a mystery but determining its configuration should help in the debate as to whether it is the cause or an effect of asymmetry.

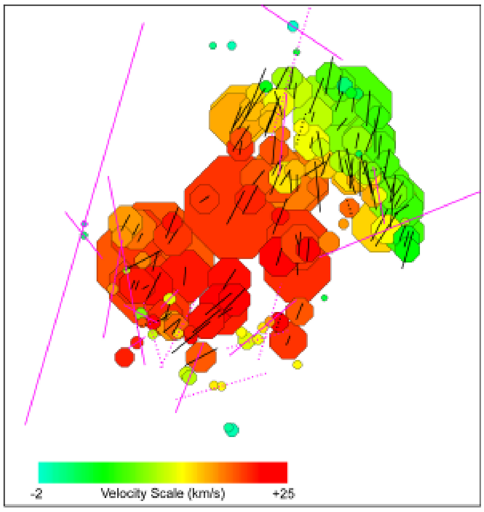



*Figure 20: OH maser emission around NML Cyg with the polarization vectors shown in pink for the 'old' shell and in black for the new more collimated wind.*

# MERLIN OPERATIONS

In addition to the normal operations of MERLIN, the implementation of *e*-MERLIN has also continued and, as new facilities have become available, they have been used for astronomical observations. In fact, development work has continued throughout the observing period and, consequently, the time during which MERLIN has been used for specific test measurements has been included as a separate entity in the operating statistics. Examples of this are: following the adjustment of the Lovell telescope surface, MERLIN, including the Lovell telescope operating at 5 GHz for the first time, was used to obtain a pointing model and a new hologram of the surface; the performances of new wideband C-Band feeds and receivers, which have been installed on the E-systems telescopes, have been assessed. Although not fully completed during the period of this report, nevertheless the implementation of these wideband systems enabled 6 GHz methanol and excited OH line observations to be made for the first time using a majority of the MERLIN telescopes. Prior to this, only single baseline observations at these frequencies were possible.

A summary of the operational status of MERLIN for the calendar years 2003 and 2004 is given in Figure 21. As only limited engineering and maintenance work were undertaken on the Cambridge and Defford telescopes during the 2004 summer months, these telescopes could be used from 5 August for single baseline observations at 5 GHz of two supernovae that occurred in external galaxies (SN2004dj in NGC 2403 and SN2004et in NGC 6946). The operational requirements were very minimal as far as scheduling of the observations was concerned, and the receivers, remaining untouched, continued to operate throughout the period. These observations over a three-month period resulted in light curves and accurate positions for the supernovae, from which several publications have resulted ([4];[17]; Argo *et al.* 2006; Beswick *et al.* 2005). As in previous reports, the sector labelled 'reduced' observations indicates the sum total of short periods when some fault or bad weather affected or prevented the operation of a single telescope, the loss of which was not considered to have a significant effect on the final images produced other than a degradation in the signal to noise. In comparison with previous values of between 6% and 10%, the figure of 17.6% appears to be particularly high. However, the current period also includes lower priority observations made in the absence of a single telescope which was not available because of *e*-MERLIN engineering work. Assuming that only half of the 9.9% summer observing period should be considered as full-time observations, the resulting percentage total observing period of 63.5%, equivalent to 7.6 months, is considerably above the target of 80% of 7 months.

The MERLIN operational bands have effectively been increased from 3 to 4 during the past two years, with all but two of the telescopes (Defford and Lovell) having been equipped with receivers covering the 6 GHz frequency band. Delays in the further adjustment of the new surface of the Lovell telescope mean that this telescope is still considered to be non-operational at 6 GHz frequencies. As can be seen from the summary of MERLIN time allocations (Figure 22), observations at these frequencies now make up 17.5% of the total. This represents a considerable increase in comparison with the previous two years, when only single baseline observations, which took up ~6% of the time, were possible at 6 GHz. The increase in the number of 6 GHz observations has been mainly at the expense of those at 5 GHz, where the average allocation time has decreased from 50.6% to 38.7%. As always, the actual time spent in observations within each band has been set by astronomical demand as determined by the MERLIN Time Allocation Group, the EVN programme

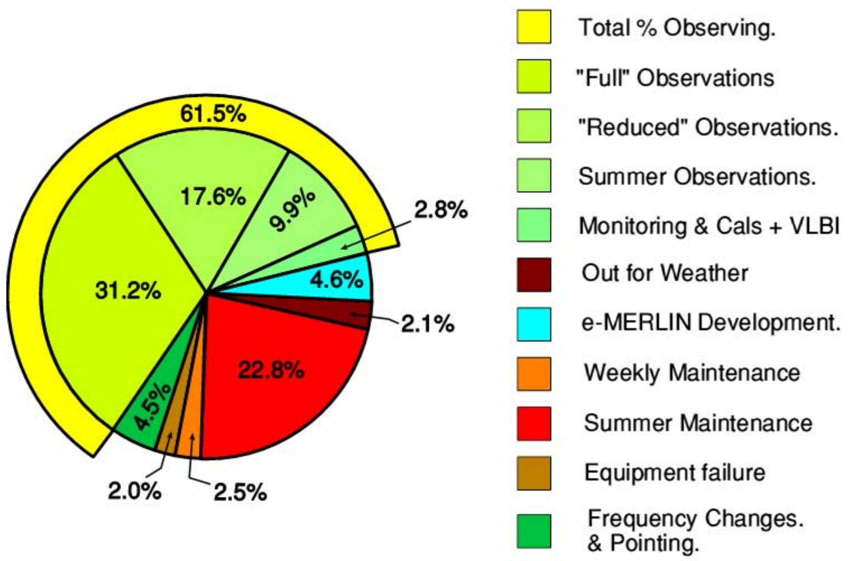
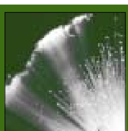



*Figure 21: Summary of the operational status of MERLIN during 2003 and 2004.*



committee for the MERLIN + VLBI observations and, in the case of K-Band observations, the state of the weather. However, the number of frequency changes has been reduced to minimise the time demands on the engineers, who have also been working on *e*-MERLIN development. It is to be noted that the Lovell telescope has been included in MERLIN PATT approved observations for a total of ~74 days, almost doubling the sensitivity.

Of the programmes allocated time by PATT during 2003 - 2004 (including long-term status programmes carried forward from previous Semesters), ~84% of the A-priority and 79% of the B-priority have been completed to date (Appendix B). Most of the L-Band A-priority programmes not completed are those which have long-term status until Semester 05A and which are still continuing. Interference at red-shifted hydrogen frequencies has also prevented completion of some of these. Incompletion of the C-Band 5 GHz and 6 GHz A-priority programmes has been because of the unavailability of the Lovell telescope, in particular at 6 GHz frequencies. As indicated earlier, whenever a single telescope has been absent because of *e*-MERLIN development, lower priority observations have been undertaken. This has resulted in many C-priority programmes (nominally designated fill-in) being completed. These observations do not appear in the statistics presented on page 20. It is to be noted that the above statistics only refer to the PATT allocated programmes and therefore do not include MERLIN+VLBI runs allocated by the EVN programme committee.

In comparison with the previous two years, there has been a considerable reduction in the number of MERLIN visitors who have come to Jodrell Bank Observatory to process their data (from 70 to 37, although a number have come on several occasions and their total stay has been very many weeks in total). This is partly due to increased and easier access to the MERLIN archive. Not only is the number of astronomers who are accessing the archive remotely increasing, but also the much easier access to data for the MERLIN staff has enabled them to make more edited and calibrated spectral line data remotely accessible to off-site users.

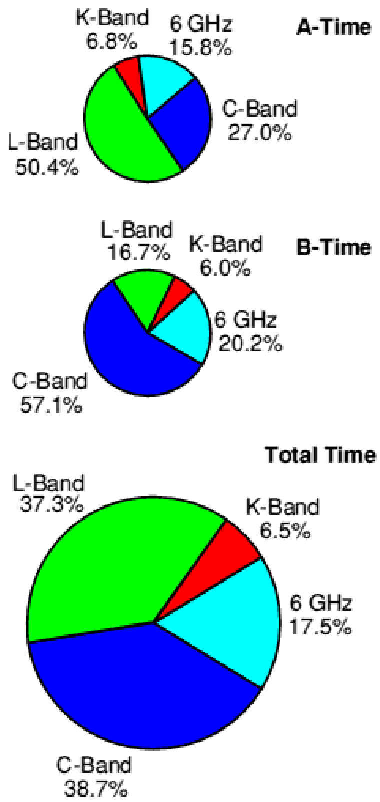
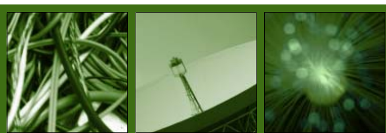



*Figure 22: Summary of MERLIN time allocations for each observing band and proposal rating.*



# VLBI OPERATIONS

The European VLBI Network (EVN) carries out VLBI observations that typically involve 9 telescopes from 6 European countries plus China. The array has a maximum baseline length of over 9000 km, but is often used in conjunction with 10 or more other telescopes around the world to provide a global array with milliarcsecond resolution. The National Facility plays a key role in the EVN, with the Lovell Telescope providing one of its cornerstone large telescopes. Since all the telescopes are permanently staffed, the EVN can sustain the highest data rate of any VLBI array, which, in conjunction with its large telescopes, makes it the most sensitive network in the world.

