EUROPEAN VLBI NETWORK

BIENNIAL REPORT 2017–2018
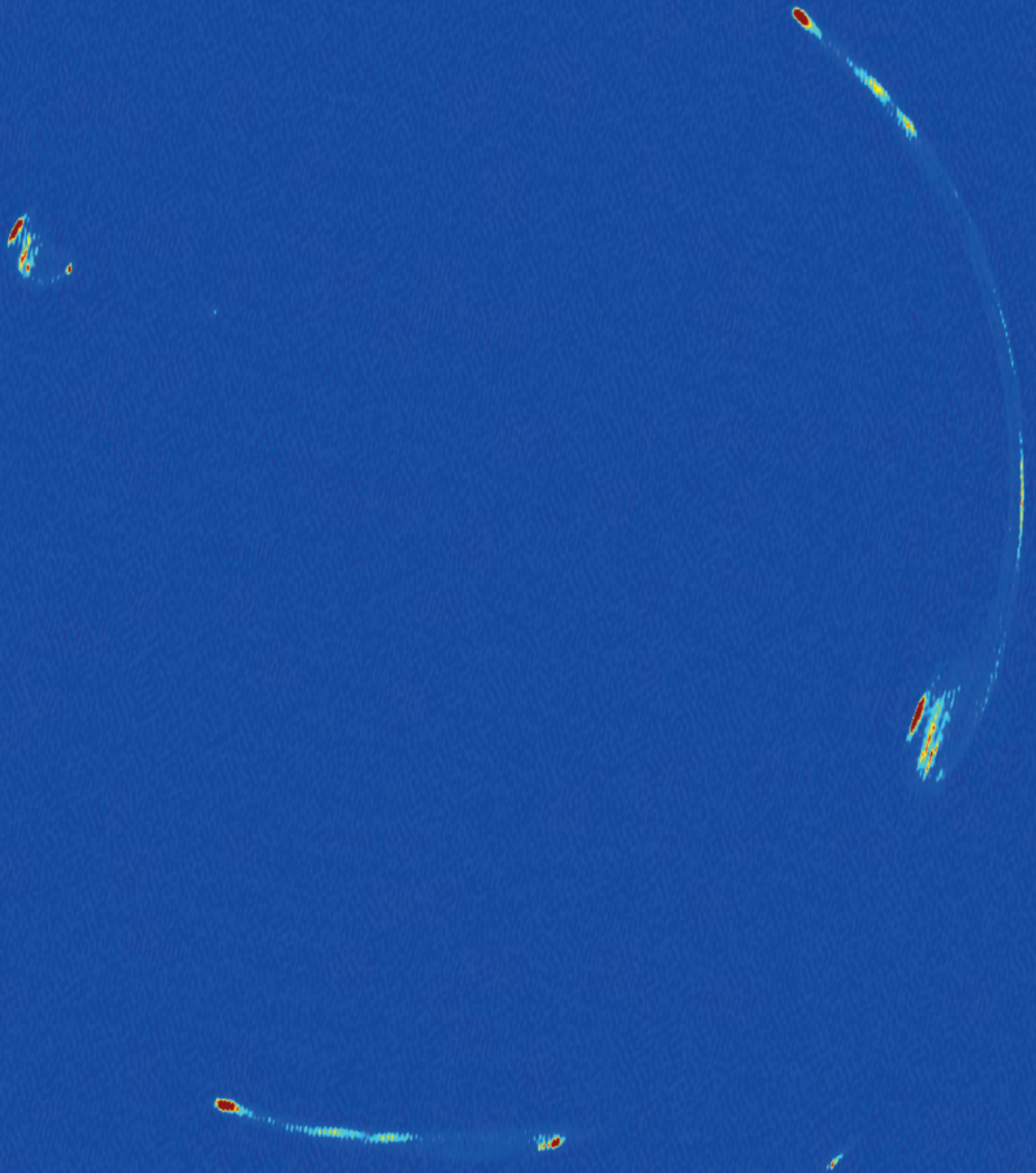
EUROPEAN
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NETWORK

EVN biennial report 2017-2018

November, 2018

Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Front page: Image credit: C. Spingola, see section Dark matter distribution and clumpiness in Galactic Halos constrained by Global VLBI observations of a gravitational lens arc for details.

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1 Foreword from the EVN Consortium Board of Directors chairperson

I am very pleased to introduce this European VLBI Network Biennial Report, covering the years 2017 and 2018. The mission of the EVN is to provide its users access to a unique radio astronomy infrastructure to facilitate high impact science. That this goal is being achieved is illustrated by the EVN science highlights described in this report;

Amongst these results, related to some of most important phenomena/questions in current astrophysics are;

- The first precise location of a Fast Radio Burst (Marcote et al. 2017).

- Constraining the Dark matter distribution and its clumpiness in Galactic Halos (Spingola et al. 2018).

- Tracing the first jet from a Tidal Distribution Event around a Supermassive Black Hole (Mattila et al. 2018).

- Calibrating the masses if Pre-Main Sequence stars using EVN astrometry observations of binary systems (Azulay et al. 2017).

- Testing General Relativity via precise measurement of Gravitational Redshift (Litvinov et al. 2018).

Many more high quality science results can be found described in these pages and within the full list of EVN publications given in chapter 9. The above results are made possible by the dedication of telescope/correlator staff to EVN operations and via the continuous development of the array. Today is an exciting time for the EVN in which all technical elements exist for the array to greatly expand its sensitivity over the coming years. A milestone along this path was met during 2017/2018 when EVN 2 Gbps recording became fully operational for users in disk sessions. Real time eVLBI 2 Gbps at has also become the norm, including to the Chinese and Russian EVN stations. Less visible to users, but operationally very important, has been the deployment of FlexBuff storage around the network allowing EVN sessions to be electronically shipped removing the need to physically transport recording media.

The last years have also seen expansion in the EVN network with the Kunming telescope becoming a regular third Chinese telescope contributing to the EVN. Additionally first fringes have been demonstrated to both the Kutunse converted satellite dish in Ghana and to MeerKAT in South Africa; telescopes which in the years to come are expected to join the long-term EVN partner telescope at Hartebeesthoek in South Africa in

providing long North-South baselines to the EVN. The converted telescope in Ghana is the first element of a planned African VLBI Network (AVN) which we expect to become the EVN's close partner in the future. This collaboration is especially important with SKA becoming operational during the coming decade, and SKA1-mid being designed to be phased-up and so available as a VLBI element for increased sensitivity. Many of the above expansion initiatives toward new telescope sand the future SKA for VLBI have been catalyzed by the JUMPING JIVE EU project.

There have also been an enormous technical advances in adding the e-MERLIN array to the EVN. During the last year full streaming of data to the EVN correlator at JIVE has been made operational. This allows all participating e-MERLIN telescopes to be cross-correlated with all other EVN telescopes, so improving uv coverage and calibration. This capability has long been ranked as one of most desired EVN developments by users and is now operational.

As we look to the future within the EU RadioNet project there is ongoing work on the ambitious BRAND project to investigate simultaneously observing the whole 1.5-15.5 GHz band, from which much will be learned to guide future receivers to be deployed on the EVN. Development of software for wide-band fringe fitting is also part of RadioNet, with these algorithms planned to be incorporated in future releases of the CASA based fringe-fitting that have been developed and released by JIVE.

Finally it is gratifying to acknowledge the growth and expansion of our EVN user community with a record attendance of 170 participants from 25 countries at the 14th EVN Symposium held in Granada, Spain in October 2018. It was in particular positive to note the large number of younger users attending. I congratulate the local organizers for running a truly memorable symposium and look forward to the next symposium in 2020.

John Conway
Chair, EVN Consortium Board of Directors (July 2017 – June 2019)

2 The European Consortium for VLBI

2.1 EVN Consortium Board of Directors membership

The EVN is governed by a Consortium, founded in 1984 following 4 years of EVN observing made under less formal arrangements. The Directors of EVN Member Institutes form the Consortium Board of Directors (CBD). A list of Board membership during 20132014 is given below. A list of Board membership during 2017-2018 is given Tab. 2.1 and 2.2.

Table 2.1: Full EVN CBD members, 2017-2018

Name		Institute
Valdis Avotins		Ventspils International Radio Astronomy Centre, Ventspils, Latvia
Rafael Bachiller		National Astronomical Observatory, Instituto Geográfico Nacional, Madrid, Spain
Ludwig Combrinck	until November 2017	South African Radio Astronomy Observatory,[1] Hartebeesthoek, South Africa
Fernando Camilo	from December 2017	South African Radio Astronomy Observatory,[1] Hartebeesthoek, South Africa
John Conway	Chair from July 2017	Onsala Space Observatory (OSO), Chalmers, Onsala, Sweden
Simon Garrington		Jodrell Bank Observatory (JBO), University of Manchester, Jodrell Bank, UK,
Xiaoyu Hong	until April 2018	Shanghai Astronomical Observatory
Zhiqiang Shen	from May 2018	Shanghai Astronomical Observatory
Alexander Ipatov	until July 2017	Institute of Applied Astronomy, St. Petersburg
Dmitrii Ivanov	from August 2017	Institute of Applied Astronomy, St. Petersburg
Andrzej Marecki		Torun Centre for Astronomy
Wang Na		Xinjiang Astronomical Observatory
Steven Tingay	until April 2017	Institute of Radio Astronomy, Bologna
Tiziana Venturi	from May 2017	Institute of Radio Astronomy, Bologna
Huib van Langevelde	until December 2017	JIVE ERIC
Francisco Colomer	from January 2018	JIVE ERIC
René Vermeulen	Chair until June 2017	ASTRON
Anton Zensus		Max-Planck Institut für Radioastronomie

[1] See section 5.9

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Table 2.2: EVN associate CBD members, 2017-2018

Name		Institute
Do-Young Byun	until April 2018	Korea Astronomy Space Science Institute, Daejeon
Taehyun Jung	from May 2018	Korea Astronomy Space Science Institute, Daejeon
Christiano Brum		Arecibo Observatory
Torben Schueler		Geodetic Observatory Wettzell
Joni Tammi		Metsähovi Radio Observatory, Aalto University

The CBD meets twice per year to discuss EVN activities, to make EVN policy decisions and to appoint EVN Officers (Chairs of the Program Committee and Technical & Operations Group, and the Scheduler), and members of the Program Committee. Meetings are attended by the EVN Officers and also by representatives of EVN observing partner organizations (e.g. NRAO and RadioAstron), and other individuals who may be invited to address topical meeting agenda points. The locations and dates of CBD meetings during 2017-2018 are given in Tab. 2.3.

Table 2.3: CBD Meetings during 2017-2018

Place	Date
Torun, Poland	9-10 May, 2017
Onsala, Sweden	14-15 November, 2017
Shanghai, China	15-17 May, 2018
Dwingeloo, the Netherlands	28 November, 2018

3 Selected EVN Scientific Results

3.1 Extragalactic science

3.1.1 Probing the innermost regions of AGN jets and their magnetic fields with RadioAstron II. Observations of 3C 273 at minimum activity

RadioAstron is a 10 m diameter orbiting radio telescope mounted on the Spektr-R satellite, launched in 2011. It operates at cm-wavelengths, and since 2013 is routinely performing observations, offered through yearly announcement of opportunities (AO), supported by a global network of ground radio telescopes including the EVN. The RadioAstron active galactic nuclei (AGN) polarization Key Science Project (KSP) aims at exploiting the unprecedented angular resolution provided by RadioAstron to study jet launching/collimation and magnetic-field configuration in AGN jets. The targets of the KSP are some of the most powerful blazars in the sky (BL Lac, 3C 273, 3C 279, OJ 287, 0716+714, 3C 345, 3C 454.3, CTA 102), observed during all the AO until now (from 1 to 5). As a first result of the KSP, space-VLBI with RadioAstron reached for the first time an angular resolution of 21 μas at 22 GHz, during observations of BL Lac (Gómez et al. 2016). At these angular scales, not probed before in a blazar jet, evidence for emission upstream of the VLBI core was found, together with evidence of helical magnetic fields threading the jet.

Observations of 3C 273 at 22 GHz presented in Bruni et al. (2017), see Fig. 3.1, were performed during AO-1 (2014), one year after the ones carried out for the early science program on the same source, that resulted in an extremely high brightness temperature measurement (10^{13} K, Kovalev et al. 2016). A global array composed by VLBA (Sc, Hn, Nl, Fd, La, Kp, Pt, Ov, Br, Mk), EVN (Hh, Mc, Nt, Tr, Jb, Ef, Ys), LBA (At, Mp, Ho, Cd), and two Kvazar antennas (Sv, Zc), plus Kalyazin (managed by ASC, Russia), and Green Bank (formerly NRAO, USA) supported observations, that were designed to reach a maximum baseline of about 9 Earth diameters (ED). However, fringes on space-baselines were detected at maximum distance of about 1 ED due to the low-state of the source, as also shown by OVRO single-dish monitoring at 15 GHz.

Bruni et al. (2017) found that the nuclear brightness temperature is two orders of magnitude lower than the exceptionally high value detected in 2013 with RadioAstron at the same frequency (1.4×10^{13} K, source-frame) and with the same instrumental setup, and even one order of magnitude lower than the equipartition value. The kinematics analysis at 43 GHz (from VLBA-BU-BLAZAR data) shows that a new component was ejected about 2 months after the 2013 epoch, visible also in our 22 GHz map presented here. Consequently, this was located upstream of the core during the brightness temperature peak. These observations confirm that the previously detected extreme brightness tem-

perature in 3C 273, exceeding the inverse Compton limit, is a short-lived phenomenon caused by a temporary departure from equipartition. Thus, the availability of interferometric baselines capable of providing μas angular resolution does not systematically imply measured brightness temperatures over the known physical limits for astrophysical sources.


