

**EUROPEAN**



**NETWORK**

**Biennial Report  
2007–2008**





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## Foreword by the Chairman of the Consortium

The European VLBI Network (EVN) is the result of a collaboration among most major radio observatories in Europe, China, Puerto Rico and South Africa. The large radio telescopes hosted by these observatories are operated in a coordinated way to perform very high angular observations of cosmic radio sources. The data are then correlated by using the EVN correlator at the Joint Institute for VLBI in Europe (JIVE). The EVN, when operating as a single astronomical instrument, is the most sensitive VLBI array and constitutes one of the major scientific facilities in the world.

The EVN also co-observes with the Very Long Baseline Array (VLBA) and other radio telescopes in the U.S., Australia, Japan, Russia, and with stations of the NASA Deep Space Network to form a truly global array. In the past, the EVN also operated jointly with the Japanese space antenna HALCA in the frame of the VLBI Space Observatory Programme (VSOP). The EVN plans now to co-observe with the Japanese space 10-m antenna ASTRO-G, to be launched by 2012, within the frame of the VSOP-2 project. With baselines in excess of 25.000 km, the space VLBI observations provide the highest angular resolution ever achieved in Astronomy.

This Biennial Report highlights the scientific results obtained with the EVN and describes some of the technical and operational activities of the member institutes over the period 2007-2008. As the report shows, the EVN is providing astronomers with a detailed view of the most energetic phenomena in the universe, including expanding supernovae, pulsars, flare stars, star-forming regions in molecular clouds, the environment surrounding nearby and distant galaxies, gravitational lenses, starburst galaxies, and distant active galactic nuclei.

The technical activities during 2007-2008 have been particularly fruitful. Spectacular progress has been achieved in building the e-EVN. This is a real-time VLBI interferometer constructed by transferring the data, through the GEANT2 research network, to the correlator in JIVE and by processing it in real time.

The member institutes of the EVN, together with additional partners, have been very successful players in the successive Framework Programmes of the European Union. Several RadioNet and EXPRoS projects have strengthened and extended the collaboration in Radio astronomy across Europe, in particular during 2007-2008, and these activities are foreseen to even increase in the next future.

The EVN is close to celebrating its 30<sup>th</sup> anniversary; the Network is living today in very exciting times with the development of e-VLBI, the extension of the array by including additional antennas, and the increase in performance of receivers and data handling. By filling the gap in frequencies between ALMA (Atacama Large Millimeter Array) and the SKA (Square Kilometer Array) – the most ambitious Radio astronomy projects for the future decades – the EVN has a bright and fruitful future ahead of it.

**Rafael Bachiller, Observatorio Astronómico Nacional (IGN), Spain  
Chairman, EVN Consortium Board of Directors.**

**Francisco Colomer, Observatorio Astronómico Nacional (IGN), Spain  
Secretary, EVN Consortium Board of Directors.**



# 1. The European Consortium for VLBI

The European VLBI Network (EVN) was formed in 1980 by a consortium of five of the major radio astronomy institutes in Europe (the European Consortium for VLBI). Since then, the EVN and the Consortium have grown to include 12 institutes with telescopes in Spain, UK, the Netherlands, Germany, Sweden, Italy, Finland, Poland and China, a 16 station data processor at JIVE in Dwingeloo and a 9 station data processor at MPIfR in Bonn. In addition, the Hartebeesthoek Radio Astronomy Observatory in S. Africa and the NAIC Arecibo Observatory in Puerto Rico are active Associate Members of the EVN. Together, these individual centers form a large scale facility, a continent-wide radio telescope. The EVN is linked on a regular basis to the 7-element Jodrell Bank MERLIN interferometer in the UK to create a very sensitive "regional network", and to the USA NRAO Very Long Baseline Array and the NASA Deep Space Network to create a "Global Network".

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

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

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

The EVN, in stand-alone or global mode, also observed together with the orbiting radio telescope HALCA launched in February 1997 by the Institute of Space and Astronautical Science (ISAS) in Japan as part of the first dedicated Space VLBI mission VSOP (VLBI Space Observatory Programme). Preliminary agreements between EVN and ISAS for the fore-coming VSOP-2 mission have been arranged.

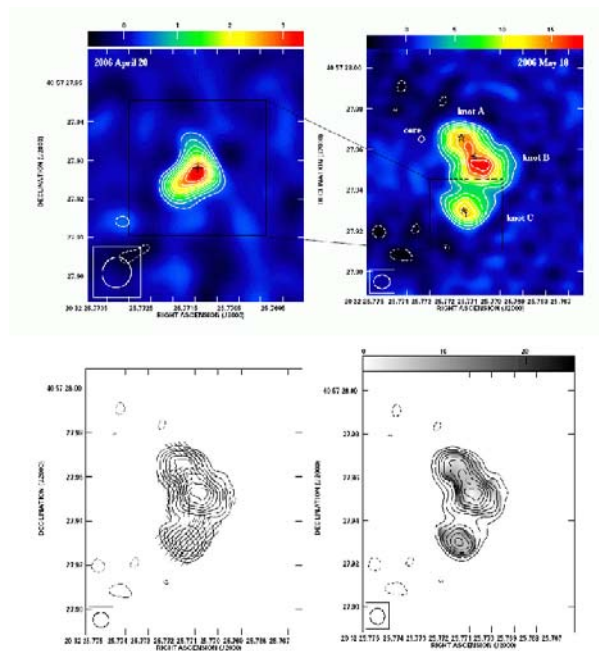




## 2. Scientific highlights on EVN research

The scientific research carried out by various groups using EVN facilities cover a wide range of topics, from the Solar System and nearby Universe to the very distant objects. Here we present some highlights of these studies ranging from those dealing with the distant Universe to those dealing with star formation in the Galaxy, Astrometry, etc.

An important scientific milestone reached in 2007 was the acceptance for publication in the Monthly Notices of the Royal Astronomical Society (MNRAS) of the first papers resulting from e-VLBI science observations. Other papers had been published as conference proceedings, but this first publication of letters in a refereed journal was a turning point of maturity for e-VLBI. The first paper, "First e-VLBI observations of GRS 1915+105", by Rushton et al., was published in the January 2007 issue of MNRAS. The second paper, "First e-VLBI observations of Cygnus X-3", by Tudose et al., was published in the February 2007 issue.



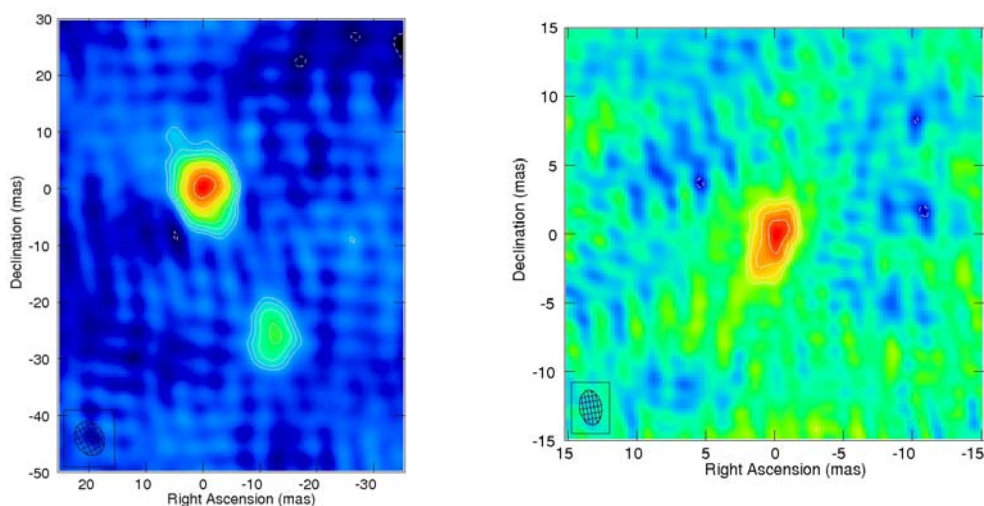
The observations by Tudose et al. (2007) captured the X-ray binary system Cygnus X-3, both in quiescence (April 2006) and during a huge, active outburst (May2006). The total intensity and (the very first VLBI) polarization images are shown.

Both papers discuss data taken within the first open call for observations available to the whole scientific community using the six EVN telescopes which were available at that time: Cambridge (UK), Jodrell Bank MkII (UK), Medicina (Italy), Onsala-20m (Sweden), Torun (Poland) and Westerbork (The Netherlands). Data was sent from each of the participating telescopes at a sustained data rate of 128 Mbps to the EVN correlator at JIVE (The Netherlands).

## 2.1 Galaxies and cosmology

### ***A compact symmetric object at $z=6.12$ ?***

The highest redshift quasars receive considerable attention since they provide strong constraints on the growth of the earliest supermassive black holes. They also probe the epoch of reionisation and serve as "lighthouses" to illuminate the space between them and the observer. The source J1427+3312 ( $z=6.12$ ) was identified as the first known radio-loud quasar at  $z>6$ . S. Frey (FOMI SGO), L.I. Gurvits, Z. Paragi (JIVE), and K.E. Gabanyi (FOMI SGO & ISAS JAXA) observed this quasar in phase-reference mode with ten antennas of the EVN at 1.6 GHz on 11 March 2007 and at 5 GHz on 3 March 2007 (project EF020).



The naturally weighted EVN images of J1427+3312 at 1.6 GHz and 5 GHz. The positive contour levels increase by a factor of square root of 2. The first contours are drawn at -50 and 50 microjansky/beam.

J1427+3312 was clearly detected at both frequencies. At 1.6 GHz, it shows a prominent double structure. The two components are separated by 28.3 mas, corresponding to a projected linear distance of  $\sim 160$  pc. Both components with sub-mJy flux densities appear resolved. In the position of the brightest component at 1.6 GHz, a mas-scale emission feature at 5 GHz was also detected. The radio spectrum of this feature is steep with a spectral index of -0.6. The double structure and the separation of the components of J1427+3312 are similar to those of the young compact symmetric objects (CSOs). There are several indications of the youthfulness of this radio source. Based on its similarity to CSOs, one could speculate that the kinematic age of this extremely distant quasar is not more than a few thousand years.

## ***GHz-Peaked-Spectrum (GPS) radio sources at 1.6 GHz***

Liu et al. (2007) obtained the results of VLBI observations of nineteen GHz-Peaked-Spectrum (GPS) radio sources at 1.6 GHz. Of them, 15 sources were selected from the Parkes Half Jansky (PHJ) sample (Snellen 2002) and 4 others were from a previous observation list. The aim of the study was to investigate the structure of GPS sources, searching for Compact Symmetric Objects (CSOs) and studying the absorption for the convex radio spectra of GPS sources.

Total intensity 1.6 GHz VLBI images of 17 sources were obtained for the first time. Of them, 80% show mini-double-lobe radio structure, indicating that they are young CSOs or candidates, and their host AGNs could be edge-on to us. This result suggests that there is a high incidence of mini double-lobe sources (or CSOs) in the PHJ sample. The sources J0323+0534, J1135-0021, J1352+0232, J2058+0540, J2123-0112 and J2325-0344 with measured redshift, showing double-lobe structure with sizes of <1 kpc and stable source flux density, are classified as CSOs. Three sources J1057+0012, J1600-0037 and J1753+2750 are considered as core-jet sources according to their morphologies and flux variability. Figures show the EVN images of 4 sources in our sample as below.

On the other hand, Luo et al. (2007) reported quasi-simultaneous VLBI images of the GHz-Peaked-Spectrum radio source OQ208 obtained with the Very Long Baseline Array at 1.4, 1.7, 2.3, 5.0, 8.4, 15.4 GHz and the European VLBI Network at 6.7 GHz. The low frequency (1.4, 1.7 and 2.3 GHz) observations revealed a weak and extended steep-spectrum component at about 30 mas away at position angle  $-110^\circ$ , which may be a remnant emission. The radio structure of OQ208 consists of two mini-lobes at 5.0, 6.7, 8.4 and 15.4 GHz. The spectral analysis further confirmed that the southwest lobe undergoes free-free absorption and finds that the free-free absorption is stronger in the inner region. By fitting the 8.4 GHz images from 1994 to 2005, a separation speed of  $0.031 \pm 0.006$  mas/yr between the two mini-lobes was obtained. This indicates a jet proper motion of  $0.105c \pm 0.020c$  and a kinematic age of  $219 \pm 42$  yr for the radio source.

The EVN and VLBA data revealed a weak extended emission in radio source OQ208 at 1.4 and 1.6 GHz, which could be a remnant of past activity.

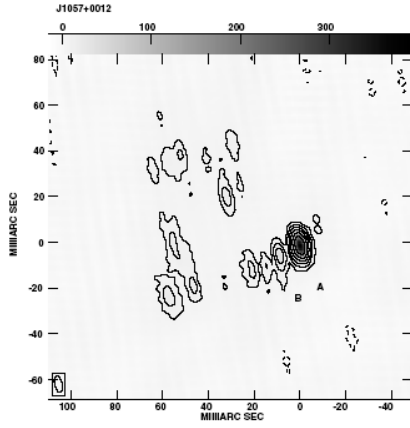


Fig. 5. J1057+0012 at 1.65 GHz. The restoring beam is  $7.3 \times 3.3$  mas with PA  $13.4^\circ$ , the peak is 390 mJy/beam, and the first contour is 6 mJy/beam.

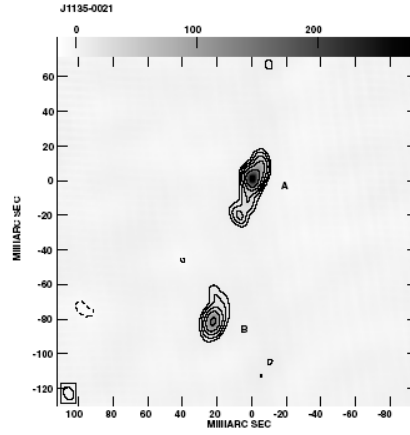


Fig. 7. J1135-0021 at 1.65 GHz. The restoring beam is  $7.8 \times 5.3$  mas with PA  $20.4^\circ$ , the peak is 281 mJy/beam, and the first contour is 8 mJy/beam.

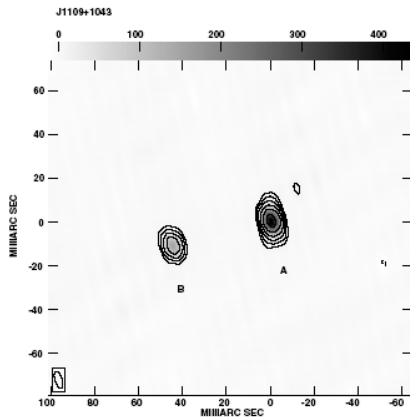


Fig. 6. J1109+1043 at 1.65 GHz. The restoring beam is  $7.9 \times 3.3$  mas with PA  $16.5^\circ$ , the peak is 434 mJy/beam, and the first contour is 10 mJy/beam.

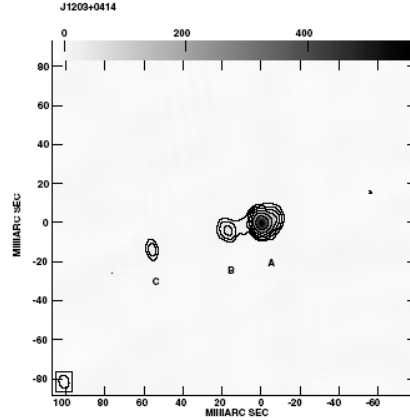
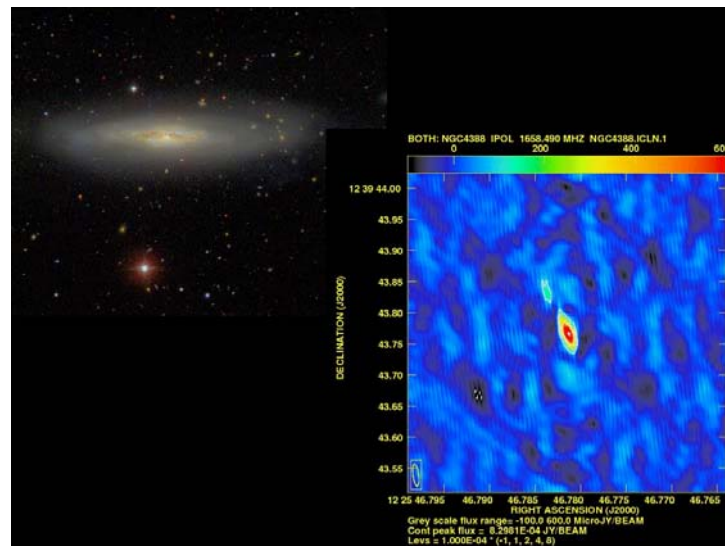


Fig. 8. J1203+0414 at 1.65 GHz. The restoring beam is  $7.0 \times 4.9$  mas with PA  $15.2^\circ$ , the peak is 575 mJy/beam, and the first contour is 10 mJy/beam.

## ***EVN observations of parsec scale cores in Seyfert galaxies***

Active Galactic Nuclei (AGN) are traditionally divided in radio quiet (RQ) and radio loud (RL). While the latter are common targets of VLBI observations, only a few of the most nearby RQ sources have been imaged at milliarcsecond resolution. However, such observations are expected to provide key elements to the understanding of the physics of the disc-jet connection, e.g. by revealing compact high-brightness temperature cores.

In order to achieve a comprehensive understanding of the broadband properties of RQ AGN (and eventually clarify the nature of the RL/RQ differences), Marcello Giroletti (INAF/IRA, Bologna) and collaborators are studying a distance-limited sample of 27 Seyfert galaxies. VLA observations taken from the literature have revealed radio cores at the mJy level in these galaxies and 6 targets were selected to be observed with the EVN at 1.6 and 5 GHz in 2007 session 2 and 2008 session 1.

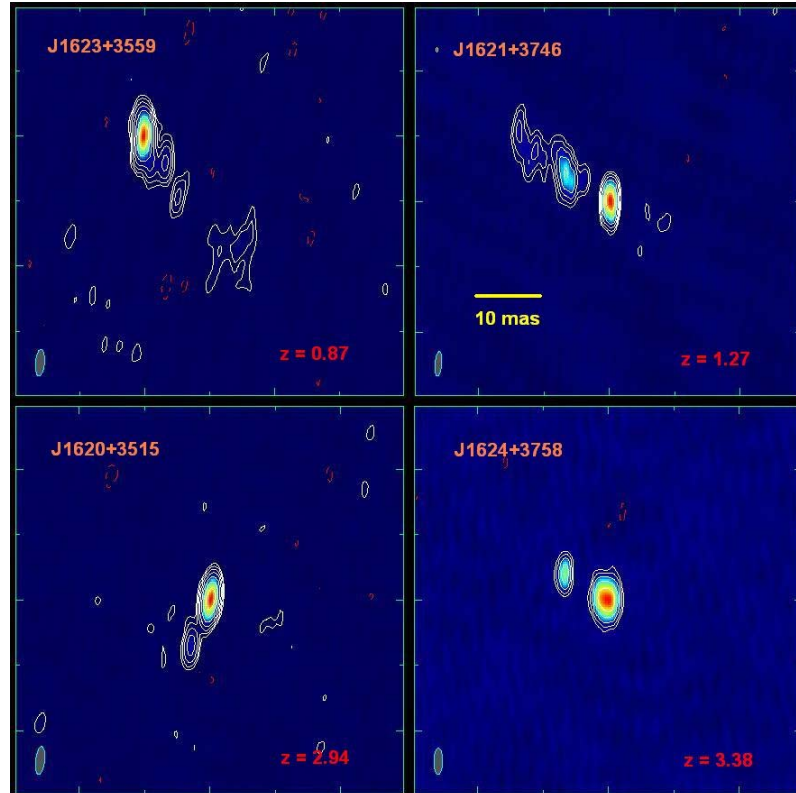


Images of NGC 4388 - Top left: An SDSS optical image of this beautiful Sy2 galaxy; bottom right: our (preliminary) EVN phase referenced map of its central region. The participating telescopes are Jb, Wb, Ef, On, Mc, Tr, Sh, Ur, Nt, Hh; the observing frequency is 1.6 GHz.

Despite unfavorable observing conditions, the authors have been successful in revealing compact components in 4 out of the 6 sources: NGC 4051, NGC 4388, NGC 4501, and NGC 5033, three Seyfert galaxies of type 2 (or 1.9) and one of type 1.5. The flux densities are barely at the milliJansky level, but thanks to the great sensitivity provided by the 1 Gbps recording rate, these are all solid detections. Further analysis and accurate review of transfer solution from the phase calibrators will hopefully improve the images, e.g. confirming the possible jet-like feature visible in NGC 4388 (see figure). The results were presented at the 9<sup>th</sup> EVN Symposium in Bologna, and are discussed in a forthcoming publication by Giroletti & Panessa.

## ***An efficient way to image SDSS quasars with VLBI***

The Deep Extragalactic VLBI-Optical Survey (DEVOS) aims at constructing a sample of compact radio sources up to two orders of magnitude fainter than those usually studied with VLBI. S. Frey (FOMI SGO), L.I. Gurvits, Z. Paragi (JIVE), L. Mosoni (Konkoly Obs.), M.A. Garrett (ASTRON), and S.T. Garrington (JBO) performed 5-GHz phase-referencing observations with 8 antennas of the EVN (EF016, 2 March 2007) targeting 26 radio sources within two adjacent 2-deg radius fields around the compact calibrators J1616+3621 and J1623+3909. The recording data rate was 1 Gbit/s, the project lasted for 6 hours.

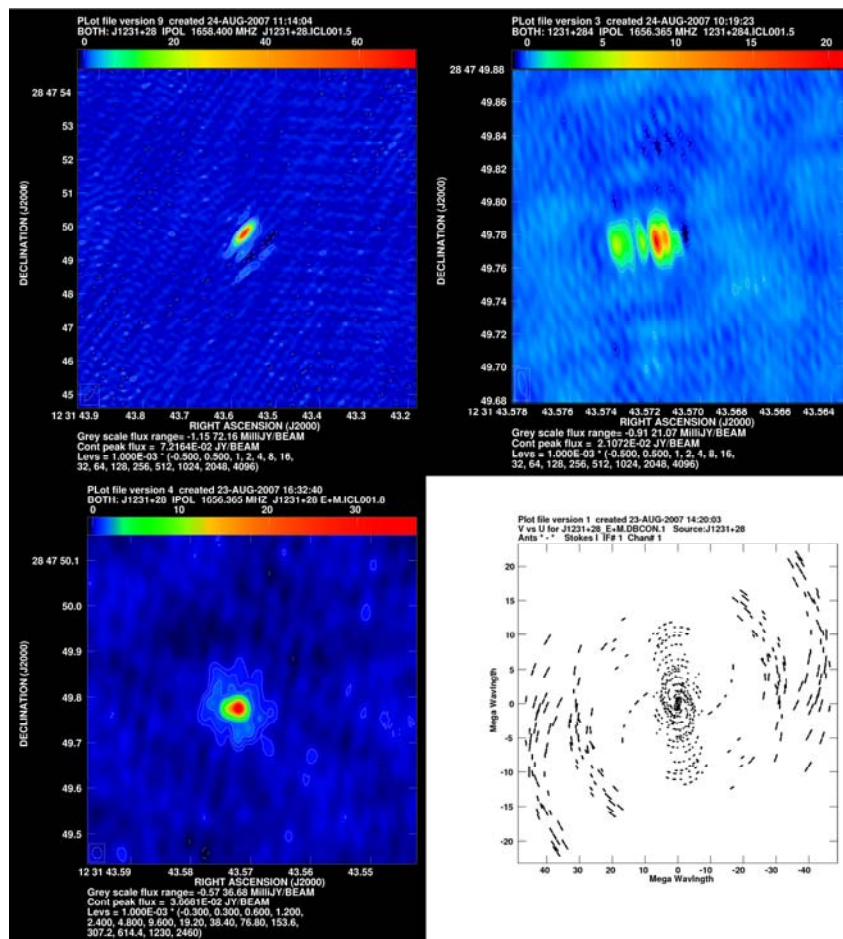


Images of four quasars with core-jet morphologies in a wide range of redshifts are shown here as an illustration. Peak brightnesses (from the top left corner) are 83.5, 13.5, 27.5 and 8.6 mJy/beam. Typical 3-sigma lowest image contours were 0.3 mJy/beam in the survey. The details of the observations as well as the results and notes on some individual quasars are reported in A&A (477, 781)

Optical identifications of the quasars were ensured by selecting them from the Sloan Digital Sky Survey (SDSS). Twenty-two of the target sources (85%) that are unresolved both in SDSS (i.e. optical quasars) and in the VLA Faint Images of the Radio Sky at Twenty-centimeters (FIRST) survey catalogue ( $<5''$ ,  $>20$  mJy) have been successfully detected with the EVN. Most of them had never been imaged with VLBI. (Two other VLBI detections are probably chance positional coincidences with SDSS quasars.) Therefore the authors found an efficient way to identify potential VLBI targets with mas-scale compact radio structures at  $>1$  mJy flux density level, based on available optical and lower-resolution radio catalogue data.

## Structure of BL Lac objects identified in the 'Deep X-ray Radio Blazar Survey'

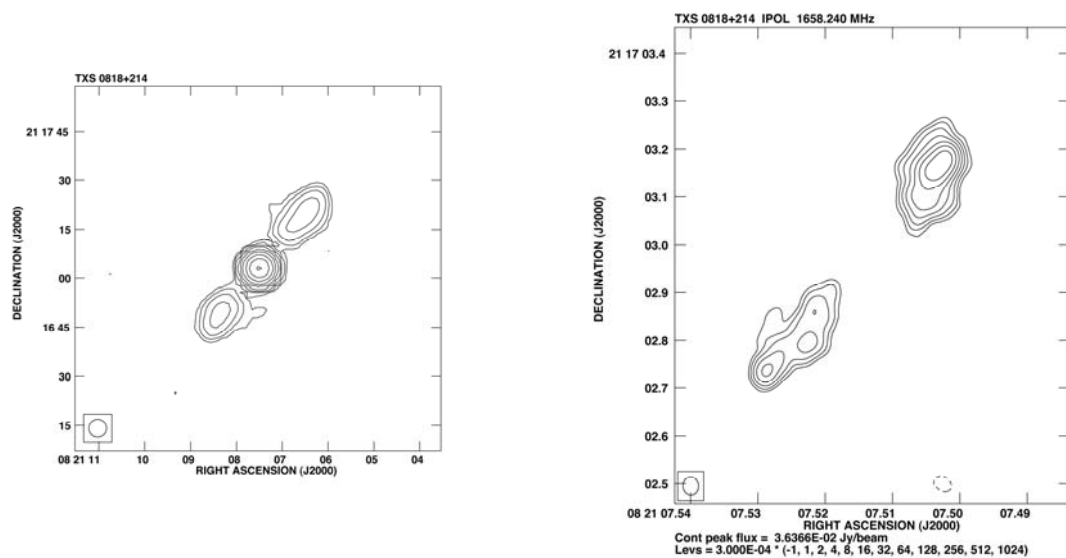
Hayley Bignall and Cormac Reynolds (JIVE) worked with summer student Gabriele Surcis on analysis of EVN+MERLIN data on BL Lac objects identified in the 'Deep X-ray Radio Blazar Survey' (DXRBS). These objects have properties spanning the range between classical X-ray- and radio-selected BL Lac samples. The results show that many of the sources have complex structures between milliarcsecond and arcsecond scales. Lower resolution images obtained with the VLA (by Hermine Landt, CfA) and ATCA (Hayley Bignall) suggest that these sources do not belong to a single parent population viewed at different angles, as would be the case in the standard AGN unification scheme, but rather than there are differences in the intrinsic source properties as well. The VLBI data will reveal similarities and differences in the mas-scale structure of these sources.



The figure above shows high-resolution 18cm images of the BL Lac object thought to be associated with X-ray source WGA J1231+2848. The top right-hand panel is from observations using 10 antennas of the EVN. A lower resolution image from simultaneous MERLIN data is shown in the top left panel. An intermediate-resolution image made after carefully combining the data from both arrays is shown in the lower left panel, while the lower right panel shows the combined (u,v) coverage.

## Core-Dominated Triples

The usual FR II structure of a radio galaxy can be substantially modified by cessation and a subsequent re-ignition of the activity. The signature of such an event is most convincing if it takes the form of a smaller double embedded by a larger, double-lobed structure. If both doubles share the common center and are well aligned the whole object is labeled a double-double radio galaxy (DDRG). It can be, however, that we observe a DDRG at an early stage of the development of the inner double so that it is not resolved in the images showing the overall structure. Thus, “at first sight”, the source of such kind appears as a core-dominated triple (CDT). Marecki (TCfA) and his collaborators carried out a systematic search through the FIRST catalogue for CDTs by means of an automated procedure and we selected several sources for follow-up observations with MERLIN at 5 GHz. They revealed one source of particular interest: 0818+214.



0818+214. Left panel: VLA map extracted from FIRST. Right panel: EVN+MERLIN map of the central component seen above.

In the FIRST image, 0818+214 appears as a CDT (left panel in the figure above). To explain the nature of its bright “core”, i.e. to answer the question whether 0818+214 is actually a DDRG or not, Marecki et al. carried out an EVN+MERLIN observation at 18 cm. The resulting image of the “core” of 0818+214 (right panel in the figure) shows it as a double located at P.A.=  $-40^\circ$ . Given that the two components are asymmetric – the northwestern one is appreciably brighter than the southeastern one – it could be that the subarcsecond-scale structure is of a core-jet type. However, after combining the 18-cm EVN+MERLIN image with the earlier 6-cm MERLIN image and calculating the spectral index, the inner structure of 0818+214 proves to be a mini-FR II, and the object as a whole turns out to be the most compact (in terms of the span of the outer lobes) DDRG to date. Given that DDRGs are known to be giant (Mpc-sized) radio sources, the case of 0818+214, which is clearly less than 1 Mpc, poses a challenge for the theory of DDRGs.

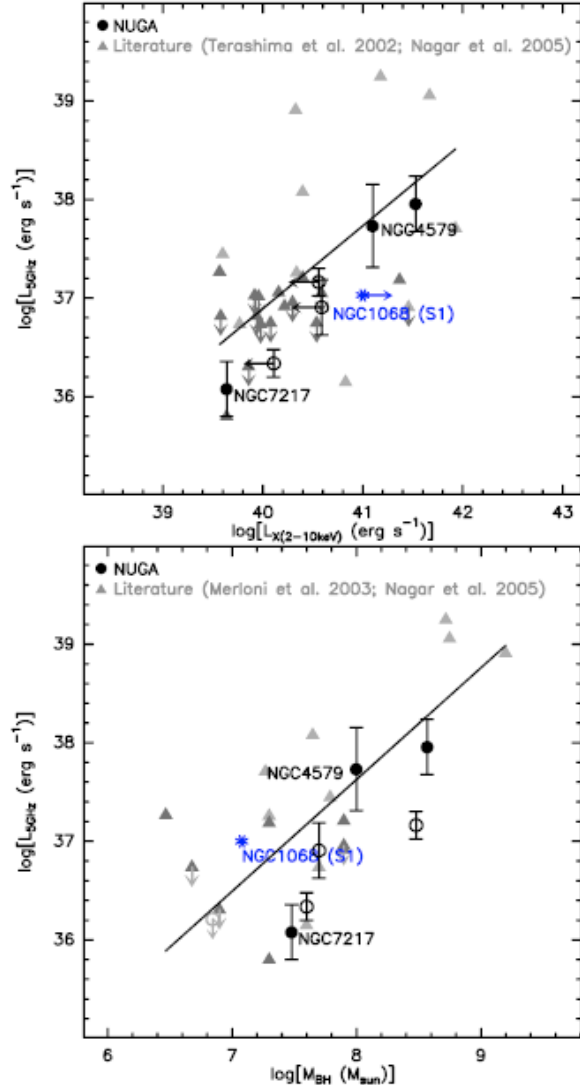


## Imaging of Low Luminosity Active Galaxies

Krips et al (2007, A&A, 464, 553) reported results from a radio snapshot imaging survey of seven nearby low luminosity active galaxies (LLAGN) using a combination of MERLIN and EVN/VLBA observations at both 18 and 6 cm. The sample of galaxies observed was selected the NUClei of GALaxies survey (NUGA); a sample of galaxies which have been extensively studied at other wavelengths.

Despite the importance of Supermassive Black-hole (SMBH) activity in regulating galaxy formation, comparatively little is known about SMBH activity at low radiative luminosities. This is a significant gap in our understanding of feedback and the role of SMBH in galaxy growth and evolution, since it is now known that mechanical jet power can be energetically more significant than supernova feedback even at low AGN luminosities (Nagar et al. 2005; A&A, 435, 521; Koerding et al. 2008, MN, 383, 277). The major difficulty in studying low luminosity AGN is precisely their low radiative output with respect to their surrounding host galaxy. However, just because an AGN is radiatively inefficient does not make it mechanically inefficient – in fact at low luminosities the total power is almost certainly mechanically dominated via the jet – making sensitive, high resolution radio observations, such as presented by Krips et al (2007), a crucial tool in studying these objects.