During the period 2003-2004, the National Facility 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 6, 18/21 and 90 cm, and the 32-m Cambridge telescope at 1.3, 5, 6 and 18/21 cm. In addition, the MERLIN telescope at Darnhall was used for VLBI observations at 5 cm. National Facility telescopes were scheduled for 118 VLBI projects - a total of 1653 telescope hours. Seventeen of these experiments were joint EVN+MERLIN observations for which MERLIN provides short baselines allowing source structure to be mapped on scales from a few milliarcseconds to several arcseconds. Diagrams showing the use of National Facility telescopes and observing bands during 2003-2004 are shown in Figure 23. During this two-year period, a total of approximately 241 telescope hours (14.5%) were lost due to technical problems at the time of observation, astronomer/operator error or weather. Most of this percentage was due to the failure of a local synthesiser during the November 2003 session. A breakdown of the failure rates is shown in Figure 24.

The May 2003 session was a busy one as most of the February 2003 session was moved to May 2003 so that a serious crack in the Effelsberg azimuth track could be repaired. The first C-band observations using the Lovell telescope were performed during the November 2003 session. Although the VLBI equipment and the telescope itself performed excellently at this new frequency, a failure in a local synthesiser, which caused a 220 kHz frequency offset, compromised all the C-band observations with the Lovell telescope. In contrast, the May 2004 session saw no time lost due to weather or technical difficulties. Part of the reason for the success rate in May 2004 was the reliability and ease-of-use of the Mk5 disk-based recording units. For the November 2004 session, the Mk2 telescope did not return from engineering work on the drive system in time for its allocated K and C-band observations. The K-band observations were cancelled, but for C-band (5 cm) the MERLIN antenna at Darnhall was substituted for the Mk2. Since the 5 cm observations were mostly narrow-band (2MHz channels), the limited MERLIN microwave link bandwidth was not a constraint and the astronomers were thus provided with the requested data. In fact, since Darnhall was equipped with a new cooled *e*-MERLIN C-band receiver, its sensitivity was much better than would have been achieved with the Mk2 telescope.

By May 2004, a wear fracture was beginning to become apparent on the Lovell telescope wheel girder, as a result of which its use for phase referencing was further restricted. Since this time, astronomers

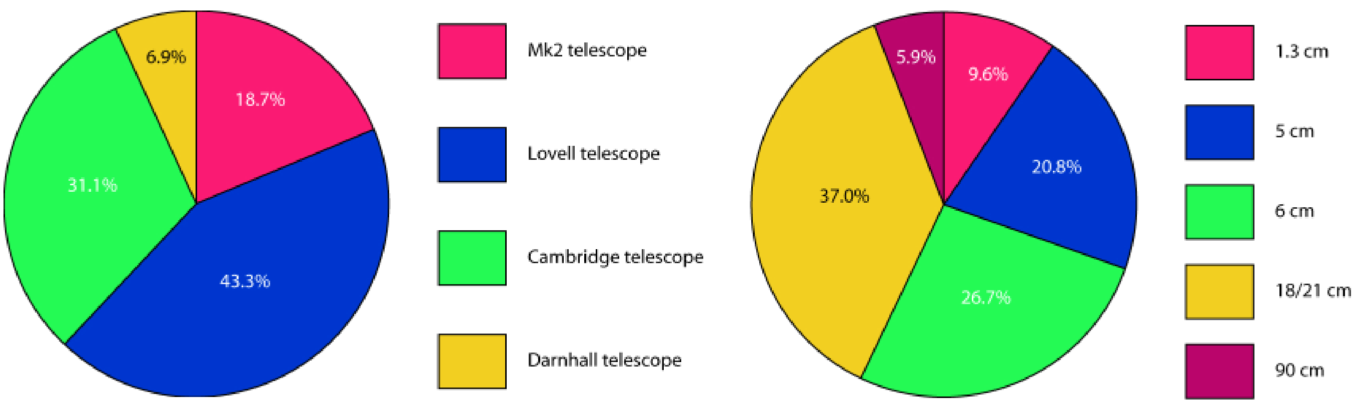



*Figure 23. (right) Percentages of total allocated VLBI observing time spent with different National Facility telescopes for 2003-2004. (left) The percentage of total allocated VLBI observing time spent at each of the observing wavelengths for 2003-2004.*

have been given the opportunity of switching to the Mk2 telescope instead as a temporary solution. As a longer-term solution to including the Lovell telescope in phase referencing observations, a dedicated experiment was run in 2004 to assess whether the Mk2 telescope can adequately track Lovell phase corrections. It was found that delays could be easily tracked over a 10 minute cycle time (the current Lovell constraint) and further investigations are ensuing to allow this method to be generally available. Part of this investigation also includes the possibility of recording both Mk2 and Lovell data on a single Mk5 unit, allowing Cambridge to be included in the VLBI and/or MERLIN array.

Two major advances in the National Facility VLBI capabilities have been made since the last Biennial Report. Firstly, both MkIV and VLBA recorders now have disk-based replacements. The Mk5 units, designed by MIT Haystack Observatory and supplied by *Conduant*, are direct replacements for the older tape-based recorders. Both Mk5 systems are now in regular use for both FTP and real-time VLBI testing, as well as user experiments. In fact, only the experiments to be correlated in Socorro are now recorded on tape. The other significant change is that the PPARC-funded VLBI-dedicated Gigabit fibre Internet link to JIVE, to be used solely for e-VLBI applications, was commissioned in December 2004. A test observation on 20th December 2004 was crucial for the National Facility since it was the first to use the new dedicated fibre. Good fringes were obtained at 128 Mbps and 256 Mbps using both tcp/ip and udp data transfer, although success was intermittent at 512 Mbps due to data-rate problems on the network. Overall, the test was very encouraging.

Further control and monitor software improvements have been made. In particular, the use of 'ONOFF' (automatic gain-elevation and CAL diode temperature acquisition) for the Mk2 and Lovell telescopes has now been successfully implemented by resolving conflicts between the Field System control software and the local antenna control software. It is still not possible to measure total power through the microwave link for Cambridge, although solutions to this problem are being developed for the *e*-MERLIN era.

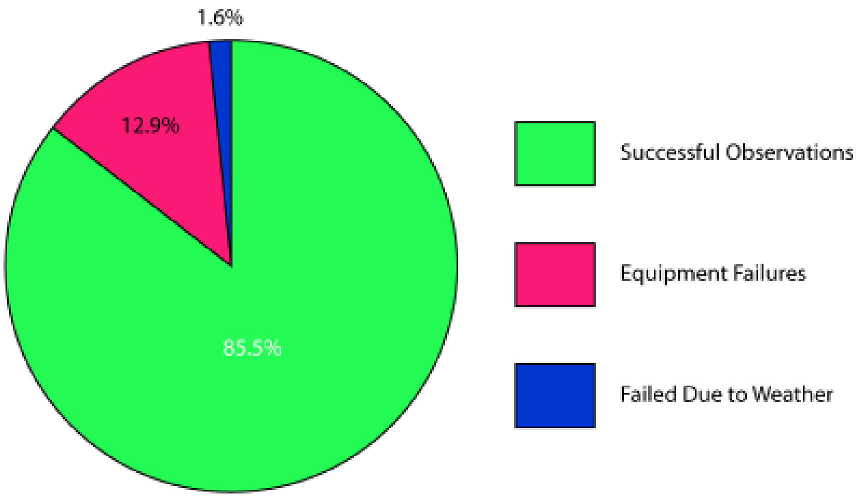



*Figure 24: Operational statistics for VLBI observations carried out by the National Facility in the period 2003-2004.*

# STATISTICS

☐ During the two-year period covered by this report, MERLIN observations were made for 61.5% of the time. A further 4.5% of the operating time was taken up with frequency changes and essential pointing calibration.

☐ 84% of MERLIN PATT Priority A observations and 79% of Priority B observations were completed successfully.

☐ 102 proposals were received for the use of MERLIN during semesters 03A, 03B, 04A and 04B (Figure 25). 73.6% of these had at least one UK proposer and 42% had UK PIs. The oversubscription factor for the period was 2.1.

☐ During 2003 and 2004, 214 individuals were named on MERLIN proposals, from 92 institutes worldwide. 85 of these were based in the UK, from 21 institutions.

☐ Excluding JBO researchers, 19 separate MERLIN observers came to the National Facility to process their data in 2003 and 18 during 2004.

☐ The National Facility was scheduled to take part in 1653 telescope hours of VLBI observations during 2003 and 2004.

☐ During the period 2003 to 2004, the EVN Programme Committee received 109 proposals, of which 16 had UK PIs and a further 11 had UK Co-Is.