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Clean I map.  Array:  ACHMRKHEMTHRSSZGBFKLMNOP
1226+023 at 22.236 GHz 2014 Jan 18
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Map center: RA: 12 29 06.700, Dec: +02 03 08.598 (2000.0)
Map peak: 1.84 Jy/beam
Contours %: −0.5 0.5 1 2 4 8 16 32 64
Beam FWHM: 0.37 x 0.294 (mas) at 12.3°
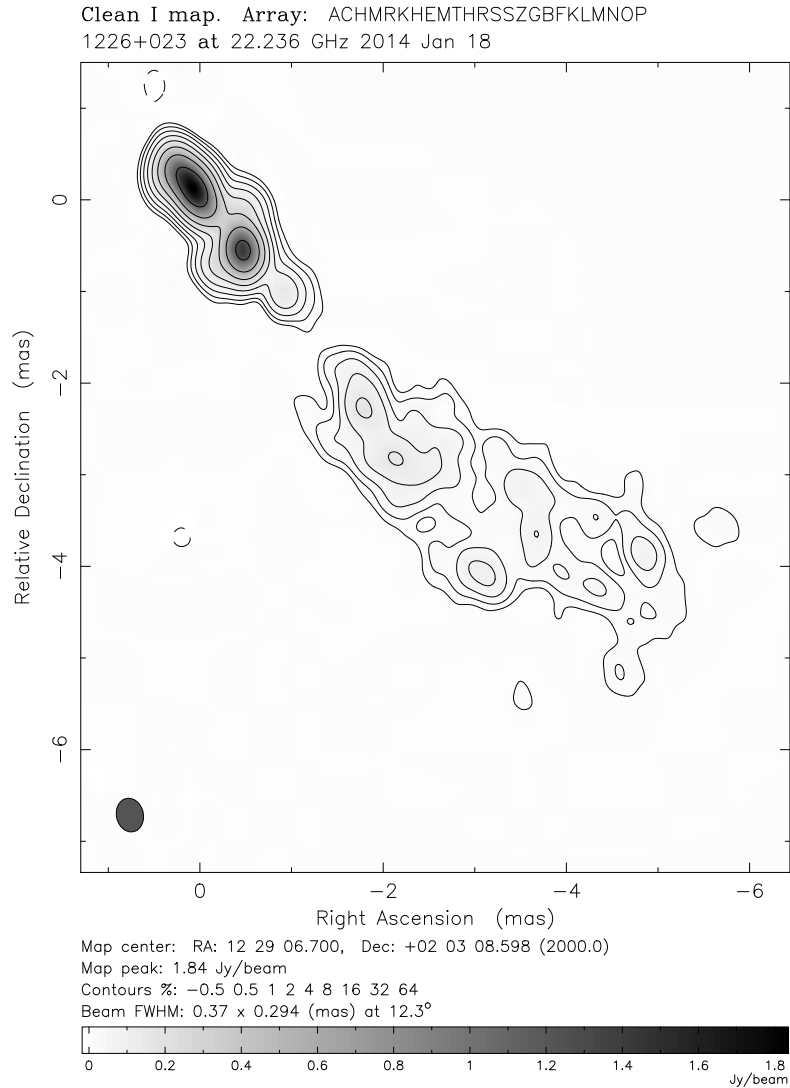
Figure 3.1: *Map of 3C 273 at 22 GHz obtained with the global ground array plus RadioAstron, using uniform weighting. The lowest contour significance is 5σ.*

Published in: Bruni et al. (2017).

3.1.2 VLBI observations of four radio quasars at z> 4: blazars or not?

Blazars are active galactic nuclei whose relativistic jets point nearly to the line of sight. Their compact radio structure can be imaged with VLBI on parsec scales. Blazars at extremely high redshifts provide a unique insight into the AGN phenomena in the early Universe. Four radio sources at redshift z> 4 were observed with the EVN in e-VLBI mode at 1.7 and 5 GHz in 2015 and 2016 (project code: EC054). The targets were previously classified as blazar candidates based on X-ray observations. VLBI imaging was used to confirm the blazar nature of these sources.

The results were partly expected – and partly surprising. Dual-frequency EVN data show that the source J2134-0419 (z=4.35) has a compact one-sided core-jet structure extended to ∼10 mas angular scale, Fig. 3.2. The core brightness temperature indicates a relativistically beamed jet, as expected from a blazar.
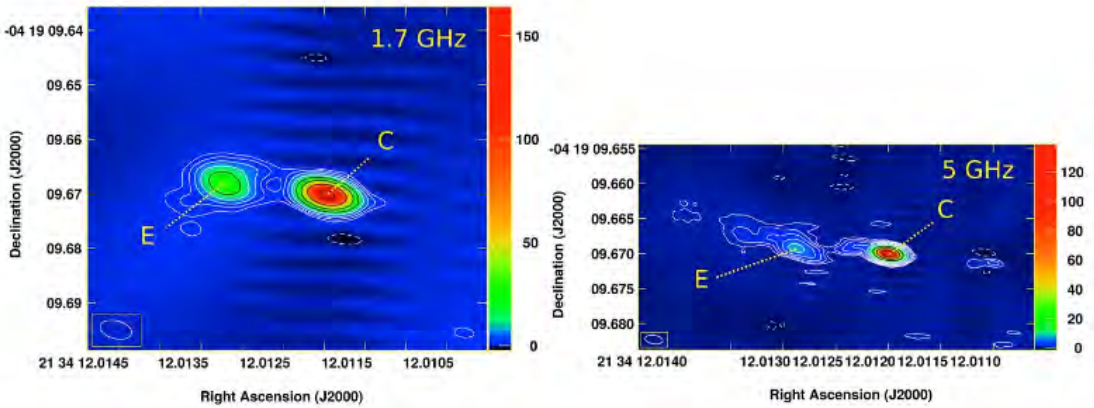
Figure 3.2: *Dual-frequency EVN images of J2134-0419, a genuine blazar with a one-sided jet and a Doppler-boosted compact core (C). The colour scale indicates the intensity in* $mJy\,beam^{-1}$.

Another target, J0839+5112 (z=4.39) has a compact radio structure typical of quasars. There is evidence for flux density variability and its radio core has a flat spectrum. However, the less extreme brightness temperature derived from the EVN data suggest that its emission is not Doppler-boosted.

The real surprise came from the remaining two targets, J1420+1205 (z=4.03) and J2220+0025 (z=4.21), Fig. 3.3. Both of them show radio properties totally unexpected from radio AGN with small-inclination jet. Their radio emission extends to arcsec scales and the Doppler factors of the central components are well below unity. Their weak nuclear radio emission is incompatible with the blazar scenario. These two sources rather resemble double-lobed radio AGN with large inclination with respect to the line of sight. This is in contrast with the blazar-type modelling of their multi-band spectral energy distribution (SED).
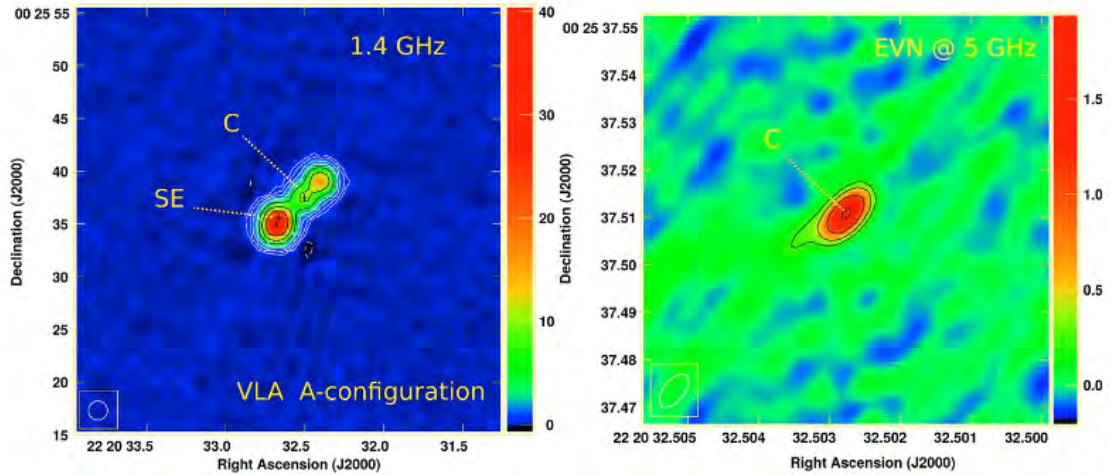
Figure 3.3: *The left panel shows the 1.4 GHz VLA A-configuration image of J2220+0025 (Hodge et al. 2011). The two crosses indicate the positions of our weak EVN-detected components at 1.7 GHz. The central component (labeled as C) is also seen at 5 GHz with the EVN (the tapered image is on the right) and is coincident with the optical quasar position. The colour scale indicates the intensity in $mJy\,beam^{-1}$.*

It is possible that other X-ray emitting, highly radio-loud AGN also mimic the typical blazar properties, yet they belong to different types of sources. This may contribute to the apparently larger fraction of blazars found in the early Universe. Sensitive imaging at intermediate resolution with e-MERLIN has recently been proposed to map the extended structure in J1420+1205, J2220+0025, and another similar radio source known from the literature, to possibly reveal both of the symmetric lobes and the large-scale jets.

These EVN results call for the refinement of the broad-band SED modelling, pose an interesting question about the physical origin of the high-energy emission in J1420+1205 and J2220+0025, and draw the attention to the importance of VLBI imaging observations for reliably classifying blazars at high redshifts.

Published in: Cao et al. (2017).

3.1.3 Space-VLBI observations resolve the edge-brightened jet in 3C 84 (NGC 1275) at $30\,\mu as$ from the core

An international team of researchers from eight different countries has imaged with unprecedented accuracy the newly forming jets of plasma from the core of NGC 1275, the central galaxy of the Perseus cluster, identified with radio source 3C 84. Radio images made with an array including the RadioAstron Space Radio Telescope (SRT) and a global array of ground radio telescopes resolve the jet structure ten times closer to the central engine than what has been possible in previous ground-based observations.

These space-VLBI observations were obtained within the RadioAstron Nearby AGN Key Science Project coordinated by T. Savolainen. 3C 84 was observed on September

21-22, 2013. In addition to SRT, more than two dozen ground radio telescopes, including the EVN, the KVN, Kalyazin and the NRAO VLBA, GBT and the phased JVLA participated in the experiment. First results are now published in Giovannini et al. (2018).

The 22 GHz space-VLBI image shows that the edge-brightened jet in 3C 84 is surprisingly wide, with a transverse radius greater than 250 gravitational radii at a de-projected distance of 350 gravitational radii from the core, Fig. 3.4 . If the bright outer jet layer is launched by the black hole ergosphere, it has to rapidly expand laterally closer to the central engine. If this is not the case, then this jet sheath is likely launched from the accretion disk.
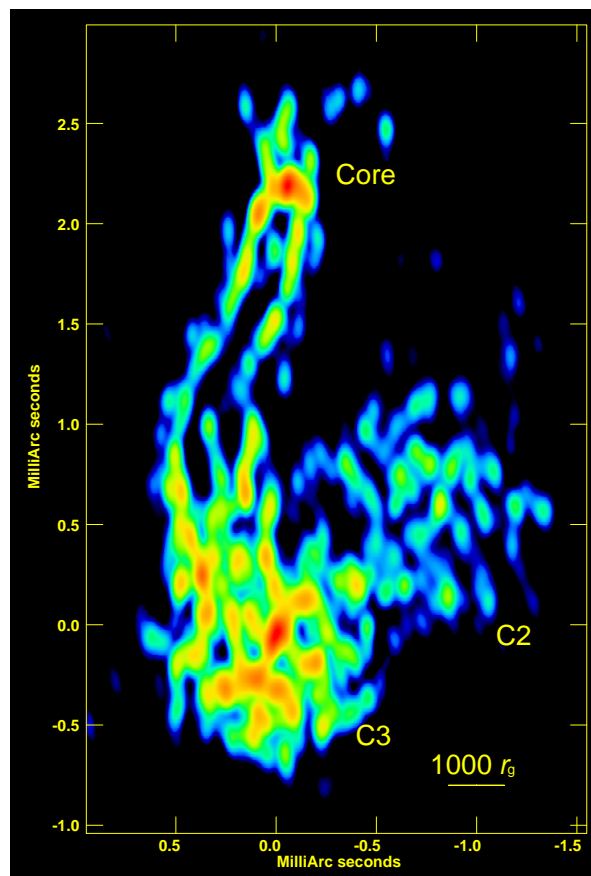
Figure 3.4: *Radio image at 22 GHz of the central parsec in 3C 84 obtained with the space-VLBI array. The half-power-beam-width (HPBW) is 0.10×0.05 mas at PA 0°. The noise level is $1.4\,mJy\,beam^{-1}$ and the peak intensity is $0.75\,Jy\,beam^{-1}$. The radio core and emission features C2 and C3 are indicated in the image.*

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Another major result discussed in the paper is that the previously known, almost cylindrical jet collimation profile on the scales larger than a few thousand gravitational radii extends down to a scale of a few hundred gravitational radii. It indicates a flat density profile of the external confining medium. This result is in contrast with the M87 jet collimation profile. One obvious difference between M87 and 3C 84 jets is the young age of the latter. The dynamical age of the C3 feature (the head of the restarted jet in 3C 84) at the time of the space VLBI observation is only about 10 years. The dynamical age of the jet is less than what is likely needed for the relaxation of the system, and we may not be seeing the final structure of the jet.

Published in: Giovannini et al. (2018).

3.1.4 First unambiguous localisation and characterisation of a Fast Radio Burst

Fast radio bursts (FRBs) are bright ($\sim$ Jy) and short ($\sim$ ms) bursts of radio emission of unknown physical origin. Until now, unambiguous associations with multi-wavelength counterparts have uncertainty regions of at least several square arcminutes.
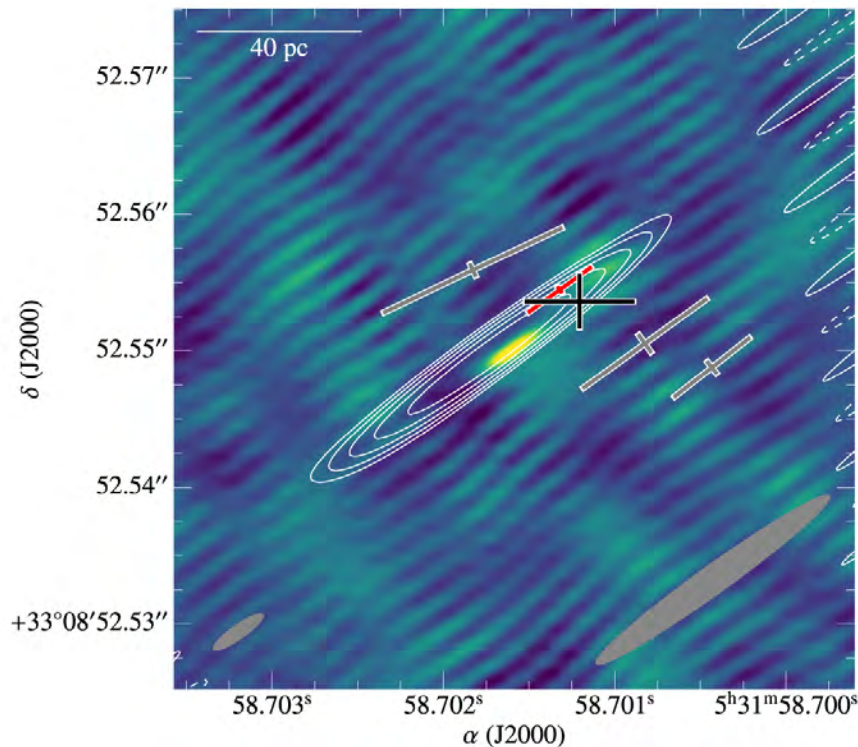
Figure 3.5: *EVN image of the persistent source at 1.7 GHz (white contours) together with the localisation of the strongest burst (red cross), the other three observed bursts (grey crosses), and the position obtained after averaging all four bursts detected on 2016 September 20 (black cross). From Marcote et al. (2017).*

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Chatterjee et al. (2017) have for the first time pinpointed the location of an FRB. Using Expanded Very Large Array observations of the only known repeating FRB, named FRB 121102, they were able to determined its sky position with an uncertainty of ~ 100 mas, and reported an unresolved, persistent radio source and an extended optical counterpart at this location, neither of them corresponding to any known class of Galactic source. Marcote et al. (2017) report EVN observations which simultaneously detect both the bursts and the persistent radio emission at milliarcsecond angular scales and show that they are co-located to within a projected linear separation of 40 pc (12 mas angular separation, at 95 % confidence), Fig. 3.5. The EVN observations were correlated with the SFXC correlator at JIVE. The observations also limit the size of the suspected source of origin to $\sim$0.2 mas. It is argued that the two scenarios for FRB121102 that best match the observed data are a burst source associated with a low-luminosity active galactic nucleus, or a young (< 1000 year) supernova remnant (SNR) powered by an energetic neutron star.