In this study these radio observations were used to compare the derived radio luminosities of LLAGN with their black hole mass, estimated via the respective stellar velocity dispersions, and their X-ray luminosities. These comparisons suggest correlations among these quantities even at high angular resolution, thus supporting the existence of a fundamental plane; the three dimensional parameter space of radio luminosity, X-ray luminosity, and black-hole mass (e.g. Falcke, Koerding & Markoff 2004). However, in two objects NGC1068 and NGC7217 sampled, these observations demonstrate that this fundamental plane could be violated if the radio emission is produced not by direct synchrotron processes but rather by electron scattered synchrotron or free-free emission, even though the latter are also expected to be closely connected to X-ray activity.

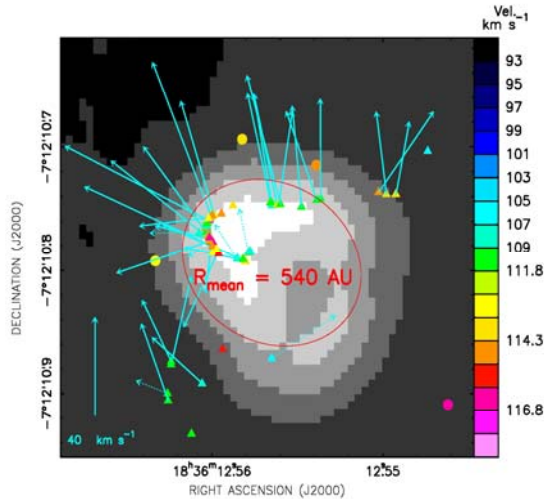


Comparison of 5GHz radio data with X-ray luminosities (upper panel) and with Black-hole masses (lower panel).

## 2.2 Stellar evolution in the Galaxy

### ***Massive star-formation in G24.78+0.08 explored through VLBI maser observations***

The hypercompact HII region G24.78+0.08 A1 is ionized by an O9.5 ( $20 M_{\text{Sun}}$ ) star and located at a distance of 7.7 kpc. Previous interferometric observations in a variety of tracers have shown that this star powers a bipolar molecular outflow and lies at the center of a massive toroid rotating around the outflow axis. Recent VLA + Pie Town 7mm continuum observations complemented by VLBA proper motion measurements of water 22.2 GHz masers have revealed that the hypercompact HII region is expanding on a very short time scale, on the order of about 40 yr only. Note that the age estimate is distance independent, as it depends on the ratio between the angular radius of the HII region and the maser proper motion in the plane of the sky.



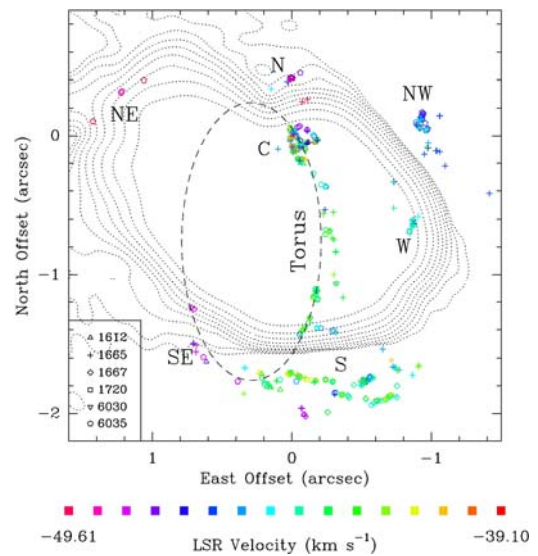
7mm continuum image of the hypercompact HII region G24 A1 (grey scale) obtained with the VLA plus w:st="on" Pie Town link. The red ellipse shows the Gaussian elliptical fit of the continuum emission, resulting into a mean radius of 540 AU. Triangles denote water maser spots observed with VLBA, with measured proper motions shown by arrows. The amplitude scale of the proper motion is shown on the bottom-left corner of the plot. Dots denote methanol maser spots observed with EVN. Symbol colors refer to different spot line-of-sight velocities as given in the wedge on the right-hand of the plot.

With the EVN, Luca Moscadelli (Arcetri Astronomical Observatory, Italy) observed the methanol 6.7 GHz masers and found several emission centers distributed around the hypercompact HII region, with a larger angular separation from the ionizing star than that of the water masers. Two alternative interpretations are suggested: 1) methanol masers trace ambient gas not yet perturbed by the expanding outflow traced by the water masers; 2) methanol masers trace the same outflow as water masers do. Future EVN epochs at 6.7 GHz (with a time baseline of 1-2 yr) will allow to measure the proper motion of the methanol masers and to discern between the two possible interpretations.

## Structure of W3(OH) from 6 GHz OH masers observations with the EVN

W3(OH) is a nearby well-studied massive star-forming region with many bright masers. Vincent L. Fish (MIT Haystack Observatory) and Loránt O. Sjouwerman (NRAO) observed the rotationally-excited 6030 and 6035 MHz OH masers with the EVN at very high spectral resolution (0.024 km/s) in order to understand the large-scale morphology of W3(OH) and small-scale maser substructure. Thanks to the high sensitivity and angular resolution afforded by the EVN, they were able to detect 292 distinct maser features and identify 117 Zeeman pairs, each providing a local measurement of the magnetic field around W3(OH).

Many of the brightest 6030 and 6035 MHz masers trace the inner edge of a rotating molecular toroidal structure with a density gradient falling off sharply to the east. The excited-state masers, which can trace denser and warmer material, make it much easier to unravel this structure than would ground-state masers alone, and the EVN is the only instrument that can map the 6030 and 6035 MHz masers in W3(OH) with sufficient angular resolution. Magnetic fields in the southeast and northeast have reversed polarity compared to the dominant direction indicated by the OH masers in the western half of W3(OH). The northeastern masers, seen only in the 6035 MHz transition, are blueshifted compared to the systemic velocity of the H II region and the rest of the OH masers and are likely associated with a champagne flow in the ionized emission.



Structure of W3(OH) as derived from the EVN observations of Fish & Sjouwerman (2007)

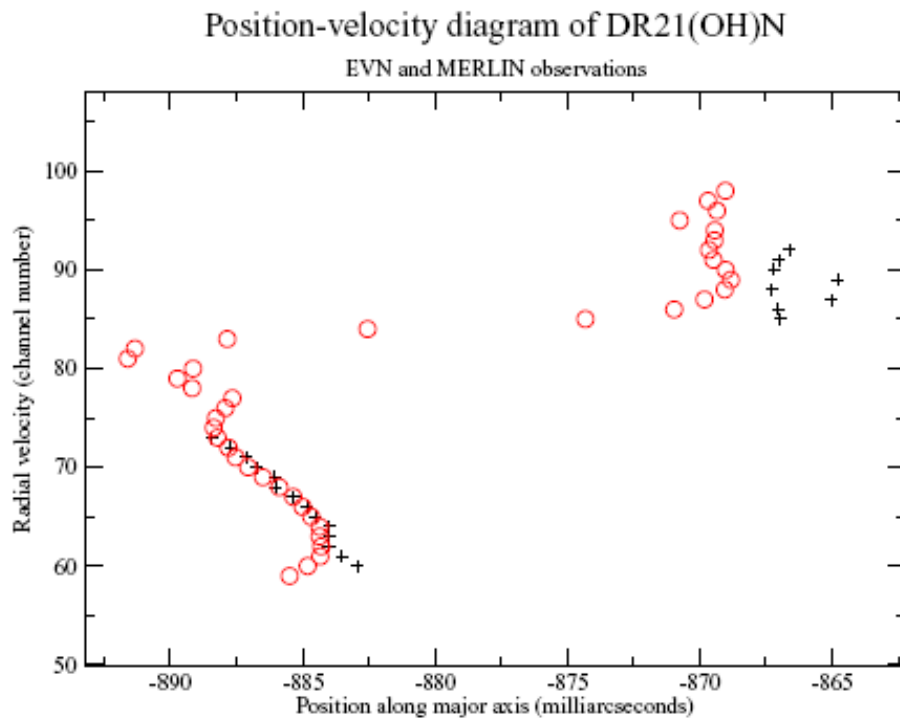
Many masers show position shifts across their line width, suggesting that OH masers are not simply pointlike structures even at the resolution of the EVN. Masers in the 6030 MHz transition almost always spatially overlap brighter 6035 MHz masers with identical LSR velocities, magnetic fields, and velocity gradients, indicating that the conditions that produce 6030 MHz masers are strongly favorable for 6035 MHz maser production as well. The large range in conditions probed by different maser clusters in W3(OH) make it a promising laboratory for understanding massive star formation and maser phenomena.

This work is published in Fish & Sjouwerman (2007, ApJ, 668, 331).

## ***Methanol masers in DR21(OH)N: a candidate circumstellar disc***

The EVN has been recently used to directly image methanol maser emission with milliarcsecond resolution in the candidate circumstellar disc in a massive star-forming region DR21(OH)N. Recently published MERLIN observations (Harvey-Smith et al 2008, MNRAS, 384, 719) of this star-forming region discovered a highly unusual double-peaked, spatially extended, methanol maser source. These MERLIN observations showed the molecular gas traced by the methanol masers to rotating with a Keplerian profile, suggesting that these masers were tracing a rotating disc of material falling onto a central massive star.

However, to confirm these MERLIN findings, high resolution EVN follow-up observations of the methanol masers has been essential. Using these EVN follow-up observations Harvey-Smith & Soria-Ruiz (2008, MNRAS, 391, 1273) have been able to directly measure the motions of the molecular gas around the young, massive central star, confirming that this material is probably tracing a circumstellar disc. Ultimately using these precision velocity measurements combined with modeling of the maser emission and the disk itself, it may be possible to also estimate current mass of the central star.

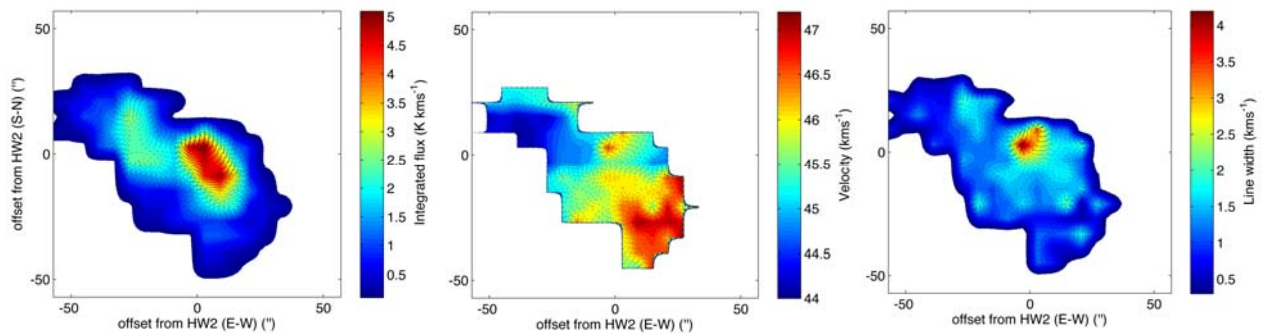


Position-Velocity diagram of 6.7-GHz methanol masers in DR21(OH)N showing a direct comparison between recent EVN observations (crosses) and MERLIN (circles). The P-V diagram shows the velocity signature of a Keplerian rotating disc.

## ***Methanol masers in prototypical star forming region Cep A***

Kalle Torstenson and Huib van Langevelde (JIVE) continued their studies of methanol masers associated with high mass star formation. In collaboration with Floris van der Tak (SRON Groningen) and Wouter Vlemmings (Bonn University). Interesting results were obtained on the nearest high mass star forming region Cep A, which is studied as the archetypical source in the sample.

Analysis of Harp data taken with the JCMT allows the derivation of the rotation temperature and column density of the thermal methanol gas. The methanol is clearly associated with the central source in this famous HII region and the derived temperature peaks at the location where the maser is found. Combined with earlier dust maps, it is possible to get a handle on the abundance. Methanol is believed to be a short-lived species in the gas phase, requiring a shock process to be released from interstellar grains. The data shows a large scale outflow from the central source where also the masers reside, consistent with the masers arising close to the place where the methanol is released.

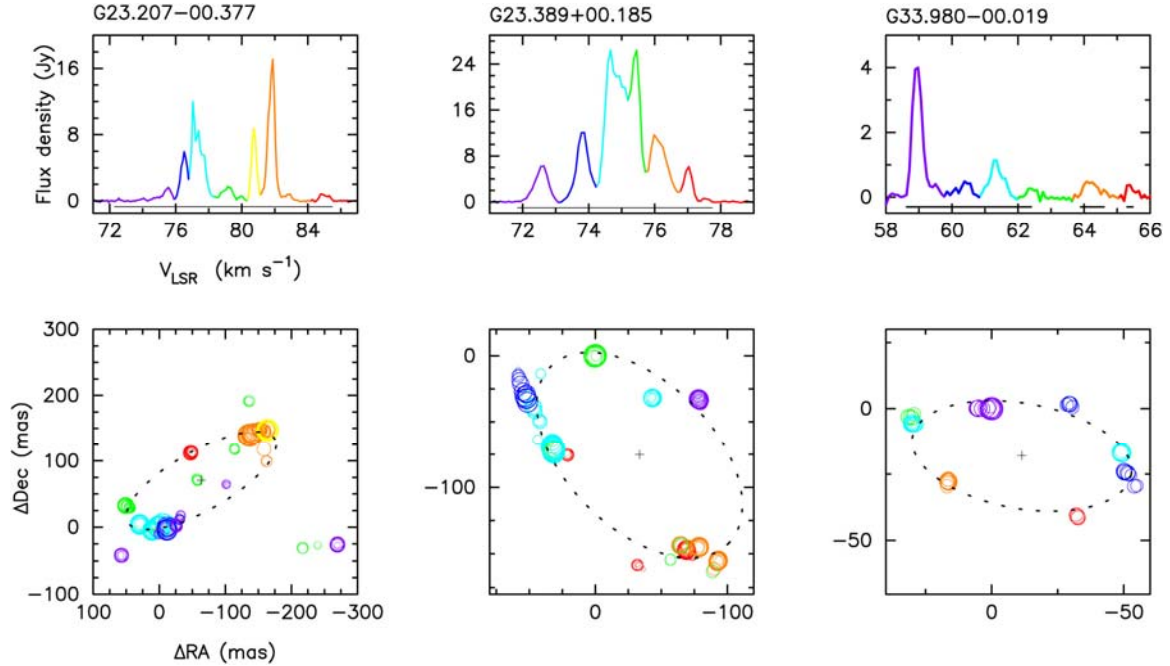


Thermal methanol in Cep A. From left to right the integrated flux, the velocity field and the line width of the methanol ( $7_{17}-6_{16}$ ) E-type line. This is the strongest unblended line in the JCMT Harp spectra.

The direction of the outflow is also roughly consistent with the orientation of the methanol masers on a much smaller scale as observed with the EVN. The methanol masers that straddle the waist of Cep A are interpreted as outlining a large scale ring structure perpendicular to the outflow axis of the central source. Remarkably, the velocity field does not show a rotation signature, but seems to be dominated by a radial motion. It could be hypothesized that the ring outlines an accretion shock, where in-falling gas hits the accretion disk.

## Discovery of a new class of ring-like methanol masers

Bartkiewicz and Szymczak (TCfA) together with van Langevelde and Torstensson (JIVE), Richards (JBCfA) and Pihlstrom (UNM) have completed EVN studies of 31 methanol maser sources selected from the Torun untargeted survey. The data obtained are unique due to their high angular ( $\sim 5 \times 15$  mas<sup>2</sup>) and spectral (0.09 or 0.18 km/s) resolutions, a sensitivity of  $\sim 15$  mJy and astrometric precision of  $\sim 5$  mas.

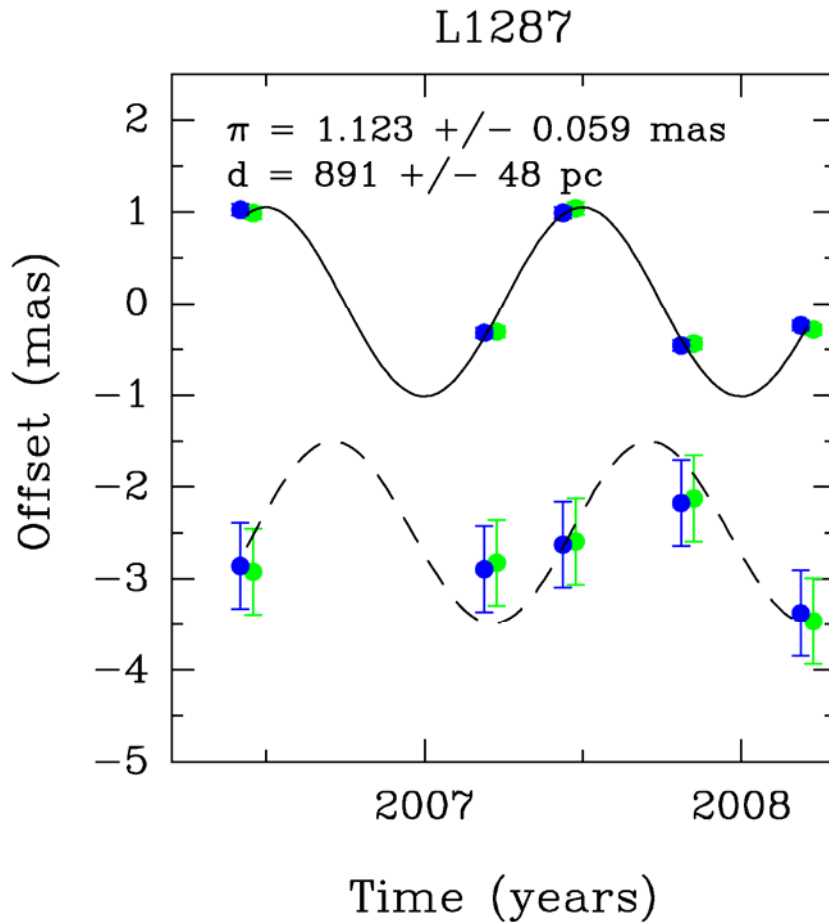


Spectra and maps of the 6.7GHz methanol line in sources with ring-like morphology detected with the EVN. The name of the source is the galactic coordinates of the brightest spot. The thin bars under the spectra show the velocity ranges of spots displayed. The best-fitting ellipse and its centre are marked by dotted curve and a cross, respectively.

The observations revealed a wide diversity of geometries of methanol maser sources and showed for the first time that in a large fraction of sources the distribution of the spots is ring-like. In 9 out of 31 sources the morphology can be easily fitted by an ellipse (see figure). Their eccentricity ranges from 0.38 to 0.94 and the sizes of major axes from 54 to 384 mas. Such a spot distribution strongly supports the scenario of an inclined disc or torus around a massive protostar or young star. However, fitting a simple model or a rotating and expanding ring suggests that in general the expansion/infall dominates. This can occur at the interface between the disc/torus and outflow. Moreover, all nine ring-like masers coincide with mid-infrared emission observed with Spitzer and show extended emission in the IRAC 4.5 micrometers band. That strongly supports the hypothesis of a central embedded star and existence of shocked molecular gas in protostellar outflows. The main conclusion inferred is that the methanol emission arises from shocked material associated with a disc/torus, possibly from interaction with the outflow.

## Parallax measurements of Methanol masers

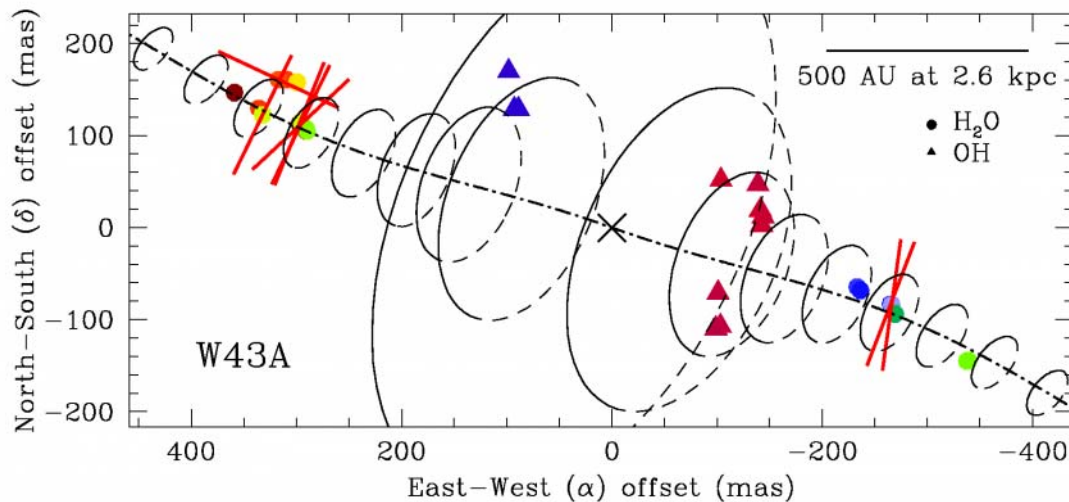
Huib van Langevelde (JIVE) together with Andreas Brunthaler and Kazi Rygl (MPIfR Bonn) are working on the use of methanol masers to obtain distances to high mass star formation regions and indeed the overall scale of the Milky Way. In this programme the first EVN parallax measurements were obtained for dark cloud L1287.



The figure above illustrates the preliminary parallax results for the dark cloud L1287 measured using the 6.7 GHz methanol maser emission. The Right Ascension (solid line) and declination (dashed line) signatures of the parallax are shown. Each maser channel which was used for the parallax fitting is indicated by a different color.

## Evolved stars: magnetic fields and distances

Nikta Amiri and Huib Van Langevelde (JIVE) and Vlemmings (Bonn University) have been studying the role of magnetic fields in structuring the outflow of evolved stars that are in transition to become a planetary nebula. MERLIN observations of the OH maser in the water fountain source W43A reveal circular polarization. When interpreted as the Zeeman effect, the measured magnetic field is 100 micro gauss. This is consistent with the previous estimate of the magnetic field of 70 micro gauss extrapolated from water maser polarization observations. Together these measurements seem to confirm that magnetic fields play an important role in shaping the circumstellar material in the transition to Planetary Nebulae.



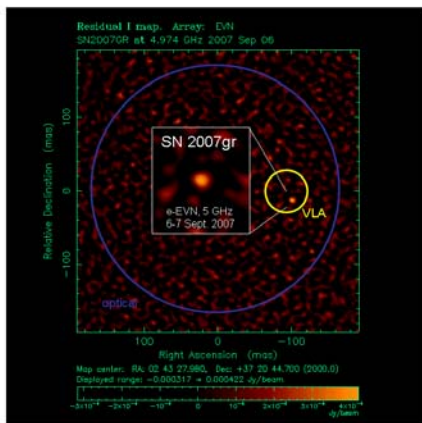
Spatial distribution of OH and H<sub>2</sub>O maser features in W43A. The offset positions are with respect to the reference feature. H<sub>2</sub>O features are indicated by filled circles and OH components are shown as triangles. Red and blue show the redshifted and blueshifted features.

The same team also started a VLBI campaign of OH/IR stars that have a previous distance determination from the so-called phase lag method. The goal is to determine whether these stars have enough compact maser emission to allow a parallax measurement with VLBI. This would be an independent check of the phase lag distance and its underlying assumptions. In particular it is interesting to check whether the OH maser shells are spherical. Processing of the data from the first campaign revealed that the masers show dominant structure on the shortest EVN baselines, and the observations were repeated in 2008 using a special mode that combines the EVN with four of the UK based telescopes that participate in MERLIN.



## ***e-VLBI Detection of SN 2007gr***

SN 2007gr was discovered at magnitude 13.8 with KAIT on August 15.51 UT, 2007 in the bright spiral galaxy NGC 1058 at a redshift of  $z = 0.001728$  (Madison and Li, CBET 1034, 2007) which corresponds to a distance of about 7.3 Mpc. The source was at discovery the 3rd brightest SN of the year, and was classified as Type Ib/c (and a possible Hypernova). This type of supernova is thought to arise from the core collapse of a Wolf-Rayet star, and has drawn increasing attention in recent years owing to their sparse association with long duration gamma-ray bursts. Since such core collapses are believed to generate ultra-relativistic jets, observable among other wavelengths in the radio, the only means to confirm or rule out potential jet superluminal expansions in these sources, is very high sensitivity and high resolution afforded only with VLBI imaging.



Dirty map of the SN 2007gr field, with approximate error boxes around the optical and the VLA coordinates. The supernova is clearly detected on the dirty map, in agreement with the VLA position.

Radio observations of SN 2007gr with the VLA on Aug 17.41 UT indeed revealed a radio source with a flux density of 610 microJy (Soderberg Atel 1187, 2007). Following this, a Target of Opportunity e-VLBI observation was organized with the EVN. The aim was to attempt milliarcsecond-scale detection of this supernova. The observations took place on 6-7 September for 12 hours (21:00-09:00 UTC) at 4.97 GHz with the array of Darnhall, Jodrell Bank (MkII), Medicina, Onsala, Torun and Westerbork (phased array) telescopes. Each telescope sent data to the correlator at a rate of 256 Mbps, except for Darnhall which contributed with an effective data rate of 128 Mbps due to microwave link limitations. Four dual polarization 8 MHz subbands were observed. The target was phase-referenced to the nearby calibrator J0253+3835. Further calibrators were observed that were used to calibrate the flux scale of the VLBI dataset by comparing the WSRT synthesis array data and VLBI amplitudes. The achieved rms noise level was 75 microJy/beam.

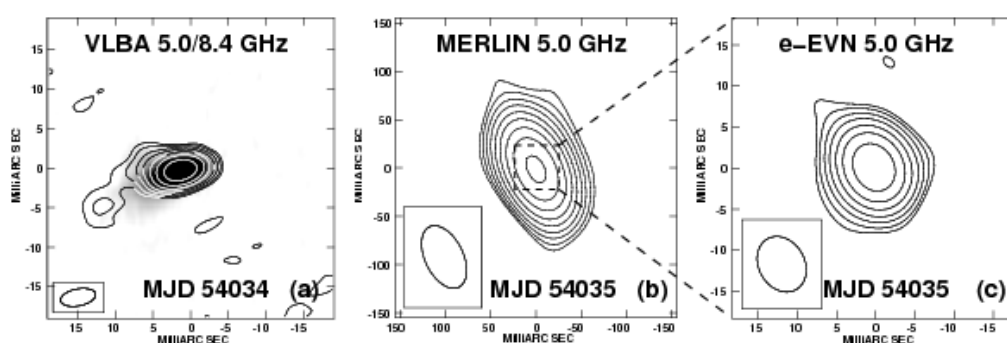
The supernova was detected with a flux density of 422 microJy, corresponding to a signal to noise ratio of 5.6. Its position was in agreement with the VLA coordinates (see figure). At the epoch of the observations the source was apparently unresolved. This result was quickly published in the Astronomer's Telegram (ATel 1215). Future high resolution observations are planned to follow the expansion of SN 2007gr. If detected as an extended radio image in its early evolutionary phase, this might be the first case of a relativistic jet found in a nearby core collapse supernova.

## 2.3 Galactic transients

### *e-EVN monitoring of microquasar candidate LSI+61 303*

LSI +61 303 is a microquasar candidate that is active from radio wavelengths to the gamma-ray regime. The exact nature of the binary system is however not clear; recent VLBA measurements suggested that the activity in fact comes from the interaction of a pulsar wind with its companion's.

The MAGIC collaboration carried out an observing campaign with the MAGIC telescope, CHANDRA, VLBA, MERLIN and the e-EVN. The radio monitoring was coordinated by Miguel-Angel Perez-Torres (IAA, Granada, Spain), and the e-EVN data were processed by Zsolt Paragi at JIVE. At the epoch of e-EVN observations the source did not show extended emission from the 10-100 mas scales, which has been seen at earlier epochs. There was a hint of correlation seen between the X-ray and the TeV gamma-rays during the campaign suggesting that in these two high energy regimes the emission comes from the same electron population, which is different from the electron population producing the radio emission. The results were published in the *Astrophysical Journal*.

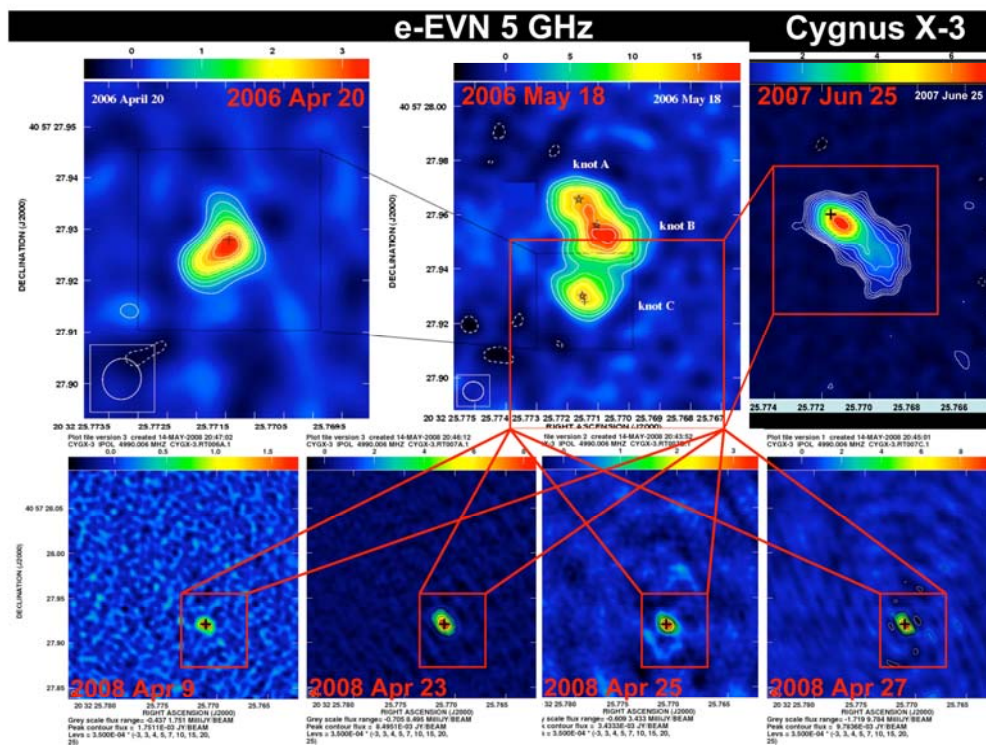


The figure above shows the high resolution LSI +61 303 images obtained during the MAGIC observational campaign. There was no apparent correlation between radio and X-rays/gamma rays, indicating that the emission is coming from different electron populations.

## Radio flares in microquasar Cyg X-3

The microquasar Cyg X-3 has been active in recent years. The triggered e-EVN proposal by Valeriu Tudose (Univ. Amsterdam), Anthony Rushton (JBO), Zsolt Paragi (JIVE), Rob Fender (Univ. Southampton), Ralph Spencer (JBO) and Mike Garrett (ASTRON) was activated on 9 April 2008 when the source showed signs of an accretion disk state change in the X-rays. This particular state had never been targeted at milliarcsecond resolution in the radio regime.

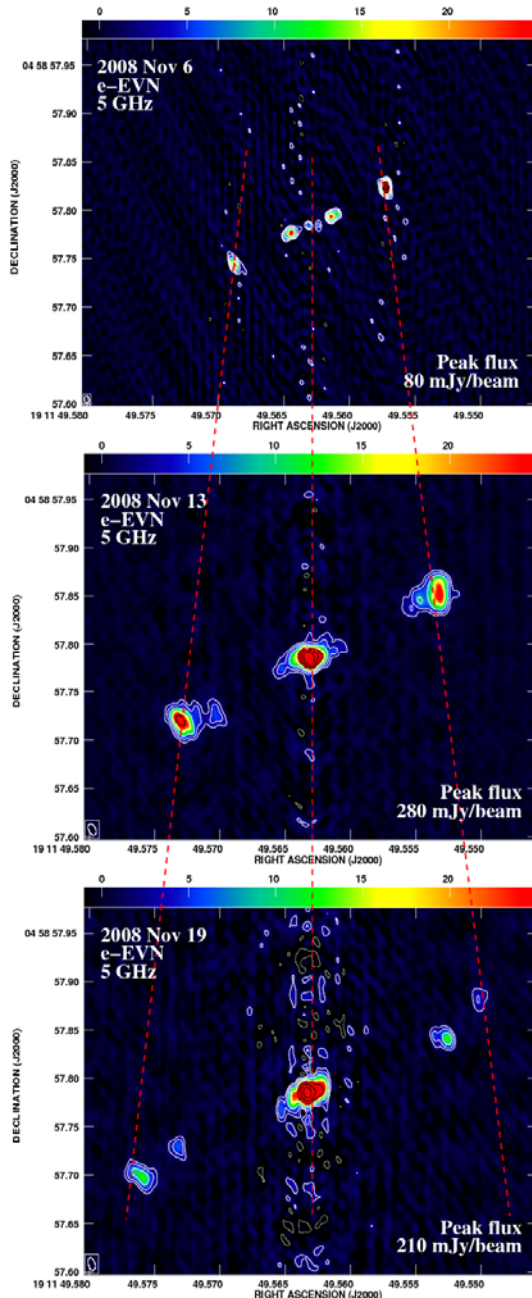
A single radio component (earlier assumed to be a permanent jet-ISM interaction feature) was detected at a lower emission level than in 2007, consistent with the radio core quenching scenario in the soft X-ray state. The identification of the radio core allowed the group to estimate the proper motion of Cyg X-3. As expected following the state change, Cyg X-3 began a strong radio flare which was observed at three epochs separated by a few days. The group will use the e-EVN as well as archival VLBA data to separate the core flux from the occasional jet emission. Such a separation will allow a clearer classification of accretion disk states in the system and a measurement of the proper motion of Cyg X-3.