☐ The number of papers based on National Facility observations in refereed journals during the reporting period remains at approximately 50 per year. The proportion of MERLIN-only papers (as opposed to MERLIN+VLBI or VLBI-only papers) has dropped slightly during this period. National Facility staff have published a further 14 refereed papers that do not contain observations resulting from NF telescopes. Inclusion of the 2004 EVN Symposium papers and unrefereed papers relating to the NF telescopes brings the total number of publications to 131 (Figure 26).

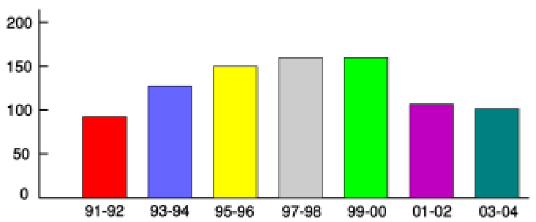



*Figure 25: The number of MERLIN proposals received in the period 1991-2004.*

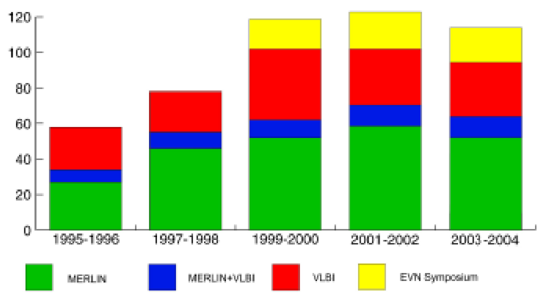



*Figure 26: National Facility publications over the period 1995-2004. The bar chart includes all refereed publications involving NF telescopes. An indication of the total number of NF publications is given by the addition of EVN Symposium papers for the preceding six years. The chart excludes refereed papers by NF staff that do not contain observations resulting from NF telescopes (14 papers).*

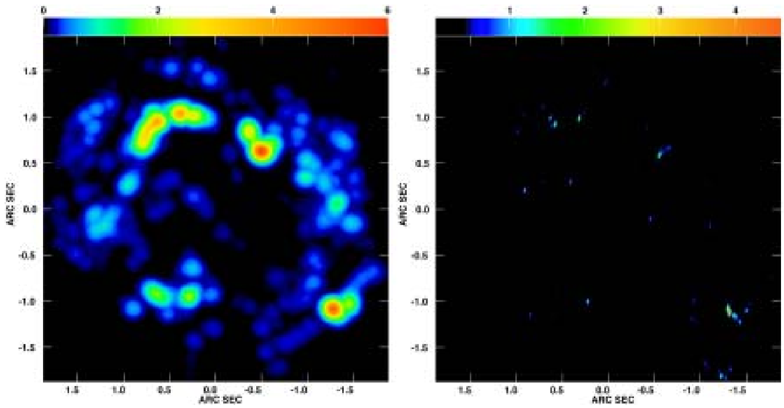



*Figure 27: The e-VLBI image (right) of OH masers around IRC+10420 shows the hotspots with enough precision to measure proper motions in a few years whilst the MERLIN image (left) shows more diffuse emission.*

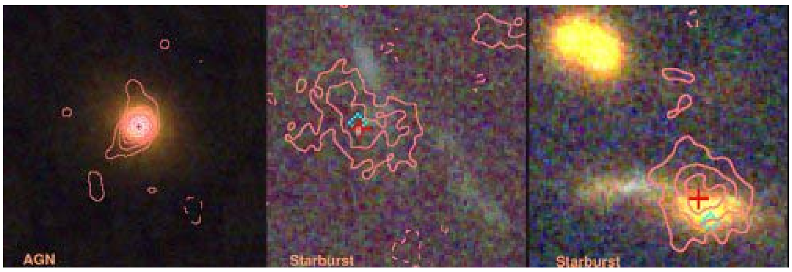
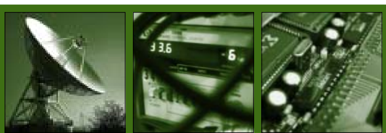



*Figure 28: HST images overlaid with MERLIN+VLA contours and the positions of the radio (red) and X-ray (blue) peaks, for a radio AGN and two starbursts hosting obscured AGN.*



# ARCHIVES & RADIONET

## THE MERLIN ARCHIVE

The MERLIN Archive can be searched for observations of particular sources or regions of sky and preliminary images resulting from a 'pipeline' processing of the data displayed. The speed with which MERLIN data can be processed has greatly increased during the reporting period owing to numerous developments. Firstly, all post-correlation data are now stored on disk. Scripts have also been developed for automatic data processing, for selecting data (target plus calibrators in a given configuration and time range) in the local MERLIN format, for deriving basic calibration information and converting them to FITS format for site-independent further analysis, for populating the archive with calibrated visibility data and sample images and for extracting visibility data on-demand for archive users. Furthermore, the efficiency of the database has been improved and a pipeline is provided (in the form of a documented AIPS procedure) for users to download and run interactively, or automatically, on their own desktop or laptop.

At present, the scripts are operated by MERLIN staff but these will be inserted into web services for MERLIN Archive and Virtual Observatory users. The supply of calibrated visibility data was in response to the most frequent demand from MERLIN users, and hundreds of sources have been retrieved, mostly over the Internet.

## EVN & JIVE DEVELOPMENTS

A pipeline is now running in production mode at the EVN correlator at JIVE for the initial stages of VLBI data processing, performing the many, complex, early stages of calibration (e.g. correcting for clock offsets). All data for each experiment are assembled into a single file. The EVN Archive can be searched on-line to give information about observed sources and to provide access to diagnostic plots and, increasingly, to the data itself. This is a necessary counterpart to the development of e-VLBI. For example, in the first real-time spectral line experiment (OH masers in IRC+10420), the data were first transmitted over the Internet from JBO, Westerbork, Onsala and Torun to the EVN correlator. The pipeline was run the day after the observations ended and the data product, in the form of a single multi-source FITS file, was transferred back to JBO over the Internet together with diagnostic plots. Images were produced within three days of the experiment (Figure 27) instead of the three or so months, which was, until recently, the fastest normal access time.

## RADIONET

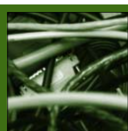
National Facility and Jodrell Bank Observatory staff are also active in RadioNet (www.radionet-eu.org) and Virtual Observatory projects (AstroGrid and the Euro-VO, formerly AVO). In fact, RadioNet is coordinated by the Director of the National Facility. RadioNet is a project funded by the European Commission's Sixth Framework Programme; it has 20 partner institutes including all of the principal radio astronomy facilities in Europe. RadioNet runs three classes of activity:

- Trans-National Access (TNA), which enables users from eligible European countries to use the European radio telescopes more easily;
- Joint Research Activities (JRA), three R&D programmes focusing on interferometric software development (ALBUS), focal-plane array receiver work (PHAROS) and mm and sub-mm wave receiver initiatives (AMSTAR);
- Networking Activities, which provide funding for activities ranging from management to science, engineering and software workshops.

The National Facility benefits from RadioNet in several ways. First, MERLIN and the EVN are TNA facilities and can thus provide travel and subsistence for non-UK based users from eligible European countries to travel to Jodrell Bank Observatory or JIVE for data analysis and other assistance. Secondly, the ALBUS JRA is developing software to improve the calibration of interferometry; in addition, it has produced *parselTongue*, a scripting language originally designed to provide a convenient interface to AIPS operations.

One of *parselTongue*'s other uses is that it will translate terms comprehensible to all astronomers (position, resolution etc.) into the languages required for various local data reduction packages. This was one of the major requirements identified by most of the observatories that responded to the International Virtual Observatory Alliance radio working group questionnaire. This group has also ensured that VO standards and data models cater for radio interferometry products. One example of the implementation of this was a follow up to the first VO science paper (Padovani *et al.* 2004). A comparison of radio and X-ray luminosities of very faint sources in the HDF (N) found that the majority of sources with radio emission of starburst origin host obscured AGN identified by hardened X-ray emission (Figure 28).





# ENGINEERING

Most of the engineering work in 2003 and 2004 was directed towards *e*-MERLIN developments, which are reported elsewhere. In addition to this, two major projects were undertaken (by our own staff) and one telescope was repainted (by contractors) during the 2003 and 2004 summer maintenance periods, together with a number of minor works such as the refurbishment of equipment cabins.

## Replacement of Defford & Mk2 Telescope Control Systems

Following the successful replacement of the obsolete control systems on the three E-Systems telescopes between 1999 and 2002, similar upgrades were implemented on the Defford and Mk2 telescopes in 2003 and 2004 respectively. Both of these telescopes date from the 1960s, and the amount of work involved in replacing the control systems was considerably greater than might be imagined, because it proved necessary to replace almost every cable, switch, etc. in order to meet current standards and ensure reliability (Figure 29).