Further Gemini North observations by Tendulkar et al. (2017) show that the bursts originate about $\sim$200 mas away from the center of a low-metallicity dwarf galaxy at z$\sim$0.2. The optical properties they report do not add support to the AGN interpretation, although they cannot conclusively rule it out.

Published in: Marcote et al. (2017).

3.1.5 A dust-enshrouded tidal disruption event with a resolved radio jet in a galaxy merger

Tidal disruption events (TDEs) are transient flares produced when a star is ripped apart by the gravitational field of a supermassive black hole (SMBH). In a TDE, roughly half of the star's mass is ejected, whereas the other half is accreted onto the SMBH, generating a bright flare that is normally detected at X-ray, ultraviolet (UV), and optical wavelengths. TDEs are also expected to produce radio transients, lasting from months to years and including the formation of a relativistic jet, if a fraction of the accretion power is channelled into a relativistic outflow.

An international team of astronomers have, for the first time, directly imaged the formation and expansion of a fast-moving jet of material ejected when the powerful gravity of the SMBH in the nucleus of Arp 299-B (D=45 Mpc) ripped apart a star that wandered too close to the cosmic monster. It is one of the two merging galaxies (Arp 299-A and Arp 299-B) forming the Arp 299 system, which hosts prolific supernova factories in its nuclear regions.

The team tracked the event with radio and infrared telescopes, including the EVN, for over a decade. The patient, continued observations with the EVN and other radio telescopes around the world, eventually showed the source of radio emission expanding in one direction, just as expected for a jet (Fig. 3.6). The measured expansion indicated that the material in the jet moved at an average of about one-fourth the speed of light. The crucial piece of information solving the puzzle of this event was provided by VLBI observations, as the inferred angle of the jet to the line-of-sight was in clear disagreement

with expectations from a "normal" AGN jet, while in the case of a TDE this angle can have any value.

The gravitational field of the SMBH in Arp 299-B, with a mass 20 million times that of the Sun, shredded a star with a mass more than twice that of the Sun. This resulted in a TDE that was not seen in the optical or X-rays because of the very dense medium surrounding the SMBH, but was detected in the near-infrared and radio. The soft X-ray photons produced by the event were efficiently reprocessed into UV and optical photons by the dense gas, and further to infrared wavelengths by dust in the nuclear environment. Efficient reprocessing of the energy might thus resolve the outstanding problem of observed luminosities of optically detected TDEs being generally lower than predicted.
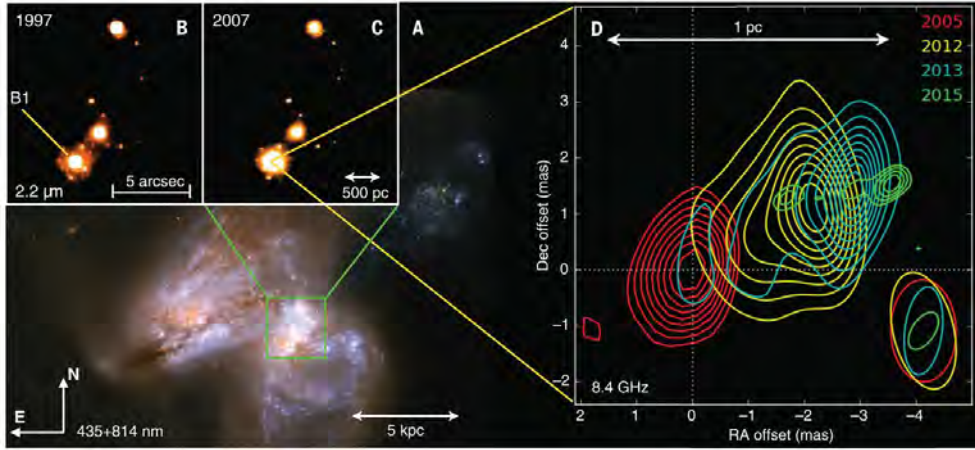
Figure 3.6: *The tidal disruption event Arp 299-B AT1 and its expanding radio jet. (A) A color-composite optical image from the HST, with high-resolution, near-IR 2.2 micron images [insets (B) and (C)] showing the brightening of the B1 nucleus. (D) Radio evolution of Arp 299-B AT1 as imaged with VLBI at 8.4 GHz [7×7 mas^2 region with the 8.4 GHz peak position in 2005, indicated by the dotted lines]. The VLBI images are aligned with an astrometric precision better than 50 μas. The initially unresolved radio source develops into a resolved jet structure a few years after the explosion, with the centre of the radio emission moving westward with time at an average intrinsic speed of 0.22 times the speed of light. The radio beam size for each epoch is indicated in the lower-right corner.*

The case of Arp 299-B AT1 suggests that recently formed massive stars are being accreted onto the SMBH in such environments, resulting in TDEs injecting large amounts of energy into their surroundings. However, events similar to Arp 299 B AT1 would have remained hidden within dusty and dense environments, and would thus not be detectable by optical, UV or soft X-ray observations. Such TDEs from relatively massive, newly formed stars might provide a large radiative feedback, especially at higher redshifts where galaxy mergers and luminous infrared galaxies like Arp 299 are more common.

Published in: Mattila et al. (2018).

3.1.6 Global VLBI observation of the neutral atomic hydrogen gas outflow in the radio galaxy 3C 236

The energy released by an active galactic nucleus (AGN) can heat and expel gas from the host galaxy thereby affecting star formation and the accretion of matter onto the supermassive black hole. One of the striking signatures of this interaction are outflows of ionised, molecular and atomic gas that have been observed in a number of AGNs. In particular, outflows of neutral atomic hydrogen (HI) gas from the cold interstellar medium are often observed in young and restarted radio galaxies. In these objects, the HI gas is observed in absorption and the radio jets are the likely driver of the outflow. Because of the relatively low redshift of these objects, the 21 cm line of HI falls in the L-band allowing us to utilise the high angular resolution offered by VLBI.

Global spectral-line VLBI observations have been obtained to map the outflow in 3C 236 using the VLBA, the Arecibo radio telescope and the EVN stations in Effelsberg, Westerbork, Jodrell Bank and Onsala at a central frequency of 1.293 GHz (project code: GN002B). The data were correlated at JIVE as a continuum pass with 4 IFs each with 16 MHz bandwidth and 32 channels and a spectral-line pass with 1 IF of 16 MHz and 512 channels. The bandwidth is significantly larger than in the previous HI VLBI observation by Struve & Conway 2012 enabling us to cover the entire HI absorption system.

The central region (500 pc) of 3C 236 is believed to be the result of a recent restarted phase of radio emission. At low resolution, the HI absorption spectrum of 3C 236 shows a deep narrow feature related to an HI disk (associated with the large scale dust-lane) and a broad wing discovered with the WSRT (Morganti et al. 2005) and confirmed by the VLA. This wing is blue-shifted and has a width of about $1000 \, \mathrm{km \, s^{-1}}$, which suggests a fast HI outflow.

The VLBI observation, reaching an angular resolution of about 20 mas, has allowed us to identify the properties of this HI outflow. At least part of the outflowing gas appears to be in the form of gas clouds which can be identified in Fig. 3.7, because they are not following the regular rotation of the disk-related gas. Three of them are observed towards the nucleus of the radio source having a size of less than 40 pc and covering about $600 \, \mathrm{km \, s^{-1}}$. The fourth cloud is detected towards the south-east radio lobe at a distance of about 270 pc and it is extended. These clouds have masses ranging between 0.28 and $1.5 \times 10^4 \, M_\odot$.
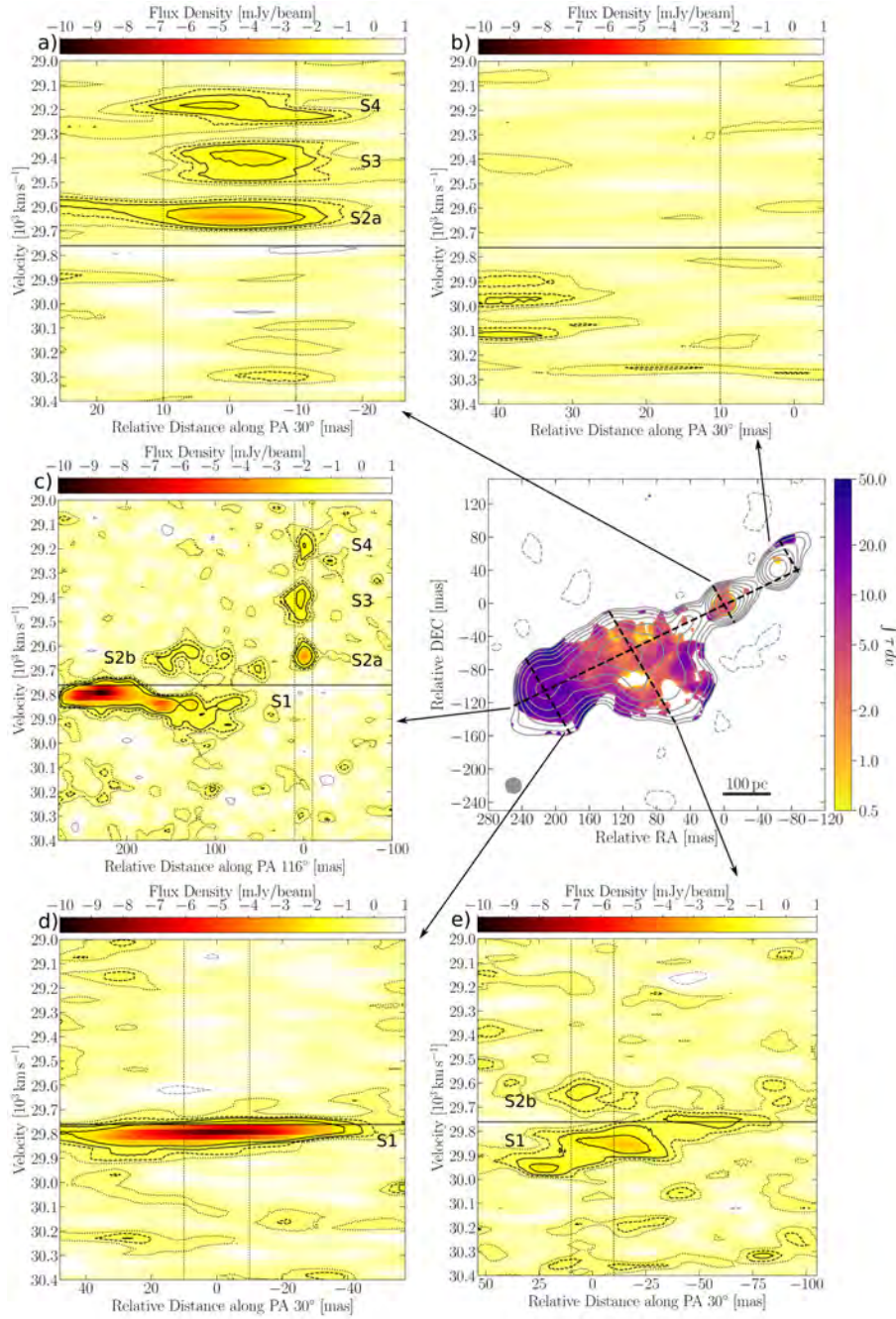
Figure 3.7: *Panels a to e: Position-velocity plots along slices of different position angles of the radio sources. The black contour lines represent -1, -2, -3, -5 times the noise level and the gray contour line is set to 3 times the noise level. The central panel shows the continuum radio emission as black contour lines starting at three times the noise level and the integrated optical depth in colour. The gray circle and the dotted vertical lines represent the synthesized beam of 20 mas. Features S2a, S2b, S3 and S4 correspond to clouds of outflowing HI gas, while S1 is caused by disk-related HI gas (from Schulz et al. 2018).*

These findings indicate that the outflow is to some extend clumpy and originates within the central few tens of parsec of the radio galaxy. This has important implications for the comparison with numerical simulations. Indeed one prediction of the simulations is that the impact of a radio jet on the surrounding medium is highly enhanced when it enters a clumpy medium. This supports the idea that radio jets play an important role in the evolution of the host galaxy. These results illustrate the importance of VLBI for the understanding of the physical condition of the medium around active black holes: in the context of the upcoming large-scale blind HI absorption surveys conducted at lower angular resolution, VLBI will provide key follow-up observations.

Published in: Schulz et al. (2018).

3.1.7 Dark matter distribution and clumpiness in Galactic Halos constrained by Global VLBI observations of a gravitational lens arc

Gravitational lensing occurs when a massive foreground galaxy lies between the observer and a distant background object. Depending on the alignment, the light from the background object is often highly distorted and magnified, giving valuable information on the mass distribution of the foreground lensing galaxy. Therefore, modelling the surface brightness distribution of the lensed images can reveal the structure of the lensing galaxy, and in particular, discern the properties of dark matter. In the case of the latter, the extremely high angular resolution provided by VLBI can in principle be used to test the smoothness of galaxy-sized dark matter haloes on mas-scales. Unfortunately, most lensed objects are rather compact when observed at the very high angular resolution provided by VLBI, which limits the number of observational constraints to any lensing mass model and can lead to degeneracies between the choice of mass model and the properties of dark matter.

Recently, Cristiana Spingola (Kapteyn Astronomical Institute) and John McKean (ASTRON) observed the gravitationally lensed radio source MG J0751+2716 at 1.65 GHz with the global VLBI array (project GM070; PI: McKean). The 18.5 hour observation comprised 24 antennas of the EVN and the VLBA, including the Lovell, Effelsberg, Robledo and Green Bank telescopes. The data were recorded at 512 Mbps and correlated at JIVE to produce 8 spectral windows with 8 MHz bandwidth and 32 channels each, through both circular polarisations. At the time, this experiment was the largest to be correlated at JIVE, in terms of number of antennas and bandwidth, and the resulting imaging quality was excellent.