The figure above shows the e-EVN images of Cyg X-3 during different accretion disk states in the period 2006-2008. With these observations the core of the system was clearly identified.

## A long-lived flare in microquasar SS433

On October 28<sup>th</sup> 2008 RATAN-600 reported a major flare in the famous microquasar SS433. Valeriu Tudose (Univ Amsterdam) and Zsolt Paragi (JIVE) organised e-EVN monitoring observations together with Paolo Soleri (Univ. Amsterdam), Rob Fender (Univ. Southampton), Sergei Trushkin (SAO, Russia), Mike Garrett (ASTRON), Ralph Spencer and Anthony Rushton (JBO).



The first epoch data on November 6<sup>th</sup> showed three pairs of radio components located symmetrically on both sides of the presumed position of the core of the system, two of which were already resolved. Assuming that the radio ejecta were moving at a rate of about 8 mas/day, the furthest components at about 100 mas from the core were ejected at around October 24<sup>th</sup> and perhaps the RATAN-600 observations on October 28<sup>th</sup> caught the aftermath of this event.

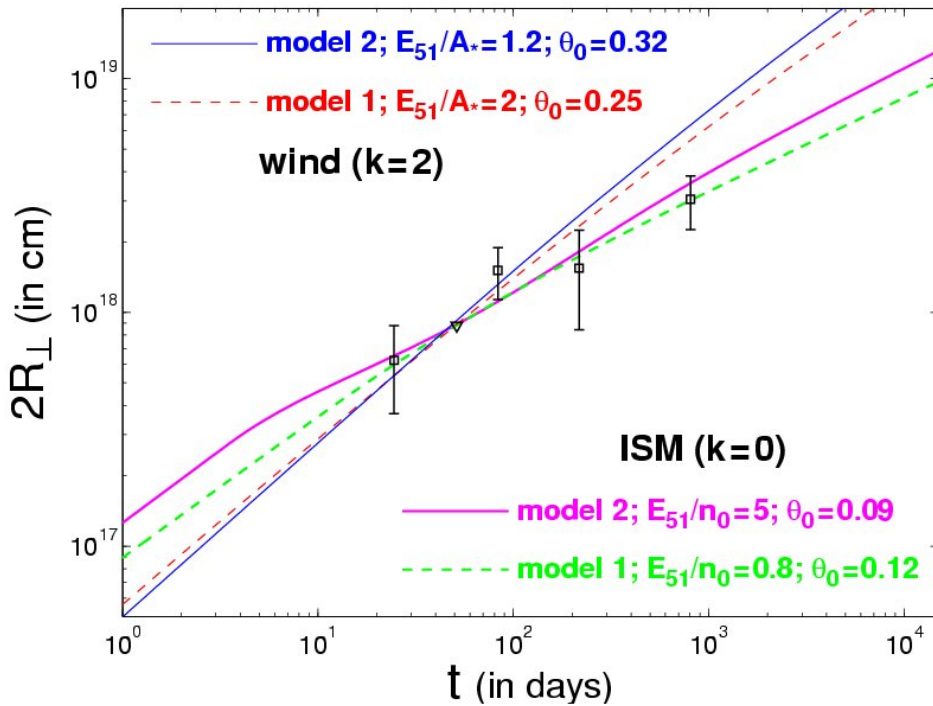
The two components at about 25 mas from the core could have been ejected around November 3<sup>rd</sup>, date which also corresponds to the rebrightening event witnessed by RATAN-600. The results were reported in ATel #1836. Continuing observations with RATAN-600 and the e-EVN (on November 13<sup>th</sup> and 19<sup>th</sup>) showed a long-lived flaring activity in the system.

The figure shows the e-EVN images of this spectacular flare in SS433 obtained on 2008 November 6<sup>th</sup>, 13<sup>th</sup> and 19<sup>th</sup>.

## 2.4 Gamma ray sources

### ***Stirring the Embers: High Sensitivity VLBI Observations of GRB 030329***

Pihlstrom, Y.M., Taylor, G.B., Granot, J. & Doeleman, S. observed the radio afterglow 806 days after the gamma ray burst of 2003 March 29 (GRB030329), using high sensitivity VLBI observations at 5 GHz. The observations were coordinated through the EVN, and included the GBT, Effelsberg, Arecibo, WSRT tied array and the 25m Mark II Jb telescopes. These observations clearly demonstrate that the expansion velocity has slowed down over time, with a transition to the non-relativistic regime at about 1 yr. The evolution of the image size favors a uniform external density over a wind-like stratified external medium, although the latter model cannot be completely ruled out yet.



Tentative fits of theoretical models for the evolution of the source size to the image size of the radio afterglow of GRB030329. In model 1 there is relativistic lateral spreading of the jet, while in model 2 there is no significant lateral expansion until the jet becomes non-relativistic. The ISM models the external density is uniform, and the wind model uses an  $r^{-2}$  profile.

## ***The intriguing gamma-ray source 3EG J2020+4017/IGR J2018+4043***

The enigmatic gamma-ray source 3EG J2020+4017, the brightest steady state unidentified EGRET source, was discovered back in 1981 in the field of the Gamma-Cygni supernova remnant (SNR G78.2+2.1) with the COS B satellite. Several studies covering most of the electromagnetic spectrum have been carried out since then searching for the origin of this high-energy emission.

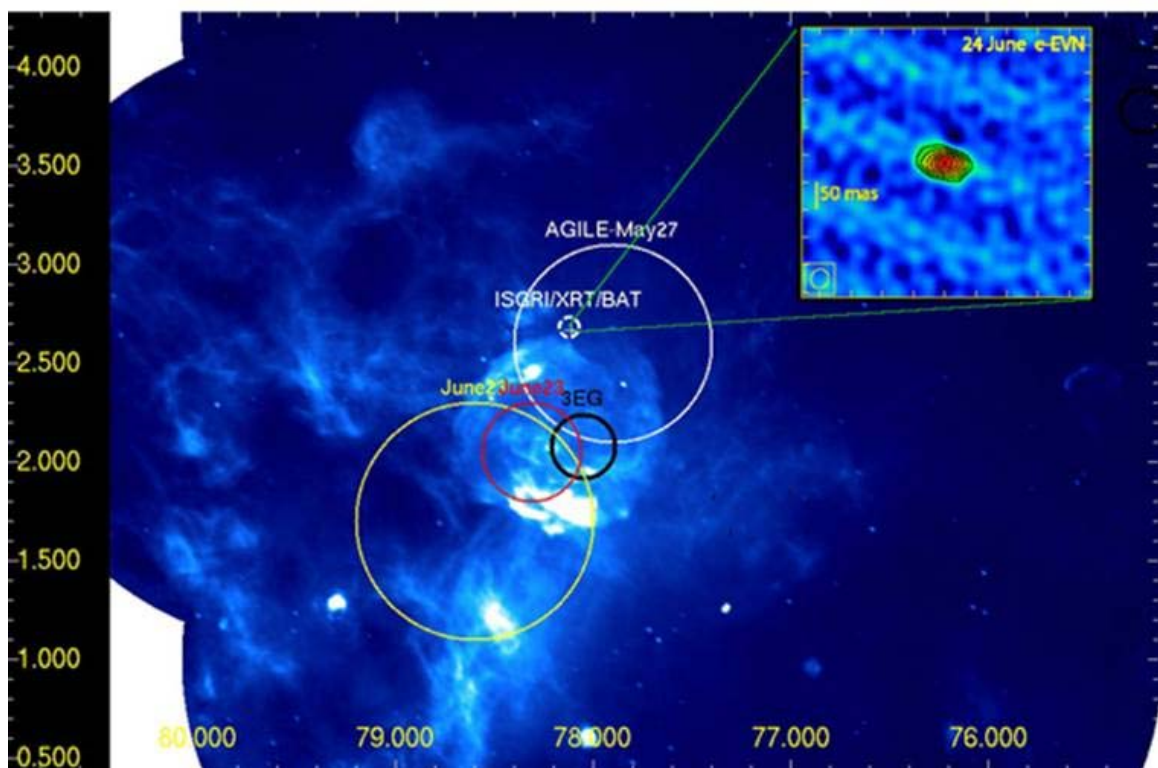
Using the INTEGRAL/ISGRI instrument, Bykov et al. (2004, A&A, 427, L21) discovered the hard X-ray source IGR J2018+4043 in the field of the SNR and suggested that the EGRET and ISGRI sources could be the same object. Further observations of IGR J2018+4043 carried out with Swift XRT (Kennea et al. 2006, ATel#788) revealed a point-like source consistent with the ISGRI source position and it was suggested to be an AGN or a Galactic X-ray binary. Later, an absorbed extended ( $\sim 10$  arcsec) counterpart was discovered for this point source, based on the analysis of Archival optical, infrared and radio data. This emission is positionally coincident with the IR galaxy 2MASX J20183871+4041003.

On April 28 2008, Longo et al. (ATel#1492) reported the detection by the AGILE mission of significant and variable gamma-ray emission (with photon energies above 100 MeV) from a source in the Cygnus region in a position compatible with 3EG J2020+4017. They suggested that a possible counterpart within the  $\sim 1$  degree AGILE error box can be the galaxy 2MASX J20183871+4041003. This detection stimulated further investigations: Ajello et al. (2008, ATel#1497) reported the presence of a Swift/BAT source in the error box of the AGILE source, Halpern (2008, ATel#1498) argued that there is no evidence of current blazar activity from the candidate point source based on infrared I-band images, and Dubner et al. (2008, ATel#1518) discovered a source exactly at the position of the IGR J2018+4043/2MASX J20183871+4041003 source based on 20 cm and 6 cm VLA-C observations. On May 27 2008, Giuliani et al. (ATel#1547) informed a rebrightening of the variable AGILE source.

Cheung carried out new VLA observations of the radio source discovered by Dubner et al. using in this case the array in the D-configuration, concluding that the radio source is unpolarized and not variable, making it unlikely to be a blazar or X-ray binary origin. This lack of variability was later confirmed in the X-ray range by Pandel et al. (2008, ATel#1595) based on XMM-Newton observations.

On June 23<sup>rd</sup> 2008, the AGILE team reported a possible re-brightening of the gamma-ray source beginning on June 20 and also the detection of a slightly shifted gamma-ray point source based on the integration of several months of data. It has to be noted that the positions reported by AGILE in the successive communications are inconsistent with each other.

Despite the uncertainty in the exact location of the AGILE source, because of the lack of other bright hard X-ray sources in a  $\sim 1$  degree vicinity of 3EG J2020+4017, one may conclude that IGR J2018+4043, 3EG J2020+4017 and the new AGILE source are the same object. In this direction, Trejo et al. (2008, ATeL#1597) carried out the highest resolution radio observations of the candidate counterpart at 1.6 GHz, using 7 antennas of the e-EVN network on June 24<sup>th</sup> 2008. These observations showed that the source has a compact, but partially resolved structure, consistent with AGN activity in the host. Further observations are planned at 5 GHz to reveal the detailed structure and minimize the effect of scatter-broadening which likely affect the data. The observed AGN activity indicates that this target is a good candidate counterpart to the peculiar variable gamma-ray source, but the final answer will be given by Fermi/GLAST.



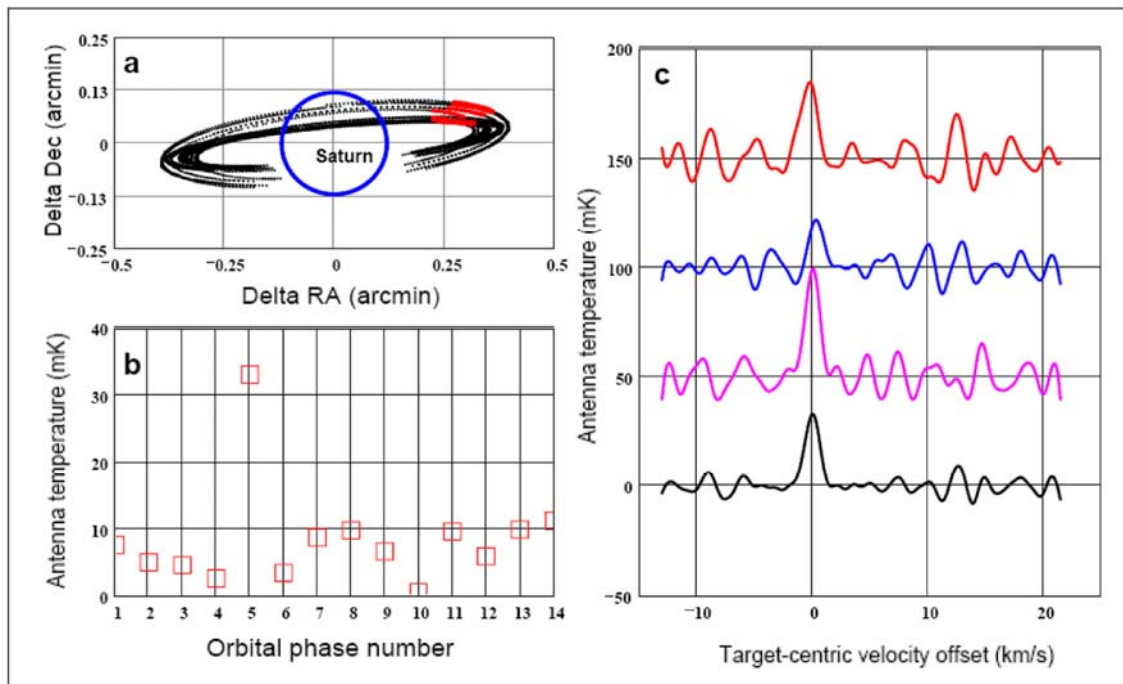
The hard X-ray and radio source IGR J20187+4041 was in the error box of an AGILE flare on 27 May 2008. e-EVN observations showed a faint, compact structure, with apparently no flaring activity. Later AGILE observations and analysis showed that the flare was likely not related to IGR J20187+4041.

## 2.5 Solar system

### Water in the Saturnian system

An observing campaign to search for 22 GHz water maser emission from the Saturnian system was carried out by Medicina (INAF-IRA, Italy) and Metsähovi (TKK-MRO, Finland) radio telescopes, which was coordinated by Sergei Pogrebenko and Leonid Gurvits (JIVE). During the 2006-2008 observing campaign more than 300 hours of data were collected. A direct-FFT on-line hardware spectrometer was used at Medicina station, while at Metsähovi the spectral analysis was done off-line: data were first recorded on disks using various data capture units and then processed with a high performance software spectrometer, developed at MRO. Resulting spectra were analyzed at JIVE.

Water maser was detected in emission, associated with different bodies of the Saturnian system: Titan, Hyperion, Enceladus and Atlas. The results were published by Pogrebenko et al. in *Astronomy and Astrophysics*.



The figure above shows the spectra reduced for the orbital motion of Atlas, the most secure detection of our observing campaign. Orbital phase 5, which has the highest SNR detection (6.5 sigma), corresponds to the orbital segment shown in red in the upper left panel. The high SNR of this detection and its persistence over one year of observation (as illustrated on the right panel) allowed us to associate the maser emission with a spot lagging the position of Atlas by several thousand km along its orbit rather than Atlas itself, suggesting that the emission may originate in the edge regions of rings A and F, disturbed by the motion of the satellite.



## 2.6 Astrometry

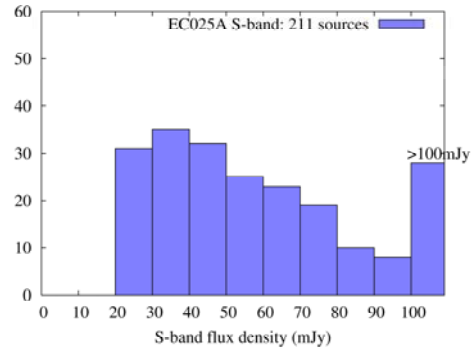
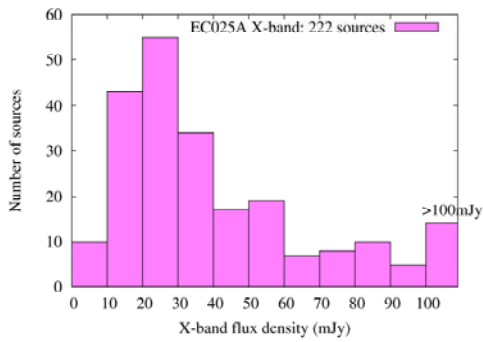
### ***Search for candidate radio sources for the link with the future GAIA frame: results from initial EVN observations***

The European space astrometry mission GAIA, to be launched by 2011, will survey about one billion stars in our Galaxy and 500,000 Quasi Stellar Objects (QSOs), brighter than magnitude 20. Unlike Hipparcos, GAIA will construct a dense optical celestial reference frame directly in the visible, based on the QSOs with the most accurate positions. For consistency between the optical and radio positions, it will be important to align the GAIA frame and the International Celestial Reference Frame (ICRF) with the highest accuracy. However, it is found that only 10% of the current ICRF sources ( $\sim 70$  sources) are suitable to establish this link, either because they are not bright enough at optical wavelengths or because they have significant extended radio emission that precludes reaching the highest astrometric accuracy. In order to improve the situation, a VLBI survey dedicated to finding additional high-quality radio sources for aligning the two frames has been initiated.

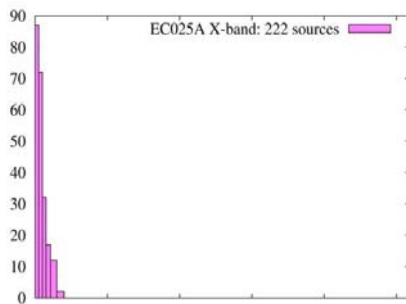
G. Bourda, P. Charlot (LAB), R. Porcas (MPI) and S. Garrington (JBO) selected a sample of sources for a survey consisting of about 450 targets, as weak as 20 mJy in the radio band and with optical magnitude V brighter than 18 (to ensure very accurate positions with GAIA). The targets were selected by cross-correlating optical and radio catalogues (Véron & Véron 2006 and NVSS, respectively), excluding known ICRF and VCS (VLBA Calibrator Survey) sources and with a declination limit of  $-10^\circ$  for possible observing with northern VLBI arrays. Initial observation of these targets was carried out in June and October 2007 with a network comprising 4 EVN telescopes (Effelsberg, Medicina, Noto, Onsala) recording at 1024 Mb/s (experiments EC025A and EC025B). The goal of these observations was to determine the VLBI source detectability and to demonstrate the feasibility of observing such weak sources with a geodetic-style S/X mode.

The results of EC025A, consisting in observations of 224 such targets, most of which also belong to the CLASS catalogue, are highlighted here. Excellent detection rates of 99% at X band (222 sources detected) and 95 % at S band (211 sources detected) were obtained. The mean correlated flux densities have a median value of 32 mJy at X band and 55 mJy at S band (see Figure). The X-band flux density distribution for the sources observed in EC025A was compared to the flux distribution in the ICRF and VCS catalogues. This comparison shows that the sources in EC025A are on average 20 times weaker than the ICRF sources and 7 times weaker than the VCS sources (see Figure). The spectral index  $\alpha$  of the 211 radio sources detected at both frequencies was also estimated; its median value is -0.3 and most of the sources have  $\alpha > -0.5$ , hence confirming that these sources must be core-dominated.

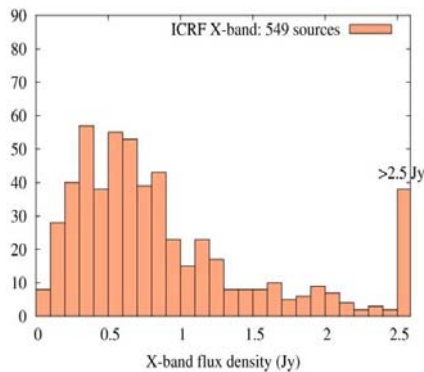
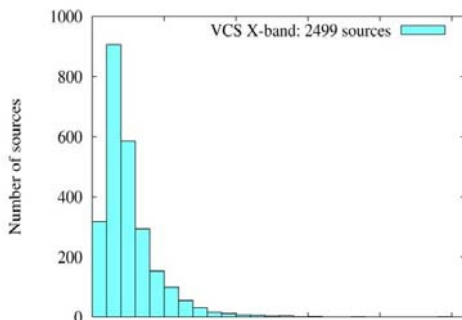
The next stage for this project, to be carried out with the global VLBI network, will image all the detected sources (in both EC025A and EC025B) to identify those that have the most compact VLBI structures. Such compact (and optically-bright) sources will be prime candidates for the GAIA link. The ultimate goal will be to measure their astrometric positions with the highest possible accuracy.



Mean correlated flux density distribution (units in mJy), at X band and S band, for the sources detected in our initial experiment EC025A (June 2007).



Comparison of the X-band flux density distribution (units in Jy) for the sources detected in EC025A and those from the VCS and ICRF catalogues.



## **3. EVN Network Operations**

### **3.1. EVN Program Committee (EVN PC)**

The EVN PC is an independent body appointed by the EVN CBD, to carry out the scientific and technical assessment of all standard EVN, e-VLBI and Global VLBI requests for observing time. A Call for Proposals is distributed three times a year, with proposal deadlines on 1st February, 1st June and 1st October. The EVN PC usually meets one month after each deadline to evaluate the proposals received. Each EVN PC member provides a review and a pre-grade of the proposals before the meeting, then a thorough discussion on each proposal and the final evaluation are carried out during the meeting itself. Summary comments and the detailed comments of each PC member are sent to the PI afterwards.

Since February 1<sup>st</sup> 2008, e-VLBI proposals are evaluated together with the standard EVN proposals, three times a year, for observations during the scheduled e-VLBI sessions, which are organized every 4-6 weeks, and last 24 hours.

#### **3.1.1 Membership**

The EVN PC comprises 8 observatory members, including a representative from the EVN data processor at JIVE, whose particular responsibility is to assess the feasibility of the proposed observations from their observatory perspective. In addition, 3 at large members are part of the EVN PC, chosen from non-EVN institutes to complement the astronomical experience of the observatory members. Global proposals requesting either an NRAO station or correlation at Socorro are sent by the PIs to NRAO as well; proposals requesting the Arecibo Radio Telescope or the MERLIN array are sent to representatives at these institutes for an additional technical review. The EVN PC Scheduler is member of the EVN PC and participates in each EVN PC meeting, but he does not carry out a scientific evaluation of the proposals and is not active part in the discussion.

Patrick Charlot from Bordeaux Observatory has been Chairman of the EVN PC from 2003 to June 1<sup>st</sup> 2008, when Tiziana Venturi (INAF, Istituto di Radioastronomia) was appointed Chairperson. The three at large members were appointed in January 2007, and a number of changes in the Observatory representatives also took place. In 2007 Simon Garrington (JBO) was replaced by Tom Muxlow; in 2008 Rene Vermeulen (ASTRON) was replaced by Richard Strom; J. Alcolea (OAN) was replaced by Jean-François Desmurs; Dong Rong Jiang (ShAO) was replaced by Ziqiang Shen. The membership of the EVN, as of 31 December 2008, is shown in the next Table.

EVN PC Member	Institute
Tiziana Venturi (Chairperson)	INAF-IRA, Bologna
Bob Campbell	JIVE, Dwingeloo
Patrick Charlot	Bordeaux Observatory
Jean-Francois Desmurs	OAN, Madrid
Michael Lindqvist	Onsala Space Observatory
Andrei Lobanov	MPIfR, Bonn
Tom Muxlow	Jodrell Bank Observatory
Ziqiang Shen	Shanghai Observatory
<i>At large members:</i>	
Andrea Merloni	MPE, Garching
Marc Ribo	University of Barcelona
Andrea Tarchi	INAF-OA Cagliari
Richard Porcas (EVN Scheduler)	MPIfR, Bonn

The composition of the EVN PC during 2007-2008

### 3.1.2 Meetings and proposal statistics

The six meetings in 2007 and 2008 were held in Jodrell Bank (March 21<sup>st</sup> 2007), Onsala (June 29<sup>th</sup> 2007), Cagliari (November 8<sup>th</sup> 2007), Bordeaux (March 17<sup>th</sup> 2008), Garching (June 27<sup>th</sup> 2008), and Barcelona (November 21<sup>st</sup> 2008). On the occasion of the EVN PC meeting in Garching, a mini-symposium was successfully organized by Andrea Merloni. The meeting had an informal character and was intended as an opportunity for the whole Garching/Munich astronomical community (young postdocs and students in particular) to familiarize with Very Long-Baseline Interferometry and very high resolution radio astronomy. Introductory talks to the EVN, and to LOFAR and ALMA and their relation to VLBI, as well as scientific presentations were included in the program.

A total of 18 e-VLBI proposals were received in 2007 (9) and 2008 (9). Moreover, the EVN PC received 3 ToO requests 2007 and 7 in 2008. Finally, 8 e-VLBI short requests were received in 2008. The number of standard EVN and Global proposals received has been in the range 11-15 for each deadline, for a total of 35 proposals in 2007 and 42 in 2008. If we consider all types of proposals received and evaluated by the EVN PC, we have 47 in 2007 (~55% EVN-only, ~19% Globals, ~19% e-VLBI, ~6% ToO), and 58 in 2008 (50% EVN-only, ~22% Globals, ~16% e-VLBI, ~12% ToO). A small fraction of the proposals (both standard and e-VLBI) requests multi epoch observations.

As always, 6cm and 18cm are the most requested observing bands, with 5 cm observations following in the priority list. In December 2008 the first e-VLBI run at 18 cm was carried out. Now 6cm and 18cm are regularly scheduled, in different days, during the e-VLBI sessions.

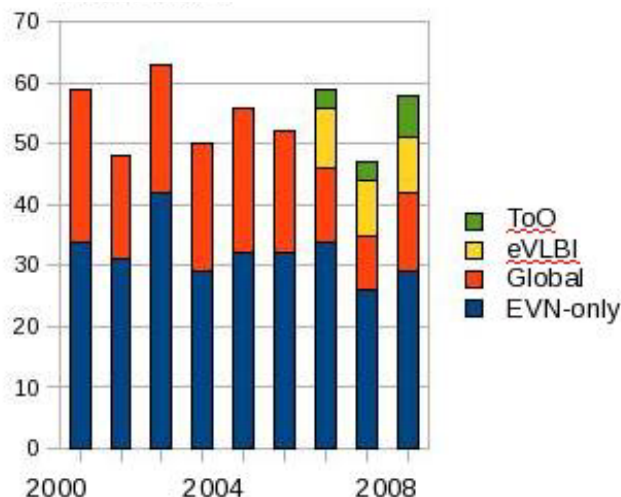
The EVN proposals received cover a wide range of scientific areas, and some of them are opening new fields for long baseline interferometry. The proposed studies cover all stages in stellar evolution, from star formation to supernova remnants, weak and obscured AGN as well as "classical" studies of powerful radio galaxies and quasars, galactic and extra-galactic transients, galactic astrometry and reference frames. Deep observations of individual objects as well as observations of samples have been proposed.

### 3.1.3 The EVN Users community

The PIs of EVN and Global proposals are drawn from a large international users community; the largest majority (of the order of 80%) of PIs come from European institutes and universities, and the remaining mainly from US and China. The teams requesting e-VLBI come mainly from Europe.

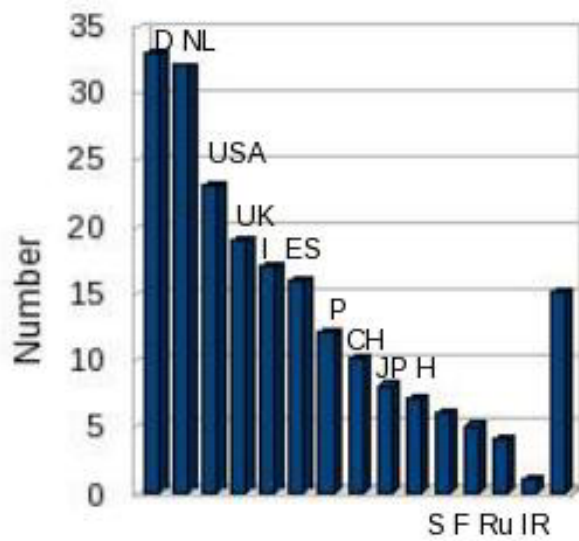
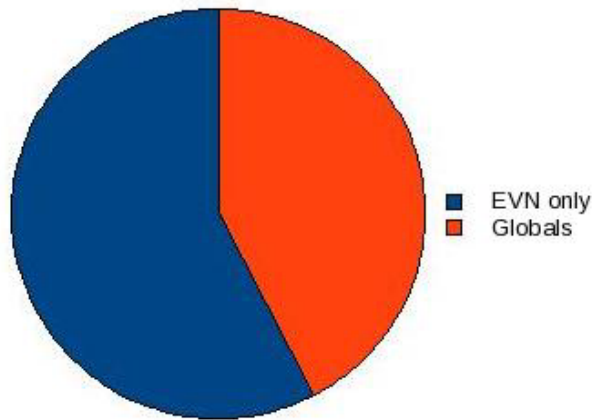
The EVN PC is also a useful channel of communication within the EVN users community. The Call for Proposal, circulated via email, and the Guidelines for Proposal Submission available as web page, provide important guidance on the proposal preparation. New and inexperienced users often contact the EVN PC, the EVN Scheduler and/or the JIVE support scientist for specific questions.

An EVN Users' Meeting was held in September 2008 during the 9th EVN Symposium, organized by INAF-IRA in Bologna. The agenda covered the whole process of VLBI, from proposal writing and schedule preparation, to correlation and data analysis. Some EVN users were asked to report on their recent experience with the EVN, and were encouraged to provide feedback on the whole system. The Users' Meeting was very successful, with a wide attendance, and a lot of feedback, both along positive and more critical lines, was received.



Total number of proposals submitted to the EVN PC in the period 2000 - 2008, divided into EVN-only, Globals, e-VLBI and ToO

Fraction of EVN-only and Global proposals in the period 2000-2008



Distribution of PIs from EVN Institutes for all the proposals received in the period 2000-2008. The last column refers to the rest of the world.

## **3.2 Scheduling and Operations**

### **Normal EVN sessions scheduled in 2007-2008**

#### **2007 Session 1: 28 Feb - 21 March**

Wavelengths: 6cm (+MERLIN), 1.3 cm, 18/21 cm (+MERLIN), 5cm

This session followed the very short session 3 of 2006. At the time of scheduling it was foreseen that both Urumqi and Shanghai might be unavailable for session 2 (they would be needed for tracking the Chinese Lunar Explorer space mission), thus limiting the capabilities of that session. For this reason session 1 was long, using the entire 3-week reserved period. Arecibo was not available for this session, preventing 1 global project from being scheduled. Before the session the Jodrell Lovell Telescope was found to have a serious crack in one of its wheels and had to be withdrawn from the session. Projects were observed with the Mk2 telescope instead. The Effelsberg telescope was back in operation for the EVN, following the replacement of the sub-reflector and modifications to the prime focus cabin in autumn 2006.

The session contained 1 global project (at 21 cm), and 3 observations using MERLIN. The 1.3cm section contained only a single user observation. This was for a monitoring project requiring an urgent epoch, which could not be observed in session 3 2006 due to the unavailability of Effelsberg and the Chinese antennas. A number of projects were observed using the most sensitive recording mode at 1 Gb/s, including studies of samples of both SDSS quasars and Type-II quasars. At 6cm, the X-ray binary LS 5039 was observed at 3 epochs, with a spacing between epochs of 2 days. At 5cm a 2nd epoch was observed of a 5-epoch project to measure the parallax and proper motion of Galactic methanol masers.

#### **2007 Session 2: 31 May - 20 June**

Wavelengths: 6cm (+MERLIN), 18 cm (+MERLIN), 5 cm (+MERLIN), 13/3.6 cm

Due to delays in the Chinese Lunar Explorer space mission it seemed likely that the unavailability of Urumqi and Shanghai would be shifted to session 3 2007, making it desirable to schedule as many projects as possible requiring these antennas in session 2. Unfortunately, not all such projects could be scheduled due to limitations on the MK5A disk supply. An additional constraint was that the Jodrell Lovell Telescope was unavailable for daytime observations after June 10<sup>th</sup> 2007, due to the summer painting program. It proved possible to match this unavailability with "GST gaps" forced by the approved projects, and by scheduling the 5cm section (which uses only the MK2 telescope at Jodrell) at the end of the session. The GBT was not available for this session, preventing one global project from being observed.

A single global observation was scheduled (observations of the 1612 MHz OH maser line in the circumstellar envelope of W43A). All currently approved 5cm projects were scheduled in this session, including a number which could not be observed before as they require MERLIN. The dual S/X-band section contained a single, 48-hour, 1 Gb/s project to identify optical quasars which are also compact radio sources, in order to increase the sample of sources which can be used to link the radio and optical (GAIA) reference frames.