## Corrosion Protection

The Pickmere telescope was painted by contractors in 2004 using one of the modern paint systems that have proved effective in doubling the recoating interval (from 5 to 10 years) at little extra cost. Despite these improved paint systems, inadequate funding is threatening the structural integrity of the telescopes by restricting the frequency of painting to a level below that regarded as optimum.

*Figure 30: A new e-MERLIN C-band feed fitted on the Mk2 and Defford antennas.*

*Figure 29: Some of the life expired material removed from the Defford telescope.*

*Figure 31: An L-band feedhorn being installed on a MERLIN E-Systems telescope.*

# *e*-MERLIN DEVELOPMENTS

The focus of the *e*-MERLIN project is to upgrade the instantaneous bandwidth of MERLIN from 2 x 15 MHz to 2 x 2 GHz. Together with improvements in receiver design and the incorporation of the Lovell Telescope, this will increase the sensitivity of MERLIN by a factor of about 30 at the prime observing frequency of 5 GHz. The key to this bandwidth upgrade is the replacement of the microwave links, which return the signals from the MERLIN telescopes to the correlator at Jodrell Bank Observatory with new optical fibre links. Achieving this bandwidth has required the development of new feeds, polarisers and amplifiers, new IF and digital transmission systems as well as the construction of the fibre links themselves. The new correlator is being developed by DRAO in Canada.

The project has been funded by The University of Manchester, the Northwest Development Agency, PPARC, the University of Cambridge and Liverpool John Moores University.

## Receivers

*e*-MERLIN will retain the three prime frequency bands used on MERLIN (L-band: 1.3-1.7 GHz; C-band 4-8 GHz and K-band 22-24 GHz). The new C-band system involves new feeds (four different designs for different telescopes), polarizers and amplifiers to work over a 4-8 GHz band. Left and right circular polarizations are extracted using a quadridge orthomode transducer (OMT) and a 90-degree hybrid coupler. The OMT was designed at JBO and was a significant challenge in terms of broad-band performance and the precision engineering required. The hybrid coupler uses high temperature superconducting materials and is being designed in conjunction with the University of Birmingham. The low noise amplifiers (LNAs) use InP technology and are adapted from a MPIfR design and achieve a noise temperature of about 5K across most of the 4 – 8 GHz band. A new cryostat has been designed and constructed to house the OMT, LNAs and coupler.

Three of the systems were completed and installed in autumn 2004 and were used to produce the first MERLIN images of interstellar methanol and excited OH emission at 40 milliarcsecond resolution. The remaining receivers will be installed in 2005. In order to allow a rapid change between the C- and L-band receivers, a new lens, horn and lens mechanism has been designed for three of the telescopes. The lens itself is a 1.7m-diameter, 350-kg piece of polyethylene, cast and machined in sections. It can be swung into place and located at the millimetre level by a screw-driven carriage. All three lens mechanisms have now been installed, and following initial problems with material used in the lens, the lenses themselves will be installed in 2005/6.

## IF and Digital Electronics

The *e*-MERLIN IF system will use a common X-band IF (8.0-12.5 GHz) and a new commercial synthesizer. Subsequent down conversion to 2-4 GHz or 0.5-1 GHz for the 4Gs/s and 1 Gs/s samplers uses a second LO generated from the existing MERLIN sythesisers, which provide a pair of 250-500 MHz outputs. IF and LO switches provide the option of either observing two polarizations with the same 2 GHz band or one polarization with two adjacent 2 GHz bands.

There will be two pairs of samplers at each telescope: one commercial pair at 1 Gs/s with at least 8 bits for observations with a bandwidth of 500 MHz or less and one pair at 4 Gs/s with at least 3 bits for full-bandwidth observations. The wideband samplers may be those developed by The University of Bordeaux for ALMA, or commercial devices now being released.

*Figure 32: Laying the fibre optic cables for e-MERLIN begins in sight of the Pickmere antenna.*

The analogue IF system is now being prototyped in the lab and will be tested on a local telescope in 2005. The digital sampler boards have been designed and will also be tested in 2005.

## Optical Fibre Connections

The data transmission network is the key to the sensitivity increase of *e*-MERLIN and the most costly part of the project. Since the telescopes are in rural locations, away from the fibre backbones that connect the main centers of population, significant lengths (of order 100 km in total) of new fibre installation are required. Furthermore, the data capacity requirement is a constant and sustained data rate of approximately 30 Gb/s from each telescope. For comparison, the highest capacity academic links in the UK are 10 Gb/s and the total UK public internet traffic is 30 Gb/s (average), so commercial rates for the *e*-MERLIN bandwidth were likely to be prohibitive. After an open commercial procurement, a solution has been selected with a single contractor responsible for all the new fibre installation (Fujitsu Telecommunications UK) and dark fibres being leased from three of the major UK data networks for a 15-year period.

Installation of the new fibre began in June 2004 and was completed on schedule in April 2005. The installation of the new fibre sections used a combination of moleploughing, where a 40-mm duct is ploughed directly into the verge; horizontal directional drilling, where a steerable drill is used to install typically 100-m lengths of 63-mm duct; and traditional trenching (Figure 33). The horizontal drilling has been used to minimize environmental disruption, to tunnel under major and minor roads, rivers and canals and to go deeper underground (2-3m) in cultivated fields to avoid damage by farm machinery. The fibre cable itself is blown into the duct in lengths of up to 2 km using specialised equipment. The routes then follow mostly minor roads for typically 5-30 km to reach the Global Crossing or other trunk fibre. Most of the Global Crossing trunk fibre is laid alongside rail routes; the other trunk routes follow major roads.

*Figure 33: Moleploughing equipment and the cable duct for the e-MERLIN optical fibre network.*

The optical amplification equipment is now being installed at various co-location sites (Peterborough, Nottingham, Birmingham, Crewe) in the *e*-MERLIN optical fibre network.

Optical test equipment is now being used to commission the optical fibre links. The local links have been tested at 10 Gb/s and are well within the expected performance in terms of loss and dispersion. Optical testing of the entire network will be completed in 2005.

## Correlator

The correlator for *e*-MERLIN is being built by DRAO, Penticton (Canada), using the same WIDAR architecture as the much larger correlator being built by the same group for the EVLA. FIR filters split the 2 GHz input band into 16 128-MHz subbands each of which is separately correlated and integrated before being seamlessly stitched together. Correlation is done with 4-bit samples using correlator chips with 2048 complex lags, giving 0.25 MHz frequency resolution for each of the four polarization combinations. For *e*-MERLIN, 16 baseline boards, each usually allocated to correlating one sub-band for 8 x 8 telescopes will be used.

We are currently working towards achieving 'first fringes' with the new prototype correlator in the summer of 2006. The full correlator is expected in 2007/8, by which time all the IF and 4 GHz sampler installation will be complete, so that routine observations with all telescopes, in all bands at up to 2 GHz bandwidth should be taking place in mid-2008.

# FINANCES

The operation of MERLIN and VLBI as a National Facility is funded by a special rolling grant awarded by PPARC to the University of Manchester (PPA/G/O/2002/00646). The grant holder is Professor A. G. Lyne, the Director of Jodrell Bank Observatory, and the value of the current award is £4,613,582 for the period October 2003 to September 2005.

The disposition of the budget by activity area is shown in Figure 34. The UK contributions to the cost of VLBI support activities at JIVE and the employment of a European CRAF frequency protection manager are now met directly by PPARC, but increasing the value of the award are substantive contributions towards the capital costs and annual maintenance charges of the *e*-MERLIN fibres.

An additional grant for £200,000 (PP/C507153/1) has been awarded by PPARC for the development of broadband VLBI, including provision for enhanced disk recording capability and fibre connection between Jodrell Bank Observatory and Manchester for real-time linkage to JIVE via national and international research networks.