The deep global VLBI imaging of MG J0751+2716 detected extended gravitational arcs at high significance, showing the complex surface brightness structure of the background radio source in unprecedented detail (see Fig. 3.8). Due to the complexity of this system, the imaging was performed using multi-scale cleaning within the wsclean algorithm (Offringa et al. 2014). The total flux density of the target is 350 mJy and the off-source rms is $41\,\mu$Jy beam^{-1}. Never before have such extended $(200-600\,\mathrm{mas})$ gravitational arcs been detected at an angular resolution of a few mas.
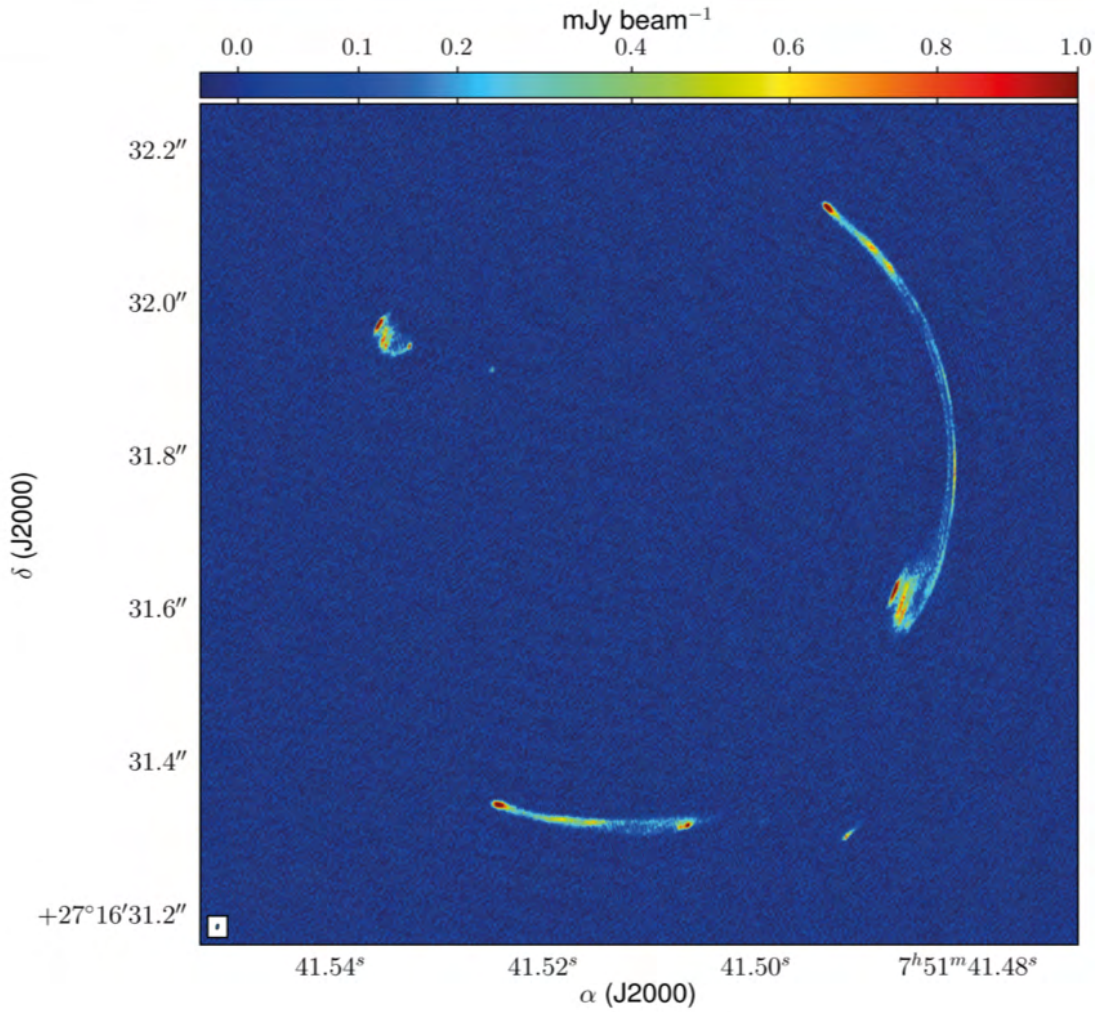
Figure 3.8: *Global VLBI imaging of MG J0751+2716 at 1.65 GHz obtained by using uniform weights and multi-scale cleaning in wsclean. The off-source rms is 41 μJy beam^{-1} and the peak surface brightness is 2.9 mJy beam^{-1}. The restored beam is 5.5×1.8 mas^2 at a position angle -9.8°, and is shown within the white box in the bottom left hand corner.*

The excellent uv-coverage and surface brightness sensitivity provided by the array have been fundamental for a precise study of the extended arcs from MG J0751+271 on mas-scales. Spingola et al. (2018) analysed these observations and identified lensed emission that corresponded to the same source component in each of the gravitational arcs, providing a very large number of constraints to the mass model, which also sampled a large radial and tangential extent of the lensing mass distribution. When performing the mass modelling of this system using a smooth mass distribution, they found a discrepancy between the observed and predicted positions of the lensed images, with an average position rms of the order of 3 mas, which is much larger than the measurement errors (40 μas on average). A possible explanation for the offset between the observed

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and model- predicted positions is the presence of some additional mass structure (e.g. Metcalf & Madau 2001), for example, from an abundant population of low mass sub-haloes within the lensing galaxy or along the line-of-sight, as are predicted by the cold dark matter model of galaxy formation. However, since the lensing galaxy lies in a small group of galaxies, it was not clear whether this extra mass is in the form of these sub-haloes, or from a more complex halo for the galaxy group.

Furthermore, the lens mass model suggests an inner density slope for the main lensing galaxy that is steeper than what is predicted for an isothermal density profile. This is consistent with studies of other low-mass early-type satellite galaxies in dense environments, and is in agreement with the two-phase galaxy formation scenario (Guo & White 2008).

Published in: Spingola et al. (2018).

3.2 Galactic sources

3.2.1 Young, active radio stars in the AB Doradus moving group

Precise determination of dynamical masses of pre-main-sequence (PMS) stars is necessary to calibrate PMS stellar evolutionary models, whose predictions are in disagreement with measurements for masses below $1.2\,M_\odot$. To do this calibration, binary stars in young, nearby moving groups are particularly good candidates, since all members share a common age. In particular, stars belonging to the AB Doradus moving group (AB Dor-MG) seem to be optimal for this study: AB Dor-MG is the closest moving group (its mean distance to the Sun is $30\,\mathrm{pc}$), the estimated age is relatively accurate (50-120 Myr), and it contains stars with significant emission at radio wavelengths. This last feature is essential, because it allows the use of radio interferometry techniques to obtain astrometric information.

Azulay et al. (2017) report on observations in phase-reference mode using the Very Large Array (VLA) at $5\,\mathrm{GHz}$ and the EVN at $8.4\,\mathrm{GHz}$ of the stars HD 160934, EK Dra, PW And, and LO Peg, all belonging to the AB Dor-MG.
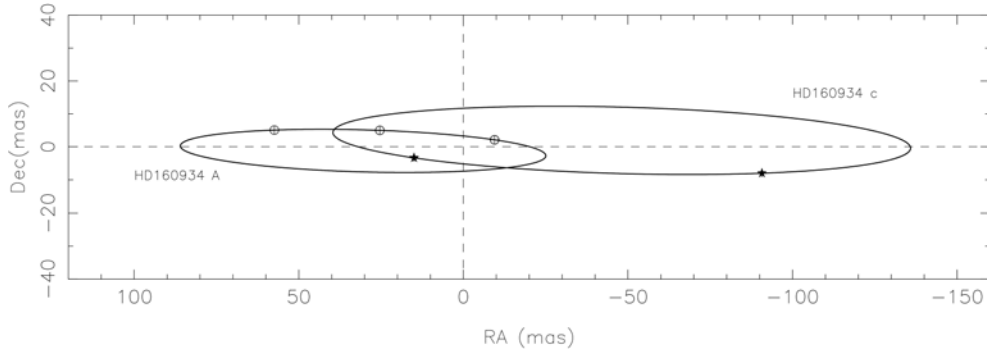
Figure 3.9: *Absolute orbits of the binary components HD 160934 A and HD 160934 c. The positions of the component A (circles) and c (star symbols) are indicated. The centre of mass of the system is placed at the origin.*

The orbital information derived from these observations was analysed along with previously reported orbital measurements (mostly based on NIR observations), which allowed them to determine precise, model-independent, dynamical masses of both components of the star HD 160934, A and c ($0.70 \pm 0.07\,M_\odot$ and $0.45 \pm 0.04\,M_\odot$, respectively), Fig. 3.9. Moreover, they revised the orbital parameters of EK Dra and they determine the sum of the masses of the system to be $1.38 \pm 0.08\,M_\odot$. They also explored the binarity of the stars LO Peg and PW And, finding a clear detection, but no-binarity, in the case of PW And and finding a non-detection in the case of LO Peg, reflecting the variability of the radio emission.

Comparisons of their dynamical masses with the prediction of PMS evolutionary models confirm that the models underpredict the masses of PMS stars by 10-40 %. They also inferred that the origin of the radio emission corresponds to extreme magnetic activity of the stellar corona that triggers gyrosynchrotron emission from non-thermal, accelerated electrons .

Published in: Azulay et al. (2017).

3.2.2 An Astrometric Search for a Sub-stellar Companion of the M8.5 Dwarf TVLM 513-46546 Using Very Long Baseline Interferometry

Gawroński et al. (2017) published a detailed astrometric study of M9 ultracool, very low-mass dwarf TVLM513-46546 that is placed at the brown dwarf boundary. The observations performed between March 2011 and March 2015 at 6 cm with the e-EVN (proposal codes: EG053, EG065, EG082) were combined with the archival VLBA data (Fig. 3.10). The target was detected at each epoch with the quiescent emission flux in the range 180-300 μJy. Four short-duration flaring events with very high circular polarisation were also noticed. Combined VLBI astrometric observations allowed to rule out companions more massive than Jupiter in orbits with periods longer than ~1 yr. A new systematic statistical approach allowing for proper optimization of astrometric model in the presence of unspecified error factors was presented in this work.

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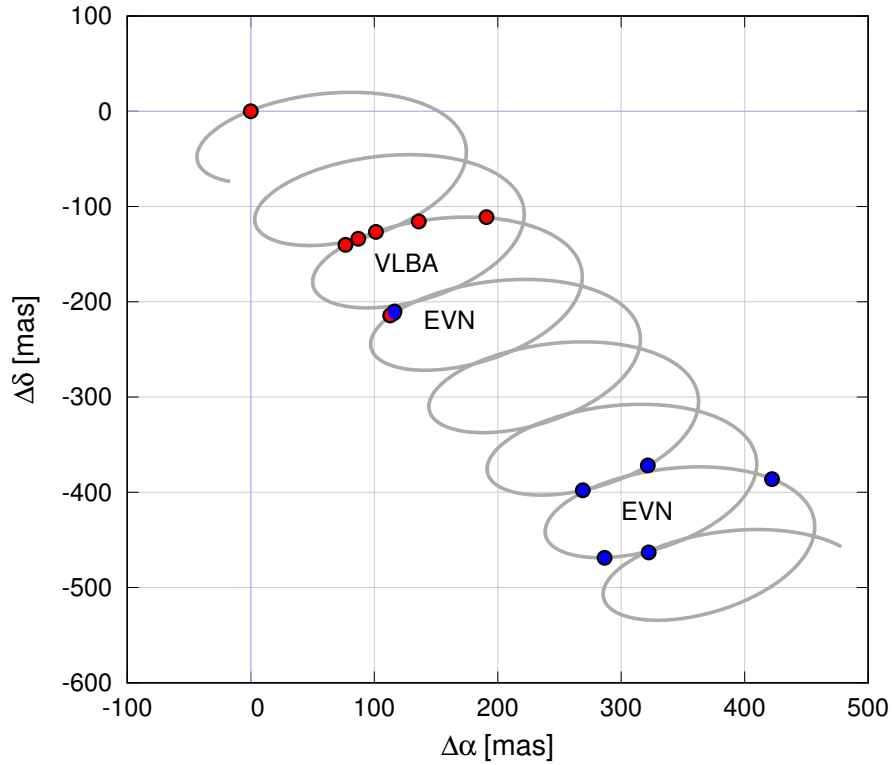
Figure 3.10: *Sky-projected, five-parameter astrocentric model of TVLM513 positions (grey curve) overplotted with the VLBA (red filled rectangles) and with all new EVN detections (blue filled circles, this work), relative to the first observation in (Forbrich et al. 2013).*

Published in: Gawroński et al. (2017).