### **2007 Session 3: 18 Oct - 6 Nov**

Wavelengths: 18/21cm, 7mm, 13/3.6cm, 5cm, 6cm

This session contained only a small number of user projects (10) because both Urumqi and Shanghai were unavailable (they were needed for tracking the Chinese Lunar Explorer space mission). The resulting block schedule was rather inefficient but all projects not requiring Urumqi or Shanghai were scheduled. A total of 5 observing bands was scheduled (18/21cm 2 projects; 7mm 1 project; 13/3.6cm 1 project; 5cm 2 projects; 6cm 2 projects). There were 6 global projects (4 using the GBT, available for the first time after track repairs) and 4 EVN-only. Arecibo was scheduled for 1 project, but delays to painting resulted in it being withdrawn shortly before the session (October 4). The DSN 70m antenna at Robledo was made available for 1 project at S/X band. One of the eVLA antennas was used for the first time at 6.7 GHz, together with the EVN, for a methanol astrometry experiment.

A Target of Opportunity (ToO) proposal was received on 25 September, requesting observations at 6cm of sn2007gr. The proposing mechanism given in the EVN ToO policy was followed. After rapid review, and approval, it proved possible to schedule this after the end of the currently scheduled projects but within the block time originally reserved for session 3. This project also requested and was granted time on the GBT.

### **2008 Session 1: 28 Feb - 19 Mar**

Wavelengths: 18cm, 1.3cm, 13/3.6cm, 6cm, 5cm, 6cm

During this session both the Seshan (Shanghai) and Nanshan (Urumqi) telescopes were needed for ~2 days per week for tracking the Chinese Lunar Explorer space mission CHANG'E, providing an additional constraint on the scheduling of projects. Our Chinese colleagues have been very helpful in making sure that the EVN observations don't clash with those of the space mission. All eligible projects at 5, 1.3 and 13/3.6 cm were scheduled. Only the highest rated projects at 18 and 6cm could be scheduled.

A total of 29 user observations were scheduled, from 15 proposals. The VLBA correlator was used for 2 projects, the others being correlated at the EVN correlator at JIVE. 5 Global observations were scheduled, and one 4-h "short observation" was approved by the EVNPC Chair. The DSN 70m antenna at Robledo was scheduled for 7h for one 13/3.6 cm project. The second observation of a ToO proposal, received



on 22 January, was scheduled (together with Arecibo and 2 VLBA antennas) at the end of the session. This required a receiver change back to 6cm - many thanks to the observatories for being so accommodating!

### **2008 Session 2: 30 May - 18 June**

Wavelengths: 1.3cm, 18cm, 6cm, 5cm

This session proved something of a nightmare to schedule, given the number of well-rated projects requiring additional, non-EVN telescopes. There were 5 global projects scheduled requiring 8 separate observations. Of these, the GBT was needed for 4 observations, Arecibo for 6, phased-VLA-27 for 2, phased-eVLA for 4 and Robledo for 1. MERLIN was required for some projects at both 18 and 6cm. The VLBA correlator was used for only 1 project, the rest being processed at the EVN correlator at JIVE. In addition, and as for the previous session, both the Seshan (Shanghai) and Nanshan (Urumqi) telescopes were needed for ~2 days per week for tracking the Chinese Lunar Explorer space mission CHANG'E, providing an additional constraint on the scheduling of projects.

A total of 22 user observations were scheduled. For the first time the new Yebes 40m antenna (Ys) took part in the 1.3cm section of the session, observing user project EB037C and the network monitor run. A special, additional, test observation at 1.3cm was also scheduled at some telescopes in order to explore the EVN performance at higher frequencies at K-band. Another "first" was the participation of the phased-eVLA (using a subset of eVLA antennas with receivers capable of observing at 6.1 GHz) in 4 observations together with Arecibo for project GB064, 2 also with the GBT. All eligible projects at 1.3cm and 5cm were scheduled. All projects with grades 1.5 or better were scheduled at 18 and 6cm, except for one for which no suitable GST interval was available at the GBT.

### **2008 Session 3: 16 October - 4 November**

Wavelengths: 7mm, 13/3.6cm, 6cm, 18cm, 1.3cm

Again, for this session the main scheduling difficulties arose from the inclusion of many non-EVN telescopes in the observations, in addition to the restricted use of the Chinese antennas caused by the CHANG'E mission. Arecibo was required for 3 projects, the GBT for 4 and the VLA for 2 (one with single telescope, the other with the phased array). The 70m DSN dishes at both Robledo and Goldstone were used for 1 project, and Robledo was offered (and accepted) for another at a later stage of planning. MERLIN was used together with 1 project at 18cm. There were 5 global projects, one being correlated at the VLBA correlator; a single antenna at WSRT was used for this project, as the phased array could only be recorded using MK5B which cannot be correlated in Socorro with the hardware correlator. Shortly before the start of the session the failure of the Hartebeesthoek telescope was announced. As there seemed little prospect of a repair in the near future, PIs were advised to accept the time scheduled although this will degrade some projects.

A total of 16 user observations were scheduled; more could have been observed if the EVN had more disk-packs at its disposal. All except 2 projects with grades 1.6 or better were scheduled. The 3 antennas of the Russian QUASAR geodetic network were included in 3 parts of one project. The Yebes 40m telescope was included for all projects at 13/3.6cm and 1.3cm. Again I thank the Onsala, Noto and Effelsberg observatories for permitting the scheduling of a 5th wavelength (7mm) in the session.

## e-VLBI scheduling in 2007-2008

New rules for submitting and scheduling proposals for the dedicated e-VLBI runs were introduced for the 1 June deadline in 2007. All normal and "trigger" proposals are submitted at the normal deadlines. Normal and trigger proposals are scheduled in block schedules for each run by the EVN Scheduler, following EVNPC review. Short observations (<2h) may be proposed up to 3 weeks before the run and added to the block schedule in any gaps. Trigger proposals may be activated up to 0800 UT on the day before the e-VLBI run.

Date	λ	Hours	PROPOSALS SCHEDULED
21AUG07	18cm	6h	1 normal proposal
06SEP07	6cm	14h	1 short observation + 1 ToO
09OCT07		0h	no proposals scheduled
15NOV07	(6cm)	0h	1 trigger proposal (not triggered)
11DEC07	(6cm)	0h	1 trigger proposal (not triggered)
21JAN08	(6cm)	0h	1 trigger proposal (not triggered)
24JAN08	(6cm)	0h	1 trigger proposal (not triggered)
05FEB08	(6cm)	0h	1 trigger proposal (not triggered)
08APR08	6cm	22h	1 normal proposal + 1 trigger proposal (TRIGGERED !)
20MAY08	6cm	3h	1 short observation + 1 trigger proposal (not triggered)
24JUN08	18cm	6h	3 short observations + 1 trigger proposal (not triggered)
09SEP08	(6cm)	0h	1 trigger proposal (not triggered)
30SEP08	18cm	2h	1 short observation + 1 trigger proposal (not triggered)
13NOV08	6cm	10h	1 trigger proposal (TRIGGERED !)
19NOV08	6cm	10h	1 trigger proposal (TRIGGERED !)
04DEC08	6cm	24h	3 normal proposals + 1 trigger proposal (not triggered)

Summary of each of the e-VLBI runs scheduled in 2007-2008.

## Target of opportunity observations

The following target of opportunity proposals were scheduled during the period 2007-2008:

SUBMIT	1	SCHEDULED
29AUG07	6cm	06SEP07 e-VLBI run
26SEP07	6cm 2007 Session 3	
22JAN08	6cm	A Ad hoc observations on 6/7 February
		B 2008 Session 1
18APR08	6cm	A Ad hoc e-VLBI observations on 23 April
		B Ad hoc e-VLBI observations on 25 April
		C Ad hoc e-VLBI observations on 27 April

## MK5 disk usage

Numbers corresponding to the 2007-2008 Sessions (assumes 90% of time recording):

2007	Session I	373.7 TB
2007	Session II	305.2 TB
2007	Session III	260.4 TB (no Chinese antennas)
2008	Session I	411.6 TB
2008	Session II	451.3 TB
2008	Session III	508.0 TB

### **3.3 Technical Developments and Operations**

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

The TOG was chaired by Walter Alef of MPIfR (vice-chair Michael Lindqvist of Onsala) and met twice during the period of this report: at the IGN – Observatorio Astronómico Nacional in Yebes, Spain on November 12, 2007, and at INAF – Istituto Di Radioastronomia Bologna, Italy on September 22, 2008. All meetings were supported by RadioNet (funded from the European Community's sixth Framework Programme under RadioNet R113CT 2003 5058187). Reports from the meetings are available on the EVN web-site (<http://www.e-VLBI.org/>).

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

Three members of the TOG were involved in the program committee of the TOW (Technical and Operations Workshop) 2007 at MIT Haystack Observatory, USA, and three TOG members served as lecturers. 21 participants from EVN institutes attended the courses to improve their knowledge of VLBI observing.

The main emphases of the TOG activities during the period of this report were maintaining the high level of performance achieved in the previous years, improving the reliability of the operation as a whole, and boosting the quality of the network calibration. New technical developments have been initiated such as the implementation of digital backends, Mark 5B upgrades (planned for 2009) and increasing the recording bandwidth to 4 Gbit/s.

Significant achievements to be noted are:

- The automatic ftp tests during the Network Monitoring Experiments (NME), where a portion of a scan is directly sent to the software correlator computer at JIVE, have proven to be very valuable since it gives almost direct feedback to the stations.
- The disk pool was increased to 1250 TB which were procured by the EVN member institutes for recording VLBI observations at the telescopes.

- The calibration of the amplitude of the observed interference fringes could be improved further.
- It was agreed to upgrade the EVN to DBBCs (digital base-band converters) and Mark 5B recorders in 2009.
- A process was implemented to prevent observations with different versions of user schedules at different telescopes.
- A TOG proposal to the EVN directors to upgrade the EVN to 4 Gbit/s recording was accepted. Implementation will follow the DBBC/Mark 5B upgrade.



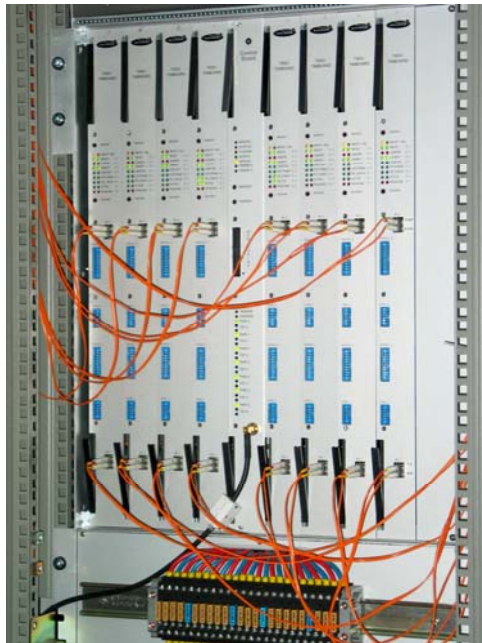
## 4 VLBI technical developments and EVN operations support at member institutes

### 4.1 ASTRON, Westerbork Synthesis Radio Telescope, The Netherlands

The Westerbork Synthesis Radio Telescope (WSRT) took part in all disk-recorded EVN sessions in 2007 and 2008, as well as in a large number of e-VLBI observations.

The Mark IV Data Acquisition Rack (DAR) and the Mark5A recorder (which was upgraded with a new motherboard in mid 2008) were used for all sessions until Session 2008/2.

The Field System computer (as well as the spare) were upgraded to FS-Linux 7 (Raid 1) and are running Field System Version 9.10.3



The two faces (input and output) of the new Tied Array Distribution Unit (TADU-max) that has been commissioned and taken into production during 2007-8 for use in WSRT tied array observations, including VLBI.

After a period of commissioning in 2007-2008, from Session 2008/3 VLBI-operations in WSRT make full use of the new digital Tied Array Distribution Unit (TADUmax) system, which in combination with a Mark5B recorder replaces the old analog adding system, the field system and the Mark5A recording system.

TADUmax has opened a new era in the use of the WSRT for VLBI. The new system, which is operationally more transparent and is producing better quality data, has performed up to expectations in Session 2008/3 (Oct 2008) as well as in a number of e-VLBI sessions with the Mark5B under full control from JIVE.

It is expected that the TADUmax/Mark5B combination will be used for all experiments that require the full array. For experiments where only a single telescope is required (e.g. 5cm observations and observations requiring a large field of view) the combination of the Mark4 DAR, Field System and Mark5A will be used (this way the rest of the array can observe a separate project simultaneously).

One of the consequences of using the TADUmax system is that more different frequency setups for our backend must be used. Hence more time to phase up the array (estimated at 10-15 min) is needed in the gaps between experiments. So gaps of at least 30 minutes (slewing included) between experiments in the schedule, as is the current practice, will be appreciated.

In 2007, a modification to the frequency mixing and filtering scheme for single dish use was made, to allow the full (160MHz per IF cable) bandwidth from the receivers to be made available at the VLBI rack. This had the additional benefit that the mixing scheme was simpler and that it was more straightforward to allow the high band patching by changing 2 filters.

The 34.4 km dark fiber between Westerbork and JIVE, used for e-VLBI, was upgraded in mid 2008 to use multiple wavelengths (CWDM), with each wavelength able to carry 1 Gbps. Furthermore, FTP file transfers scheduled in EVN network monitoring experiments can now be done automatically.

Much effort was spent in 2007-2008 to prepare all the systems in Westerbork for remote control. All Westerbork based staff have moved to Dwingeloo, and WSRT operations are now conducted from the new Control Room in Dwingeloo, with site visits to the WSRT only as the need arises. While for Session 2008/3 VLBI operations were still conducted from the Westerbork site, it is envisioned that in the future, VLBI operations will also be done remotely from the new Control Room. This is already the current practice for e-VLBI.



## **4.2 Bundesamt für Kartographie und Geodäsie (BKG), Wettzell, Germany**

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

The 20m-RT in Wettzell (RTW) mainly supports geodetic VLBI-activities since 1983. According to the 'IVS master plans', RTW is the most engaged VLBI network station with 24h-geodetic-VLBI-sessions since nine years (132 campaigns in 2007; 141 campaigns in 2008). The daily one-hour INTENSIVE-sessions (INT) in order to determine UT1-UTC were continued in addition to the 24h-sessions (312 campaigns in 2007; 375 campaigns in 2008).



The Wettzell 20m radio telescope in its rural environment.

VLBI-observations require high reliability of all participating stations; therefore careful service of all components is essential to ensure successfully performed VLBI-measurements through the year(s). Additionally the 20m-RTW has to be kept on a high technical standard and has to be improved according to technological advances.

The main improvements during the period covered by this report were:

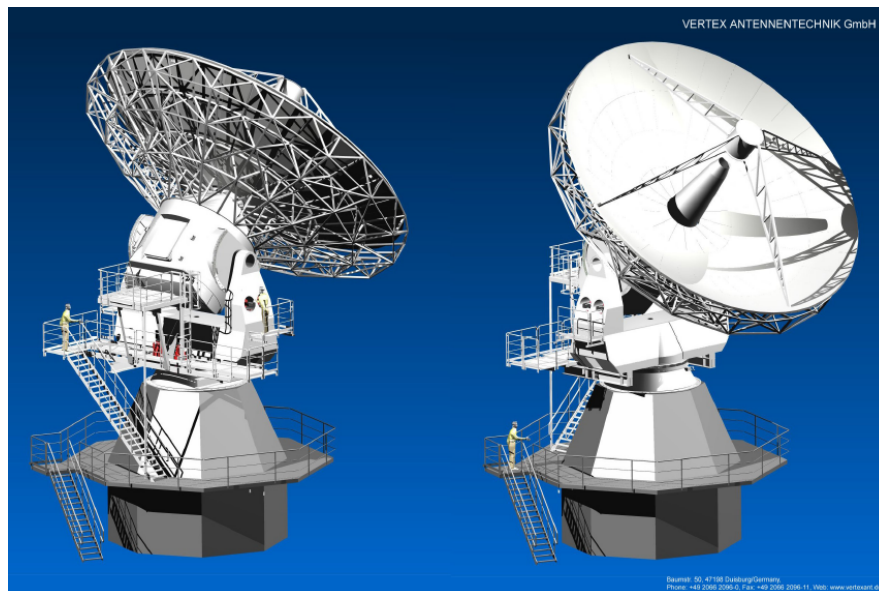
- Integration of a test-bed for the new digital baseband converter (DBBC)
- Improvement of the internet connection to 622Mbps for e-VLBI
- Implementation of an PC-EVN for the data transmission to the Bonn correlator and establishment of regular e-transfers also to GSI, WASH for the INTENSIVE-sessions
- Establishment of a new e-VLBI buffer storage as RAID6-system with effective 60TByte volume and first tests
- Establishment of Mark5B
- Improvement of the cryogenic system by studies with the replacement dewar

- Software implementations for an extension for the VLBI field system regarding remote controllable operation and first remote control tests with Wettzell, O'Higgins and TIGO
- Geodetic reference point determination with laser tracker and a new mathematical model done by Michael Lösler (Uni Karlsruhe)

### The new TWIN Telescope Wettzell (TTW) Project

During the period 2007-2008 a new VLBI-project, the Twin Telescope Wettzell (TTW) was launched by the Bundesamt für Kartographie und Geodäsie. The TTW-project is the first rigorous attempt to realize the future instrumentation for service oriented geodetic and astrometric VLBI, based on the VLBI2010 vision of the International VLBI Service. The concept includes a pair of 13.2-m radio telescopes to realize a continuous observation of the Earth rotation. The radio telescopes will be fast moving with velocities up to 12°/s in azimuth and 6°/s in elevation in order to increase the observation time and decrease the slewing time during a VLBI session. Yielding more observations per unit time enables us to approach the challenging goal to realize terrestrial reference frames with 1 mm accuracy on the global scale. This is the anticipated goal for the Global Geodetic Observing System (GGOS) proposed by the International Association of Geodesy.

The technical specifications for the TTW project have been prepared by the Wettzell staff. They considered also some details from the ALMA-project. The bidding was finished by the end of 2007. Since 2008 Vertex Antennentechnik GmbH is contracted to execute the TTW project. The TTW is designed with a ring-focus optics, which has several advantages for the implementation of a new broadband feed covering a band presumably from about 2 GHz (S-band) up to 14 GHz or later even up to 18 GHz. The telescope erection is expected in 2009 – 2011.



Simulated view of the Twin Telescope Wettzell.

## **4.3 Hartebeesthoek Radio Astronomy Observatory, South Africa**

### **The 26m antenna at Hartebeesthoek**

During 2007/8, the 26m antenna was used for both astronomical and geodetic VLBI on a routine basis. The demand from the EVN increased steadily during the period.

A test ambient dual-polarization K-band receiver was installed at the beginning of 2007. Preliminary calibration results indicated that the new surface was good up to at least 24GHz and highlighted a long-standing problem in the anti-backlash implementation of our telescope controller which was resolved afterwards.

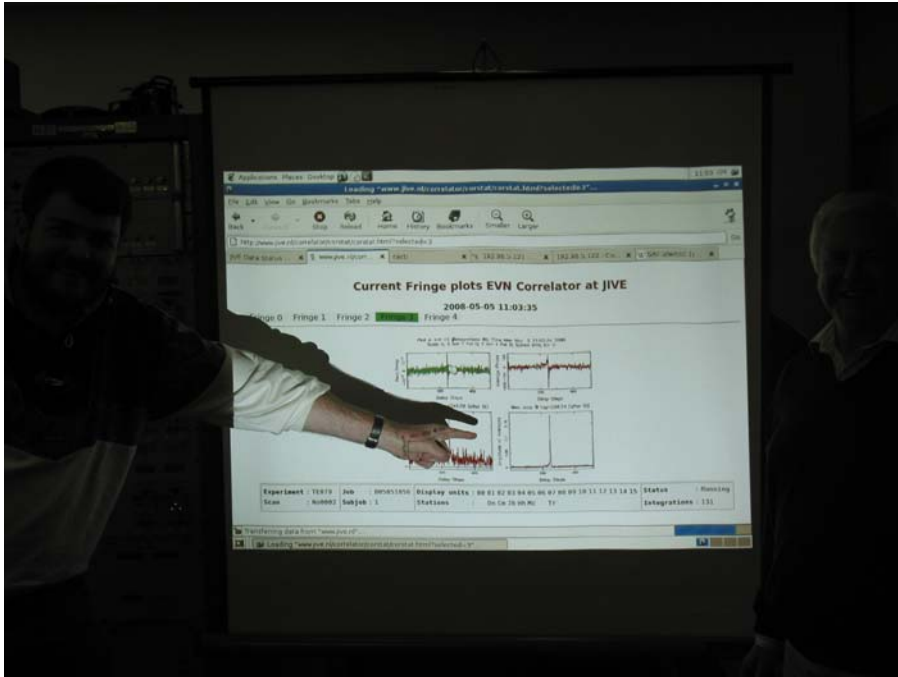
The old H-maser (EFOS-6) ceased operation in 2007 pending installation of a new vacuum pump, but the new H-maser (EFOS-28) continued to perform well over this period.

The Mark5A recorder completely supplanted the use of magnetic tape, and the Mark IV tape recorder was wheeled out of the VLBI area, with our somewhat flaky S2 recorder to follow shortly. The Mark5A recorder itself was upgraded with a new dual-processor motherboard with additional RAM and all the parts for a transition to Mark5B are available on site.

### **First e-VLBI fringes**

On May 5, 2008, an important e-VLBI fringe test was successfully conducted when the observatory participated in the world wide network for real time astronomical research. In a milestone VLBI experiment, the 26m telescope at Hartebeesthoek linked up with observatories in Poland, Sweden, Italy, the UK (and even briefly to Arecibo in Puerto Rico) to form a giant virtual telescope. Data was shared between these observatories - via the internet - at a data transfer rate of 32 Mb/s. The test was orchestrated by JIVE and witnessed at HartRAO by a delegation from the EU.

The test would not have been possible without a new 40-strand 2.3 km "last mile" fibre cable installed from the Hartebeesthoek observatory to our nearest neighbor where some fiber-based telecommunication infra-structure already exists and a single Gbps circuit has also been lit. An interim upgrade of our local circuit to 2Mbps was expected in January 2008. However development of the new South African National Research Network (SANReN) as proposed by government includes extending a 10Gbps fiber backbone infrastructure to Hartbeesthoek in the next year or two. Additionally the South African research community have been able to purchase an affordable 10Gbps IRU (irrevocable right of use) on a new under-sea international (SEACOM) cable to Milan, due to be operational from July 2009 (if government approval for the landing of the cable can be secured.)



The staff at Hartebeesthoek during the successful test in which e-VLBI fringes were obtained

## The "Karoo Array Telescope"

As part of the SKA activities in South Africa, it was planned to build an L-band 80-telescope array, MeerKAT, in the Karoo region of the Northern Cape. A 15m prototype composite antenna, known as XDM, has been erected at HartRAO and is currently being commissioned. It was equipped with a cluster of L-band feeds and used to test KAT hard- and soft-ware. Digital backends for use with the 26m as an interferometry test-bed are expected soon. This could lead to a new 21cm VLBI capability in due course

## 26m antenna bearing failure

In October, 2008, the 26m antenna suffered a serious failure of the bearing at the Southern end of the Polar shaft. Discussions with local industry are underway to commission a repair. In the meanwhile, efforts are underway to instrument the XDM antenna at S/X-bands to, at least in part, fulfill our VLBI commitments.

## 4.4 Institute of Radio Astronomy - INAF, Italy

### Medicina Station

During the period 2007-2008, the e-VLBI system has routinely performed in Medicina at 512 Mb/s, and reaching finally a throughput of about 1 Gb/s in some test observations.

Subsequent purchases of MK5 disks carried the station capacity to 128 TB and 24 TB more are in the assembling phase now. So the total available capacity will soon be of 152 TB. The maintenance of the VLBI system, particularly that one related to the upgrade of the MK5 firmware and FS software is continued smoothly. A MK5B+ is available and some preliminary tests done.

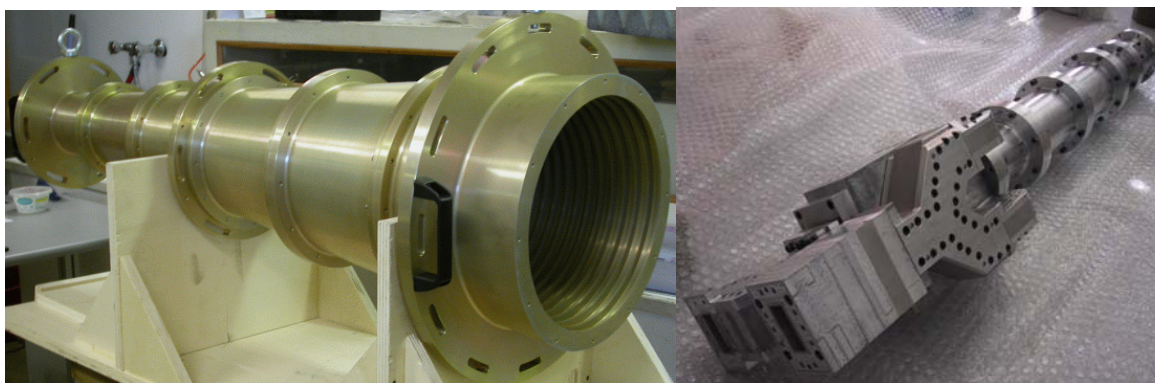
The construction of the multibeam receiver in the 18-26.5 GHz band (see figure) was completed in March 2008, and since then the system was tested on 32m Medicina antenna. The central horn has been used in the 2008 fall VLBI session.



The multibeam mounted in secondary focus together with the 5 and 6 cm receivers

A new receiver in the 5.7-7.7 GHz band is in the final stage of realization (in the figure, the feed system is shown). Again it will be tested on Medicina antenna hopefully in fall 2009.

The implementation of a new observing software system, allowing many different modes for continuum and spectroscopy observations, is going on. It is based on ACS (Alma Common Software) and the Field System will be part of it.

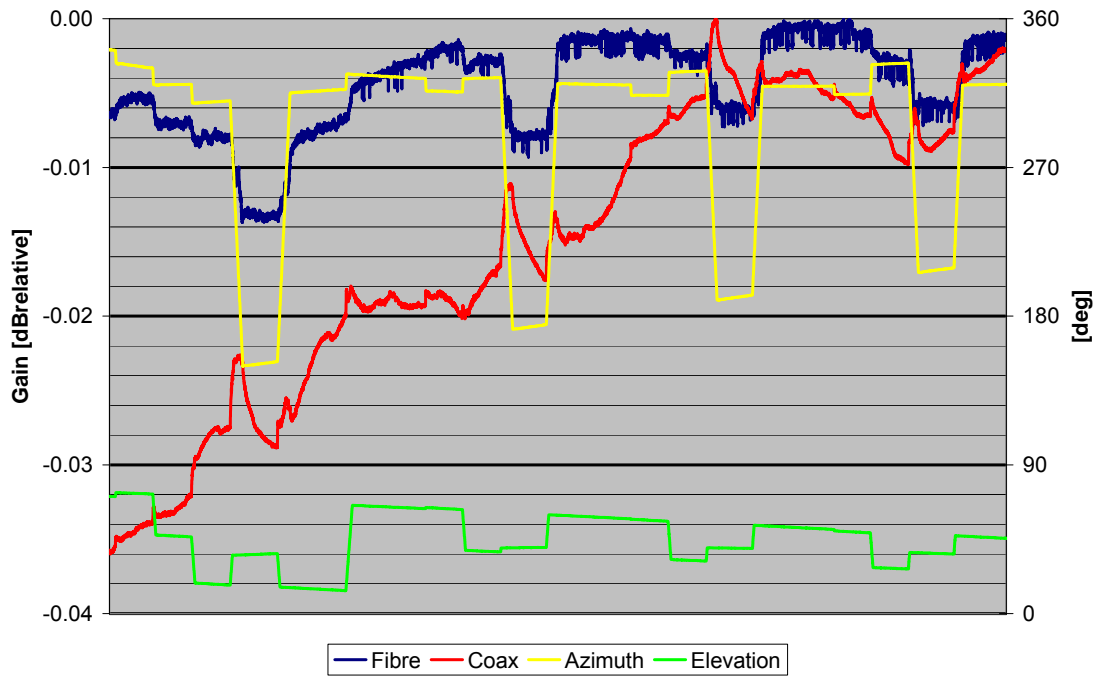


The feed system of the new 5.7-7.7GHz receiver

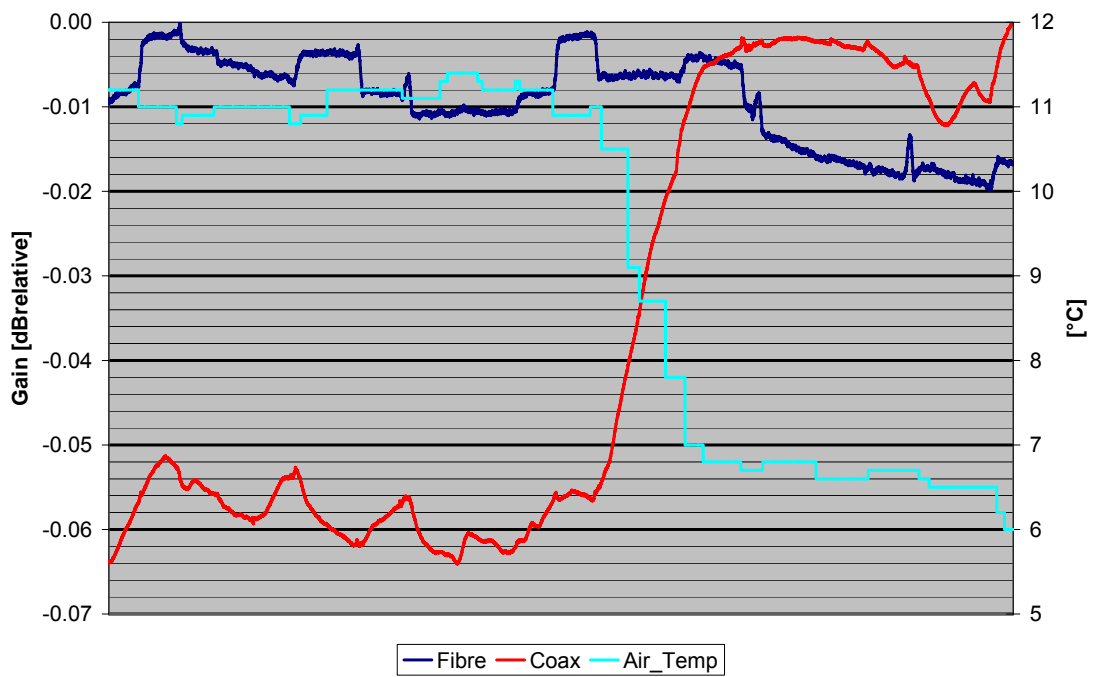
In late November 2008, a measurement campaign has been done at the Medicina VLBI antenna to compare the transmission stability of fiber and coaxial cables with respect to the mechanical stresses (cable bending in wrap systems due to antenna movements) and changing of the environmental parameters (temperature, humidity and wind speed). Two loops along the antenna, one in optical fiber and one in coaxial cable, have been realized. In particular the loops went from the control room up to the secondary focus room and down again to the control room. This way it has been possible to check the stability of the cables only, since all the electronic devices were at constant and controlled temperature in the control room. The fiber loop has been built by using 2 of 12 fibers of a gel-filled loose tube cable, which was installed on the antenna in summer 2003. The coaxial cable loop was composed by a spare pair of the ones normally used to bring down the receiver outputs from the antenna to the MK4.

The measurement campaign has been done in piggy-back mode, we didn't have the control of the antenna position, which was set by observing schedules. All the data collected show a better behavior of the fiber cable with respect to the coaxial one, both in amplitude and phase and both versus antenna motions (azimuth and elevation) and environmental conditions (mainly air temperature, see figure on next page).

An analogous measurements campaign done at the Effelsberg antenna in early November 2008, result of a collaboration between the staff at both observatories, shows results in agreement with the ones obtained at Medicina.



Gain variation versus antenna movements



Gain variation versus air temperature

## **Noto Station**

During the past few years the main issue for optimal antenna functionality has been the status of the azimuth rail. It's actually uncertain whether INAF will support the repair expenses due to the required high cost.

A new antenna driving software has been completed and installed; this software is able to support all the functionalities available with the TIW ACU that is able to control with a better precision. The new software also disposes of a web interface.

The 43 GHz receiver was working for some months with only one polarization and the repair of a front-end amplifier has been done in the NRAO laboratories. The amplifiers have been replaced and both EVN and single-dish observations were successfully realized.

The 86 GHz receiver is still an issue. Functionality measurements in laboratory showed pretty high system temperature so the receiver has been moved to MPI in Bonn to be repaired. The front-end mixer has been replaced and a thermal control added to the local oscillator. A new testing campaign is expected for the first months of 2009.

The SXL receiver (X wide band and double polarization) built some years ago and never adopted in the antenna will be modified to take into consideration the extra weight that prevented easy and safe the operations at the antenna. A new project is now in progress to simplify the receiver greatly and to insert the ADC+FILE10G of the DBBC system into the primary focus. The signals will be transferred through optical fibers to the control room.