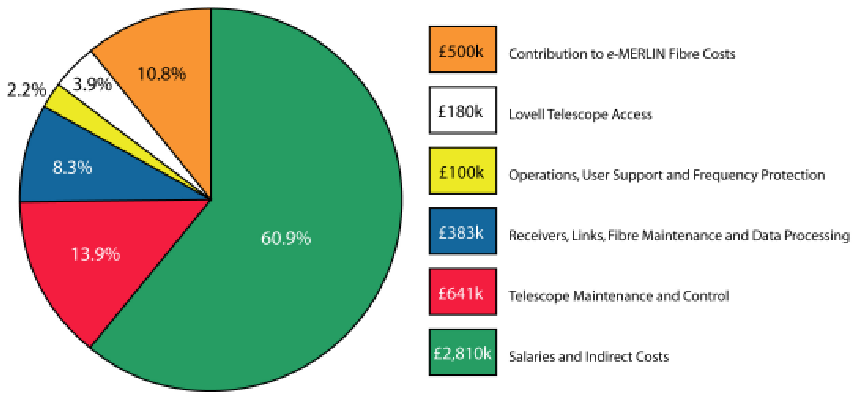
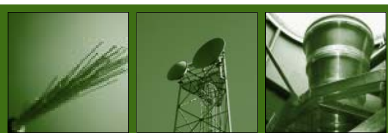



*Figure 34: Summary of National Facility operating finances for the period 2003-2004.*



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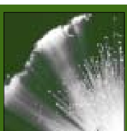
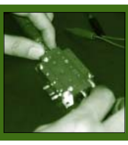
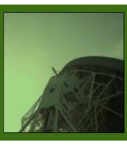






# APPENDIX A

## National Facility Committees & Personnel (31/12/04)

### NATIONAL FACILITY STEERING COMMITTEE

Dr J. A. Yates (Chairman)
University College London

Professor G. de Bruyn
ASTRON, Netherlands

Dr G. A. Fuller
University of Manchester (UMIST)

Dr G. G. Pooley
University of Cambridge

Dr C. G. Mundell
Liverpool John Moores University

Dr G. Woan
University of Glasgow

PPARC Secretary: Dr S. Berry

### PATT MERLIN TIME ALLOCATION GROUP

Prof. T. P. Ray (Chairman)
Dublin Institute for Advanced Studies

Dr T. M. Gledhill
University of Hertfordshire

Dr M. J. Hardcastle
University of Hertfordshire

Dr M. J. Kukula
Royal Observatory Edinburgh

TAG Secretary: Dr T. W. B. Muxlow
(MERLIN National Facility)

The National Facility employs 25.75 FTE staff on the operation of MERLIN & VLBI and development activities for *e*-MERLIN. The *e*-MERLIN project funds an additional 6.0 FTE. Some of the personnel listed opposite spend only part of their time on National Facility activities.

### NATIONAL FACILITY PERSONNEL & ASSOCIATED STAFF WORKING ON *e*-MERLIN AND FIBRE DEVELOPMENTS

#### Management & Administration — 3.25 FTE funded by the NF

| | |
|---|---|
| Prof P. J. Diamond | National Facility Director |
| Dr J. A. Battilana | Chief Engineer |
| Dr D. Stannard | Scientific Administrator |
| Mrs J. Eaton | Personal Assistant to JBO Directors |
| Mrs S. M. Freer | Accounts Administrator |

#### Telescope Maintenance & Control — 8.50 FTE funded by the NF

| | |
|---|---|
| Mr R. J. Comber | Engineer (telescopes) |
| Mr G. J. Kitching | Senior Experimental Officer (engineering) |
| Mr C. J. Scott | Telescope Maintenance Supervisor |
| Mr J. Bartle | Telescope Fitter |
| Mr D. T. Clarke | Telescope Fitter |
| Mr P. Clarke | Telescope Fitter |
| Mr F. P. Manning | Electrical Supervisor |
| Miss A. M. Bayley | Systems Programmer |
| Mr I. D. Freer | Senior Controller & Control Supervisor |
| Mr G. A. Johnson | Control Technician |
| Mr J. Dyer | Control Technician |

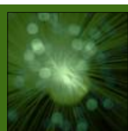
#### Receivers, Links & Data Processing — 6.75 FTE funded by the NF

| | |
|---|---|
| Mr N. Roddis | Engineer (receivers) |
| Mr E. J. Blackhurst | Receiver Technician |
| Mr J. A. Edgley | Supervising Technician |
| Mr D. Lawson | Receiver Technician |
| Mr C. D. Baines | Engineer (operations) |
| Mr J. W. Marshall | Cryogenics Technician |
| Mr M. H. Butlin | Engineering Technician |
| Dr M. Bentley | Senior Experimental Officer (links & developments) |
| Mr A. Blackburn | Links Technician |
| Mrs R. McCool | Engineer (fibres) |
| Mr I. Morison | Engineer (operations) & PR Officer |
| Mr D. C. Brown | Senior Experimental Officer (digital & fibres) |
| Mr P. Burgess | Senior Experimental Officer (VLBI) |
| Mr L. R. Parry | Digital Technician |
| Dr A. J. Holloway | Systems Manager |
| Dr C. A. Jordan | Systems Programmer |
| Mrs B. V. Hancock | Computer Assistant |
| Dr R. G. Noble | Senior Experimental Officer (data processing) |

#### Operations & User Support — 7.25 FTE funded by the NF

| | |
|---|---|
| Dr P. Thomasson | MERLIN Manager |
| Dr S. T. Garrington | *e*-MERLIN Project Manager |
| Dr T. W. B. Muxlow | Senior Experimental Officer (operations) |
| Dr A. G. Gunn | National Facility Support Scientist |
| Dr R. J. Beswick | National Facility Support Scientist |
| Dr M. W. Asif | Telescope Array Controller |
| Mr A. M. Howson | Telescope Array Controller |
| Mr A. MacKay | Telescope Array Controller |
| Mr C. I. Mance | Telescope Array Controller |
| Mr I. J. Manfield | Telescope Array Controller |
| Mr M. E. Roberts | Telescope Array Controller |





# APPENDIX B

## MERLIN Observations in Semesters 03A to 04B

The MERLIN Time Allocation Group (TAG) awards time in the following categories:

**A and TO: Highest Priority** - Observations are not guaranteed, but in the past all of the observations in this category have usually been completed. TO time is for Target of Opportunity observations. Should these not arise they are covered by additional B priority time.

**B: Lower Priority** - No commitment is given to complete observations in this category, though a significant number are usually observed. For certain projects, this may include observations with a subset of the MERLIN array.

**C: Fill-in** - Short observations of a few hours duration for projects in this category may be used to fill scheduling gaps in the A and B programme.

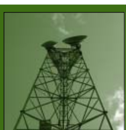
A time is allocated for 80% of the contracted time within a semester when all MERLIN antennas are available and after provision has been made for National Facility EVN commitments and any agreed outstanding engineering programmes.

| Runs Observed/ Runs Approved | A-Time | B-Time | TO-Time |
|---|---|---|---|
| L-band | 63/69 (91%) | 14/14 (100%) | 13/20 |
| 5 GHz | 33/40 (83%) | 43/48 (90%) | |
| 6 GHz | 15/22 (68%) | 9/17 (53%) | |
| K-band | 6/9 (67%) | 0/5 (0%) | |

*Table 3: Observing success rates for observations performed in semesters 03A to 04B. Note that some of the L-band observations have long-term status to semester 05A and have not yet been completed.*

### MERLIN Semester 03A Time Awards

| CODE | TITLE | PI | L-Band | C-Band | K-Band |
|---|---|---|---|---|---|
| 03A/02 | Target of opportunity observations of classical and recurrent novae | S. P. S. Eyres | | 4 Runs TO | |
| 03A/06 | HI absorption observations toward the ULIRG IRAS 17208-0014 | E. Momjian | 1 Run A (Lovell) | | |
| 03A/07 | Imaging Galactic HI absorption toward 3C111 and 3C123 | M. Faison | 3 Runs A (Lovell) | | |
| 03A/08 | High-frequency/high-resolution IPS studies of the inner solar wind | A. R. Breen | C Time | | |
| 03A/09 | Re-observation of HI absorption against NGC2623 | A. Pedlar | 1 Run A (Lovell) | | |
| 03A/10 | The maser kinematics of the proto-planetary nebula IRAS 19312+1950 | H. Imai | 3 Runs B | | |
| 03A/12 | Looking for MSO faders, the prematurely 'dying' CSS sources | M. Kunert | 2 Runs B (Lovell) | | |
| 03A/13 | An HI absorption study of the Medusa galaxy | S. Aalto | 1 Run A (Lovell) | | |
| 03A/14 | HI absorptions against local active galaxies | R. J. Beswick | 5 Runs B (Lovell) | | |
| 03A/15 | MERLIN L-band imaging of the kpc-scale Jet of 3C279 | T. Cheung | 1 Run B | | |
| 03A/17 | 18 cm imaging of gravitational lens candidates | D. Haarsma | 1 Run B (Lovell) | | |
| 03A/18 | Continuum observations of IC 4593 | I. Bains | 3 Runs B (Lovell) | | |
| 03A/19 | Extended structure in CLASS B0631+519 | T. York | 1 Run A (Lovell) | | |
| 03A/20 | Deep observations of CLASS B0445+123 | N. J. Jackson | 1 Run A (Lovell) | | |
| 03A/23 | Astrometry of methanol maser sources | M. Szymczak | | C Time (Methanol) | |
| 03A/24 | Imaging OH masers around high mass proto-stellar objects | G. Fuller | 4 Runs A (Lovell) | | |
| 03A/27 | Monitoring the circumnuclear star-burst of NGC7469 | L. Colina | 1 Run B (Lovell) | | |