3.2.3 Another look at AM Herculis

Precise estimation of annual parallaxes for selected targets with the use of independent techniques are essential in the GAIA era. VLBI astrometry seems to be a perfect choice as a reference for the GAIA measurements. Gawroński et al. (2018) reported EVN astrometric campaign performed in the e-VLBI mode at 6 cm, dedicated to AM Her. Using six astrometric measurements it was possible to estimate the annual parallax for this system with the sub-mas accuracy ($\pi = 11.29 \pm 0.08$ mas, $d = 88.8 \pm 0.6$ pc). Proper motion of AM Her is showed in Fig. 3.11. AM Her is a prototype of the so-called polars, active compact binary systems. In polars, very strong magnetic field of the primary white dwarf (10-250 MG) prevents the creation of an accretion disc and the matter transferred from the secondary follows the magnetic field lines and falls onto the magnetic pole/poles of the primary. The accretion is occasionally ceased in these systems and during these episodes polars fall into the quiescent phase with decreased optical brightness.
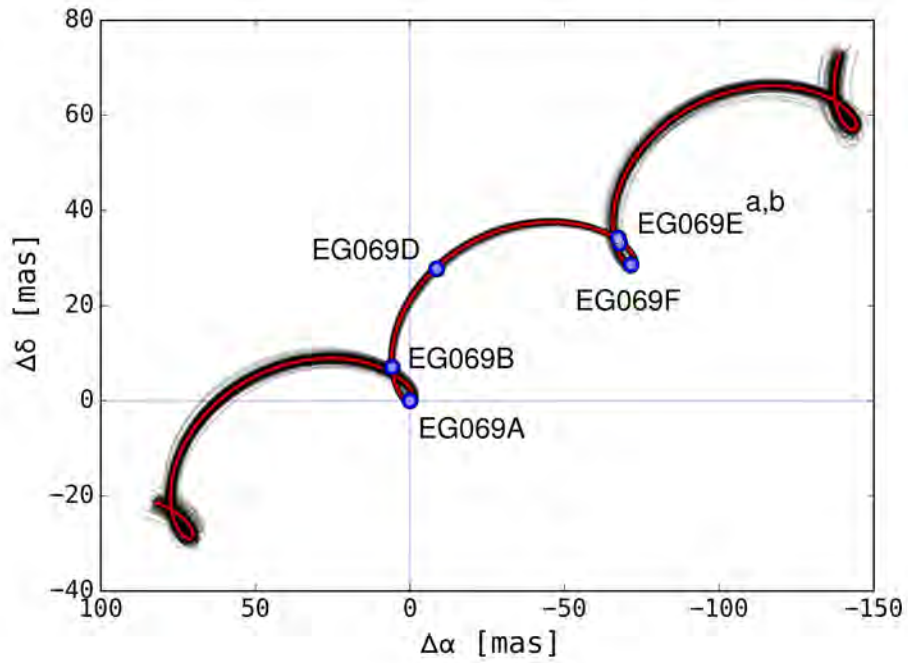
Figure 3.11: *Sky-projected parallactic motion of AM Her for all e-EVN observations. Red curve is for nominal solutions. Thin grey curves are for 100 randomly selected samples from the MCMC-derived posterior (see Gawroński et al. (2018) for details).*
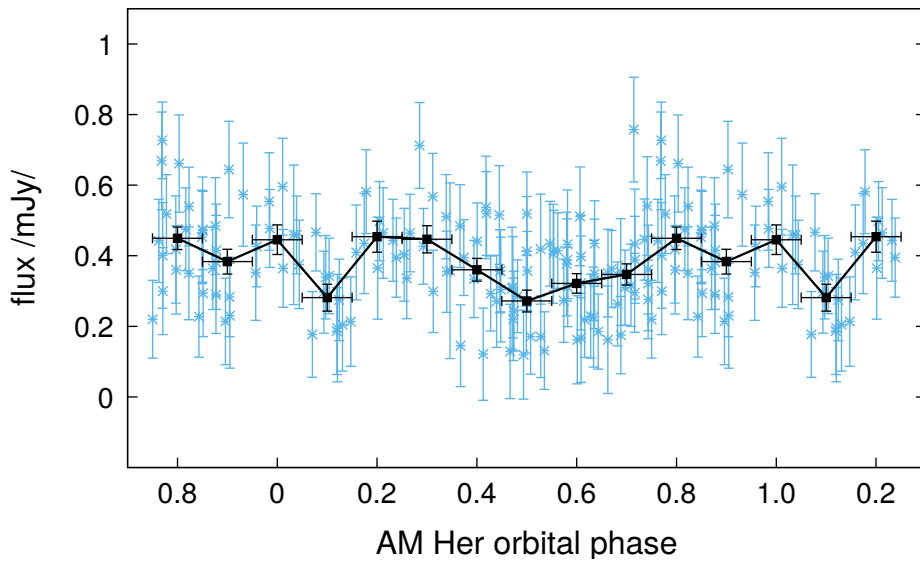
Figure 3.12: *AM Her quiescent radio flux at 5 GHz phased with the orbital motion of the system. Cyan points represent measurements based on individual scans and black points binned values.*

e-EVN observations were conducted during the long AM Her quiescent phase. It allowed to study the radio flux evolution at the time of small activity of AM Her. Gawronski et al. (2018) showed that AM Her radio flux is likely modulated with the orbital phase Fig. 3.12., and this could be explained if the secondary red dwarf is also magnetically active. In this picture, the gyrosynchrotron emission arises between the secondary surface and L1 point. The magnetic activity of the secondary could explain the puzzle of AM Her as a persisted radio source. This attribute also most likely distinguish AM Her from other polars.

Published in: Gawroński et al. (2018).

3.2.4 The feedback of an hypercompact HII region on its parental molecular core

Hypercompact (HC) HII regions (typically, $\leq 0.03\,\mathrm{pc}$ in size and $\geq 10^{10}$ pc cm^{-6} in emission measure) represent the first step in the ionisation/expansion of an ionised region around a newly born early-type star. The study of their physical and dynamical properties is fundamental to shed light on the process of formation of more massive ($\geq 15\,M_\odot$) stars, specifically to investigate how the ionisation and radiation pressure affect the preexisting accretion/ejection structures.

Inside the most prominent molecular core (named A1) of the high-mass star forming region G24.78+0.08 (bolometric luminosity of $\sim 2 \times 10^5\,L_\odot$ at a distance of 7.2 ± 1.4 kpc), previous VLA (1.3 cm and 7 mm) observations have revealed an intense (10 mJy beam^{-1} at 1.3 cm) hypercompact (size $\approx 1000\,\mathrm{AU}$) HII region. Recent high-angular resolution ($0.2''$) ALMA observations has detected strong emission in the H30α line (at 231901 MHz) emerging from the HC HII region (Cesaroni et al. 2017).

The kinematics of the ionised gas has been probed by studying how the position of the compact H30α emission peak changes in velocity, by fitting the emission in the channel maps with a 2-D Gaussian. Figure 3.13 reveals that a well-defined $\mathrm{V_{LSR}}$ gradient is observed in the H30α line. It is directed at PA=$39°$ (about parallel to the major axis of the VLA 7 mm continuum image) and extends over quite a large velocity range, from $\approx 85\,\mathrm{km\,s^{-1}}$ to $\approx 139\,\mathrm{km\,s^{-1}}$ going from SW to NE. The velocity gradient, $22\,\mathrm{km\,s^{-1}\,mpc^{-1}}$, is one of the highest so far observed towards HC HII regions. The dynamical mass inferred from this $\mathrm{V_{LSR}}$ gradient is $M\mathrm{dyn} \geq 96\,M_\odot$, much larger than the mass of the ionising star, $\approx 20\,M_\odot$, estimated from the radio and bolometric luminosity. That rules out the interpretation of the $\mathrm{V_{LSR}}$ pattern in terms of rotation/infall. The simplest interpretation of the observed $\mathrm{V_{LSR}}$ gradient in the H30α line is in terms of a fast, bipolar outflow blowing from the massive YSO, placed at the centre of the H30α pattern and responsible for the gas ionisation.
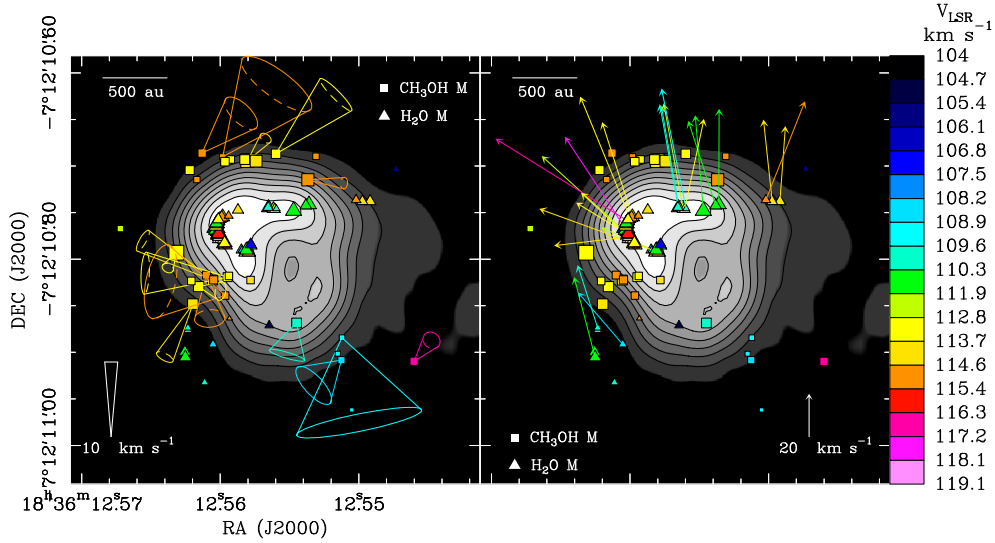
Figure 3.13: *The grey-scale image represents the 7 mm continuum emission observed with the VLA A-Array. The white triangles and yellow squares mark the VLBI positions of the H_2O 22 GHz and CH_3OH 6.7 GHz masers, with symbol area proportional to the logarithm of the maser intensity. The coloured dots give the channel peak positions of the $H30\alpha$ line emission, with colours denoting V_{LSR} as indicated in the wedge on the right of the plot. The dashed black line marks the axis of the spatial distribution of the $H30\alpha$ peaks. The VLBI maser and VLA continuum absolute positions have been corrected for the apparent motion between the corresponding observing epochs and the ALMA observations, and should be accurate within 10 mas. The $H30\alpha$ positions has been offset by 10 mas (less than the expected ALMA position accuracy) both to E and S, to obtain a better alignment with the axis of the radio continuum emission.*

The interaction of the fast-moving ionised gas with the surrounding molecular environment is suitably traced with both water and methanol masers. While water masers arise just at the border of the ionised gas, methanol masers are observed at relatively larger separation from the centre of the HC HII region (see Fig. 3.13). Figure 3.14 shows the 3-D velocities of the water and methanol masers, derived via multi-epoch, sensitive VLBA and EVN observations, respectively. The water maser proper motions witness the fast ($\approx 40\,\mathrm{km\,s^{-1}}$) expansion of dense, shocked circumstellar gas towards N and E of the HC HII region. Methanol masers are observed to the N, SE and S of the HC HII region, and their overall motion indicates expansion away from the ionised gas at significantly lower velocities (mainly $\leq 10\,\mathrm{km\,s^{-1}}$) than the water masers.

This work on the G24.78+0.08 HC HII region illustrates the power of complementing thermal interferometric and maser VLBI observations for a detailed view of the massive star formation. Future studies on this object aim at determining the degree of collimation of the ionised flow to test whether we are observing the onset of the stellar wind from an O-type star.
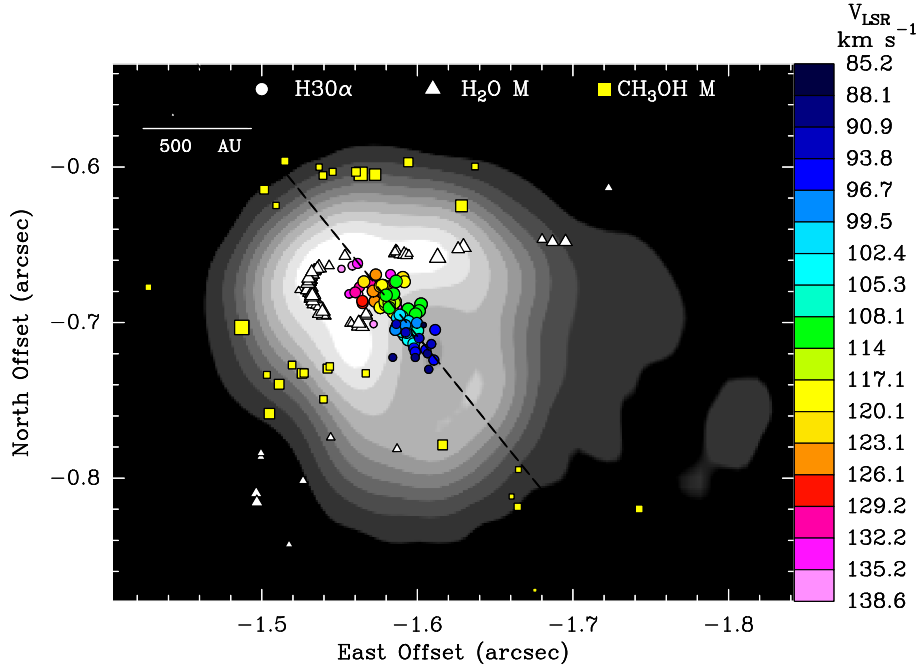
Figure 3.14: *3-D motions of the methanol (left panel) and water (right panel) masers in G24.78+0.08 A1. In both panels, the grey-scale image and black contours (10 to 90 %, at step of 10 % of the image peak of $11\,mJy\,beam^{-1}$) reproduce the VLA A-Array 7 mm continuum. Coloured triangles and squares report the absolute positions (evaluated at the date 2003 September 4) of the 22 GHz water and 6.7 GHz methanol masers, respectively, with colours denoting V_{LSR} as coded in the wedge on the right of the plot. In the left panel, the 3-D velocities of the methanol masers are shown with cones, with opening angle representing the uncertainty in the direction of motion. The white cone in the left bottom corner gives the scale for the velocity amplitude. In the right panel, the sky-plane velocities of the water masers are indicated with arrows. The white arrow at the right bottom shows the velocity scale.*

Published in: Moscadelli et al. (2018).

3.3 General physics

3.3.1 Probing the gravitational redshift with an Earth-orbiting satellite

An international team of scientists have performed a test of general relativity using the 10 m space radio telescope RadioAstron. The ultra-stable on-board hydrogen maser frequency standard and the highly eccentric orbit make RadioAstron an ideal instrument for probing the gravitational redshift effect, which constitutes a test of the Local Position Invariance aspect of the Einstein Equivalence Principle (EPP). The highly eccentric orbit around the Earth evolves due to the gravitational influence of the Moon, as well as other factors, within a broad range of the orbital parameter space (perigee altitude 1,000-80,000 km, apogee altitude 270,000-370,000 km). The large gravitational potential variation, occurring on the time scale of ~ 24 hr, causes a large variation of the on-board

H-maser clock rate, which can be detected via comparison with frequency standards installed at various ground radio astronomical observatories.

Litvinov et al. 2018 presents the techniques as well as some preliminary results. They expect to reach an accuracy of the gravitational redshift test of order 10^{-5}, a magnitude better than that of Gravity Probe A mission, which yielded the best such test to date. All data has been taken and data processing is ongoing, their preliminary results agree with the predictions of the EPP.

Published in: Litvinov et al. (2018).

3.4 SETI

3.4.1 Towards an e-MERLIN/EVN SETI Capability

The last few years have seen a huge resurgence of interest in SETI research. Initiatives such as Mr. Yuri Milner's Breakthrough Listen project have transformed the landscape, with the first large systematic surveys now being conducted by appropriately equipped telescopes such as the GBT and Parkes (Siemion et al. 2013). NASA has also signaled its intention to begin to fund future radio SETI efforts, in addition to the search for "techno-signatures" in general. While most SETI observations employ large single dishes, the new generation of radio telescopes operating at cm-wavelengths, tend to be composed of distributed dish arrays e.g. the MeerKAT telescope in South Africa is a good example. While the conventional approach of SETI researchers is to beam-form such arrays (essentially making them look like huge single dishes), it's interesting to consider what advantages there might be to conduct SETI observations using interferometric techniques. One well known advantage of employing long baseline interferometers arrays for SETI is that such instruments are significantly less affected by radio frequency interference (RFI), greatly reducing the enormous number of false positives that arise from terrestrial and satellite communication systems (Rampadarath et al. 2012).