A complete DBBC system was built for Noto. This process has been accelerated because of the numerous problems met with the analog base-band converters. Such problems were the cause of failures in several VLBI geo experiments.

A MK5C/B+ unit is going to be ordered to operate with the DBBC system. Initially both systems will operate in parallel, then after a complete debugging of the new terminal the old one will be dismissed.

### ***DBBC Project***

The main technological activity in the Noto station was the DBBC development project and the construction of several units in very close collaboration with the Max Planck Institute for Radioastronomy in Bonn.

The hardware and firmware of the new DBBC2 with its processing element Core2 board was realized and tested. The Core2 uses Virtex 5 LX220 FPGAS, but can also be populated with the bigger 330 model. The initially planned DBBC have configuration bandwidth from 1 up to 32 MHz. DBBCs with larger BW are available for the Core1 and will be adapted to the Core2 modules. The firmware in its present version can provide 4 DBBCs (U+L) on one FPGA, so a set of only four Core2 boards can produce the functionality of 16 bbs. The filter shapes have been



improved. The tuning precision was increased via a new designed LO that remove the limitation of the exact xxx.99 MHz tuning.

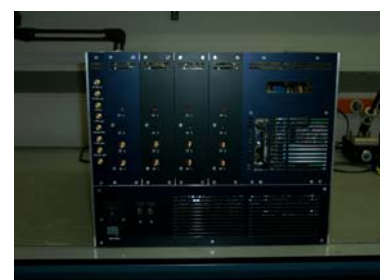
A fixed filter-bank firmware with real output, which was also developed in collaboration with the Arcetri Observatory, still requires some testing.

The control software has to be upgraded from the Core1 to the Core2. The staff at the Wettzell station has been working in strict collaboration with the DBBC development group on the integration in the Field System. The process to migrate the operating system from Windows XP to Linux was started, and all the software is being rewritten for such new environment.

Two DBBC.2 systems have been installed in Wettzell in November 2008. A third system in Wettzell will be upgraded from ver.1 to ver.2. Additional prototype backends DBBC.2 are ready to be tested and delivered to Effelsberg, Yebes, and New Zealand. Two more systems already delivered to Arcetri and Irbene need to be upgraded to the ver.2. to be operative with the standard observing requirements, as they behave only few Core1 boards.

The hardware component of the FILA10G system, the interface between the DBBC (or any VSI device) to the 10G network, has been completed. An international team composed by personnel of IRA, MPIfR, Metsähovi, and SHAO is currently developing the firmware. The board will act as interface for the MK5C or as direct connection to the network at 1–2–4–10–20 Gbps. It can be used as standalone element between VSI and network. VDIF protocol is adopted as data format.

The backend will be produced by a spin-off company named HAT-Lab which will start operation in March 2009, as numerous bureaucratic procedures have been necessary that took much longer than expected. Today, at the time of writing these lines, INAF communicated the last few items to be covered for a final approval.



DBBC: front view (left), internal (center), and rear view (right)

New laboratories are now available at the new building of the Noto station which was completed in 2008. A part of such laboratories will host the spin-off company in charge for the construction of the DBBC systems.

## **Sardinia Radio Telescope**

The Sardinia Radio Telescope (SRT) is a general purpose, fully steerable antenna of the National Institute for Astrophysics. SRT is funded by the Italian Ministry for Research, the Sardinian Region, and the Italian Space Agency.

The SRT is under construction in the Gerrei territory, about 40 km (less than one hour by car) far from Cagliari, the capital region of Sardinia. For sake of simplicity, the erection phase of this observational facility can be seen to comprise 3 macro-activities:

### ***Erection of the structure***

The alidade has been fully and successfully assembled and welded. Whole back up structure (BUS) elements have been fully delivered at site, while assembling works on ground are on time.

Beam wave-guide mirrors, subreflector panels, wheels and bogeys and reduction gears have been also completed and delivered at site.

The quadrupode and the subreflector support structure are under construction.

The actuators and the mechanical structure of the subreflector and the actuators for the primary, gregorian and beam wave-guide foci are completed.

The main Az/EI servo system is under construction while the servo systems for moving the subreflector, the primary, secondary and beam wave-guide receivers are completed.

All the 1008 primary mirror panels are ready, together with the 1116 mechanical actuators for the active surface. They are connected in the same fashion they will be on the antenna and the system is under test at the Medicina laboratories. Panels and actuators will be sent to the site within summer 2009.

### ***Receivers***

Three receivers for commissioning are under development:

- a 7 horn-two polarizations multibeam in the 18-26.5 GHz K-band. It is completed and presently under test at the 32m Medicina antenna. It will be placed in the gregorian focus of SRT
- a single horn in the band 5.7-7.7 GHz. It will be completed within summer 2009 and tested at the 32m Medicina antenna
- a dual frequency coaxial receiver in the bands 305-425 MHz and 1.3-1.8 GHz is under construction.



1116 actuators connected

### ***Back-ends***

A total power back-end for continuum observations that can be automatically connected to all SRT receivers, multibeams included, has been completed and it is currently being tested connected to the K-band multibeam at the 32m Medicina antenna.

A prototype of a new back-end for full Stokes measurements capable to exploit the whole 14x8GHz wide band of the K-band multibeam is under construction.

A filter bank machine for pulsar observation is mostly completed.

Two types of digital back-ends using FPGA (Field Programmable Gate Array) are ready at Medicina to be tested. They are intended for spectroscopy, pulsar and continuum observations.

A DBBC together with a MK5C are being ordered for VLBI observations.

### ***Software***

The SRT system software will be based on ACS (Alma Common Software), a Linux based framework software for:

- local and remote monitoring and controlling all antenna devices,
- events and alarm logging system,
- load balancing and failure tolerance features,
- platform and license free system,
- emerging standard in radio telescopes control

A new observation software, called ESCS (Enhanced Single-dish Control Software), ACS based, will be able to manage observing modes, calibrations, data acquisition, data output (MBFITS), data archive and documentation. The main software instruments used in ESCS are the following:

- TCP/IP and CORBA for communication protocol
- C++ for programming language
- QT libraries and JAVA for graphical interfaces
- XML for database scheme
- Doxygen as automatic documentation tool
- UML (Unified Modeling Language) to schematize the system architecture

The pointing of the antenna under ACS has been tested successfully at the 32m Medicina antenna, and a first pilot survey in K-band using on-the-fly mapping, one of the main features of ESCS, has been made with this antenna.

### ***Plants***

The designs for the electrical plant, air conditioning of the rooms, helium pipelines and compressor for cryogenics, and cables on the antenna have been completed.

### ***Civil and Technological infrastructures***

Local activities for civil and technological infrastructures erection have started by mid of November 2008. This will provide the actual Station, i.e. the buildings which will host offices, technical departments, laboratories, and so on.

### ***Local activities***

INAF has established a provisional area for logistics and science department. Monitoring of the RFI and weather conditions, GPS survey, water vapor radiometer measurements, video and photographic documentation are up and running. Two webcams allows everybody to watch for what is going on at yard. For more information, check the SRT home page at:

<http://www.srt.inaf.it/>

Furthermore, the INAF-Cagliari Astronomical Observatory is deeply involved in outreach activities, which are aimed to strengthen the link between local people and astronomy.

## **4.5 Jodrell Bank Observatory, UK**

### **EVN Observational Activities**

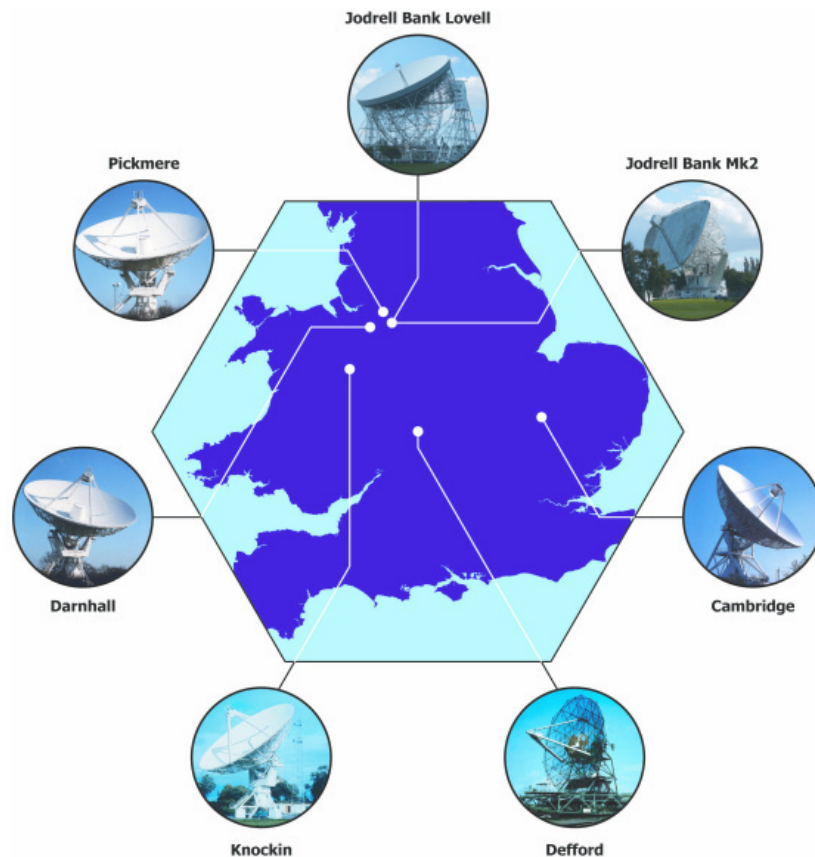
During the period 2007-2008, the MERLIN/VLBI National Facility, based at Jodrell Bank Observatory, participated in all six EVN observing sessions. These involved the 25-m Mk2 telescope at 1.3, 5, 6 and 18/21 cm, the 76-m Lovell telescope at 6cm and 18/21 cm, and the 32-m Cambridge telescope at 1.3, 5, 6 and 18/21 cm. During 2007-2008, National Facility telescopes were scheduled to observe 135 VLBI projects, for a total of 1914 telescope hours. 30 of these experiments were joint EVN+MERLIN observations, during which MERLIN provides short baselines allowing source structure to be mapped on scales from a few milliarcseconds to several arcseconds. During this two year period a total of about 99 telescope hours (5.2%) were lost due to technical problems at the time of observation, astronomer/operator error or adverse weather.

One joint MERLIN experiment at 18cm in the May/June 2008 session (ea038), in addition to the Mk2 telescope, used MERLIN antennas Cambridge, Darnhall, Knockin and Defford. In this project, on the fundamental properties of OH/IR stars, single polarization data from the four MERLIN outstations were successfully recorded on a single disk pack. This was achieved by using four MERLIN phase-rotator cards connected to the four IFs of the VLBA data acquisition rack (DAR), and driving the array under MERLIN control. This is possible because the MERLIN microwave link limits the available bandwidth of telescopes to 14 MHz, whereas VLBI experiments typically use 64 MHz per telescope. This technique thus makes full use of the 'unused' channels on the VLBA rack, supplying additional baselines to the EVN with minimal effort. This process was first tested in February 2008 to record three MERLIN telescopes on a single diskpack, as a preliminary test of procedures to obtain SKA beam-forming test datasets. This is becoming a standard method of providing more EVN baselines as well as common MERLIN baselines for joint VLBI+MERLIN observations. Software updates have now been made to provide control of a secondary VLBI antenna using the same VLBI Field System (FS) interface on the VLBA DAR, rather than with MERLIN control. Further modifications of software at JIVE now allow the correlator to independently process these multi-telescope observations without having to duplicate datasets for each telescope in the array.

### **VLBI instrumentation**

The VLBA Field System (FS) PC has been upgraded to an XP2100 based CPU, PCI serial and HPIB hardware, and a more recent Debian 'Etch' Linux distribution. We have not yet considered the timeline for replacement of the Mk4 and VLBA IF racks, with either an iBob/DBE (digital back end) or with an EVN DBBC (digital baseband converters). The Mark5 machines have also had an upgrade, but currently remain at Mark5a specification. An upgrade of one recorder to Mark5b specification will probably take place during 2009. An I/O board in one of the Mark5 recorders was replaced in 2008 and appears to have rectified 'data throttling' problems with that recorder.

The e-VLBI (internet-based VLBI data transmission and correlation) operation has been developed substantially, in conjunction with JIVE and the other EVN stations, and with our local network providers. A total of 27 e-VLBI experiments were run in 2007-2008. One of these resulted in the first 22 GHz real-time fringes for the Mk2 and Cambridge antennas. Real-time fringes are now consistently achieved at 512 Mbps with improved correlator automation. The JBO-Manchester fiber link (at 10 Mbps) upgrade is now completed, though the link beyond to Onsala currently supports 4 Mbps. A further 4 Mbps upgrade is planned for the JBO-JIVE route in 2009. Tests have recently been performed to allow the Mk5-554 recorder to send the full 1024 Mbps from the Mk2 telescope to JIVE. Further work has been performed to integrate the VLBI and e-VLBI observing systems into the e-MERLIN infrastructure.



The Multi-Element Radio Linked Interferometer Network (MERLIN) is an array of seven radio telescopes distributed over central England

### **e-MERLIN**

The e-MERLIN upgrade, which connects the 5 remote telescopes and the Lovell and Mk2 telescopes at Jodrell Bank at 30 Gb/s each, via a dedicated optical fibre network to a new correlator at JBO has progressed well. The optical fibre network is in place, the new 4-8 GHz receivers have been installed, the new broad-band IF equipment and samplers are being tested and the first station board of the new correlator, being developed by DRAO, Penticton, arrived at the end of 2008. First fringes using the new digital transmission equipment from two telescopes and the first elements of the correlator are expected in Spring 2009.

## **4.6 Max-Planck-Institute for Radio Astronomy, Germany**

### **MPIfR correlator**

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

#### **Improvements achieved in 2007-2008**

- In 2007 the correlator software was enhanced to partly execute on a Linux computer and to handle more antennas. This is a joint project of MPIfR and MIT Haystack.
- Playback and correlation from Mark 5B recorders was implemented and is used regularly. Correlation of data rates up to 2 Gbps is also possible, but could not yet be tested.
- All tape units were decommissioned. At the end of the reporting period 12 playback units were connected to the correlator: 8 Mark 5A and 4 Mark 5B.
- About 400 TB in 150 disk-packs have been assembled and tested at Bonn for supporting GMVA and EVN operations.
- e-VLBI data transfer is now routinely done for some antennas involved in geodetic observations and fringe tests with some of the GMVA antennas.

### **Correlator Operation**

A new near real-time UT1 rapid observation - INT3 - was introduced. It is observed once per week with 3 antennas: Wettzell (Germany), Ny Ålesund (Spitzbergen, Norway), and Tsukuba (Japan). It is a joint project of MPIfR, BKG (German Mapping Authority), the Geodetic Institute of the University of Bonn and the above mentioned antennas. The data of those 1 hour long observations are transferred to Bonn via Internet. The geodetic data-base is available for analysis about 6 hours after the observation.

The number of observations correlated stayed at a high level in 2007 and 2008. The total percentage of correlation time over total time was about 35% which is about the same as in previous years. About 40% of the correlation time was used for astronomical correlation, 60% for geodetic projects. This corresponds to 47 astronomical projects and 267 geodetic experiments. The number of geodetic observations has increased due to the INT3 observations.

## **mm-VLBI**

In May 2007 VLBI test observations were conducted at 1.3 mm together with MIT Haystack Observatory. Data were recorded with rates of two and four Gbit/s, which is four and eight times higher than in previous tests. The gain in sensitivity correspondingly is a factor of two and 2.8. Participating telescopes were Pico Veleta (Spain), HHT (Mt. Graham, AZ, USA), one CARMA dish (CA, USA) and the JCMT (Hawaii), which was fiber-linked to the SMA. Due to technical and weather problems no transatlantic fringes were found. On some of the US baselines fringes with a SNR of up to 40 were measured. This also led to a new size estimate of Sgr A\* of 3-4 Schwarzschild radii.

## **Software Correlator**

The now nearly 10 year old MK IV hardware correlator will be replaced by the DiFX software correlator in 2009/2010. The development of DiFX (Deller et al, 2007) is shared now by a group of developers at NRAO, MPIfR, CSIRO, and INAF. In 2008 a small computer cluster with 60 nodes and nearly 500 computer cores was procured (~ 4 TFlops Linpack) for DiFX. The correlator room was re-built to make space for the cluster and 16 Mark 5 units (including the units connected to the MK IV correlator).

The results of a first geodetic comparison test were presented at the "18<sup>th</sup> European VLBI for Geodesy and Astrometry (EVGA) Working Meeting" in Vienna in spring 2007. This comparison showed excellent agreement between DiFX and the MK IV correlator (a publication is in press). Further developments needed are the implementation of phase-cal extraction and a direct export path to the geodetic analysis path.

## **Technical developments at the 100m Effelsberg telescope**

In 2007 and 2008, the commissioning of the new subreflector was continued. A series of test observations confirmed the high surface accuracy (about 60 micron) of the elliptical mirror as well as the proper operation of the hexapod, the active surface (with 96 actuators) and the automatic focus exchange mechanism.

The "focus curves" (which correct the changes of the focus position when tilting the telescope due to homology) have been newly determined for many receivers. Calibration observations showed that the sensitivity of the telescope increased by more than 50% for the high frequency receivers mounted in the secondary focus. At the same time, these measurements confirmed that the gain-elevation curves are flatter than before due to the active surface (correcting residual deformations of the main dish).



The development of new multi-frequency receiver boxes for the prime focus continued. In 2007 the first box containing two receivers was tested successfully in the telescope. Eventually, such boxes should contain up to four receiving systems, increasing the observatory's frequency agility and allowing the capability to keep more receivers ready for use.



The 100-m radio telescope in Effelsberg

### **DBBC AD board**

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

The technical specifications of this equipment are the following:

- Analog input: 0-3.3 GHz
- Max Sampling Clock single board: 2.2 GHz
- Max Instantaneous Bandwidth in Real Mode: 1.1 GHz
- Max Instantaneous Bandwidth Complex Mode: 2.2 GHz
- Output Data: 2 x 8/10-bit @ 1/4 SClk DDR or 4 x 8/10-bit @ 1/8 CClk DDR

A prototype DBBC (Version 2) will be installed at Effelsberg in spring 2009.

A board with two 10 Gbit optical Ethernet connectors is being developed. It will allow higher output data-rates for the DBBC. It will also be used for transporting sampled raw data from a "digital receiver", which is under development, to the control building for further processing. It is expected that the development phase will be finished in spring 2009.

### **Digital converter for linear to circular polarization**

The bandwidth of circularly polarized receivers is limited. The desire for larger bandwidths for VLBI led to a project to convert linear polarization to circular digitally. Based on the FPGA-boards of the DBBC project an algorithm has been developed for this task. It will be tested early 2009.

### **e-VLBI**

In 2007 a dedicated fiber was laid which connects the telescope to the institute in Bonn and further on to the European backbone GEANT. First fringes with data transferred through the fiber were found at the Bonn correlator in December 2007. A 1 Gbit line to GEANT and a direct 10 Gbit connection to JIVE are available since early 2008. Effelsberg regularly takes part in e-VLBI test observations.

### **Tropospheric Corrections**

In the framework of the EU FP6 RadioNet project it was studied how the disturbing influence of the troposphere on high-frequency VLBI observations can be reduced. The fluctuations in the "wet" part of the troposphere (water vapor) lead to changes in the path delay and therefore to phase fluctuations which reduce the coherence and the precision for phase-referencing observations. Measurements with a water vapor radiometer (WVR) and GPS were investigated.

The measurements via WVR were partly successful and suggested how to improve the WVR design. The GPS measurements with application of the corrections to an observation at 5 GHz were not successful. It turned out that the influence of the ionosphere still dominates at 5 GHz. The tests will be continued at 22 GHz.

## **4.7 Metsähovi Radio Observatory, Finland**

### **VLBI Observational Activities**

The 14-m antenna at Metsähovi performs both astronomical and geodetic VLBI observations in conjunction with three global networks of VLBI: the European VLBI network (EVN), the International VLBI Service (IVS; in collaboration with FGI), and the Global Millimeter VLBI Array (GMVA). Furthermore, Metsähovi has actively taken part in spacecraft VLBI tracking observations organized by Joint Institute for VLBI in Europe (JIVE) in cooperation with the European Space Agency (ESA) as well as real-time dUT1 experiments with Japan and Sweden.

### **VLBI Sessions in 2007 - 2008**

In 2007 to 2008 Metsähovi took part in eight (2007) and nine (2008) geodetic off-line and real-time e-VLBI sessions. Together with the Global mm-VLBI Array (GMVA), the 14-m antenna observed also four sessions, in May and October of both years. Five regular EVN sessions were conducted using the only available receiver (K-band frequency) at the station.

### **e-VLBI Sessions in 2007 - 2008**

Metsähovi has had 10G since 2006. All Germany or Japan correlated geodetic sessions were performed regularly either in real-time or using Tsunami e-VLBI. The fuseMk5A file system software has enabled astro/geo VLBI stations without PC-EVN to perform fast off-line e-VLBI.

Short JIVE e-VLBI checks up to 512 Mbps using Mark5A were performed successfully in 2007 and 2008. Lacking correlator capacity, EVN and GMVA sessions were however sent with traditional courier.

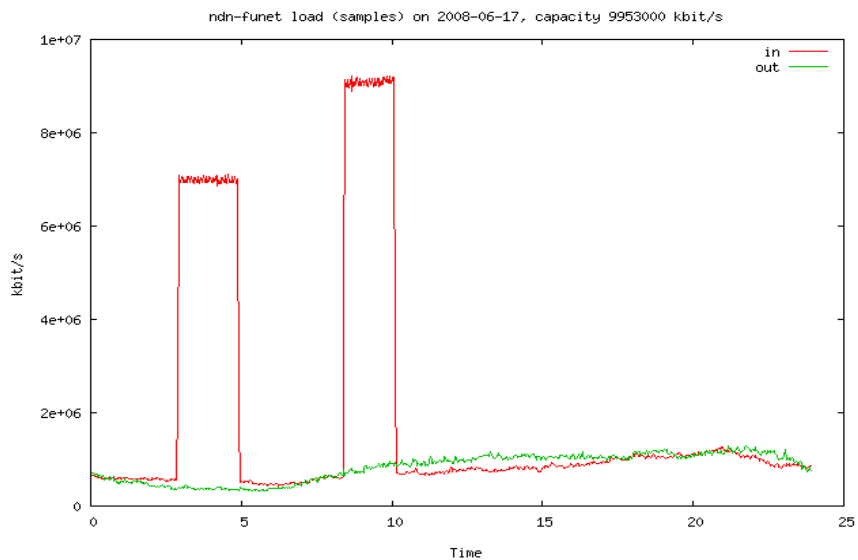
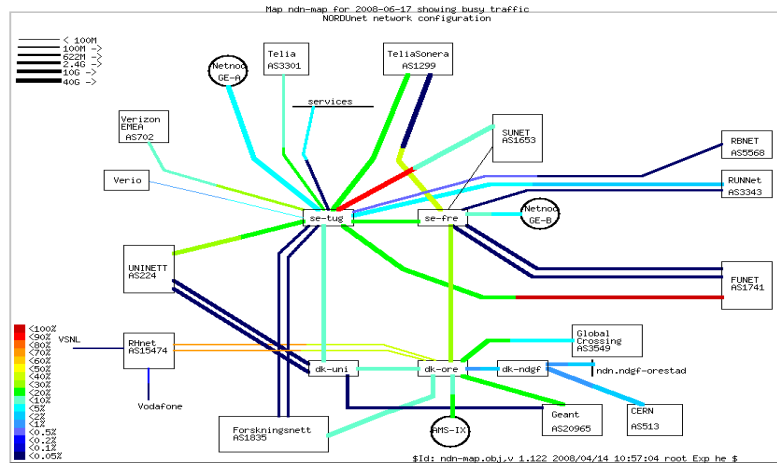
Real-time 128 and 256 Mbps observation sessions with Tsukuba, Kashima and Onsala EVN stations were performed achieving near real-time dUT1 estimates. There was a live demo held in the JGN2 Symposium 2008.

### **EXPreS project developments**

Selective real-time channel dropping for 896 Mbit/s was demonstrated with Metsähovi Tsunami in late 2006 to early 2007. An update to Tsunami in 2008 sustains rates over 7 Gbps. During 2008 some stations have begun off-line Tsunami transfers for astronomic VLBI data in the EVN, too, in addition to previous daily geodetic transfers.

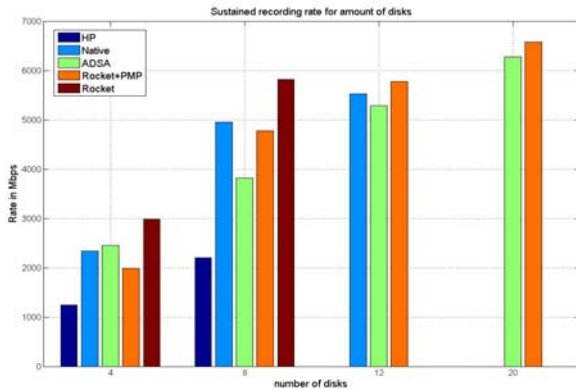
An FPGA-based test Digital Backend has been designed on an iBOB board at Mh. The system sends digitized analog IF's via 10 Gigabit CX4 lines. A polyphase filter bank has been implemented as well but the performance is limited by the lack of internal memory of the board and the FPGA chip. The system has been evaluated without PFB in maser and spacecraft observations and in 10G network tests during 2008.

Real-time 4 to 8 Gbps radio signal streaming was demonstrated between Mh and On in 2008.



Internet 6-8 Gbps traffic between NorduNET and Funet on one Onsala/Metsähovi 10G test day (top). NorduNET load map during the 8 Gbps test (bottom). Images © by NorduNet 2008.

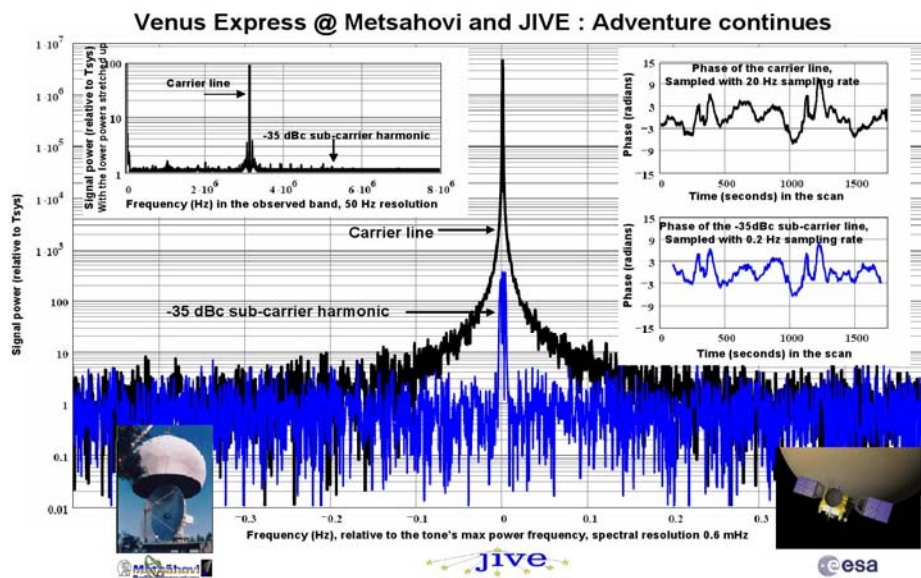
A shippable data storage system 4G-EXPREs capable of over 4 Gbps was developed in 2008 for VLBI use. It allows Mark5C-compliant network recordings at over 4 Gbps to 20 disks (30TB). We plan to further evaluate and do demonstrations of 4 Gbps during 2009, hopefully reaching 8-10 Gbps sustained.



Early 2008 test of RAID controllers and port multipliers show COTS hardware for 4-6 Gbps rates to Mark5C-like 10G NAS (left). Shippable 4G-EXPREs SATA diskpack prototype on a rack-tray (right).

Assistance was provided to Italian DBBC FiLa 10G development by the end of 2008.

A VLBI software correlator core for IBM Cell processors with 512Mbit-per-node correlation was made available in 2007 for EVN astro/geo. During 2008 together with JIVE a set of VLBI phase-referenced spacecraft tracking and spectral analysis software were developed. These were exercised in several single-dish experiments tracking ESA Venus and Mars Express spacecraft and may be used in ESA Cosmic Vision. Further, JIVE/EVN co-observations led to detection of water masers in the Saturnian system.



The ESA VEX S/C was observed with Metsahovi 14m antenna at X-band on July 11 2008. Data were processed and analyzed using the high-performance software developed at Metsahovi and analytical tools developed at JIVE. We made what we promised at the previous picture, issued 3 weeks ago, and even more: we got 0.6 mHz resolution,  $10^{6.7}$  dynamic range, and phase lock to the VEX as if it could be at 100 AU, in the Kuiper belt or even farther.

## VLBI Instrumentation

1.3cm K-band LCP+RCP receiver continues to be available. 0.7cm is still in receiver laboratory waiting for replacement of LNAs.

Tests indicate that the room temperature part of the receiver works correctly according to the block diagram and theoretically calculated signal levels and frequencies were measured.

Currently there is an effort to put the receiver in operation during the summer 2009. The problematic custom-made MMIC chips are to be replaced with commercially available ones. According to data sheets the performance of these devices is good. However the operation at cryogenic temperatures is still a question.

13/3.6cm standard S/X (not wideband X with the third IF3) geo-RCP-only receiver is available. It is owned by Finnish Geodetic Institute (FGI) and using it for astronomy requires arrangements, thus prospective PIs need to contact Metsähovi directly. The 2/8 GHz Geo-VLBI receiver has proven to be reliable. A minor service operation for LO module was done in autumn 2008. A SMA T-junction was replaced with a new power divider for 5 MHz. This helps to keep the PLL locked with lower reference signal power level.

### 3 and 2 mm SIS Receivers:

- May 2007: Both channels functional, at the laboratory noise temperature was 140 K (A channel), 90 K (B channel). Up on the telescope sensitivity again worse.
- Oct 2007: Both channels functional, at the laboratory noise temperature was 73 K (A channel), 138 K (B channel). With the receiver up on the telescope, measurement in control room showed a bit degraded sensitivity
- May 2008: Both channels functional, noise temperature 170 K (A channel), 80 K (B channel). Up on the telescope, the sensitivity values were opposite for the two channels. Probably the cables had changed places.
- Oct 2008: Only one channel functional. Mixer was replaced for the dead channel, but after cooling down, the other channel proved dead. The session was run with LCP polarization only, because yet another mixer replacement, with temperature cycling, carried a risk of total failure, and the time to session start was running short. The working channel was the "direct channel" and LCP was selected by turning the polarization plate in front of the input window to +45 degree position. After the session it was noticed that a mirror bearing was stuck, and the resulting data was therefore not valid.

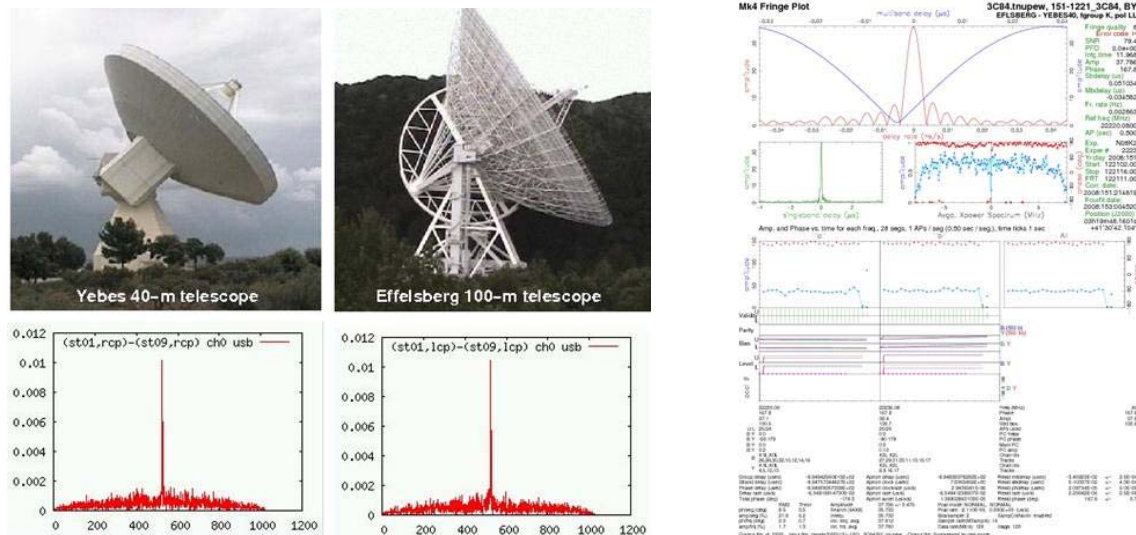
The new HEMT front-end based 3mm receiver is reaching completion. The aim is to have it tested before the end on June 2009 and have the first session with it in October 2009. The May session is likely to be run with the outgoing SIS receiver.

The 2mm receiver was tested at the laboratory in October 2008. Noise temperature was 120 K.