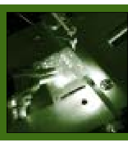
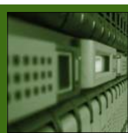
| | | | | | |
|---|---|---|---|---|---|
| 03A/29 | The OH satellite lines in Arp220 | C. J. Lonsdale | 2 Runs A (Lovell) | | |
| 03A/32 | Relativistic ejections from X-ray transients | R. P. Fender | | 4 Runs TO | |
| 03A/33 | 20cm observations of NGC3079 | K. A. Wills | 2 Runs A (Lovell) | | |
| 01B/24 | The proper motions of young pulsars | B. Anderson | 6 Runs A (Lovell) | | |
| 02B/01 | High-resolution imaging of an unbiased sample of SCUBA galaxies | R. J. Ivison | 20 Runs A (Lovell) | | |
| 02B/10 | Radio-loud BAL QSOs: massive galaxies in formation? | S. Rawlings | 12 Runs B | | |
| 02B/11 | Radio properties of typical high-redshift radio sources | S. Rawlings | 8 Runs A | | |
| 02B/20 | Simultaneous observations of Galactic $\gamma$-ray sources with INTEGRAL | R. E. Spencer | 10 Runs A | | |
| 02B/22 | Imaging shock structure(s) within PSR B1951+32's plerion & CTB80 | A. Golden | 8 Runs A | | |
| Director's Override | | | 2 Runs TO | | |

## MERLIN Semester 03B Time Awards

| | | | | | |
|---|---|---|---|---|---|
| 03B/02 | Relativistic ejections from X-ray transients | R. P. Fender | | 6 Runs TO | |
| 03B/03 | A Sensitive Search for Extragalactic Methanol Masers | L. Harvey-Smith | | 4 Runs A (Lovell) | |
| 03B/04 | TOO Observations of Transient Jets from Symbiotic Stars in Outburst | C. Brocksopp | | 3 Runs TO | |
| 03B/06 | Enhanced sensitivity observations of Z And - a pilot project | S. P. S. Eyres | | 4 Runs B | |
| 03B/07 | MERLIN $H_2CO$ absorption studies of nearby Starburst galaxies | R. J. Beswick | | 1 Run A (Lovell) | |
| 03B/08 | MERLIN $H_2CO$ absorption studies of nearby Active Galactic Nuclei | M. Strong | | 1 Run A (Lovell) | |
| 03B/09 | Identification of Weak Microquasars | R. E. Spencer | | 7 Runs B + C-Time | |
| 03B/10 | Astrometry and Polarization Imaging of the T Tau System | K. J. Johnston | | 5 Runs B | |
| 03B/11 | Radio Star Observations for a Radio/Optical Frame Tie | K. J. Johnston | | 2 Runs A (Lovell) | |
| 03B/12 | Restarted activity in AGN with compact radio structures | A. Marecki | 4 Runs A + 1 Run B + C-Time | | |
| 03B/13 | 5GHz continuum observations of IRAS 17208-0014 and NGC7674 | E. Momjian | 4 Runs A (Lovell) + C-Time | | |
| 03B/14 | Mapping of proto-star environments in methanol line | M. Szymczak | | 5 Runs B | |
| 03B/15 | HD125858: an unusual radio star? | G. A. Wynn | | 5 Runs B | |
| 03B/16 | Simultaneous MERLIN and Chandra X-Ray Observations of RS CVns | A. Brown | | 9 Runs B | |
| 03B/17 | Imaging the extended methanol maser emission | J. Conway | | 4 Runs A | |
| 03B/18 | Precessing Jets in the Nano-Quasar CH Cygni? | M. F. Bode | | 3 Runs A | |
| 03B/19 | MERLIN Observations of Compact COLA-N Radio Sources | J. Conway | | 8 Runs B + C-Time | |
| 03B/22 | Formaldehyde in Arp 220 - Mapping the Megamaser | W. A. Baan | | 2 Runs A (Lovell) | |
| 03A/32 | Relativistic ejections from X-ray transients | R. P. Fender | | 6 Runs TO | |
| Director's Override | | | | 2 Runs TO | |

## MERLIN Semester 04A Time Awards

| | | | | | |
|---|---|---|---|---|---|
| 04A/02 | The 6.7GHz methanol maser in OMC-1 | M. A. Voronkov | | 1 Run A | |
| 04A/03 | MERLIN $H_2CO$ absorption in the peculiar radio galaxy 3C293 | R. J. Beswick | | 1 Run A (Lovell) | |
| 04A/04 | OH 6GHz masers: probes of magnetic fields in star-forming regions | R. J. Cohen | | 6 Runs A (Lovell) | |
| 04A/05 | $H_2O$ maser motions in Cepheus A HW2 | J. F. Gallimore | | | 1 run A |
| 04A/06 | $H_2O$ masers in protoplanetary discs | J. F. Gallimore | | | 5 Runs A |
| 04A/07 | Association of OH and methanol masers in star-forming regions | L. Harvey-Smith | 2 Runs A (Lovell) + 4 Runs B | | |
| 04A/08 | Structures of radio sources in a sample selected at 15GHz - continued | G. Cotter | | C-Time | |
| 04A/09 | A radio continuum survey of LINER nuclei | E. Olsson | | C-Time | |
| 04A/10 | Compact SNRs and HII regions within NGC3077 | D. Rosa-Gonzalez | 1 Run A (Lovell) | | 2 Runs A |
| 04A/11 | The origin of the $H_2O$ maser emission in M51 | Y. Hagiwara | | | 1 Run B |
| 04A/12 | High declination X-ray binaries | I. K. Brown | | C-Time | |

| | | | | | |
|---|---|---|---|---|---|
| 04A/13 | AGN or starburst in the LINER galaxy NGC5218? | E. Olsson | | C-Time | |
| 04A/14 | What happens to the jet of the blazar 0716+714? | U. Bach | | 1 Run B | |
| 04A/15 | Monitoring radio supernovae & remnants in nearby starbursts | A. Pedlar | | 6 Runs B | |
| 04A/16 | Faraday effects and EVPA alignment in SS433 | A. M. Stirling | | 4 Runs A (Lovell) | |
| 04A/17 | 5cm and 18cm OH maser observations of K 3-35 | J. F. Demurs | 1 Run B | 1 Run B | |
| 04A/19 | The structure of X-ray bright hotspots in FRII radio galaxies | M. Hardcastle | | C-Time | |
| 04A/21 | Interplanetary scintillation studies of fast solar wind acceleration | A. R. Breen | | 3 Runs B + C-Time | |
| 04A/22 | Fast precession in LSI+61303 | M. Massi | | 4 Runs B | |
| 03A/02 | ToO observations of classical and recurrent novae | S. P. S. Eyres | | 4 Runs TO | |
| 03A/32 | Relativistic ejections from X-ray transients | R. P. Fender | | 6 Runs TO | |
| 03B/04 | ToO observations of transient jets from symbiotic stars in outburst | C. Brocksopp | | 3 Runs TO | |
| 03B/18 | Precessing jets in the nano-quasar CH Cygni | M. F. Bode | | 2 Runs A | |
| Director's Override | | | | 2 Runs TO | |

## MERLIN Semester 04B Time Awards

| | | | | | |
|---|---|---|---|---|---|
| 04B/01 | Astrometry and polarization imaging of the T-Tau system - | K. J. Johnson | | 2 Runs A | |
| 04B/03 | High-resolution imaging of the (real) Lockman Hole | R. Ivison | 9 Runs A (Lovell) | | |
| 04B/04 | Populating a full size-range of compact-medium symmetric objects | P. Augusto | | C Time | |
| 04B/05 | Resolving the disc of the Be star PSI Per | J. M. Porter | | 5 Runs A (Lovell) | |
| 04B/06 | Mapping of methanol and water masers in proto-stars | M. Szymczak | | 6 Runs B | |
| 04B/07 | Accurate positions for unbiased methanol maser survey sources | M. G. Hoare | 3 Runs A (Lovell) + 4 Runs B | | |
| 04B/08 | TOO Observations of Transient Jets from Symbiotic Stars in Outburst | C. Brocksopp | | Up to 3 Runs TO | |
| 04B/09 | The space density of high FRI radio galaxies | I. A. G. Snellen | 3 Runs A (Lovell) | | |
| 04B/10 | Ground-state and excited OH masers in star-forming regions | L. Harvey-Smith | 2 Runs A (Lovell) | | |
| 04B/11 | Simultaneous MERLIN and Chandra X-Ray Observations of RS CVns | A. Brown | | 9 Runs B | |
| 04B/12 | Detached envelopes around OH/IR stars | M. Lindquist | | 3 Runs A (Lovell) | |
| 04B/13 | MERLIN observations of HI absorption in the NGC5218 & NGC1614 | E. Olsson | | 3 Runs A (Lovell) | |
| 04B/15U | Magnetic Fields and Co-propagation of OH masers at 6 and 1.7 GHz | M. D. Gray | UMIST GTO | | |
| 04B/16 | Probing extragalactic star formation with water masers | Y. Hagiwara | | | 1 Run B |
| 04B/19 | Radio supernovae monitoring in nearby starbursts | M. Argo | | 6 Runs B | |
| 04B/20 | Simultaneous observation of Galactic $\gamma$-ray sources with INTEGRAL | R. E. Spencer | | C Time | |
| 04B/21 | 3C 403 and NGC 253 - Rare water maser galaxies | E. Xanthopoulos | | C Time | |
| 04B/22 | Relativistic ejections from X-ray transients | R. P. Fender | | Up to 3 Runs TO | |
| 04B/23U | Circumstellar masers around high mass protostellar objects | G. Fuller | UMIST GTO | | |
| 04B/24 | The expanding jet in Z Andromedae | J. L. Sokoloski | | 1 Run A | 1 Run A |
| 04B/25U | The OH maser outflow of 231.8+04.2 | A. Zijlstra | UMIST GTO | | |
| 03B/03 | A sensitive search for extragalactic methanol masers | L. Harvey-Smith | | 4 Runs A (Lovell) | |
| 03B/14 | Mapping of proto-star environments in methanol | M. Szymczak | | 5 Runs B | |
| 03B/17 | Imaging the extended methanol maser emission | J. Conway | | 4 Runs A | |
| 04A/02 | The 6.7GHz methanol maser in OMC-1 | M. A. Voronkov | | 1 Run A | |
| 04A/04 | OH 6GHz masers: probes of magnetic fields in star-forming regions | R. J. Cohen | | 6 Runs A (Lovell) | |
| 04A/06 | $H_2O$ masers in protoplanetary discs | J .F. Gallimore | | | 2 Runs A |
| 04A/07 | Association of OH & methanol masers in star-forming regions | L. Harvey-Smith | 2 Runs A (Lovell) + 4 Runs B | | |
| 04A/11 | The origin of the $H_2O$ maser emission in M51 | Y. Hagiwara | | | 1 Run B |
| 04A/17 | 5cm and 18cm OH maser observations of K3-35 | J. F. Desmurs | | 1 Run B | |
| Director's Override | | | | 2 Runs TO | |