In a recent paper presented at the International Astronautics Congress and EVN symposium, Garrett (2018) highlighted some other advantages that interferometer arrays can potentially provide. One important advantage is the presence of multiple, independent interferometer baselines in an array - these provide an important level of redundancy and additional confidence (verification) of faint and potentially transient signals - if a SETI signal is detected in one baseline, it had better also be present in the others. It is also the case that the high time and frequency resolution required by SETI, naturally leads to an interferometer array in which the entire field-of-view (only limited by the extent of the primary beam response) is available for analysis – the result is that thousands of potential SETI targets can be studied simultaneously. These targets typically range from nearby galactic stars (easily identified via their Gaia proper motions) to distant extragalactic systems but solar system objects can also be included. Another advantage of interferometry is that it's possible to make images as a function of either time or frequency (or both) - see Fig. 3.15. An important observation is that while almost all other aspects of a SETI signal are likely to be changing (especially narrow-band signals

suffering from large Doppler accelerations, interstellar scattering etc), the position of the signal on the sky is likely to be invariant (at least on times scales of a few hours). It is also interesting to note, that if a SETI signal were to be detected, radio interferometers distributed on scales of 1000's of km would play a crucial role in pin-pointing the location and nature of the extraterrestrial transmitter and the platform on which the source is fixed – for example, VLBI techniques can easily detect the orbital motion of a transmitter if it is placed on a planet in orbit around its star (note that by definition, 1 milliarcsecond subtends 1 AU at a distance of 1 kpc). Even if the transmitter is located in free space, the motion of objects with velocities in excess of 0.01 c can be detected within 1 day, much slower objects (with velocities similar to the Voyager spacecraft) can be detected within 1 year (again assuming a distance of 1 kpc).
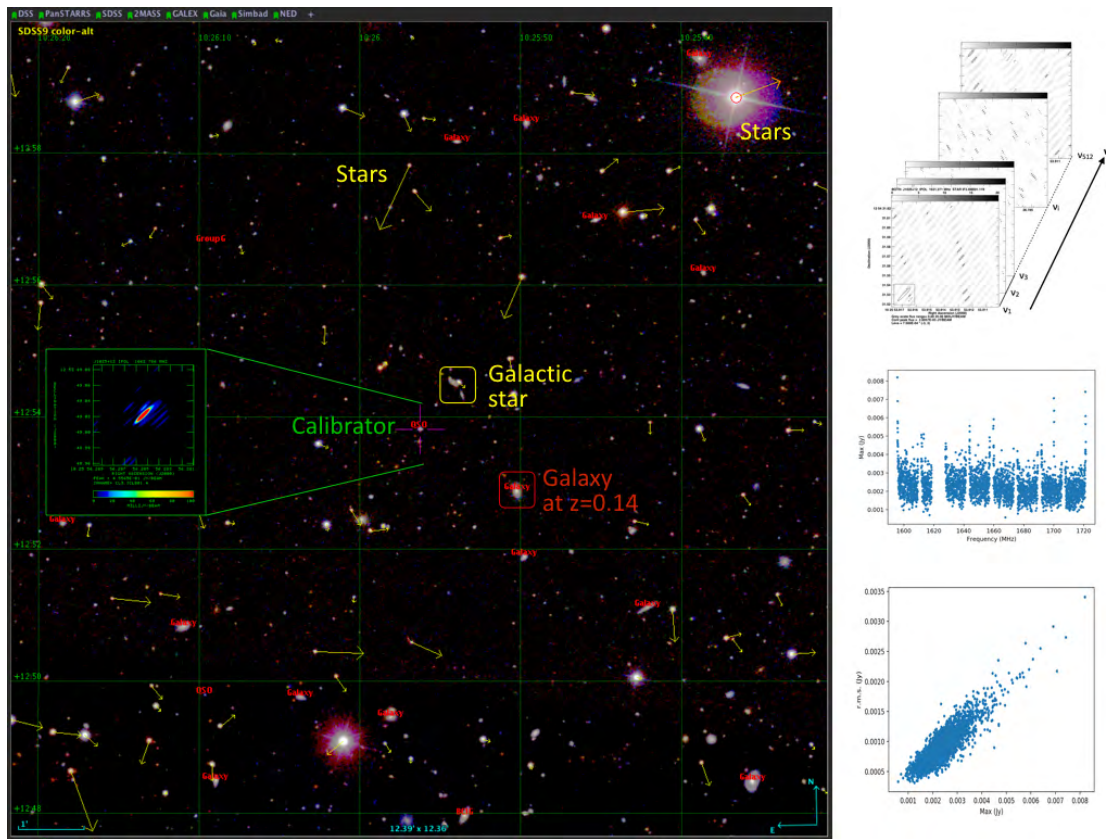
Figure 3.15: *The Sloan Digital Sky Survey (SDSS) field centred on the calibrator J1025+1253. Two targets are identified. To the extreme right, the main results of searching for peaks in the multi-channel images is presented.*

In order to get a better feel for how this might all work in practice, Garrett (2018) made use of a small subset of high-resolution data associated with EVN project ED038 - extracted from the ever useful EVN archive at JIVE. The first stage of the analysis was to subtract a bright compact calibrator. The data was then phase rotated to two targets

within the field – a galactic star located at a distance of 1 kpc and more speculatively, a galaxy with a measured redshift of z=0.14. The next step was to search the data for the presence of "narrow band" signals in both fields as a function of frequency (and time) – no signals above the 4 sigma r.m.s. noise level were detected (see Fig. 3.15). It should be noted that the data were only coarsely edited, flagging only those data known to be severely affected by gross failures e.g. off-source antennas, missing IFs etc. The data was inspected in a number of different ways – generating power spectra for individual baselines, collapsing individual baselines into a single power-spectrum, and making images of each individual frequency channels. By analysing the statistics of images generated for all available frequency channels, Garrett (2018) was able to place coarse upper limits of 3.5×10^{16} W on the galactic star and 1.4×10^{28} W (Equivalent Isotropic Radiated Power, EIRP) on the galaxy at z=0.14.

While the limits placed on the galaxy are rather large, they are not significantly in excess of the energy resources typically associated with a Kardashev Type II civilisation ($\sim 10^{26}$ W) (Kardashev 1964). If one also notes that a distributed array of coherent transmitters with excellent forward gain, could reduce this limit to much more modest levels (an array on the scale of the full SKA for example), SETI observations of extra-galactic sources (even those at cosmological distances) might not be as silly as it sounds. Finally, an e-MERLIN/EVN observation optimised for SETI can do much much better – for example, data processed by a modern software correlator can yield much higher frequency/time resolution and a larger data set could provide significantly better sensitivity limits.

Published in: Garrett (2018).

3.5 Software development

3.5.1 An automated VLBI imaging and analysing pipeline

The implementation of an automated VLBI data reduction pipeline dedicated to interferometric data imaging and analysis is presented, Fig. 3.16. The pipeline can handle massive VLBI data efficiently which makes it an appropriate tool to investigate multi-epoch multiband VLBI data. Compared to traditional manual data reduction, our pipeline provides more objective results since less human interference is involved. Source extraction is done in the image plane, while deconvolution and model fitting are done in both the image plane and the uv plane for parallel comparison. The output from the pipeline includes catalogues of CLEANed images and reconstructed models, polarisation maps, proper motion estimates, core light curves and multi-band spectra. A regression STRIP algorithm was developed to automatically detect linear or non-linear patterns in the jet component trajectories. This algorithm offers an objective method to match jet components at different epochs and determine their proper motions.
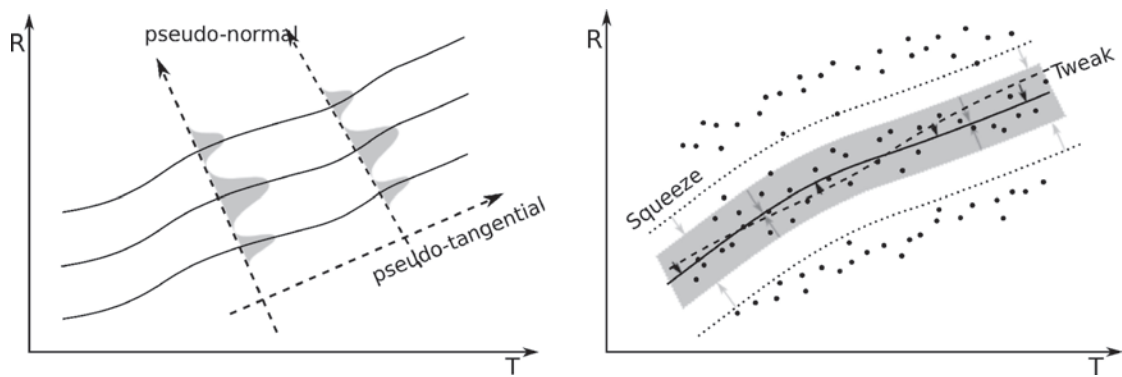
Figure 3.16: *The left panel shows the pseudo-tangential and pseudo-normal directions. The pseudo-normal direction is locally orthogonal to the pseudo-tangential direction where the pattern flows. The right panel shows the squeeze-'n'-tweak effect of the regression strip algorithm.*

Published in: Zhang et al. 2017.

4 EVN Network Operations

4.1 The EVN programme committee report

The EVN Program Committee (PC) is an independent body appointed by the EVN CBD, which carries out the scientific and technical assessment of all standard EVN, e-VLBI and global VLBI requests for observing time. The EVN PC consists of 13 voting members, 9 drawn from the EVN institutes and 4 at large representatives from other European institutes. In addition the EVN Scheduler attends PC meetings as a non-voting member. Members typically serve on the committee for a period of around 2-3 years, and are then replaced by other representatives invited by the EVN CBD. The PC membership through 2017-2018 is listed in Table 4.1, including other representatives (non-voting) who contribute to the EVN PC's.

Table 4.1: List of members of the EVN PC during 2017-2018 and their roles

Name	Institute	Role
Ivan Agudo	IAA-CSIC Granada, ES	*at-large* member
Tao An	Shanghai Observatory, CN	Member
Bob Campbell	JIVE, NL	Member and EVN corr. repr.
Danielle Fenech	Univ. of Cambridge, UK	*at-large* member from Feb. 2017
Sandor Frey	FÖMI, Budapest, HU	*at-large* member until April, 2017
Marcello Giroletti	IRA, Bologna, IT	Member until July 2017
Talvikki Hovatta	Univ. of Turku, FI	*at-large* member from Dec., 2017
Katarina Immer	ESO Garching, DE	*at-large* member until July 2017
Michael Lindqvist	OSO, SE	Member (Chair until Dec. 2017)
Andrei Lobanov	MPIfR, Bonn, DE	Member
Tom Muxlow	JBO, UK	Member
Alexey Melnikov	St. Petersburg, RU	Member
Francesca Panessa	IAPS, Rome,	*at-large* member from Dec., 2017
Antonis Polatidis	ASTRON, NL	Member (Chair between Jan. 2018-Nov. 2018)
Kazi Rygl	IRA, Bologna IT	Member (Chair from Dec. 2018)
Valeriu Tudose	ISS Bucharest, RO	*at-large* member
Alastair Gunn	JBO, UK	EVN Scheduler
Mark Claussen	NRAO,US	NRAO VLBA/VLA Scheduler
Toney Minter	GBO, US	GBO Scheduler

Table 4.2: PC Meetings during 2017-2018

Place	Institute	Period
Jodrell Bank Obs.	March 14, 2017	Trimester 17A
Bologna	June 27, 2017	Trimester 17B
Granada	November 02, 2017	Trimester 17C
Shanghai	March 20, 2018	Trimester 18A
Dwingeloo	June 30, 2018	Trimester 18B
Cambridge	November 21, 2018	Trimester 18C

4.1.1 EVN PC meetings

The EVN PC meets three times a year, typically around a month after each proposal deadline, to discuss recent proposals received, to allocate a grade to each successful proposal, and to provide detailed feedback to each PI. Meeting locations and dates for the period 2017-2018 are given in Table 4.2. All standard EVN, global VLBI and e-VLBI proposals are evaluated at the PC meetings, for observations in upcoming standard and e-VLBI scheduled sessions. 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. For the consideration of global VLBI proposals, independent grades are provided by NRAO. In addition, voting members from NRAO join the PC meetings for extended discussions (see Table 4.1). Summary comments as well as the detailed comments of each PC member are sent to the PI afterwards. Target of Opportunity proposals received outside formal deadlines are circulated to PC members by the PC Chair, grades and feedback being returned to the PI typically within a few days.