## 4.8 National Astronomical Observatory, Spain

The recently constructed 40 meter radio telescope of the National Astronomical Observatory (OAN, National Geographical Institute - IGN, Ministerio de Fomento, Spain) in Yebe performed its first astronomical VLBI observation on May 30<sup>th</sup> 2008, at the EVN session. The observations were performed at K-band (22 GHz), and successful first fringes were obtained both at the EVN correlator at JIVE, and at the MPIfR correlator in Bonn.

This was an important achievement for OAN and for the EVN. Yebe 40-m telescope observed also at S/X bands in September 2008, and C bands (5 and 6 GHz) are expected in 2009, enhancing the sensitivity and capability of the network at those frequencies.



The first astronomical VLBI observation of the Yebe radio telescope took place at the EVN observing session of May 30<sup>th</sup> 2008. Fringes were promptly obtained between the Yebe and the Effelsberg telescopes.

### EXPreS project

The OAN telescopes are located in the town of Yebe, 75 km NE of Madrid (Spain). Several commercial options have been investigated for the last-mile connection to deliver the data of the new 40-meter radio telescope, still under commissioning, to the NREN RedIRIS, which holds the GÉANT node infrastructure in the city of Alcobendas (north of Madrid and distant 94 km to Yebe via Madrid). Negotiations with RedIRIS are finished, being already possible to install the needed equipment at their premises. Dr. F. Colomer, the coordinator of EXPreS SA2, leads the efforts at the local and European level.

## **4.9 National Astronomy and Ionosphere Centre, Arecibo Observatory, Puerto Rico**

### **Hardware Update**

In June 2008, a cryogenically-cooled 327-MHz receiver was installed on the 305-m telescope, replacing the existing room-temperature receiver in that band. This receiver has native dual-linear polarization channels with an average  $T_{\text{sys}}$  of  $\sim 95$  K (for the colder part of the sky). The new receiver represents about a 30 K improvement in  $T_{\text{sys}}$  compared to the old receiver. The current system has two front-end filters of 50- and 30-MHz bandwidths centered at 327 MHz.

### **Personnel Update**

In September 2007, Dr. Emmanuel Momjian moved from Arecibo to the EVLA of NRAO at Socorro (USA).

### **Meetings**

The Arecibo Observatory hosted the EVN Consortium Board of Directors meeting on 3<sup>rd</sup> and 4<sup>th</sup> of November, 2008. Nineteen participants, directors of almost all member institutions of the EVN, plus the EVN officers attended the meeting.

### **EVN Sessions**

The Arecibo telescope's suspended platform structure was being repainted during a large part of 2007. To achieve this, the telescope was taken out of service and Arecibo did not participate in any of the three EVN sessions in 2007. There was just one e-VLBI test observation on 23<sup>rd</sup> March 2007. However, Arecibo participated in all three of the 2008 EVN sessions (in March, June and October).

In 2008, Arecibo also participated in HSA, e-VLBI, Ultra-wide band VLBI runs, plus single-dish baseband pulsar data recording (using the MK5A system). Details of some of these and other VLBI observations in the recent past follow:

(a) On May 5<sup>th</sup> 2008, e-VLBI was performed with an array including Hartebeesthoek Radio Astronomy Observatory in S. Africa. Fringes were obtained at 32 Mbps, limited by HRAO's available data rate. This run used the old ATM fibers in Puerto Rico and was the first US-Africa e-VLBI.

(b) On May 9<sup>th</sup>, e-VLBI with the 6-m TIGO dish at Concepcion, Chile. This also used the old ATM fibers and was the first North-South American e-VLBI fringes.

(c) An Ultra Wideband VLBI (UW-VLBI) test run was conducted on May 15<sup>th</sup>, between the GBT and AO, at 4 Gbps. Disc recording using a DBE (Digital Backend) and 2 x Mk5B+ recorders on loan from Haystack was made. Ten seconds of data were then transferred via ftp to Haystack, and correlated there. In 10 sec, 1700:1 SNR fringe was obtained on a 122 mJy source, the most sensitive interferometric baseline yet obtained anywhere!





The 305-m dish in Arecibo

(d) On 17-18<sup>th</sup> May, "production" disc-recording of UW-VLBI at Gbps was made. Data were recorded for complete transits at AO of a number of gravitationally-lensed radio sources to search for the presence of weak central images to the total lensed images. Data recorded at Ar and GBT were then successfully correlated at Haystack. Further results are awaiting the imaging and analysis. The DBE and Mk5B+ systems have been returned to Haystack subsequently.

(e) On 20<sup>th</sup> May, an e-VLBI test session was carried out with Westerbork, Onsala, Medicina, Cambridge, Torun, and Jodrell Bank, with the data correlated in real time at JIVE in the Netherlands. Successful sustained fringes at 128 and 256 Mbps were obtained with data from Arecibo. (The previous best was 105 Mbps.) Fringes were briefly obtained at 512 Mbps, but technical development was deemed necessary to sustain this data rate. This was the first usage of the new Centennial de PR fibers.

(f) On May 22<sup>nd</sup>, the Arecibo telescope joined with other members of the EXPReS project in a live demonstration of the first ever real-time e-VLBI observations that simultaneously used telescopes in North America, South America, Europe and Africa. This simulated a telescope almost 11,000 kilometers in diameter. The results were immediately transmitted to Bruges, Belgium, as part of a live demonstration at the TERENA (Trans-European Research and Education Networking Association) Networking Conference 2008.

(g) On 9<sup>th</sup> September, we were able to demonstrate real-time fringes between Arecibo and several European EVN telescopes at a rate of 512Mbps. This was made possible by improvements in the network connectivity from Puerto Rico to the mainland USA via the PRISANET gigabit infrastructure jointly developed by the University of Puerto Rico, Centennial of PR, and the AO, and a dedicated network path (VLAN) all the way from Arecibo to JIVE in The Netherlands.

## **4.11 Onsala Space Observatory, Sweden**

The Onsala Space Observatory (OSO) telescopes continued during 2007 and 2008 to play a full role within the global observing program for astronomical VLBI. In total 10 astronomical VLBI-sessions (6 EVN sessions and 4 global mm-VLBI sessions) were conducted. In addition, the Onsala 20m telescope has been used for some 27 geodesy VLBI experiments in 2007 and 23 during 2008. For most of the geodesy experiments the data were additionally recorded in parallel on the PC-EVN-computer that is daisy-chained to the Mark 5 unit. These data were transferred electronically using the Tsunami-protocol, and no Mark 5 modules were actually sent to Bonn during 2008. OSO also participated in the continuous geodetic VLBI campaign CONT08 in August 2008.

OSO is regularly involved in e-VLBI sessions within the EVN. To make further progress a 10 Gbps lightpath was installed in 2007. With this, the data transfer record obtained during 2008 to JIVE was 1024 Mbps. It will also be used to demonstrate, as part of the EXPReS project, 4 Gbps real time data flows from the 20m telescope (at 22 GHz) to the e-MERLIN correlator in the UK during 2009. A secondary goal is the transfer of data at a similar data rate from the LOFAR station at OSO to the correlator in the Netherlands. The geodesy group performed 19 ultra-rapid dUT1 experiment (OSO - Japan, 1.5 hours) during 2007 and 29 during 2008. The highlight during 2008 was the determination of final dUT1 results within 4 minutes after the end of the observing session.

John Conway (chair) and Michael Lindqvist are members of the e-VLBI Science Advisory Group. Michael Lindqvist is the OSO representative on the EVN Program Committee and attended its meetings. Michael Lindqvist is vice-chairman of the EVN Technical and Operations Group (TOG) since the end of 2007.

### **Technical developments**

Onsala Space Observatory (OSO) has installed a new S/X-band receiver during 2007. It has dual polarization at X-band and single polarization at S-band.

OSO installed a new 3mm receiver (single polarization) in 2007. It has successfully been used for global mm-VLBI observations.

In November 2007 OSO installed a 10 Gbps lightpath. The setup completely separates the network traffic from the telescope from that of the rest of the observatory and allows a flexible path to e.g. JIVE, e-Merlin or the LOFAR correlator.

The Mark 5 unit was completely upgraded with a new operating system (Debian Edge), motherboard, CPU and a Network Card (10 Gbps) in order to sustain higher data rates.

OSO reached the EVN goal of 150 TB (155 TB) of Mark 5 disk storage during 2008.



The 25-m radio telescope in Onsala

As part of the EXPRoS project, researchers at OSO, Metsähovi Radio Observatory, and Jodrell Bank Observatory have been working towards the goal of connecting an external antenna into the UK-based e-MERLIN radio interferometer at a data rate of 4 Gbps. Awaiting the construction of the e-Merlin correlator, several tests have instead been conducted between Onsala and Metsähovi. One test was performed at the beginning of November 2008, with data captured from the Onsala 20m telescope being recorded in real-time on a PC based at Metsähovi. The radio source being observed was the H<sub>2</sub>O maser W3 at a frequency of 22 GHz, and the sampled data were successfully transmitted and received over the academic internet at a rate of 4 Gbps for a period of 5 minutes. Processing of the data was performed at Onsala, which clearly revealed the water maser spectrum of W3.

In collaboration with the metrology department at the Technical Research Institute of Sweden, OSO has installed a time and frequency laboratory, including a new hydrogen maser, during 2007. Thus, OSO presently operates two hydrogen masers. These atomic clocks are utilized in the realization of the Swedish national time scale UTC(SP) which is the national realization of the Coordinated Universal Time UTC.

OSO has been involved in matters concerning erection of wind mills in the vicinity of the observatory, the reason being that wind mills are potentially dangerous due to the fact that their large reflecting areas may increase the level of radio frequency interference at the Onsala site.

## **4.12 Shanghai Astronomical Observatory, Sheshan Station, National Astronomical Observatory (NAOC, CAS). P.R. China**

### **Observing activities**

During the period 2007-2008, Shanghai (Sheshan) 25m radio telescope participated in five EVN observing sessions at 18, 6 and 1.3 cm bands. Sheshan station was absent from the November 2007 session because of the tracking campaign of Chinese Chang'E-1 satellite. The total observing time was about 650 hours including fringe-test experiments, SEFD measurements and e-EVN observations. In 2007-2008, a large fraction of observing time of Sheshan telescope was spent on the project of VLBI tracking Chinese Chang'E-1 satellite. That accounted for up more than 200 observations and almost 2000 hours.

The Sheshan radio telescope worked correctly in most EVN experiments. Nevertheless, in the November 2008 session, some severe pointing problems made it not possible to obtain fringes between Shanghai and other stations of the array.

### **Update and current status of equipments**

New sets of S/X receiver and feed system were installed in Sheshan telescope at the end of 2006. It works in RHCP mode, mainly for geodetic experiments. The new receivers are cryogenic with receiver noise temperature of 20 K (S band) and 35 K (X band).

The L-band cryogenic receiver installed in the main focus showed high noise temperature during 2008 network monitor experiments. The problems were associated to the aging and damage of some electronic components in the LO, RF amplifier and DC biasing board. We have replaced components and solved the problems.



Upper panels: antenna track gap and offset. Bottom panels: repairing track in 2006.



Upper panel – broken bearing; bottom panel – bearing after replacement.

In 2007 and 2008 a number of antenna repairs have been carried out:

- Since the antenna tracks were found to have big gap and offset by July 2006, and since some joints at the intersecting two tracks were corrupted, the telescope was stopped to be repaired until the end of that year. The telescope returned to normal observation by January 2007.
- In 2007 August, the bearing in one of the driving motor was badly broken down. A new bearing was replaced after two weeks of work.
- In the November EVN session, JIVE reported that fringes could not be detected on Sheshan baselines. After inspecting the system, the screws in the elevation encoder were found loose, leading to bad pointing. This problem was solved at the end of 2008.

Sheshan telescope is currently equipped with standard VLBA terminals with 14 BBCs and two IF distributors. There was no known problem associated with the terminal in 2007 and 2008 observing activities. There are two Mark 5A machines at the station. The OS system of one machine has been upgraded to Debian 2.6.18.dfsg.1-23etch1, and the Mark 5A software version is 2007y222d02h. The OS kernel version for another machine is RedHat 2.4.20-31.9. The current FS version at Sheshan station is 9.10.4. We are developing a remote-monitoring program that is to be installed at Sheshan Station. That will make the experiment preparation automatic, from fetching schedule files to creating antenna control files.

The Sheshan radio telescope successfully conducted 512 Mbps e-VLBI tests with Australian and Japanese radio telescopes in 2008 June. On 2008 June 17 a trans-continent e-VLBI demo was successfully made at 512Mbps among Chinese (Sheshan), Australian and Japanese radio telescopes. Since 2008 September the Sheshan telescope participated in scientific e-EVN observations and test experiments. In 2009 January 15<sup>th</sup>-16<sup>th</sup>, the Sheshan radio telescope participated in the 33-hour continuous 'marathon' e-VLBI observation live demonstration in the opening ceremony of the International Year of Astronomy 2009 in Paris.

### **Laboratories of Sheshan Station and future projects**

A microwave laboratory is being set up at Sheshan station. A 6.7 GHz (Methanol maser) receiver system is being designed. The receiver will be working with dual circular polarization pattern.

An electronic laboratory is being set up.

The project of building a 65m radio telescope was funded in 2008. The new telescope will be built at a location about 4 km west of the current site of Sheshan 25m radio telescope. It is planned to be completed in 2012.

### **VLBI Correlator center at SHAO**

#### **Correlator**

The correlator system of Shanghai Astronomical Observatory consists of a software correlator and a hardware correlator. They comprise the central data processing equipment of Chinese VLBI Network (CVN). The SHAO correlator is operated for the VLBI data processing of the Chang'E-1 lunar explorer. It also provides the long-term operation mission of the CE-1 lunar explorer. In December 2008, the CE-1 explorer achieved an orbit transfer from orbit altitude of 200 km to 100 km. Benefitting from the upgraded fringe search module in the software correlator, the SHAO correlator successfully fulfilled all the VLBI data correlation in nearly real time.

To meet the near-future requirements of the Chinese VLBI Network (CVN) in the deep space, geodesy and astronomy domains, research and development activities of the VLBI correlator technologies were carried out. A new correlator mainly for the geodetic project of the Crustal Movement Observation Network of China (CMONC) is being developed. In 2009 January, on the baseline of Shanghai-Urumqi, the first CVN 2-station high speed e-VLBI (256 Mbps/station) experiment was conducted by a high speed 10-station software correlator prototype running on a computer cluster.

#### **DBBC**

DBBC prototypes have been finished and mounted at the Sheshan and Urumqi stations for test experiments.

## **4.13 Torun Centre for Astronomy, Nicolaus Copernicus University, Torun, Poland**

### **EVN Operations**

The Torun station (Tr) with its 32-meter radio telescope and Mark5A recorder has participated in all the 6 regular EVN sessions at wavelengths of 21, 18, 6 and 5 cm during the period. Likewise, it took part in all the e-VLBI scheduled experiments, including many test observations and science demonstrations outside the schedules. In 2008 Magda Kunert-Bajraszewska joined the VLBI team at the Torun Center for Astrophysics (TCfA).

At 5 cm, the first two sessions of 2007 were lost because of problems with the receiver that had been upgraded shortly before the first session. In the March 2008 session all VLBI data suffered from frequent (on scale of a minute) fringe phase jumps. The problem was diagnosed to be due to malfunction of a 1pps amplifier between the formatter and the maser. The entire 5cm part of this session was not observed due to a failure of the resolver in one of the azimuth drives. The other sessions at all the wavelengths passed without any major problem.

Prompted by earlier amplitude calibration issues at Tr, in the Spring of 2007 Kaz Borkowski undertook a special campaign, which is reported in detail in the following document:

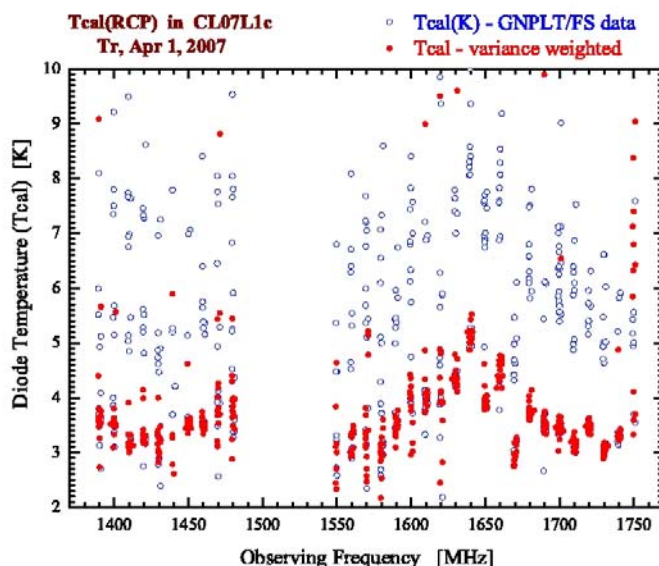
<http://www.astro.uni.torun.pl/~kb/Reports/EVNcal/EVNcalibration.html>

He found that one of the main sources of difficulties at Tr continue to be the old BBCs (a component of the VLBA terminal). This study led also to certain conclusions of interest to the entire EVN community since it indicated a few possibilities to improve the amplitude calibration of the network by inexpensive modifications in the measurement techniques as detailed in a subsequent document:

<http://www.astro.uni.torun.pl/~kb/Reports/EVNcal/Issues.htm>

The most promising of these possibilities is the averaging with weighting of measurements by the reciprocals of squared errors (or standard deviations). These errors rapidly increase whenever an RFI spike or system instability occurs, or when a measurement is taken before the antenna settles on a new position. The surprising effectiveness of the weighting is illustrated in the following figure, where RFI of L-band and instabilities render these observations practically useless if standard tools are to be applied.

The ability of the weighted averaging to so powerfully suppress wrong measurements might become priceless in near future, which is endangered by ever increasing problem of RFI. Since presently EVN is implementing new (digital) backends in all stations, also new procedures for calibration will have to be developed. That is good opportunity to introduce in them the weighting averaging.



Equivalent noise temperature of calibration diode in L-band in RCP channels obtained from observations of 1 April 2007. A simple combination of measurements gives 512 results seen as the widely scattered open circles (in blue). These exactly reproduce an output of the standard EVN GNPLT application. The same quantity calculated with weighting of individual measurements is shown as the red dots. The weighting made most of the scattered data above 4 to 5 K to drop to about correct range in the lower part of this figure.

## VLBI technical activities

In all the six sessions Field System 9.9.2 version and Mark5A version 2005y147d11h have been used. All BBC units have been ascribed distinct hardware numbers which are now visible in the FS log files.

In 2007 the antenna focal area has been rebuilt to accommodate a new OCRA (1 cm) array.

In the summer of 2008 a new module has been built for distribution of frequencies (1 MHz, 10 MHz, 20 MHz) and timing pulses (1 s, 10 s, 1 min.) throughout the station. It now delivers 1pps signal to the VLBI terminal in place of the old connection using the amplifier that caused fringe phase jumps earlier, in the Session 1/2008.

In the beginning of May 2007 the Mark5A recorder has been upgraded with a new motherboard, CPU, power supply and hard disk. The Mark5A recorder has now a 10 Gb/s switch (HP ProCurve 6410cl) with the transceivers HP 10GbE-ER in port 1 and HP 10GbE-SR in port 2, and the Intel PRO/10GbE network card with the ixgb ver. 1.0.126 driver. Soon after the last session of 2008 a second processor has been mounted on the motherboard of Mark5A recorder along with a stronger (1000 W) power supply. Presently, Mark5A operating system is Debian "Etch" version 4.0 with the package mark5a\_1.0.2-i386.deb.

e-VLBI transmission rates between Tr and JIVE have improved from 512 Mbps in 2007 to well above 1 Gbps by the end of 2008 thanks to the new 10 Gbps link.

Genek Pazderski has continued his activity to collaborate with the Irbene station to organize tests within the frame of the EVN.



#### **4.14 Urumqi Astronomical Observatory, National Astronomical Observatory (NAOC, CAS). P.R. China**



The 25-m antenna at the Urumqi Observatory

The station is located at Nanshan, 70 km south of Urumqi, capital city of Xinjiang Uygur Autonomous Region of China. The station is affiliated to Urumqi Observatory of National Astronomical Observatories, CAS. This observatory contributes to the EVN in astronomical VLBI observations as well as to the IVS in geodetic VLBI observations. Nanshan VLBI station also was one of the VLBI ground stations tracking the Chinese Chang'E satellite in real-time experiments of the Chinese VLBI Network.

Mark5A, Mark IV, Mark II and K5 recording systems are available at Nanshan VLBI station. The Field System has been upgraded to version 9.10.3. The P-cal control system has been updated, and the parameters of S/X band receivers are sampled from the FS software. The DBBC system that built in Shanghai Observatory has been equipped at Urumqi for the Chinese Chang'E lunar project in 2008. The No.11 H-maser was upgraded and it is now in good status. The other two H-masers, the MHM2010 imported from Symmetricom company in US and the No. 13 worked well. The time and frequency comparison system operates continuously since its installation at the Nanshan station in November 2005.

Urumqi station was connected at 622Mbps to CSTNet on December 15<sup>th</sup> 2008, and CSTNet opened the international network to JIVE from then. A number of e-VLBI test experiments at rate of 512Mbps between Urumqi and Shanghai were performed from that date. The international network among Urumqi, Shanghai and JIVE had achieved a great success at the data rate of 512Mbps on December 19<sup>th</sup> 2008, and fringes were detected among Urumqi, Shanghai, European and Australian telescope on December 22<sup>nd</sup> 2008. In preparation for the e-VLBI demonstration at the opening of the International Year of Astronomy 2009, a fringe test with several Asian and Australian stations took place. The participating stations were ATCA, Mopra, Hobart, Kashima, Sheshan, Urumqi, all at 256 Mb/s. These were the first real-time e-fringes to Urumqi.

In 2009, a new 1.3-cm dual polarization cryogenic receiver will be completed. Dual-band receivers for both 92cm and 49cm have been completed in 2008 and will be further tested. A room temperature 13cm dual polarization receiver will be completed. A new Mark5B+ recording system will be equipped at the end of 2009, the S/X band feed horn will be replaced by a new one in 2009.



## 5. Joint Institute for VLBI in Europe (JIVE).

### 5.1 Science Operations and Support

In the period 2007-8, the Science Operations & Support Group at JIVE saw the departure of 3 support scientists (L. Harvey-Smith, R. Soria-Ruiz, and H. Bignall) and 1 senior support scientist (C. Reynolds), while gaining 3 support scientists (S. Muehle, A. Polatidis, and J. Yang) and a senior support scientist (Z. Paragi). There was usually a delay of a few months between a departure and its offsetting gain. We anticipate the departure of two more support scientists within the first month and a half of 2009.

The chief operator (N. Schonewille) retired, and H. Tenkink filled a new position as senior operator. M. Leeuwinga moved into a new position as hardware maintenance engineer, replacing the tape-recorder engineer position held by J. Buiters who also retired. Leeuwinga retains some operator responsibilities. A new operator was taken on board (B. Harms).

### Production Correlation

#### Sessions and Their Experiments

Two tables below summarize projects observed, correlated, distributed, and released in 2007 and 2008. They list the number of experiments as well as the network hours and correlator hours for both user and test/NME experiments. Here, correlator hours are the network hours multiplied by any multiple correlation passes required (e.g., because of continuum/line, separate correlation by subband/pol to maximize spectral resolution, etc.).

	User Experiments			Test & Network Monitoring		
	N	Ntwk_hr	Corr_hr	N	Ntwk_hr	Corr_hr
Observed	53	545	910	47	231	231
Correlated	54	529	718	51	262	286
Distributed	54	529	718	54	265	290
Released	55	533	742	54	257	286

Summary of projects observed, correlated, distributed, and released in 2007.

	User Experiments			Test & Network Monitoring		
	N	Ntwk_hr	Corr_hr	N	Ntwk_hr	Corr_hr
Observed	72	689	961	48	200	208
Correlated	70	668	1110	47	194	202
Distributed	64	600	1012	45	189	197
Released	60	556	958	48	199	207

Summary of projects observed, correlated, distributed, and released in 2008.

The experiments over 2007-8 reflected the customary mix of continuum and spectral-line experiments. A growing number of continuum experiments used the higher recording rates at 512 Mbps and 1 Gbps, and some globals used 1 Gbps in EVN stations and 512 Mbps in VLBA stations, with the latter recording at 1-bit sampling to preserve uniform subbands across the array. In session 3/2008, 13 of 15 experiments recorded at these two highest data rates. Spectral-line observations included the usual L-band OH transitions and K-band water. 6.7 GHz methanol maser observations became more popular as more stations were able to join in at this frequency.

This 6-6.7 GHz band also saw some excited-OH (6030, 6035 MHz) and high-z water masers (6124 MHz). Session 3/2007 was shortened by the unavailability of the Chinese antennas (commitments to Chang'E), and session 1/2008 was markedly affected by winter weather (3 experiments abandoned outright by the PI in light of station outages, and another 6 missed Effelsberg and/or Jodrell Bank).

There were plenty of "firsts" as seen by the correlator:

- our first 7mm experiments,
- our first experiment requiring 1/8s integrations,
- our first tests at the higher K-band frequencies around 23.5 GHz,
- first time to incorporate more than one additional MERLIN out-station into the EVN correlation (3 additional out-stations in a single-pol spectral-line experiment),
- first participation of the new Yebes 40m antenna, starting at K-band and then also at S/X,
- first participation of the 3 Russian QUASAR stations (S/X, C, L),
- first participation of EVLA stations at 6.7GHz and EVLA & GBT at 6.03GHz.

We also established some new records:

- most correlator passes (17), correlator hours (153), total hours required to produce (453), and total size of resulting FITS-file data (1028.7 GB), all from the same experiment (GC029)
- most stations participating successfully in a single experiment (21; GW019A)
- longest continuous disk-based correlator sub-job having good data (10h14m30s)

There were also a variety of data-quality issues detected during correlation at various stations that were resolved by them:

- a) Onsala 180 degree phase jumps between some scans at L-band
- b) Torun phase jumps at C-band, beginning in session 3/2007 and lasting through session 1/2008, fixed prior to the April 2008 e-VLBI session
- c) Data-throttling at Cambridge in Gbps recordings.

e-VLBI made huge strides in 2007-8; by the end of the period it had become a reliable standard operating mode for the EVN. In 2007 there were 7 user experiments comprising 82 network hours, and in 2008 the corresponding numbers were 16 experiments and 115 network hours. All e-VLBI observations in 2008 used 512 Mbps, and an experiment in April set a new record for longest sub-job of 12h48m21s. Such long continuous runs have since become routine. A key development was the ability to take care of individual-station problems by taking the affected station out of the correlation temporarily without stopping the job for the whole array. In disk-based correlation, such an occurrence would trigger stopping the job and restarting before the problem, but that is a luxury not afforded to real-time e-VLBI. As an example of the fast turn-around afforded by e-VLBI, there was an observation on 30 September 2008 that was correlated, distributed, and analyzed in time to have its results included in an EVN proposal submitted by the 1 October 2008 deadline.

Five of the e-VLBI observations were target of opportunity experiments, on SN2007gr, Cyg X-3 (3 closely spaced epochs within 4 days), and SS433. In addition, there were three disk-based global Gbps ToO experiments (participating VLBA stations using 1-bit sampling at 512 Mbps) between November 2007 and February 2008, observing SN2007gr and SN2008d. As an example of the rapid turn-around, the first on SN2008d was observed 6-7 February, the last disk-pack arrived at JIVE on 14 February, and the resulting FITS files were placed on the EVN Archive on 17 February.

### **Logistics and Infrastructure**

The disk-shipping requirements are derived from the recording capacity needed by a session (from the EVN scheduler) and the supply on-hand at the stations (from the TOG chairman). Now that the VLBA has also shifted to Mk5 recording, the bookkeeping of disk-flux accounting has become more complicated. There are two sets of rules to follow:

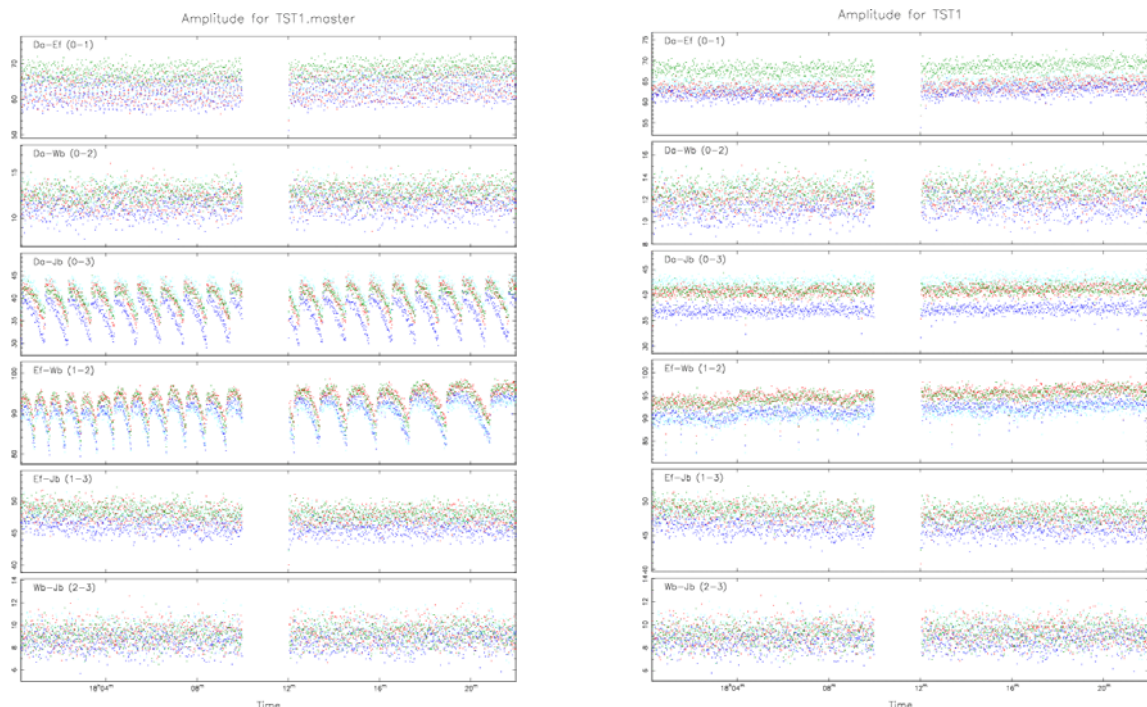
- the EVN policy that stations should buy two sessions' worth of disks, hence the disk flux should balance over the same 2-session interval. Following distribution to the stations for session 3/2008, we had "overdistributed" a net cumulative 191.05 TB of disk-pack capacity.
- the VLBA's need for sub-session turn-around, which essentially requires pre-positioning the difference between what NRAO stations will observe in globals to be correlated at JIVE and what EVN stations will observe in globals to be correlated in Socorro. Following the shipments in both directions for session 3/2008, we had "overdistributed" a net cumulative 14.33 TB of disk-pack capacity.

In an effort to accelerate recycling packs somewhat faster than the "2<sup>nd</sup>-following session" rule, we began in session 1/2008 to try consciously to correlate higher data-rate recording experiments first, to maximize the amount of releasable packs per given correlator hour early enough to recycle some packs in time for the next session. This optimization is complicated by fact that many experiments can reside on the same pack, but it has contributed to the large net "overdistribution" with respect to the original guidelines.

The data processor has 16 Mark 5A units, all housed inside temperature-controlled cabinets. Some stations now record exclusively with Mark 5B units, which we can correlate through the Mark 5A units using capabilities of the 5A+ firmware. Work progresses on developing native Mark 5B playback. We continue to encounter the occasional individual bad disk (or two) in an incoming pack. We maintain a small bench stock of disks of various sizes so that we could replace a bad disk locally if that is the most appropriate course of action (in light of warranty status, urgency of recycling, etc.), and then we would get a new disk from the pack's "owner" to replenish our bench stock. All but the highest data-rate recordings generally play back well with a bad individual disk disconnected.

### Astronomical Features

We began applying a better post-correlation fraction bit-shift correction to the phase across the band for each (baseline) visibility for experiments starting in session 1/2007. The figure below shows an example of vector-averaged amplitude as a function of time on some baselines from the 5cm NME N06M2.



New post-correlation fractional bit-shift correction effect on vector-averaged amplitudes as a function of time. Left panel: without correction; right panel: after correction.