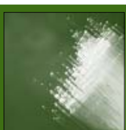
# APPENDIX C

## VLBI Observations 2003-2004

| PI | Code | Experiment Title | Telescope(s) | Wavelength | Hours |
|---|---|---|---|---|---|
| Polatidis | F03K1 | Fringe Test K-band | CmMk2 | 1.3cm | 1 |
| Peck | GP034 | Water Masers in Mrk 1066 | MK2 | 1.3cm | 8 |
| Paragi | N03K1 | NME K-band | CmMk2 | 1.3cm | 4 |
| Imai | EI005A | LI1287 Water Masers | CmMk2 | 1.3cm | 18 |
| Paragi | F03L2 | Fringe Test L-band | CmLT | 18cm | 1 |
| McHardy | EM051 | Phase Referencing of NGC4051 | CmLT+MER | 18cm | 11.5 |
| Beswick | EB024D | NGC7674 HI Absorption | LT | 21cm | 11.5 |
| Bondi | EB023C | 3C270 | CmLT+MER | 18cm | 9 |
| Beswick | EB024E | NGC7469 HI Absorption | LT | 21cm | 12 |
| Baan | EB022C | Arp220 OH-Megamaser | CmLT+MER | 18cm | 9.5 |
| Lobanov | EL029C | 3C75 | CmLT+MER | 18cm | 11.5 |
| Filho | EF009C | AGN in Nearby Galaxies | LT | 18cm | 6 |
| Polatidis | EP042E | HI in IIIZw35 | CmLT+MER | 21cm | 12 |
| Beswick | EB024F | Arp220 HI Absorption | LT | 21cm | 12 |
| Conway | EC020B | ULIRGS | CmLT+MER | 18cm | 24 |
| Paragi | N03L2 | NME L-band | Cm | 18cm | 5.5 |
| Rovilos | ER016B | A Snapshot Survey of OH Megamasers | CmLT+MER | 21/18cm | 24 |
| Paragi | GP036B | Circular Polarization in SS433 | CmLT+MER | 18cm | 11 |
| Bartel | GB046A | SN1993J in M81 | MK2 | 6cm | 12 |
| Paragi | D03C1 | MK5 Disk Test | MK2 | 6cm | 4 |
| Krips | EK017 | Parsec Emission in Seyfert Galaxies | MK2 | 6cm | 13 |
| Paragi | D03C2 | MK5 Disk Test | MK2 | 6cm | 4 |
| Jackson | GJ010A | Gravitational Lenses | MK2 | 6cm | 8 |
| Moscadelli | EM053A | $CH_3OH$ Masers in G24.78+0.08 | CmMk2 | 5cm | 6 |
| Desmurs | ED018C | OH Masers in Massive Star-Forming Regions | CmMk2 | 5cm | 3 |
| Paragi | N03M1 | NME C-band | CmMk2 | 5cm | 4 |
| Moscadelli | EM053B | $CH_3OH$ Masers in G24.78+0.08 | CmMk2 | 5cm | 6 |
| Desmurs | ED018D | OH Masers in Massive Star-Forming Regions | CmMk2 | 5cm | 3 |
| Minier | EM048 | Methanol Maser Survey in Cygnus X | CmMk2 | 5cm | 11 |
| Niezurawska | EN001 | Methanol Masers in Three Proto-stars | CmMk2 | 5cm | 16 |
| Moscadelli | EM049 | $CH_3OH$ Masers in IRAS 19217+1651 | CmMk2 | 5cm | 12 |
| Imai | EI005C | LI1287 Water Masers | CmMk2 | 1.3cm | 14 |
| van Langevelde | EL031B | Astrometry of the U Her Water Maser | CmMk2 | 1.3cm | 10 |
| Polatidis | F03C1 | Fringe Test C-band | LT | 6cm | 1 |
| Marcaide | GM048C | SN1993J | LT | 6cm | 11 |
| Paragi | N03C1 | NME C-band | LT | 6cm | 9 |
| Hagiwara | EH016A | NGC6240 | LT | 6cm | 9 |
| Ulvestad | GU003C | NGC1068 | LT | 6cm | 8 |
| Hong | EH013 | 5 EGRET-Detected AGNs | LT | 6cm | 12 |
| Paragi | D03C3 | Mk5 Disk Test | Cm | 6cm | 5 |
| Harlaftis | EH015A | Proper Motions of X-ray Binaries | LT | 6cm | 12.5 |
| Marecki | EM050 | Cores of Giant Radio Galaxies | LT | 6cm | 19 |
| Frey | EF011 | Highest Redshift Quasar SDSS J0836+0054 | LT | 6cm | 9.5 |
| Harlaftis | EH015B | Proper Motions of X-ray Binaries | LT | 6cm | 12.5 |
| Jiang | EJ006 | J1312+23 | LT | 6cm | 12 |
| Imai | GI001A | 1612 MHz OH Masers in W43A | LT | 18cm | 10 |
| Paragi | N03L3 | NME L-band | LTCm | 18cm | 6 |
| Krips | EK015B | Parsec Emission in Seyfert Galaxies | LT | 18cm | 24 |
| Diamond | GD017A | Arp220 | LT | 18cm | 14 |
| Hagiwara | EH016B | NGC6240 | LT | 18cm | 9.5 |
| Polatidis | F04K1 | Fringe Test K-band | CmMk2 | 1.3cm | 1 |
| Rioja | ER017 | Observations of Maser Sources at 22 GHz | CmMk2 | 1.3cm | 15 |
| Pradel | EP044 | CSO survey | CmMk2 | 1.3cm | 12 |
| Paragi | N04K1 | NME K-band | CmMk2 | 1.3cm | 2 |
| Polatidis | F04C1 | Fringe Test C-band | CmLT | 6cm | 1 |
| Koerding | KAH1 | NGC4736 Pilot | LT | 6cm | 4 |
| Mantovani | GM052B | Helical Structure in B1524-136 Jets | LT | 6cm | 9.5 |
| Paragi | N04C1 | NME C-band | CmLT | 6cm | 5 |