4.1.2 Proposal statistics

The EVN operates an open-sky observing policy with proposals scheduled into 3 main observing sessions per year, plus regular (monthly) additional e-VLBI days. A Call for Proposals is distributed three times a year, with proposal deadlines on 1st February, 1st June and 1st October. It is also possible to submit Target-of-Opportunity proposals. Proposal statistics from 2010 to 2018 are shown in Fig. 4.1. The total numbers of hours proposed and the EVN network hours are shown in Fig. 4.2. Since the peak in proposal numbers in 2011, the numbers of conventional proposals have subsided somewhat but the total hours requested has remained the same (with the exception of 2014 and 2016). The total network time (EVN and RadioAstron hours requested within conventional sessions) has also remained the same. The over-subscription rate for 2017-2018, (hours requested)/(EVN network hours), stands at 1.9.
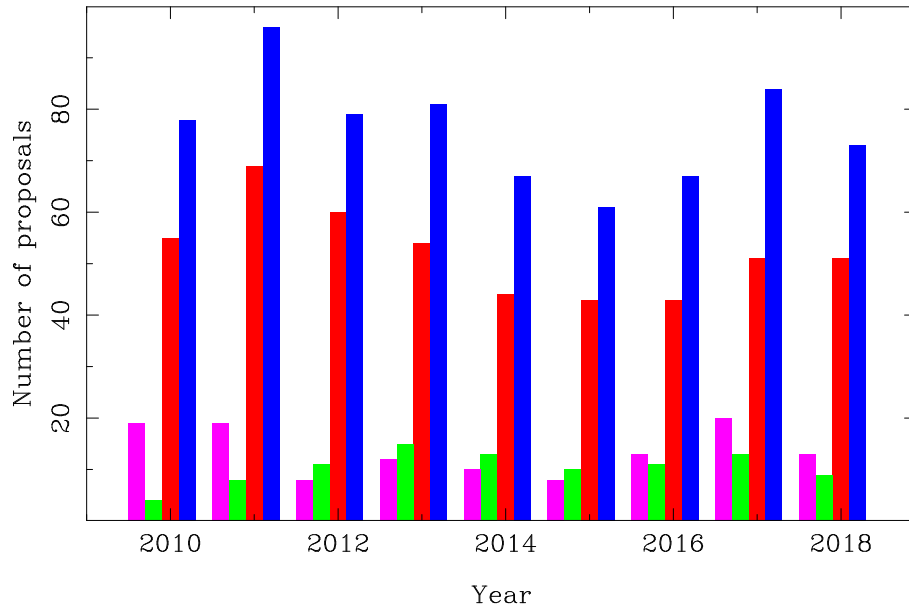
Figure 4.1: *Total numbers of proposals submitted between 2010 and 2018 (blue), subdivided into EVN alone [normal deadlines] (red), global [normal deadlines] (green) and ToO+short observations (magenta).*
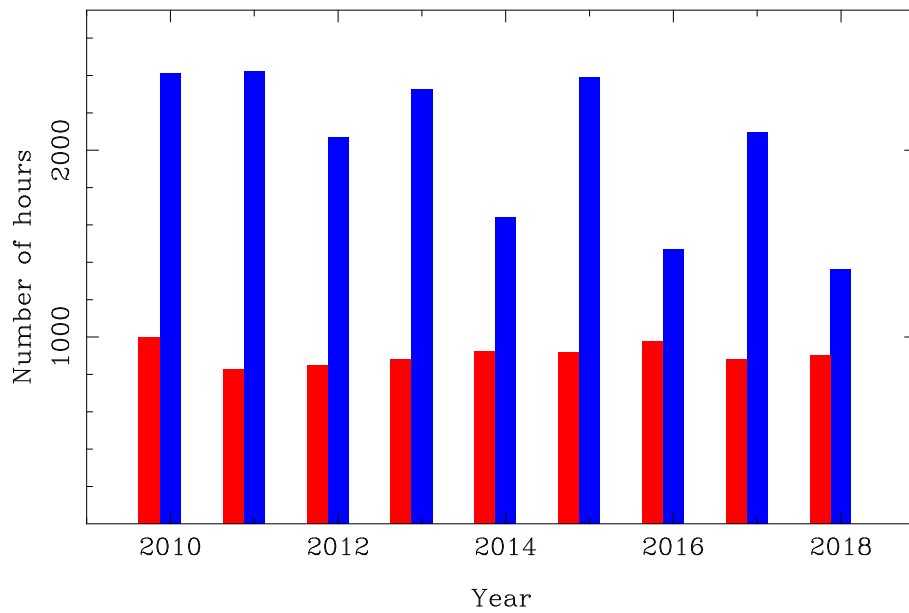
Figure 4.2: *Total number of hours proposed between 2010 and 2018 (blue) and the EVN Network hours (red).*
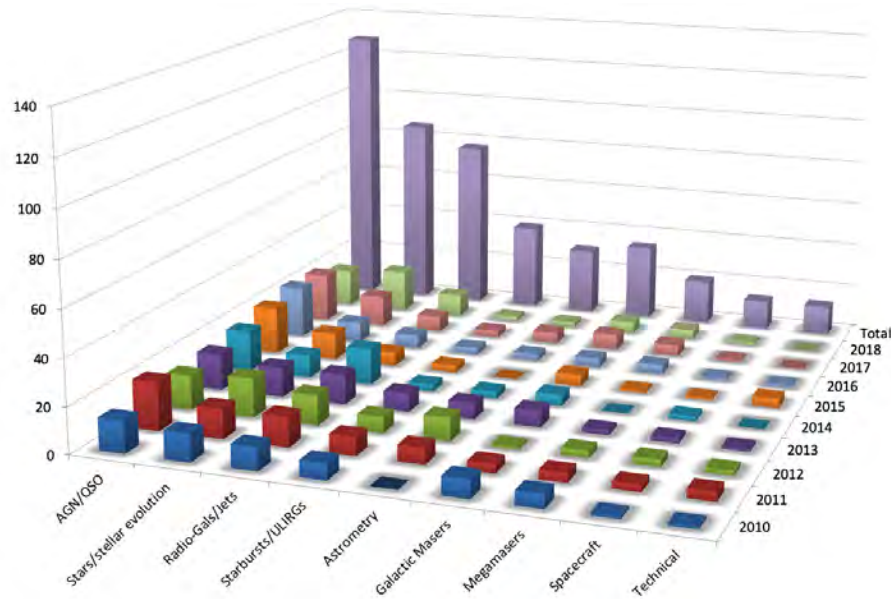
Figure 4.3: *The distribution of scientific categories for proposals submitted from 2010 to 2018.*

4.1.3 Requested science research areas and observing bands

The dominant research areas still remain those of AGN/QSO, Radio Galaxies/Jets, and Star/Stellar Evolution which account for about 70 % or more of proposals received. Thus, the research areas proposed through 2017-2018 do not differ significantly from those reported in the previous biennial reports, although there are variations between individual Trimesters (an example of a new category is Fast Radio Bursts), Fig. 4.3. The requested frequency bands are likewise dominated by these research areas resulting in large numbers of proposals requesting the 18/21 cm and 6 cm bands. However, the remaining bands are still rather populated with proposal requests, Fig. 4.4. There is a large international pool of users of the EVN and Global VLBI array which stretches significantly beyond the EVN member institutes and countries. Although the majority of PIs are based within Europe, a significant and growing number of EVN users are found worldwide.
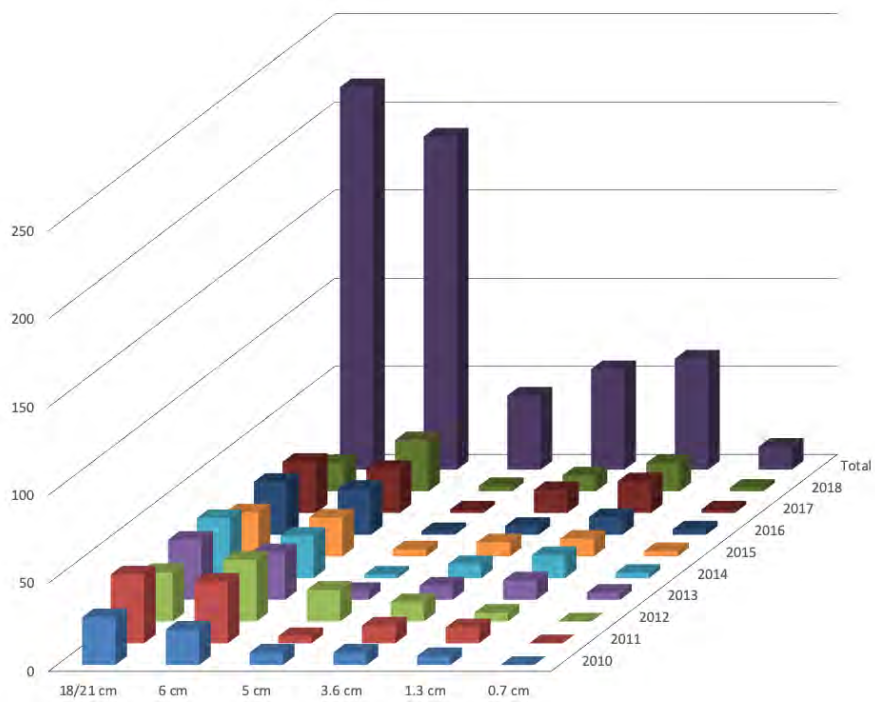
Figure 4.4: *The distribution of requested wavebands for proposals submitted from 2010 to 2018. In addition, occasionally we receive proposals also for 90 and 13 cm.*

4.2 The EVN Scheduler report

As in previous years, in each of 2017 and 2018 there were three major (disk-based) EVN observing sessions, each of three weeks duration, and ten e-VLBI runs of 24 hour duration (plus 4 hours fringe-finding time). The basic parameters of the regular disk-based sessions are summarized in Tab. 4.3 . Tab. 4.4 and Tab. 4.5 give further details of the regular disk-based EVN sessions for 2017 and 2018 respectively. Observations in each disk-based session utilised between 3 and 5 different observing bands. The efficiency (defined as the percentage of available time actually scheduled) in the disk-based sessions ranged from 33.8 to 52.0 %. This efficiency is primarily dictated by the time needed to change observing band and the demand on GST range (which is far from uniform).

Table 4.3: Summary of EVN Sessions 2017-2018

Session	Dates	Efficiency (%)	Wavelength (cm)						
			0.7	1.3	3.6	5	6	18/21	92
2017-1	23 Feb-15 Mar	33.8	✓	✓			✓	✓	✓
2017-2	25 May-15 Jun	42.1				✓	✓	✓	
2017-3	19 Oct-09 Nov	47.2		✓	✓		✓	✓	
2018-1	22 Feb-15 Mar	38.2		✓		✓	✓	✓	
2018-2	24 May-14 Jun	51.4		✓	✓		✓	✓	
2018-3	18 Oct-08 Nov	52.0	✓	✓	✓		✓	✓	

Figure 4.5 shows the distribution of EVN hours against observing band for 2017 and 2018. These figures include hours observed during regular disk-based EVN sessions, e-VLBI runs and out-of-session observations. In 2017 the total number of hours scheduled was 944.5 and in 2018 it was 1004.0. As usual, C-band and L-band observations were the most common, whilst regular and out-of-session 1.3 cm observations with RadioAstron dominate observations in 2018.

Figure 4.6 shows the distribution of observing hours against EVN station and affiliate antennas for 2017 and 2018. Of special note are the emergence of regular observations with the Sardinia Radio Telescope (Sr) during 2018 and Irbene during this reporting period, an increase in utilisation of the KVN network and the almost complete replacement of Shanghai (Sh) observations with those of Tianma (T6). Details of EVN e-VLBI observations in 2017-2018 are shown in Tab. 4.6 and details of out-of-session (OoS) EVN observations for 2017-2018 are shown in Tab. 4.7.

Table 4.4: Details of EVN Sessions in 2017, showing the number of observations, hours and TBytes scheduled, correlators used and number of observations for associated antennas.

Experiments	Session 1			Session 2			Session 3		
	#	Hours	TB	#	Hours	TB	#	Hours	TB
Total	39	170.5	1386.5	30	212.0	1459.3	28	238.0	1573.4
EVN-only	17	82.5	555.1	24	157.0	965.4	23	214.0	1261.8
Global	14	70.0	759.9	3	46.0	473.0	1	12.0	276.5
Short	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Tests	8	18.0	71.5	3	9.0	20.9	4	12.0	35.1
Correlator									
EVN	30	144.5	1137.4	30	212.0	1459.3	28	238.0	1573.4
Bonn	9	26.0	249.1	0	0.0	0.0	0	0.0	0.0
VLBA	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
eEVN	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Other	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
CAL	5	20.0	0.0	3	12.0	0.0	4	16.0	0.0
e-MERLIN	1			3			5		
VLBA	9			3			1		
VLA	4			1			0		
GBT	3			0			0		
Arecibo	8			2			3		
Robledo	10			4			3		
Goldstone	0			0			0		
RadioAstron	10			0			0		
KVN	16			0			0		
Wettzell	0			0			0		
LBA	0			1			0		

Table 4.5: Details of EVN Sessions in 2018 showing the number of observations, hours and TBytes scheduled, correlators used and number of observations for associated antennas.