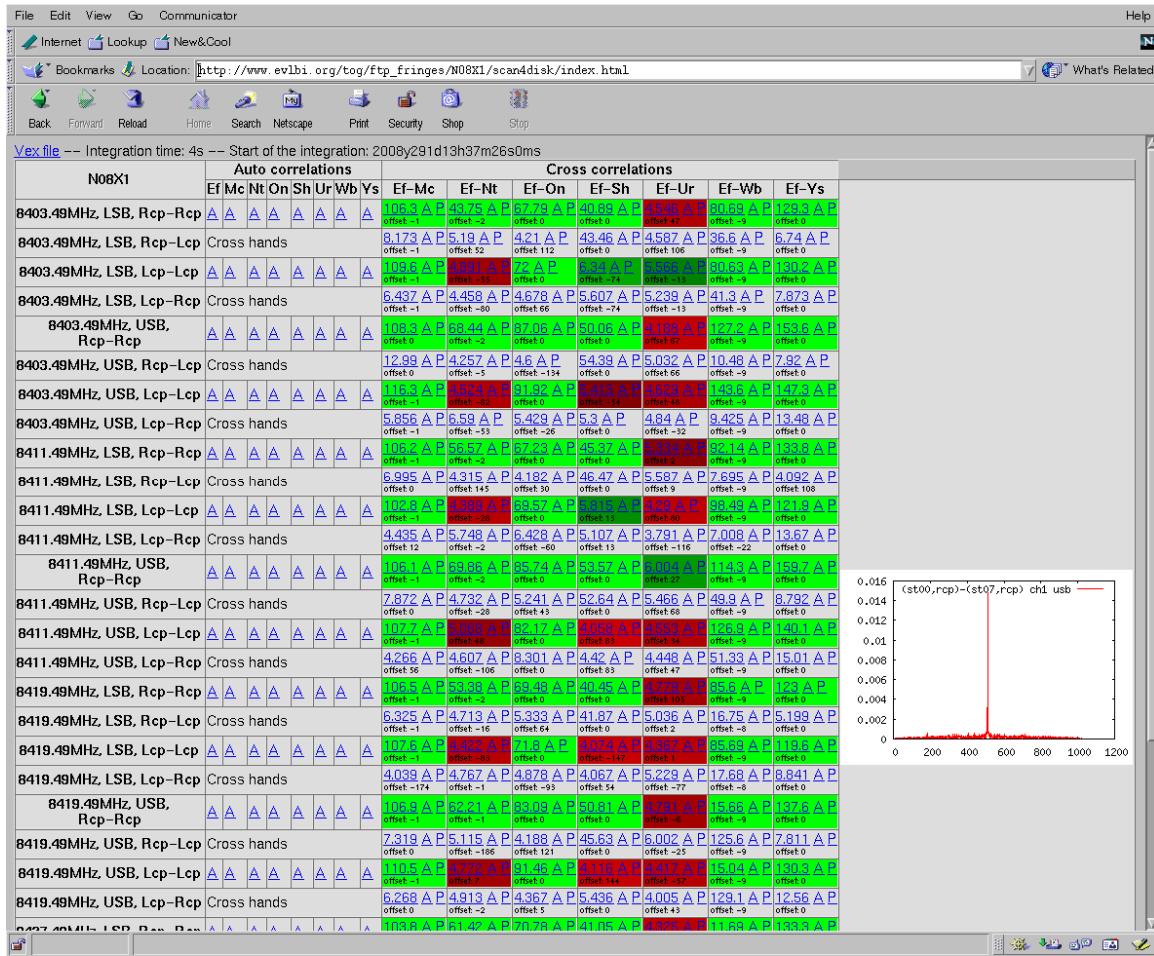
An experiment from session 3/2007 (EP062) was the first to use 1/8s integrations in production correlation. The correlator can maintain this output, as long as it is loaded at no more than half capacity. This may require specific experiments to be run in two correlator passes, each with half the subbands. We can now accommodate both passes in a single measurement set, thus requiring no VBGLU or other preliminary task in AIPS on the part of the PI.

Recirculation is a means of time-sharing the correlator resources such that data recorded at sampling rates below 32 Msample/s can achieve higher spectral resolution - essentially using "idling" correlator chip capacity to process additional lags. The maximum number of frequency points per interferometer remains at 2048, but many spectral-line experiments now have their spectral resolution limited below this by the number of stations or polarizations they use. These many-station/low-BW observations can benefit from recirculation. All values of recirculation up to 8 have been tested in terms of the resulting amplitudes and phases, with only a few items remaining to investigate more closely.

Because of the 16MHz bandwidth limit in the MERLIN out-station micro-wave link, the Cm recording has "unused" subbands in recording modes at 256 Mbps and above. For dual-pol observations above this rate, an additional out-station can be recorded onto the unused subbands; single-pol observations can incorporate three additional out-stations. Observations at or below 128 Mbps can also do this, given a separate schedule for Cm at a higher rate to accommodate additional outstations. Each recorded MERLIN station would correlate as a separate station at JIVE, thus the additional out-stations may affect the correlator loading. e-VLBI has a natural application here, as the signals for the separate out-stations can be separated on their transit to JIVE; disk-based observations would need copies of the Cm disk-pack made prior to correlation, requiring additional disk-pack availability. The additional intra-MERLIN baselines included in the EVN correlation would increase the robustness of the tie between the EVN and MERLIN  $u-v$  data-sets, which is typically limited to the single Jb-Cm baseline.

### **EVN Support**

The automatic-ftp feature added to the field system in 2006 is used in all network monitoring experiments (or a separate fringe-test experiment, when an NME is scheduled well outside working hours). This sends a specified portion of a scan directly to the software correlator computer at JIVE. At the beginning of this biennial period, we used a version of the NICT software correlator for these fringe tests. In the middle of 2007, we shifted to the software correlator being developed under FABRIC/SCARle. Correlation results go to a web page available to all the stations within a couple hours, and Skype chat sessions during the NME provide the station friends with even more immediate initial feedback. The presentation of the results on the web page has also improved considerably, now showing baseline amp and phase across the band as well as autocorrelations, and each plot is accessible by moving the cursor over color-coded baseline/subband/polarization cells. The figure shows an example of the web-based presentation of ftp fringe-test results.



An example of the web-page for an ftp fringe-test scan from the NME N08X1. The amplitude-frequency plot shown is for Ef-Ys SB3 RR.

These ftp fringe tests continue to be very successful in identifying telescope problems and thus have helped to "save" user experiments by providing feedback quickly enough for the telescope staff to effect repairs, especially as we see more new stations begin to participate in EVN observations. An example comes as recently as the very last user experiment of 2008 -- we could not find fringes to Yebes 40m in the ftp fringe-test from the K-band NME N08K4; the station was able to trace this to an IF local oscillator, which they replaced in time for the next user experiment, in which Yebes fringes were fine.

The EVN pipeline now runs under ParseITongue (a Python interface to classic AIPS). The new pipeline is considerably easier to use, more robust and has much greater scope for future development due to the improved coding environment. The pipeline scripts are available from the ParseITongue wiki (RadioNet) and should provide a good basis for other (semi-)automated VLBI reduction efforts. We continue to process all experiments, including NMEs, via the pipeline, with results being posted to the EVN web pages. The pipeline provides stations with feedback on their general performance and in particular on their gain corrections, and identifies stations/frequency bands with particular problems. Timely delivery of ANTAB



amplitude calibration results from the telescopes seems to be improving, but remains an issue in e-VLBI experiments due to the shorter time-scales involved.

A considerable amount of time between October 2007 and July 2008 went into working with Westerbork on operational tests of their new digital TADUmax back end. Thirteen separate test observations were made in that time to check out various modes typically used in VLBI, and to iron out the details of the bit-encodings and sampler statistics. The advantages of TADUmax include full coverage of 128MHz total bandwidths in Gbps observations (the previous system could get only 7/8 of the coverage) and much more rectangular bandpass shapes. The digital filters do add a channel-bandwidth dependent clock offset; log2vex can now account for this in creating the correlation-controlling vex files.

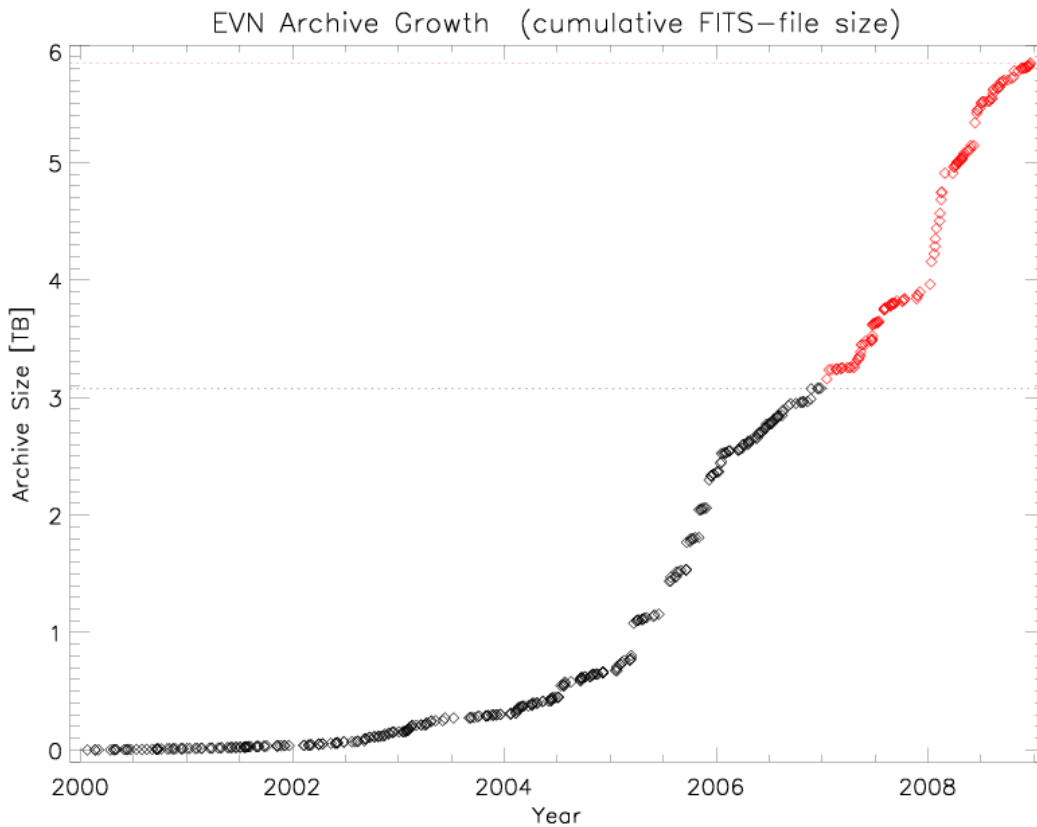
## **PI Support**

The RadioNet-driven NorthStar web-based proposal tool became the sole means to submit EVN or Global VLBI proposals starting from the 1 February 2007 proposal deadline. Later, e-VLBI proposals joined the fold. Currently, only target-of-opportunity proposals are handled outside of Northstar. Feedback is solicited from proposers after each deadline, and their insights are reviewed to continue to improve the user-friendliness of the proposal tool.

The science operations and support group continues to contact all PIs once the block schedule is made public to ensure they know how to obtain help with their scheduling, and to check over schedules posted to VLBEER prior to stations downloading them. In previous years, there had been a handful of instances in which a station observed using a superseded version of an experiment's schedule. New safety features have been incorporated into the pre-observation system that should help avoid such incidents. Indeed, with one glaring exception in session 3/2007, these have not recurred. In that case, the EVN stations all observed an older version of the schedule while the VLBA stations observed the current one - and the two versions had decidedly different scan timing patterns. We had to adjust the correlation control vexfile manually to include EVN stations only those portions of scans in which they overlapped with the proper version of the schedule, and it turned out such a schedule was actually faster to correlate scan-by-scan. Efforts to confirm that different parts of global arrays have the same version of the schedule redoubled thereafter. The pre-observation communication also provides the opportunity to inform eligible PIs about the benefits of the RadioNet trans-national access programme.

The EVN Archive at JIVE provides web access to the station feedback, standard plots, pipeline results, and FITS files for experiments correlated at JIVE. Very few PIs request distribution of their FITS files on physical media (DAT or DVD) anymore. There were 3404 FITS files downloaded in 2007-8, from people in 32 different countries (including 21 non-EVN countries, and 12 of those being outside the EU and associated states (in an FP6 sense). Public access to the FITS files themselves and

derived source-specific pipeline results is governed by the EVN Archive Policy - the complete raw FITS files and pipeline results for sources identified by the PI as "private" have a one-year proprietary period, starting from distribution of the last experiment resulting from a proposal. PIs can access proprietary data via a password they arrange with JIVE. PIs receive a one-month warning prior to the expiration of their proprietary period. We have increased the storage available on the archive machine from 4.5 TB to about 16 TB. The total size of the FITS files in the archive at the end of 2008 was about 5.85 TB (a 2.77 TB gain in the two-year period); the figure shows the growth of the EVN archive size over time.



Growth in the size of FITS files in the EVN archive. Experiments archived in this biennial period are plotted in red.

JIVE hosted 16 data-reduction visits in 2007 and 10 in 2006. In addition, through the period of the report there were seven post-graduate students who were co-supervised by members of JIVE staff, and who visited frequently. The visitors room has five dual-processor PCs running linux, one windows-based PC, and a small cluster of four interconnected top-end workstations, to accommodate processing of very large wide-field data sets (whose monitors occupy an additional two work places).

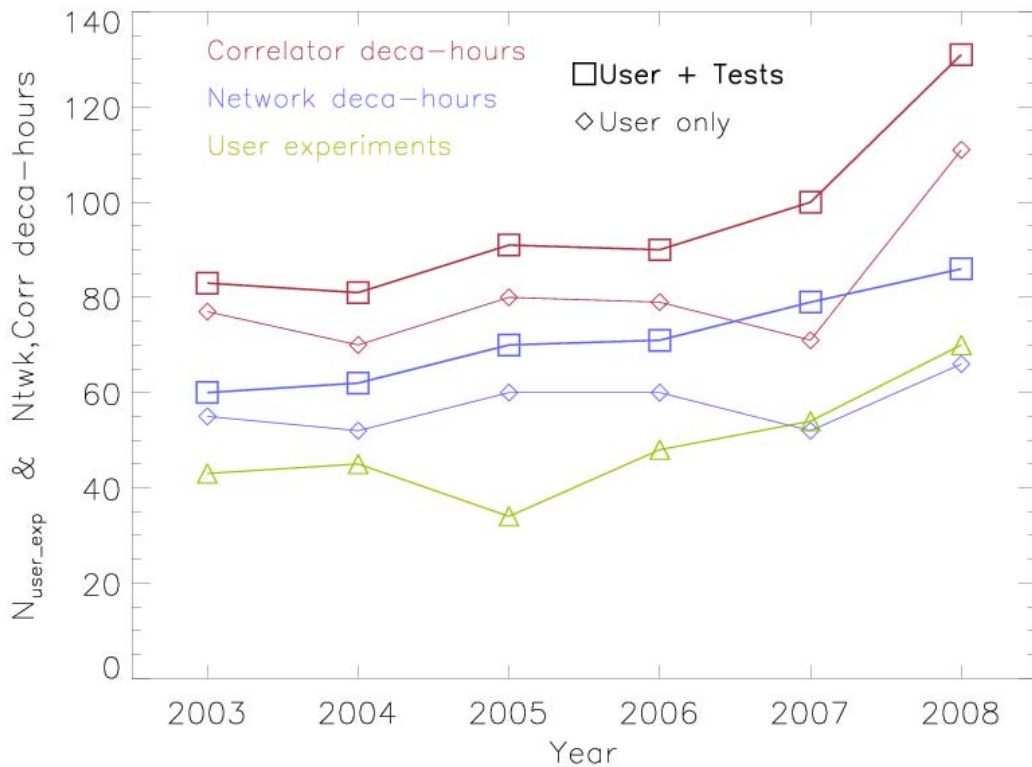
## Operations through-put plots

The enclosed figure presents the size of the correlator queue at different stages in the processing cycle, showing a snapshot of the status at the end of each week. The red line plots the number of correlator hours that remain to be correlated. The blue line plots the number of correlator hours whose data remain to be distributed to the PI. The green line plots the number of correlator hours associated with recording media that have yet to be released back to the pool (in practice, release occurs prior to the following session, leading to a blocky pattern for the green line). The weeks of correlation for the 17-pass GC029 can be seen around the end of 2007 and beginning of 2008; it took until just before session 3/2008 to completely empty the correlation queue again (red line to 0).



Size of various correlator queues, measured in correlator hours.

The next figure shows the number of user experiments and the number network and correlator hours correlated over the past six years, with the hours for user experiments (diamonds) and the combination of user experiments and NME/test observations (squares). Including both user experiments and NME/test observations yields an essentially monotonically increasing output from the correlator. Over the past two years, the number of user experiments has grown strongly thanks to the new e-VLBI observations.



Amount of correlator and network hours plus the number of user experiments correlated in each year.

### EC and International Projects: Access to the European VLBI Network

The FP6 RadioNet EVN Trans-National Access (TNA) programme provides funding to EVN telescopes to provide access to eligible projects, and supports travel by investigators from eligible projects to visit JIVE or another EVN institute. An eligible project is one in which the PI and at least 50% of the author list as a whole are associated with institutes in the EU member and associated states, excluding the Netherlands as the host country of JIVE. The table herewith summarizes various statistics from the past two years of EVN TNA activity.

UPDATE 5YR TNA REPORT		
	2007	2008
Number of experiments supported	42	44
comprising how many individual researchers	77	78
Number of different PhD students in supported groups	10	12
Total number of access hours	492	489.5
Number of data reduction visits	8	8
number of data reduction visits made to JIVE	7	5

Annual statistics for various aspects of the EVN TNA programme over 2007-8.

## **5.2 Data processor developments and upgrades**

### **Mark5 upgrades**

During the period 2007-2008 all Mark5 units were upgraded. New motherboards, CPUs, memory banks, hard disk drives and power supplies were installed, and several units were equipped with 10GE interfaces. Noticing large temperature differences within the Mark5 units, the JIVE operators devised a method to significantly improve airflow inside the Mark5 housing, thereby reducing the chance of disk pack overheating. This method was later adopted by Conduant and is now implemented in all new Mark5 units.

### **EVN data archive**

At the start of 2007, the total capacity of the EVN data archive was 5.7 TByte. Fairly soon it became clear that this space would run out within roughly one year, so the decision was made to replace all 250MB disks by 500MB disks, and fill all available slots in the raid cabinets. In order to use the total disk space as efficiently as possible, very large file-systems were needed. This in turn asked for upgrades to both operating system and drivers, which proved problematic. Replacing the aging archive machine with a modern server solved these problems. The total capacity of the archive is now 15 TB, of which 6 TB is currently in use. It is expected that this should suffice for the next 2 to 3 years.

### **Re-circulation at the EVN data processor**

Re-circulation, which enables one to optimize the use of a correlator through time-sharing its computing resources, was tested and verified and is now considered an operational capability of the EVN correlator.

### **Replacement of data acquisition platform**

A new Solaris server equipped with a high-capacity raid array has replaced the data acquisition machine after a series of correlation tests. This machine is fully interchangeable with the two correlator-control machines, providing extra resilience to the correlator system. With the installation of this machine, a re-circulation enabled version of the correlator code was installed and as a consequence, the whole system now runs permanently at 64 BOCFs.

## **Mark5A to B upgrade**

Although the Station Units have performed relatively well, spare parts are few and replacements unavailable. Upgrading the Mark5A units currently in use at JIVE to Mark5B would allow us to phase out the SUs.

Several Mark5A units were converted to B and hooked up to the correlator via Correlator Interface Boards and optical serial links, and the Haystack-developed Mark5B control software was modified for use with the EVN correlator. Testing however was seriously hampered by the initial lack of suitable 5B data. Using modified LBA data, a significant difference was found between correlation using A+ and B. Extensive consultations with Haystack engineers identified a 1-second offset. As usual, fixing proved a lot easier than finding the problem, and new tests showed no significant differences in the results from A, A+ and B playback.

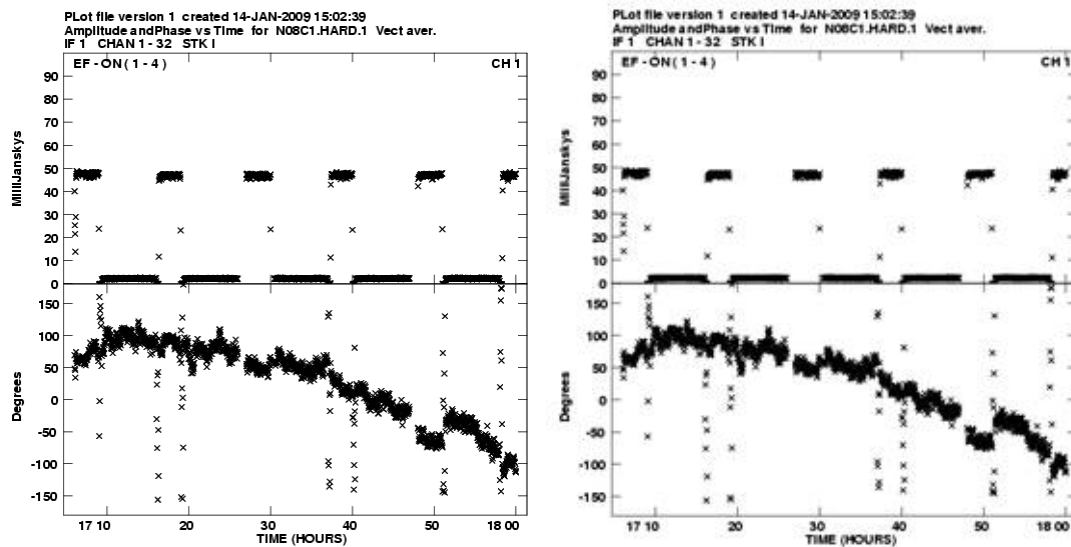
Since these tests, Westerbork, Effelsberg and Yebes have started producing B-data on a regular basis, data that however are usually played back on A+ units at JIVE. As more stations switch to B-recording, it will become possible to permanently install B-units for playback.

## **Software Correlator**

In early 2007, the SFXC software correlator produced its first fringes on astronomy data. This was a major milestone showing that the C++ implementation of the original algorithm developed for the Huygens project was functional. After that the correlator code underwent drastic changes. The code was modularized and further parallelized by using MPI. This made it possible to distribute the correlator over machines within a cluster. A module to generate the delay model was added. This model is based on the same CALC10 code used by the hardware correlator. The original configuration file format had some limitations that made it unsuitable for use in typical astronomy experiments that observe multiple sub bands and polarizations. It has been replaced with a more flexible (and simpler) format based on JSON that supplements information that is now read directly from the VEX file. The output format of the correlator also underwent a complete overhaul. Software to translate the output into an AIPS++ MeasurementSet was written. This allows the use of the same tools as used for analyzing and processing the output of the hardware correlator on SFXC output. This also makes conversion to FITS-IDI possible. Data correlated with SFXC was successfully loaded into AIPS, and a preliminary first image was produced. The module that decodes the input data has been extended to accept Mark5B and VLBA data as well as MKIV data, such that SFXC can now handle all data formats handled by the MkIV hardware correlator.

A statistical analysis of the correlator output and comparisons with the output of the existing hardware correlator was made. This work uncovered several bugs, which since have been fixed. Verification of the results continues as the code is still changing while we try to optimize it and add new features to it.

The software correlator was first used to process FTP fringe tests in May 2007. The original plan had been to run it in parallel with the NICT software correlator that was used for the fringe tests in previous years. But since the machine that had the NICT correlator installed broke down, we had to rely solely on SFXC. It worked well enough that the support group never went back to using the NICT correlator. Quite a bit of effort was spent on making web pages to display the results of the fringe tests in a way that is convenient for the operators at the stations. The new web pages are now automatically generated whenever the correlator runs (see example in page 85).



Comparison of phase and amplitude of results from hardware correlator (left) with SFXC (right), in AIPS

For the EXPReS FABRIC JRA, which aims at running the software correlator in a standard Grid environment, several web services were developed. These web services interact with the workflow manager and VLBI Grid broker being developed by our collaborators at PSNC in Poznan, Poland. The web-services implement some "domain-specific" knowledge like decoding VEX files and handling data transport. Integration of the various subsystems is still in progress.

Within the SCARLe project a collaboration was started with the AutoBAHN JRA of the GÉANT2 project. AutoBAHN is developing a system for on-demand allocation of dedicated circuits across the European research networks. This would benefit e-VLBI with a software correlator since there is not necessarily a fixed location for the correlator anymore. This collaboration resulted in a couple of demonstrations during which data were streamed from four sites spread around Europe (Ireland, Poland, Greece, Croatia) and the US (Boston) into the DAS-3 cluster in Amsterdam, correlating in real-time at 256 Mbit/s. These highly successful demonstrations took place at the GLIF workshop in Seattle (October 1-2, 2008) and at Supercomputing '08 in Austin (November 15-21).

### **5.3 e-VLBI developments**

At the beginning of 2007, the EXPReS project was well underway and gaining momentum. Scientific e-VLBI runs were taking place on a regular basis, albeit at low data rates, and many soft- and hardware modifications, both at the correlator and at the stations, had led to a much-improved operational real-time system. However, some big problems still remained to be tackled, such as the establishment of reliable high-bandwidth data transfers within Europe, long-haul data transport from telescopes on other continents and the efficient use of available bandwidth.

#### **Local network**

As a first step, the complete network at JIVE was overhauled. An HP ProCurve 5412zl router was purchased to handle up to 16 1-Gbps lightpaths and one 10-Gbps IP-switched lambda (capped at 5 Gbps) from SURFnet, and all interconnects between SURFnet, Mark5 units and control- and test computers. A second, smaller, HP switch was installed to deal with all remaining correlator-related network traffic, removing dependencies on the ASTRON internal network. New monitoring software was installed, enabling the generation of graphs of the status and data throughput of the e-VLBI network.

#### **International networks**

Several stations in Europe were connected via dedicated 1-Gbps lightpaths across GÉANT2, and new lightpaths to China and Australia were set up through the good services of the GLIF collaboration. South America was connected via GÉANT2 and the EC-sponsored RedClara network. A second connection to China, via the EC-sponsored TEIN2 network, was also established by DANTE.

In 2008 Arecibo re-joined the e-EVN through a 512-Mbps shared connection to mainland USA (with full bandwidth limited to certain timeslots), and a VLAN to JIVE via AtlanticWave and SURFnet. That year the Effelsberg Radio Telescopes also came online, providing a second tremendous boost to the sensitivity of the e-EVN.

#### **Software developments**

Throughout, efforts continued on monitoring, control and post-processing software tools. Special emphasis was put on improving the robustness and the real-time behavior of the correlator control software, enabling rapid adjustment of correlator parameters and adaptive observing. Modifications to the correlator control code were implemented which made it possible to remove and add stations in the middle of correlator jobs, without having to restart the entire job. This removed one of the main causes of data loss during e-VLBI runs and resulted in a tremendous increase of productivity.

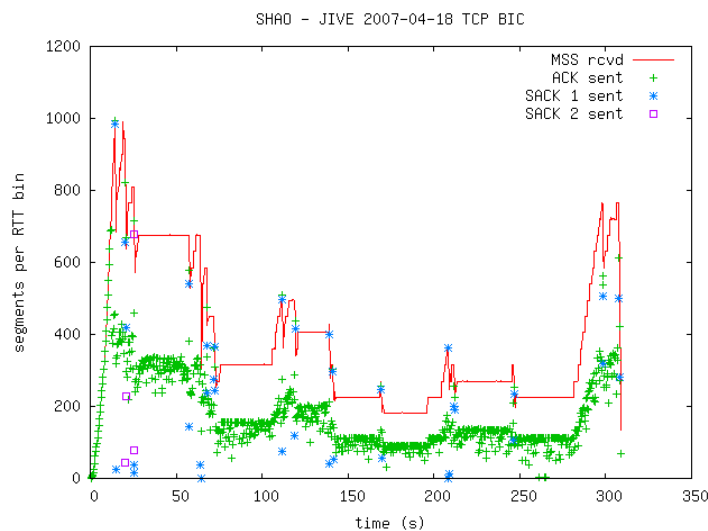


## Data transport issues

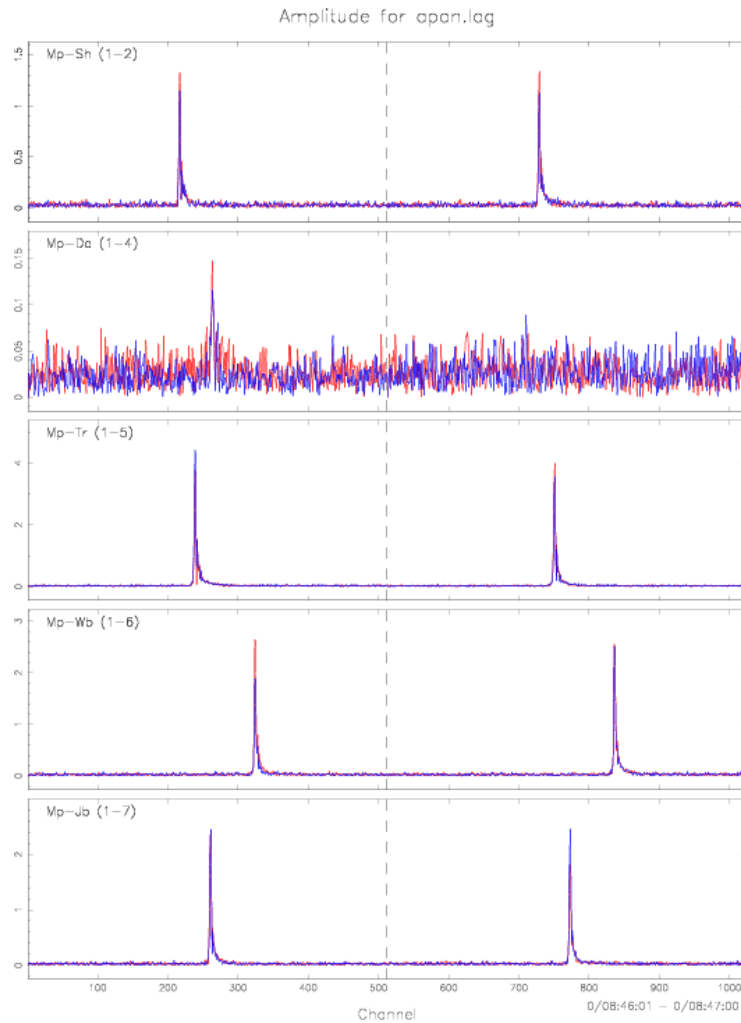
When the first e-VLBI experiments started, all data transport with the Mark5A units was done through the TCP/IP protocol. This protocol is specifically designed to guarantee fairness on the Internet, by throttling back data throughput as soon as packet loss is detected (interpreted as congestion). After such an event, the data rate is slowly increased again and will eventually (in the absence of further packet loss) reach the original data throughput. However, the recovery time increases with RTT (round trip time). As a result, this protocol is particularly unsuitable for intercontinental real-time data transfers such as needed for global e-VLBI.

Two important e-VLBI demonstrations were planned for 2007: a demo at the Asian-Pacific Advanced Networking (APAN) conference in Xi'An, China, which would involve telescopes in China, Australia and Europe, and an e-VLBI run in which data from three Australian telescopes were to be correlated in real-time at the EVN correlator in Dwingeloo (an actual EXPReS deliverable). Very soon after the start of data transfer tests, it was realized that TCP would simply not do; data throughput from Shanghai never reached more than ~20 Mbps.

UDP, a connectionless protocol, should in theory perform much better (at the cost of the connectivity of other users) but was disabled in the Haystack-developed Mark5A control code. Re-enabling UDP transfer gave very poor results, and in the end the decision was made to completely re-write the e-VLBI related portion of the Mark5A control code at JIVE. This new code features rigorous thread control and options to handle out-of-order packets, to space the packets regularly (in order to prevent bursts of data), and to selectively drop packets at the sending side while padding the data stream at the receiving end with dummy data, optimizing the use of available bandwidth.



Results of data transfer tests between Shanghai Observatory and JIVE using TCP



Real-time fringes between Mopra and several EVN telescopes

Another solution was developed for the Australian disk recording systems (LBADR), in preparation of the EXPRoS Australia-JIVE demo (planned for the first week of October 2007). Data from the LBADR units were converted on the fly to Mark5B format, transferred using the Circuit TCP (CTCP) protocol and received on Mark5A+ units at JIVE (CTCP is basically TCP without any congestion control at all). This method was successfully used in the e-VLBI demo at the APAN conference in Xi'An, resulting among others in fringes between Darnhall and Mopra (one of the longest VLBI baselines ever).

During the Australia-JIVE demo, data from ATCA, Mopra and Parkes were transferred via three dedicated 1-Gbps lightpaths to JIVE and correlated in real-time. This time the UDP protocol was used, and 512 Mbps per telescope was sustained for 12 hours with hardly any packet loss at all. As with the APAN demo, this demo also generated quite a lot of public attention.

A number of further developments followed. Ensuring that only packets containing data are dropped, while leaving data headers intact, improved the behaviour of the correlator during high data-rate e-VLBI greatly. Although very useful, packet dropping does increase the noise right across the observed bandwidth, and channel dropping, meaning that only specific sub bands are dropped at the stations, would in most cases be preferable. This method was shown to work on local machines, but not used in production because of the high CPU load involved. Implementation will follow when all e-VLBI stations have upgraded their systems with new CPUs and SMP-enabled Linux kernels, to make full use of the available CPU power. Related to this, changes were made to the correlator control software to allow different configurations at different stations, providing an additional tool to adjust data rates. Finally, simultaneous recording and transmitting of data at the station side was enabled, but has not been used operationally yet. Simultaneous playback and recording at the correlator cannot be done with Mark5A, but should be possible with Mark5B.

The JIVE-developed Mark5 control code was further adapted to work with Mark5B recording units. The Domino software however, supplied by Haystack for playback with Mark5B at the correlator, came without any support for e-VLBI. After Haystack engineers had added this functionality, further modifications were made at JIVE. In spite of successful tests with local units, tests with real data so far failed. Progress has been slow, mostly because of the small number of stations with both Mark5B units and sufficient connectivity. This situation however should improve in the coming year.