| PI | Code | Experiment Title | Telescope(s) | Wavelength | Hours |
|---|---|---|---|---|---|
| Bondi | EB027A | Mkn 273 | CmLT+MER | 6cm | 12 |
| Kunert | EK019 | Restarted Small-Scale Radio Sources | CmLT | 6cm | 12 |
| Beswick | EB026 | Main-line OH Masers in M82 | CmLT | 18cm | 18 |
| Biggs | EB025 | Phase Referencing of CLASS B0128+437 | CmLT | 21cm | 14 |
| Avruch | EA029 | Phase Calibrators in the Huygens Field | LT | 18cm | 4 |
| Bondi | EB027B | Mkn 273 | LT | 18cm | 12 |
| Paragi | N04L1 | NME L-band | CmLT | 18/21cm | 2 |
| Garrett | GG053A | Deep Global VLBI Observations of the HDF | CmLT | 21cm | 12 |
| Garrett | GG053B | Deep Global VLBI Observations of the HDF | CmLT | 21cm | 12 |
| Garrett | GG053C | Deep Global VLBI Observations of the HDF | CmLT | 21cm | 12 |
| Polatidis | F04C2 | Fringe Test C-band | CmLT | 6cm | 1 |
| Paragi | N04C2 | NME C-band | CmMk2 | 6cm | 5 |
| Brunthaler | EB029 | Phase Referencing of 3C403 | Mk2 | 6cm | 10.5 |
| Bode | EB028A | CH Cyg | CmMk2+MER | 6cm | 14 |
| Krips | GK029 | Parsec Emission in Seyfert Galaxies | Mk2 | 6cm | 6 |
| Snellen | GS021A | Nearby Young Radio Sources | Mk2 | 6cm | 12 |
| Bartel | GB049A | SN1993j in M81 | Mk2 | 6cm | 12 |
| Gunn | F04C4 | LT+MK2 Phase Referencing Test | LTMk2 | 6cm | 5 |
| Caccianiga | EC022 | Superluminal Motion in Radio Quiet AGN | LT | 6cm | 12 |
| Graham | F04C3 | Gbps Fringe Test | CmMk2 | 6cm | 3 |
| Paragi | N04L2 | NME L-band | CmMk2 | 18cm | 5 |
| Ghosh | EG030 | OH Satellite Megamaser in Arp220 | CmMk2 | 18cm | 12.5 |
| McHardy | GM053 | Phase Referencing of NGC4051 | Mk2 | 18cm | 12 |
| Snellen | GS021B | Nearby Young Radio Sources | LT | 18cm | 12 |
| Bartel | GB049B | SN1993j in M81 | Mk2 | 18cm | 12 |
| Imai | GI001B | 1612 MHz OH Masers in W43A | LT | 18cm | 10 |
| Bode | EB028B | CH Cyg | CmMk2 | 18cm | 1 |
| Vermeulen | GV017 | OH Megamaser at z~0.25 | LT | 21cm | 14.5 |
| Paragi | F04P1 | Fringe Test P-band | LT | 90cm | 3 |
| Gwinn | GG058A | Angular Broadening: Levy Flight or Random Walk? | LT | 90cm | 4.5 |
| Ramachandran | GR024A | Angular Broadening of Pulsars | LT | 90cm | 1 |
| Ramachandran | GR024B | Angular Broadening of Pulsars | LT | 90cm | 4.5 |
| Gwinn | GG056 | Substructure in Pulsar Dynamic Spectra | LT | 90cm | 19 |
| Impellizzeri | GI002 | Large Scale Jet of 0716+714 | LT | 90cm | 11 |
| Gwinn | GG058B | Angular Broadening: Levy Flight or Random Walk? | LT | 90cm | 13 |
| Garrett | GG060 | Wide-field Observations of the M81/M82 Complex | LT | 90cm | 9 |
| Gwinn | GG058C | Angular Broadening: Levy Flight or Random Walk? | LT | 90cm | 13 |
| Paragi | N04P1 | NME P-band | LT | 90cm | 6 |
| Krichbaum | GK028 | Large Scale Jet of 1803+784 | LT | 90cm | 12 |
| Ramachandran | GR024C | Angular Broadening of Pulsars | LT | 90cm | 1.5 |
| Sjouwerman | ES051 | M31 Black Hole | LT | 6cm | 12 |
| Paragi | N04C3 | NME C-band | LT | 6cm | 6 |
| Alef | EA030 | λ Andromedae | LT | 6cm | 12 |
| Argo | GA021 | Possible RSN in NGC3310 | LT | 6cm | 10 |
| Smith | GS023 | PG Quasars | LT | 6cm | 11 |
| Xiang | EX004 | CSOs in GPS Sources | LT | 6cm | 24 |
| Marcaide | GM055A | SN 1993J | LT | 6cm | 11 |
| Paragi | N04K2 | NME K-band | Cm | 1.3cm | 24 |
| Charlot | EC019 | EVN Telescope Position Test | Cm | 1.3cm | 24 |
| Imai | EI006A | LI1287 Water Masers | Cm | 1.3cm | 20 |
| Paragi | F04M1 | Fringe Test C-band | CmDn | 5cm | 1 |
| Goddi | EG029 | 6.7GHz $CH_3OH$ Masers in AFGL~5142 | CmDn | 5cm | 10 |
| Conway | EC021 | EVN+MERLIN Observations of NGC7538 | CmDn+MER | 5cm | 18 |
| van Langevelde | EL032 | Whats Brewing At the Sites of Methanol Masers? | CmDn+MER | 5cm | 24 |
| Goedhart | EG031 | G9.62+0.20E Methanol Maser Mapping | Dn | 5cm | 6 |
| Paragi | N04M1 | NME C-band | CmDn+MER | 5cm | 6 |
| Conway | EC023A | Methanol in Sources With Missing Flux | CmDn+MER | 5cm | 20 |
| Conway | EC023B | Methanol in Sources With Missing Flux | CmDn+MER | 5cm | 9 |
| Niezurawska | EN003A | Methanol Masers in (Proto)Stars | CmDn+MER | 5cm | 10 |
| Niezurawska | EN003B | Methanol Masers in (Proto)Stars | CmDn+MER | 5cm | 10 |



# APPENDIX D

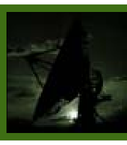
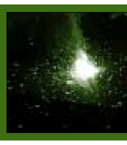
## National Facility Visitors

### Visitors 2003

P. Augusto, Portugal, University of Madeira
I. Bains, UK, University of Hertfordshire
P. Barthel, the Netherlands, University of Groningen
K. Blundell, UK, University of Oxford
R. Bolton, UK, University of Cambridge
S. Dougherty, Canada, DRAO
D. Engels, Germany, University of Hamburg
A. Fey, USA, USNO Washington
M. Giroletti, Italy, Bologna
Y. Hagiwara, Germany, MPIfR Bonn
H. Imai, the Netherlands, JIVE
K. Johnston, USA, USNO Washington
A. Kemball, USA, NRAO Socorro
B. Kramer, Thailand, Bangkok
M. Kunert, Poland, Torun
C. Lonsdale, USA, MIT Haystack
L. Mullin, UK, University of Cambridge
K. Wills, UK, University of Sheffield
E. Xanthopoulos, UK, University of Manchester

### Visitors 2004

A. Biggs, the Netherlands, JIVE
M. Bisi, UK, University of Wales at Aberystwyth
M. Bode, UK, Liverpool John Moores University
S. Bourke, Ireland, NUI Galway
S. Etoka, UK, University of Manchester
R. Fender, the Netherlands, University of Amsterdam
G. Fuller, UK, UMIST
D. R. Gonzalez, UK, UCL
B. Kramer, Thailand, Bangkok
A. Marecki, Poland, Torun
D. W. McSweeney, UK, UMIST
J. Miller-Jones, the Netherlands, University of Amsterdam
S. Nammahachak, Thailand, Udon Thani
A. Niezurawska, Poland, Torun
Z. Paragi, the Netherlands, JIVE
D. J. Saikia, India, NCRA Pune
E. Xanthopoulos, USA, LLNL
J. Yates, UK, UCL


# APPENDIX E

## National Facility Publications 2003-2004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4. Argo, M. K., Muxlow, T. W. B., Beswick, R. J., Pedlar, A., Marcaide, J. M., 2004, *Supernova 2004dj in NGC 2403*, IAU Circular 8299, 3A
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8. Bains, I., Bryce, M., Mellema, G., Redman, M. P., Thomasson, P., 2003, *High-resolution Radio Structure and Optical Kinematics of NGC 7027*, MNRAS, 340, 381
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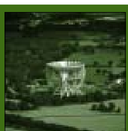

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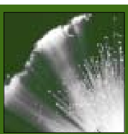

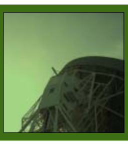

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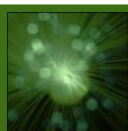

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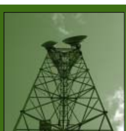

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## ACCESS TO THE MERLIN/VLBI NATIONAL FACILITY

Observing time on the MERLIN/VLBI National Facility is allocated on an open-access, peer-review basis to all astronomers worldwide. Observing time for MERLIN is allocated by the MERLIN Time Allocation Group (TAG) of the Panel for the Allocation of Telescope Time (PATT), while that for VLBI is allocated by the European VLBI Network's Programme Committee (EVN PC). Two days per semester are available to be used at the discretion of the Director of the National Facility. MERLIN is one of the participating institutes in the RadioNet (www.radionet-eu.org) project from which transnational access (TNA) within the EU to existing observing facilities is financially supported.

The deadline for the receipt of applications for MERLIN time occur twice per year, on March 15 and September 15. A call for MERLIN proposals is issued several weeks prior to each deadline. Full details on the capabilities of MERLIN and no how to apply for time can be found on the MERLIN home page at http://www.merlin.ac.uk.

The deadlines for the receipt of applications for time on the European VLBI Network (EVN), the global VLBI network and for joint EVN+MERLIN observing time occur three times per year, on February 1, June 1 and October 1. A call for proposals is issued several weeks prior to each deadline. Full instructions on how to apply for time and on the capabilities of the Network can be found on the EVN home page at http://www.evlbi.org.

All astronomers are encouraged to apply for National Facility time to complement their existing research or to use the National Facility as the main instrument for their research topics.