### **Adaptive observing**

A first test was done on August 28 2008 with dynamic scheduling, in which a schedule was changed at JIVE during an observation, the new schedule file merged with the old one, distributed to the stations, DRUDG'ed locally (via ssh from JIVE) and run at the stations. The changes were made at Torun and Westerbork, with Jodrell Bank staying on the original schedule, and as planned fringes between Torun and Westerbork reappeared after the change. No new software had to be installed at the stations; the ssh commands were executed at stations using ssh in single-command mode from scripts run at JIVE. In the future, this method could prove particularly important for rapid response observations of transient sources.

### **Merlincast**

On July 22<sup>nd</sup> 2008 a special test was done involving the MERLIN telescopes at Cambridge, Darnhall and Jodrell Bank (Mk2). In the current MERLIN network, the 'out-stations' are connected to Jodrell Bank by microwave links that have about 128 Mbps throughput. For this test, the links from both Darnhall and Cambridge were connected to the VLBA terminal. The VLBA terminal has 4 IF inputs, so each IF received data for one polarization from either Darnhall or Cambridge. The IF sampled data from both telescopes were then run through the formatter and Mark5 and transmitted to JIVE. At JIVE, the 'port monitoring' functionality of the central JIVE switch/router was used to 'snoop' on all the networking traffic towards one Mark5 and send duplicates to a second Mark5. With this setup fringes between all three stations

were achieved. This experiment was repeated on the 9th of September, this time using IP Multicast to perform the packet duplication without having to undertake major networking changes at JIVE. This resulted in the first real-time fringes to the Knockin station at MERLIN. This technique, now dubbed 'Merlincast', has the potential to significantly improve the sensitivity of the e-EVN to larger scale structures.

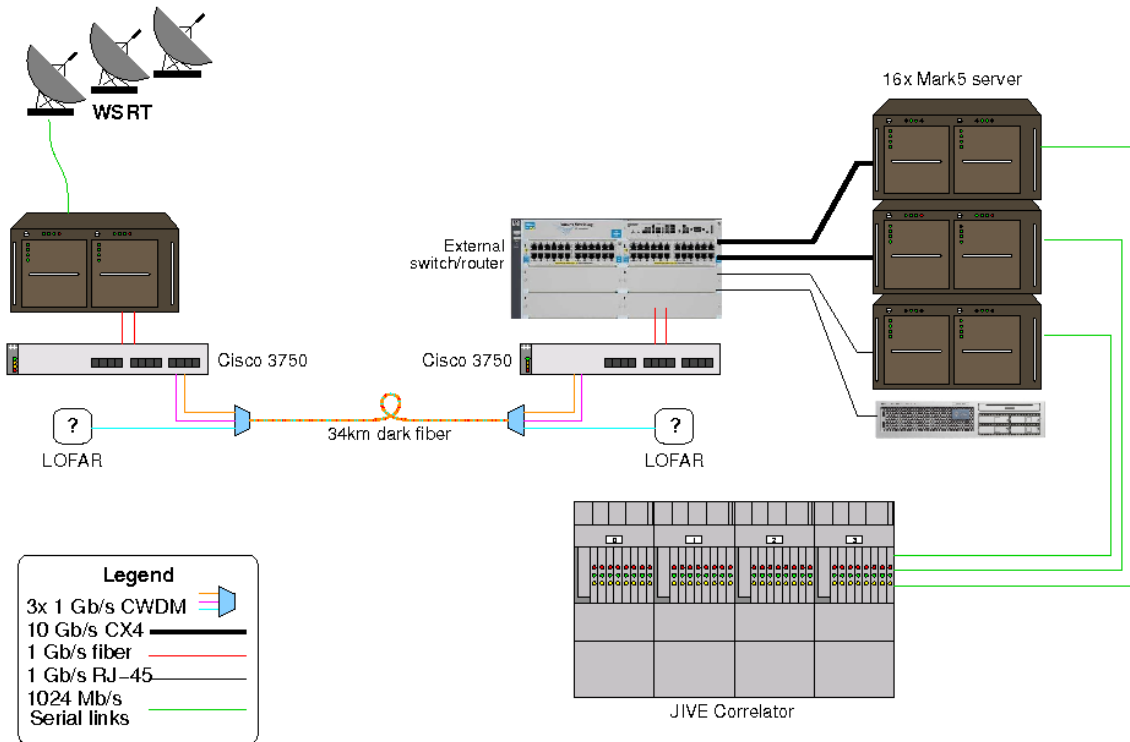
### **Towards true 1-Gbps e-VLBI**

Although the use of packet dropping in combination with UDP enables one to (nearly) fill available links to their limit, the full 1024 Mbps of e-VLBI traffic (plus overhead in the form of headers) will simply not fit on a standard 1-Gbps (= 1000 Mbps) connection. Several ways around this problem were investigated.

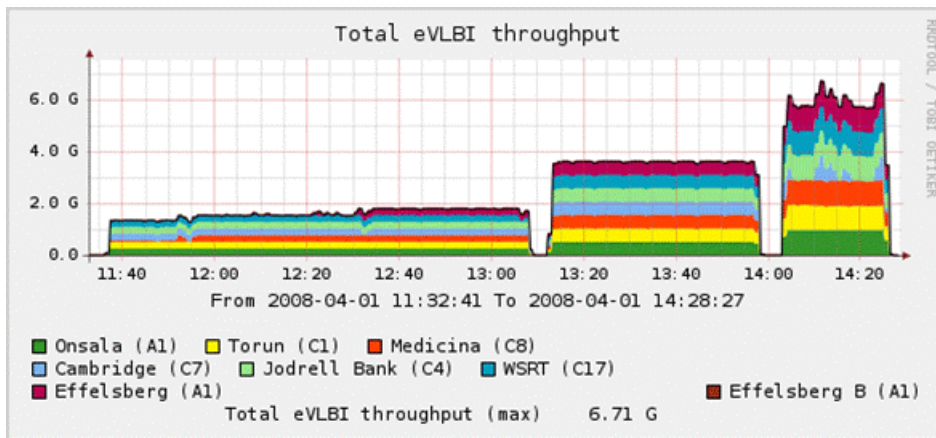
The Westerbork Radio Telescope is connected to Dwingeloo via dark fiber. Redundant CWDM equipment (kindly provided by the LOFAR group) was installed and equipped with a number of colors, 2 of which were reserved for e-VLBI traffic. In order to reach 1024 Mbps, a single data stream was divided in round-robin fashion over two independent 1-Gbps lightpaths, and recombined at the receiving end. Tests showed that transfers of 1500 Mbps were easily sustained in this way. This same method was applied to the dual 1-Gbps lightpath connections to the UK, and although shown to work in principle, use in production awaits a motherboard upgrade of one of the Mark5 units at Jodrell Bank.

The Effelsberg Radio Telescope came online in 2008, through a dedicated fiber connecting the MPIfR in Bonn to the site. To accommodate both e-VLBI traffic and data transfers from their new e-LOFAR station, a 10-Gbps connection was established via Amsterdam to both Dwingeloo and Groningen. The Effelsberg Mark5 unit is equipped with two 1-GE interfaces, and the data stream is divided in a similar way as that used for the Westerbork connection. However, the two data streams are recombined on the local switch, and sent as a single data stream through a VLAN on the 10-Gbps link.

### e-VLBI at 1024Mb/s from WSRT to JIVE



Network setup between Westerbork and JIVE



Data throughput during first e-VLBI observations with Effelsberg

Onsala Radio Observatory was connected at 10 Gbps, to allow for future e-LOFAR data transfers, and to enable real-time 4-Gbps transfers from Onsala to the e-MERLIN correlator at Jodrell Bank (part of the EXPRoS Joint Research Activity FABRIC). Torun Radio Telescope was connected at 10 Gbps to the Poznan supercomputing center; both Onsala and Torun Mark5 units are equipped with 10GE interfaces.

This synergy with other projects led to the milestone observations on November 19<sup>th</sup> 2008, during which Westerbork, Effelsberg and Onsala participated at a full 1024 Mbps.

### **Tests and operations**

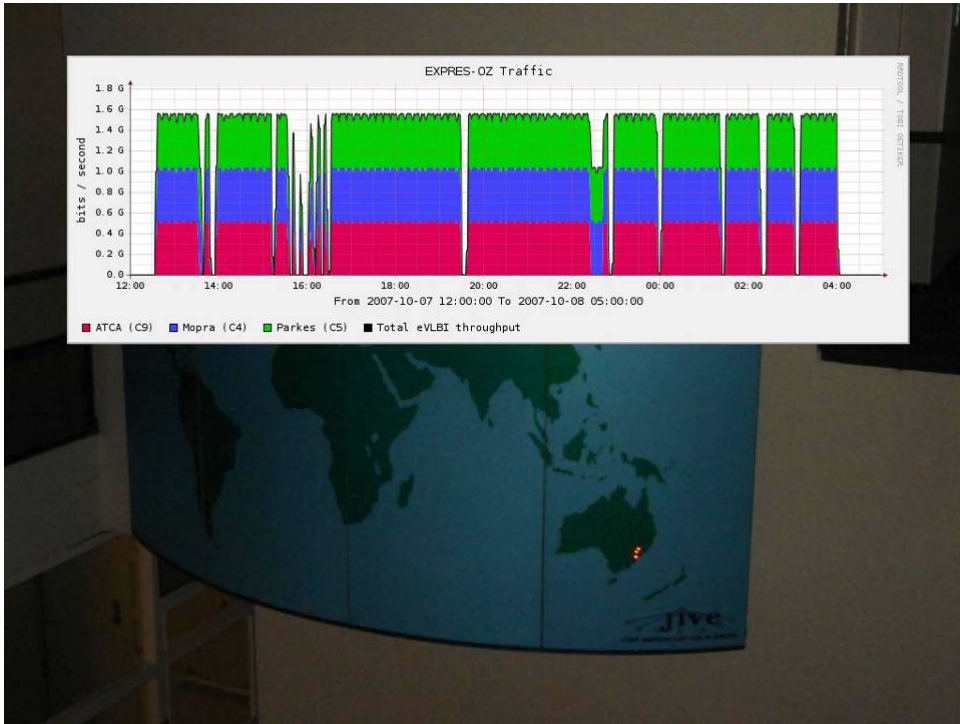
Slots of 24 hours were reserved at 4 to 6-week intervals for e-VLBI science. The four hours preceding each session were earmarked for setup and testing. Apart from this, many tests took place, depending on the availability of stations and the particular urgency of the test in question. Operational reliability and ease increased steadily throughout the last two years, and many successful science observations were conducted.

### **Demonstrations**

Live demonstrations continued to be an important element of the outreach effort of EXPRoS. Although they sometimes pose a big strain on the operational network, and can be quite disruptive, demonstrations are extremely useful in providing a focal point and speeding up developments.

The first demonstration of 2007, at the APAN conference in Xi'An, China, involved telescopes in China, Australia and Europe. Although fringes had been obtained in the past (at very modest data rates) between Arecibo and the European EVN telescopes, the distances in this demo would be considerably longer. What's more, the LBA uses a completely different data acquisition system and data format. As mentioned above, a large and diverse number of problems were solved, and after the track of the Shanghai telescope was broken and had been fixed (one week before the start of the conference!), the actual demo went without a hitch. For this demo we obtained access to the EC-sponsored trans-Siberian TEIN2 network, through the services of both Chinese Research Networks, CSTNET and CERNET. Data from the Australian telescopes was transferred via a dedicated lightpath connection provided by AARNET, CANARIE and SURFnet, and via the 'normal' Internet (which failed completely during the demo).

This was followed by the EXPRoS-Australia demo, during which data from three telescopes were transferred, at 512 Mbps each, via three lightpaths to JIVE. This demo ran for more than 12 hours and nicely illustrated how VLBI may look in the future, connecting telescopes and correlators on opposite sides of the planet in real-time.



Data transfer during EXPRES-Oz demo



e-VLBI demo display at TERENA conference

In an unexpected development Hartebeesthoek became the next station to join the e-EVN. A 1-Gbps connection between Hh and the nascent South African NREN, SANReN, in Johannesburg, and from there at 64 Mbps via London to JIVE, became available in May 2008. Hh then participated in two very successful demos, of which one was rather ad-hoc, organized for the visit of a high-ranking EC delegation to the Hh telescope site.

The second demo took place at the high-profile TERENA 2008 conference, in Bruges, Belgium, where JIVE director Huib van Langevelde was the keynote speaker at the closing plenary meeting. This demo produced fringes between TIGO, Hh, Ar, Ef, Wb, Mc and On, effectively a 4-continent correlation, with the real-time results displayed by van Langevelde in his presentation.

A smaller demo was run later in the year, during a presentation by Szomoru at the GLIF conference in Seattle, USA. By that time JIVE and the EVN had become sufficiently experienced to tackle a far more ambitious project, and towards the end of 2008 preparations started for a 24-hour real-time tracking of a single source, a truly global effort involving many non-EVN telescopes. This was to feature at the opening of the International Year of Astronomy, in Paris, in January 2009, and as such it will be reported on in the next biennial EVN report.



## 6. EVN Meetings

### *4<sup>th</sup> Workshop on CSS and GPS Radio Sources*

The 4th workshop on Compact Steep Spectrum and GigaHertz Peaked spectrum Radio Sources was held in Riccione (FC) in the week 26-29 May 2008. The need of the VLBI radio astronomical community to meet and discuss the nature of CSS sources started in 1990, when our understanding of their nature was still very poor.

From that time, the VLBI community working on this subject met regularly every 6 years, with the goal of sharing results and defining the state of the art of the knowledge.

Great progress has been done since the first meetings. First of all the study of CSS and GPS sources is no longer limited to the radio band. Infrared, optical, and X-ray observations have considerably improved our understanding, and are now essential investigation tools.

Even though it seems fairly well established that CSS and GPS sources are young, as confirmed by the estimates on their radiative and kinematic ages, the properties of the interstellar medium of their hosts raise a lot of interest, and the possible role of confinement is still under study. Over the past few years the number of CSS and GPS samples has considerably increased. This of course is important, however attention should be kept high in order to avoid confusion and mix up of very different astrophysical situations.



Participants at the 4th Workshop on CSS and GPS Radio Sources

Despite an overall better understanding of the observational properties of this class of sources and their role in the radio source evolutionary scenario, some theoretical questions are still unsolved. In particular, it is difficult to evaluate the role of the intergalactic medium in the evolution of such sources.

There seems to be room for a Fifth workshop in the series, most likely in six years from now.

The meeting has been very successful, with more than 50 participants coming from all over the world (all five continents were represented), who have kept the discussion very lively the entire workshop through. A large number of participants were either PhD students or young postdocs.

Contributions to the workshop were given by the Istituto Nazionale di Astrofisica (INAF), by the University of Bologna and by [RadioNet](#).

### ***7th International e-VLBI Workshop at Shanghai Astronomical Observatory (16-17 June 2008)***

The 7<sup>th</sup> International e-VLBI Workshop was held in Shanghai, China, on 16-17 June 2008. It was organized by the Shanghai Astronomical Observatory (SHAO) of the Chinese Academy of Sciences (CAS) and generously sponsored by Express Production Real-time e-VLBI Service (EXPReS), CAS and the National Natural Science Foundation of China (NSFC). The workshop web is available at <http://www.shao.ac.cn/e-VLBI2008/>

The workshop gathered 87 participants working on both radio astronomy and network science in 11 countries around the world. 27 oral presentations and six posters were presented on topics covering the status of e-VLBI, on-going projects in e-VLBI facilities around the world, latest scientific outcomes using high data rate and e-VLBI technology development.

Two panel discussions took place following the presentation sessions each day: internet connection and e-VLBI technology on June 16, and a standard for e-VLBI data format and transfer protocols were lively discussed on June 17. The astronomers reached a consensus to standardize the e-VLBI data format and transfer protocol, and a sub-group was set up to work on the task.



Participants at the 7th International e-VLBI Workshop at Shanghai

Two live demos were also given, demonstrating e-VLBI research on scientific and engineering work respectively.

The e-CVN demo on June 16 involved the Chinese VLBI Network consisting of four telescopes (Shanghai 25m, Urumqi 25m, Beijing 50m and Kunming 40m) and the software/hardware correlators at SHAO. It demonstrated VLBI satellite tracking in near real-time mode.

The e-APT demo on June 17 was carried out with Shanghai 25m (SHAO), Kashima 34m (NICT), Parkes 64m (ATNF), Mopra 22m (ATNF), ATCA 5x22m (ATNF) and DiFX software correlator at Parkes. The CSTNET (China), AARNet (Australia), JGN2plus (w:st="on"Japan) and CENIC (USA) provided the high-speed network involved. For this demo, data were streamed from Kashima, Parkes, Mopra and ATCA at a rate of 512Mbps. Shanghai could only work with a data rate of 256Mbps due to a suspected problem in DiFX software, although the network connection from Shanghai to Parkes correlator worked fine at 512 Mbps. This reason is being investigated. The antennas, networks and correlator ran successfully during the 12 hr observations. Before the end of the demo, an image of one of the calibrator sources (an AGN) was produced and displayed.

Overall the workshop provided an opportunity to broaden international and national cooperation in e-VLBI activities and to strengthen the cooperation between the network scientists and radio astronomers.

## ***The 9<sup>th</sup> European VLBI Network Symposium on "The role of VLBI in the Golden Age for Radio Astronomy"***

The 9<sup>th</sup> European VLBI Network Symposium on "The role of VLBI in the Golden Age for Radio Astronomy" reached its end on Friday 26 September 2008 at 16:40, as planned, after the closing speech by Rafael Bachiller, Chairman of the EVN Consortium Board of Directors.

The Symposium, sponsored by the Istituto Nazionale di Astrofisica (INAF), RadioNet, and the Istituto di Radioastronomia, was held in the Conference Centre of the "Area della Ricerca del Consiglio Nazionale delle Ricerche", Bologna.



Participants at the 9th EVN Symposium during the visit to the Medicina station

More than 140 participants, from 20 different countries (10 of which non-European) came to Bologna. The participants were affiliated with 22 universities and 26 research institutes, a very wide distribution. The Symposium lasted for 4 days, from Tuesday 23 September to Friday 26 September, with one afternoon being dedicated to the EVN Users Meeting. The total number of applications to the Scientific Organizing Committee to give a 20-minute oral contribution requested more time than was available. The SOC policy was to allow as many presentations as possible, giving priority to contributions by young participants. The result was a rather full programme with 62 presentations, 8 of which were reviews and 6 were invited talks, distributed over 12 sessions. Thanks to the session chairmen and to the collaboration of the speakers, it was possible to stay on time. There were also a large number of poster-papers: Thirty-four posters were set up, and they could be consulted for the full duration of the meeting.

The EVN Users Meeting was held at the Visitor Centre of the Medicina Radio Observatory. Participants had a guided tour of the two radio telescopes of the Observatory, the Northern Cross and the 32-m dish. The day at the Medicina Radio Observatory ended with the Symposium closing dinner at the restaurant "Aia Cavicchio". The dinner followed one of the main events of the meeting, the football match, now a tradition at the EVN Symposium. The local team, the "Local Fats", beat the "Giant Stars"-team 6 to 2. The referee of the match was from Australia, a neutral country. The Proceedings of the 9th European VLBI Network Symposium will be published by Proceedings of Science (PoS), Sissa, Trieste.

## 7. EVN Publications in 2007-2008

### 7.1 Referred journals

Albert, J., Perez-Torres, M.A., et al. (144 total): "Multi-wavelength (radio, X-ray, and gamma ray) observations of the gamma-ray binary LS I +61 303", 2008, ApJ, 684, 1351

Bach, U., Raiteri, C.M., Villata, M. et al.: "Multi-frequency monitoring of gamma-ray loud blazars: I. Light curves and spectral energy distributions", 2007, A&A, 464, 175.

Bartel, N., Bietenholz, M.F., Rupen, M.P., & Dwarkadas, V.V.: "SN 1993J VLBI IV: A geometric distance to M81 with the expanding shock front method", 2007, ApJ, 668, 924.

Bartel, N., Bietenholz, M.F.: "Shell revealed in SN 1979C", 2008, ApJ, 682, 1065.

Bietenholz, M.F., Bartel, N.: "SN 2001em: No jet-driven gamma-ray burst event", 2007, ApJ, 665, L47.

Bietenholz, M.F., Bartel, N.: "The evolution of the central component in SN 1986J", 2008, AdSpR, 41, 424.

Bottcher, M., Basu, S., Joshi, M., many others: "The WEBT campaign on the blazar 3C279 in 2006", 2007, ApJ, 670, 968.

Britzen, S., Brinkmann, W., Campbell, R.M., Gliozzi, M., Readhead, A.C.S., Browne, I.W.A., Wilkinson, P.: "The soft X-ray properties of AGN from the CJF sample. A correlation analysis between soft X-ray and VLBI properties", 2007, A&A, 476, 759.

Britzen, S., Vermeulen, R.C., Campbell, R.M., Taylor, G.B., Pearson, T.J., Readhead, A.C.S., Xu, W., Browne, I.W.A., Henstock, D.R., Wilkinson, P.: "A multi-epoch VLBI survey of the kinematics of CJF sources. II: analysis of the kinematics", 2008, A&A, 484, 119.

Britzen, S., Vermeulen, R.C., Taylor, G.B., Campbell, R.M., Pearson, T.J., Readhead, A.C.S., Xu, W., Browne, I.W.A., Henstock, D.R., Wilkinson, P.: "A multi-epoch VLBI survey of the kinematics of CJF sources. I: model-fit parameters and maps", 2007, A&A, 472, 763.

Chi, S., Garrett, M.A., Barthel, P.D.: "AGN and starbursts in the HDF-N and HFF: Deep global VLBI observations", 2008, MmSAI, 79, 1259.

Dodson, R., Fomalont, E.B., Wiik, K., many others: "The VSOP 5GHz AGN Survey. V: Imaging results for the remaining 140 sources", 2008, ApJS, 175, 314.

Ehrenfreund, P., Foing, B.H., Veillet, C, et al: "SMART-1 Impact ground-based campaign", 2007, LPI, 38, 2446.

Fish, V.L., Sjouwerman, L.O.: "Structure of W3(OH) from very high spectral resolution observations of 5cm OH masers", 2007, ApJ, 668, 331.

Frey, S.: "Celestial Reference Points", 2007, Geodezia es Kartografia, 59, 29.

Frey, S., Gurvits, L.I., Paragi, Z., & Gabanyi, K.E.: "High-resolution double morphology of the most distant known radio quasar at  $z=6.12$ ", 2008, A&A, 484, L39.

Frey, S., Gurvits, L.I., Paragi, Z., Mosoni, L., Garrett, M.A., Garrington, S.T.: "Deep extragalactic VLBI-optical survey (DEVOS). II. Efficient VLBI detection of SDSS quasars", 2008, A&A, 477, 781.

Fuhrmann, L., Krichbaum, T.P., Witzel, A, +many others: "Testing the inverse-Compton catastrophe scenario in the intra-day variable blazar S5 0716+71: III. Rapid and correlated flux-density variability from radio to sub-mm bands", 2008, A&A, 490, 1019.

Goddi, C. "Associations of water and methanol masers as milli-arcsecond angular resolution in high-mass YSOs", 2007, BAAS, 39, 2007

Goddi, C., Moscadelli, L., Sanna, A., Cesaroni, R., Minier, V.: "Associations of water and methanol masers at milli-arcsecond resolutions in two high-mass young stellar objects"2007, A&A, 461, 1027.

Harvey-Smith, L., Soria-Ruiz, R.: "EVN observations of 6.7GHz methanol masers in a candidate circumstellar disc", 2008, MNRAS, 391, 1273.

Hong, X.Y., Sun, C.H., Zhao, J.H., Jiang, D.R., Shen, Z.Q., An, T. Wang, W.H., Yang, J.: "Bending of Jets in the QSO NRAO 530", 2008, ChJAA, 8, 179.

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Kharrab, P., Gabuzda, D., & Shastri, P.: "Parsec-scale magnetic field structures in HEAO-1 BL Lacs"2008, MNRAS, 384, 230.

Krips, M., Eckart, A., Krichbaum, T.P., Pott, J.-U., Leon, S., Neri, R., Garcia-Burillo, S., Combes, F., Boone, F., Baker, A.J., Tacconi, L.J., Schinnerer, E., Hunt, L.K.: "Nuclei of Galaxies: V. Radio emission in 7 NUGA sources", 2007, A&A, 464, 553.

Larionov, V.M., Jorstad, S.G., Marscher, A.P. + many others: "Results of WEBT, VLBA, and RXTE monitoring of 3C279 during 2006-2007", 2008, A&A, 392, 389.

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- Liu, X., Cui, L., Luo, W.F., Shi, W.Z., Song, H.G.: "VLBI observations of nineteen GHz-peaked-spectrum radio sources at 1.6GHz", 2007, A&A, 470, 97.
- Liu, Y., Jiang, D.R., Wang, T.G., Xie, F.G.: "The compact structure of radio-loud broad absorption line quasars", 2008, MNRAS, 391, 246.
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- Ly, C., Walker, R.C., Junor, W.: "High-frequency VLBI imaging of the jet base of M87", 2007, ApJ, 660, 200.
- Marscher, A.P., Jorstad, S.G., D'Arcangelo, F.D., et al.: "The inner jet of an AGN as revealed by a radio-to-gamma-ray outburst", 2008 Nature, 452, 966.
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- Middelberg, E., Agudo, I., Roy, A.L., Krichbaum, T.P.: "Jet-cloud collisions in the jet of the Seyfert galaxy NGC3079", 2007, MNRAS, 377, 731.
- Mittal, R., Porcas, R.W., Wucknitz, O.: "Free-free absorption in the gravitational lens JVAS B0218+357", 2007, A&A 465, 405.
- More, A., McKean, J.P., Muxlow, T.W.B, Porcas, R.W., Fassnacht, C.D., Koopmans, L.V.E.: "Probing a massive radio galaxy with gravitational lensing", 2008, MNRAS, 384, 1701.
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- Panessa, F. Giroletti, M.: "The X-ray and radio connection in nearby Seyfert galaxies", 2008, MmSAI, 79, 1263.
- Parra, R., Conway, J.E., Diamond, P.J., Thrall, H., Lonsdale, C.J., Lonsdale, C.J., Smith, H.E.: "The radio spectra of the compact sources in Arp220: A mixed population of Supernovae and Supernova Remnants", 2007, ApJ, 659, 314.
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Raiteri, C.M., Villata, M., Larionov, V.M. + many others: "WEBT and XMM-Newton observations of 3C454.3 during the post-outburst phase: detection of the little and big blue bumps", 2007, A&A, 473, 819.

Raiteri, C.M., Villata, M., Larionov, V.M. + many others: "Radio-to-UV monitoring of AO 0235+164 by the WEBT and Swift during the 2006-2007 outburst", 2008, A&A, 480, 339.

Raiteri, C.M., Villata, M., Larionov, V.M., + many others: "A new activity phase of the blazar 3C 454.3: multifrequency observations by the WEBT and XMM-Newton in 2007-2008", 2008, A&A, 491, 755.

Rushton, A., Spencer, R.E., Strong, M., Campbell, R.M., Casey, S., Fender, R.P., Garrett, M.A., Miller-Jones, J.C.A., Pooley, G.G., Reynolds, C., Szomoru, A., Tudose, V., & Paragi, Z.: "First e-VLBI observations of GRS 1915+105", 2007, MNRAS, 374, L47.

Tarchi, A., Brunthaler, A., Henkel, C., Menten, K.M., Braatz, J., Weiss, A.: "The innermost region of the water megamaser radio galaxy 3C403", 2007, A&A, 475, 497.

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Villata, M., Raiteri, C.M., Aller, M.F. + many others: "The radio delay of the exceptional 3C454.3 outburst: follow-up WEBT observations in 2005-2006", 2007, A&A, 464, 5.

Villata, M., Raiteri, C.M., Larionov, V.M., + many others: "Multifrequency monitoring of the blazar 0716+714 during the GASP-WEBT-AGILE campaign of 2007", 2008, A&A, 481, 79.

Wu, Z.Z., Jiang, D.R., Gu, M.F., Liu, Y.: "VLBI observations of seven BL Lac objects from RGB sample", 2007, A&A, 466, 63.

Zhang, M., Jackson, N., Porcas, R.W., Browne, I.W.A.: "A search of the third lensed image in JVAS B1030+074", 2007, MNRAS, 377, 1623.



## **7.2 Publications in Conference Proceedings**

Alakoz, A.V., Slysh, V.I., & Migenes, V.: "Spectral & VLBI-structure monitoring of an OH maser flare in W75N", 2007, in "Astrophysical Masers and their Environments, IAU Symposium 242", eds. J.M. Chapman & W.A. Baan (Cambridge: Cambridge U. Press), 186.

Alberdi, A., Perez-Torres, M.A., Colina, L., Torrelles, J.M.: "High resolution radio observations of nuclear and circumnuclear regions LIRGs", 2008, in "The Universe under the Microscope", eds. R. Schoedel, A. Eckart, S. Pfalzner, and E. Ros, 12037.

Algaba, J.C., Gabuzda, D.C., Smith, P.S.: "Investigation of correlations between optical and radio polarization of AGN", 2008, in "Extragalactic Jets", eds. T.A. Rector & D.S. De Young (San Francisco: ASP), 483.

Argo, M., Pedlar, A., Beswick, R., Muxlow, T.W.B., Fenech, D.: "Main-line OH masers in M82", 2007, in Proceedings of the 8<sup>th</sup> EVN Symposium, ed. A. Marecki, 450, PoS(8thEVN)064.

Avruch, I.M., Pogrebenko, S.V., & Gurvits, L.I.: "VLBI observations of spacecraft", 2007, in Proceedings of the 8<sup>th</sup> EVN Symposium, ed. A. Marecki, 429, PoS(8thEVN)059.

Baan, W.A.: "Arp220 IC 4553/4: understanding the system and diagnosing the ISM", 2007, in "Astrophysical Masers and their Environments, IAU Symposium 242", eds. J.M. Chapman & W.A. Baan (Cambridge: Cambridge Univ. Press), 437.

Bartkiewicz, A., Szymczak, M., van Langevelde, H.J.: "Methanol masers and massive star formation", 2007, in "Triggered Star Formation in a Turbulent ISM, IAU Symposium 237", eds. B.G. Elmegreen & A. Palous, (Cambridge: Cambridge U. Press), 395.

Bartkiewicz, A., Szymczak, M., van Langevelde, H.J.: "EVN imaging of methanol masers towards massive protostars", 2007, in Proceedings of the 8<sup>th</sup> EVN Symposium, ed. A. Marecki, 274, PoS(8thEVN)039.

Beltran, M.T., Cesaroni, R., Moscadelli, L., Testi, L., Codella, C., Furuya, R.S., Goddi, C.: "Infall and the formation of a massive star", 2008, in "Massive Star Formation", eds. H. Beuther, H. Linz, & T. Henning (San Francisco: ASP), 71

Beswick, R.J.: "Radio Supernovae", 2007, in Proceedings of the 8<sup>th</sup> EVN Symposium, ed. A. Marecki, 365, PoS(8thEVN)051.

Bietenholz, M.F.: "VLBI supernova imaging in the present and with the SKA", 2007, in "From planets to dark energy: the modern radio universe", eds. P. Diamond & R. Schilizzi, PoS(MRU)042.

Bignall, H.E., Landt, H., Reynolds, C., Padovan, P., Perlman, E.: “EVN & MERLIN studies of a new sample of BL Lac objects”, 2007, in Proceedings of the 8<sup>th</sup> EVN Symposium, ed. A. Marecki, 186, PoS(8thEVN)026.

Bourda, G., Charlot, P., Porcas, R., Garrington, S.: “VLBI observations of weak extragalactic radio sources for the alignment with the future GAIA frame with the ICRF”, 2008, in “A Giant Step: from Milli- to Micro-arcsecond Astrometry, IAU Symposium 248”, eds. W. Jin, I. Platais, & M. Perryman (Cambridge: Cambridge U. Press), 324.

Bourda, G., Charlot, P., Porcas, R., Garrington, S.: “VLBI observations of weak extragalactic radio sources for the alignment with the future GAIA frame”2008, in Proceedings of Journees 2007, “The Celestial Reference Frame for the Future”, ed. N. Capitaine, 36.

Bourda, G., Charlot, P., Porcas, R.W., Garrington, S.T.: “Multi-step VLBI observations of weak extragalactic radio sources to align the ICRF and the future GAIA frame”, 2008, in Proceedings of the 5<sup>th</sup> IVS General Meeting “Measuring the Future”, eds. A. Finkelstein & D. Behrend, 25.

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Conway, J.E., Hurley, R., Parra, R., Diamond, P.J., Lonsdale, C.J., Lonsdale, C.J.: “Radio properties of the young supernovae/SNR in Arp220”, 2007, in “From planets to dark energy: the modern radio universe”, eds. P. Diamond & R. Schilizzi, PoS(MRU)045.

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Giroletti, M.: "Jet properties and evolution in small and intermediate scale objects", 2008, in "Extragalactic Jets", eds. T.A. Rector & D.S. De Young (San Francisco: ASP), 176.

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