Experiments	Session 1			Session 2			Session 3		
	#	Hours	TB	#	Hours	TB	#	Hours	TB
Total	26	192.5	1271.6	27	260.0	1380.2	34	262.0	1532.7
EVN-only	21	164.5	970.8	20	219.5	911.8	29	244.0	1459.9
Global	1	12.0	245.6	2	26.5	395.8	0	0	0
Short	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Tests	4	16.0	54.2	5	14.0	72.6	5	16.0	72.8
Correlator									
EVN	30	192.5	1271.6	21	231.0	1066.6	34	262.0	1532.7
Bonn	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
VLBA	0	0.0	0.0	1	15.0	241.0	0	0.0	0.0
eEVN	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Other	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
CAL	4	16.0	0.0	4	16.0	0.0	4	16.0	0.0
e-MERLIN	0			2			6		
VLBA	1			2			0		
VLA	1			2			0		
GBT	1			1			0		
Arecibo	0			0			4		
Robledo	0			0			2		
Goldstone	0			0			0		
RadioAstron	0			0			0		
KVN	3			9			7		
Wettzell	0			3			2		
LBA	1			0			0		
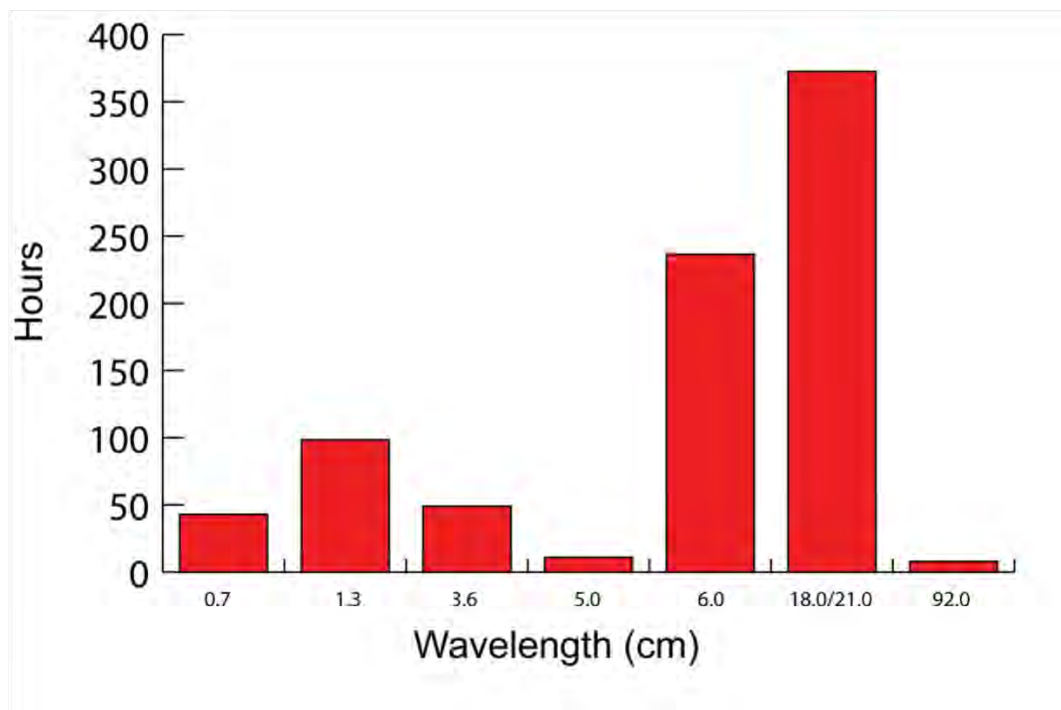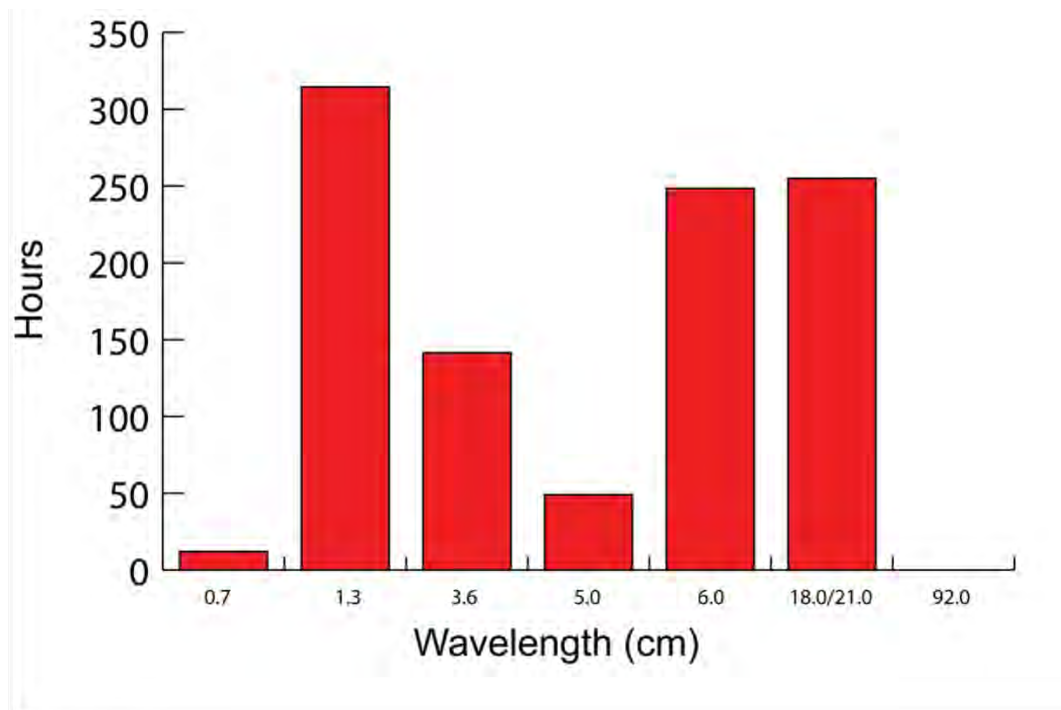
Figure 4.5: *Distribution of EVN hours against observing waveband for 2017 (bottom) and 2018 (top).*
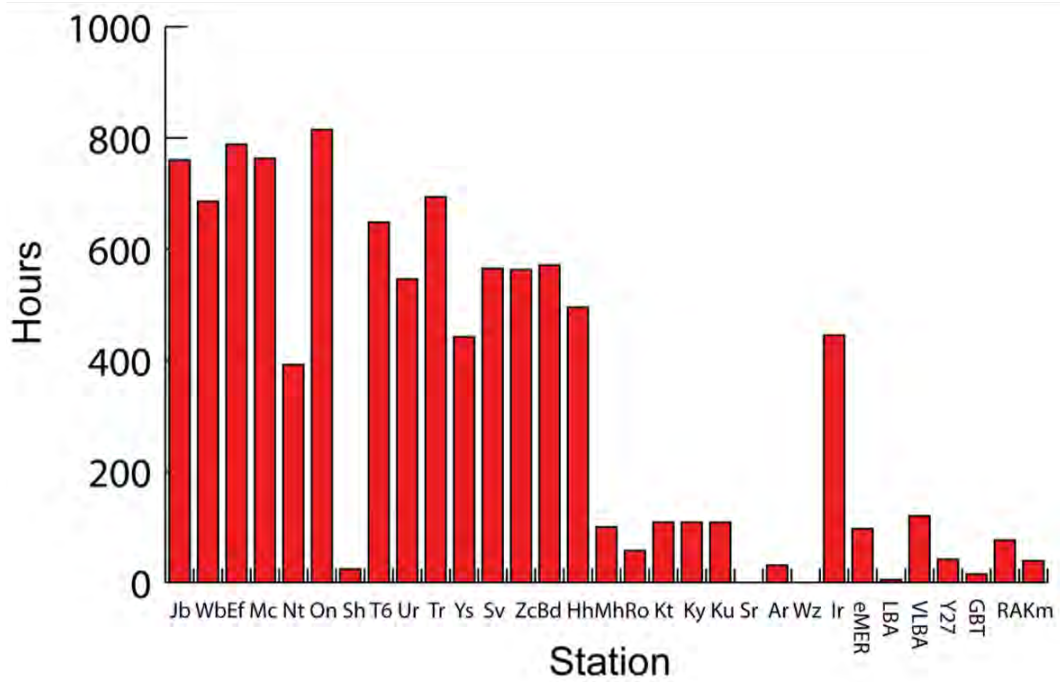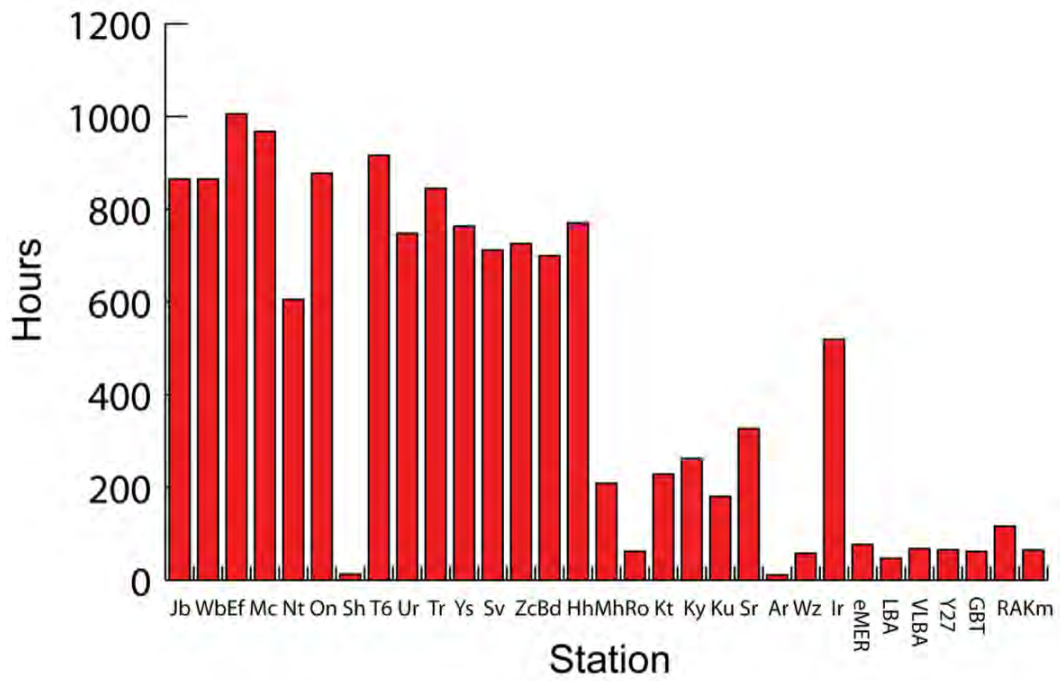
Figure 4.6: *Distribution of observing hours for EVN stations and affiliates for 2017 (bottom) and 2018 (top).*

Table 4.6: Details of EVN e-VLBI runs 2017-2018, showing dates and waveband, number of hours scheduled per run, the type of observation and the number of trigger observations scheduled and actually triggered.

Date	Band	Time	e-VLBI proposal type				
			Queued			Trigger	
	(cm)	(h)	Normal	Short	ToO	Scheduled	Triggered
2017-01-17	18.0	21.0	2	2	0	1	0
2017-02-14	6.0	11.5	3	0	0	3	0
2017-03-23	6.0	12.0	0	0	1	3	0
2017-04-11	6.0	22.0	1	1	0	3	1
2017-05-09	18.0	15.5	2	0	0	1	0
2017-06-20	6.0	19.0	2	0	0	2	0
2017-09-19	6.0	17.5	2	0	2	0	0
2017-10-10	6.0	13.0	3	0	0	1	1
2017-11-14	6.0	18.5	1	2	0	1	0
2017-12-14	18.0	23.0	2	1	0	1	0
2018-01-16	6.0	21.0	3	0	1	0	0
2018-02-06	18.0	19.0	1	1	0	1	0
2018-03-27	18.0	18.0	1	1	1	1	0
2018-04-10	6.0	27.5	1	1	2	2	0
2018-05-17	18.0	12.0	2	0	1	1	0
2018-06-19	6.0	21.5	3	1	2	2	0
2018-09-18	18.0	26.5	3	1	2	4	0
2018-10-16	6.0	16.5	2	0	1	2	0
2018-11-20	18.0	19.0	2	1	0	4	0
2018-12-04	6.0	24.0	2	1	1	3	0
Total		378.0	38	13	14	36	2

Table 4.7: Details of EVN out-of-session (OoS) observations 2017-2018 showing number of observations, hours and TBytes scheduled, correlators used and number of observations for associated antennas.

Experiments	#	2017 OoS Hours	TBytes	#	2018 OoS Hours	TBytes
Total	16	126.0	548.3	14	146.5	774.6
Correlator						
EVN	0	0.0	0.0	2	26.0	259.8
Bonn	12	68.0	548.3	11	112.5	514.8
ASC	0	0.0	0.0	0	0.0	0.0
eEVN	4	58.0	0.0	1	8.0	0.0
e-MERLIN	0			0		
VLBA	7			6		
VLA	2			6		
GBT	1			5		
Arecibo	0			0		
Robledo	7			4		
Goldstone	0			0		
RadioAstron	12			12		
KVN	4			12		
Wettzell	0			0		
LBA	0			4		

4.3 The EVN Technical Operation Group report

The TOG is in charge of the operations and technical developments of the network. It is composed by VLBI friends at the stations and personnel at the correlators. The TOG meets periodically approximately every nine months rotating the location through the different observatories. The meetings are open and are also regularly attended by non-EVN members, like the FS main developer or staff from non EVN observatories. The meetings are organized in between EVN sessions and, since 2014, every three times they precede the EVN symposium and the EVN user's meeting, looking for a direct interaction between the technical personnel and the users. Since 2016, the TOG meets together with the Global Millimeter Array (GMVA) Technical Group every other meeting. In these cases the meetings last two days, devoting one day for the TOG and another for the GTG. The goal is to exploit synergies, looking for common developments and benefiting from the exchange of information between both communities.

In the 2017-2018 period TOG meetings have been subsidized by RadioNet, as a Network Activity, within the Sustainability work package 4.1. The funds for this package are also used for partially funding trips of staff from EVN institutes that take part in the RadioNet project.

The TOG chair reports to the CBD every 6 months providing information about the EVN sessions, technical developments and any other relevant information that may help the CBD to steer the EVN. Pablo de Vicente from the Observatorio de Yebes (IGN) chaired the TOG during 2017-2018, being the vice-chair Arpad Szomoru from JIVE.

TOG Meetings: Three meetings have taken place in 2017 and 2018, for a group picture see Fig. 4.7 . Reports, minutes and the agenda are available on the EVN web site and at the RadioNet wiki page. A summary of the meeting required by RadioNet is also available publicly. The locations and dates of the meetings are as follows:

- Ventspils, Latvia. Joint GTG and TOG meeting. May 26-27, 2017. 34 attendants from 12 countries in Europe, America and Africa.

- Shanghai, China. Small overlap with the EVN programme committee. March 19-20, 2018. 42 attendants from 12 countries in Europe, America and Africa.

- Granada, Spain. Joint GTG and TOG meeting which preceded the EVN symposium. October 4-5, 2018. 36 attendants from 14 countries in Europe, America and Africa.

Figure 4.7: *Attendants to the TOG and GTG meetings in Granada in October 4, 2018.*

During this period the TOG has worked supporting and encouraging a wide adoption of 2 Gbps recording rates at the EVN stations doubling the previous recording capacity. These rates correspond to using 256 MHz bands at both polarizations and require an increase of the storing space at the stations and at the correlator. This goal has been achieved by most of the stations and surpassed by some of them.

2 Gbps recording rates are also a standard for e-VLBI. In e-VLBI observations, data are not recorded but transmitted in real time and the backends at the stations are remotely controlled by the correlator. These rates have been achieved at most of the stations. Some of the stations who have not reached such rates already have the infrastructure and will possibly take part in 2 Gbps observations in the very near future.

Table 4.8 summarizes the status of the EVN network regarding recording rates and transmission rates.

The above high recording rates have also been accompanied by the usage of disk servers, called FlexBuffs, at the stations and at JIVE correlator and high speed Internet connections to transfer the data to the correlators after the observation. There is already an automatized process for these transfers that has been defined along the TOG meetings and which allows transfers even while recording another observation. Table 4.9 summarizes the status by December 2018 at stations that use FlexBuff units. Most of them have provided a similar capacity at JIVE correlator. The storage is being constantly updated and increasing and it supports full 2 Gbps operations at the EVN.

Another important aspect of the items tackled at the TOG has been the feedback mechanism between the correlator and the stations and the presentation of results from

Table 4.8: Recording rates at EVN stations and transmission rates between the stations and the correlator. When the rate doesn't reach 2 Gbps an explanation is given in the Notes column.

Station	Recording rate (Gbps)	e-VLBI rate (Gbps)	Notes
Arecibo	2.0	0.512	Backend/Connection limits
Badary	2.0	1.7	e-VLBI to be tested
Effelsberg	2.0	2.0	
HartRAO	2.0	2.0	
Irbene	2.0	2.0	
Jodrell	2.0	2.0	
Kunming	2.0		Backend and connection limits
Medicina	2.0	2.0	
Metsähovi	2.0	2.0	
Noto	2.0	2.0	
Onsala	2.0	2.0	
Robledo	2.0		Connection limits
Sardinia	2.0	2.0	
Svetloe	2.0	0.064	Connection to be upgraded
T6 (Shanghai)	2.0	2.0	e-VLBI to be tested
Tamna	2.0		e-VLBI to be tested
Torun	1.0	1.0	Backend to be upgraded
Ulsan	2.0		e-VLBI to be tested
Urumqi	2.0	1.0	Connection limits
Westerbork	1.6	1.6	Frontend/Backend limits
Yebes	2.0	2.0	
Yonsei	2.0		e-VLBI to be tested
Zelenchukskaya	2.0	1.7	e-VLBI to be tested

Table 4.9: FlexBuff units and storage space at the stations and JIVE correlator by December 2018. Data are sent from the stations to the correlator using high speed connections.

Station	Capacity (TB)	Capacity at JIVE (TB)
Effelsberg	290	101
Hartebeesthoek	105	202
Irbene	280	253
Jodrell Bank	276	202
Medicina	360	210
Metsähovi	195	
Noto	360	253
Onsala	324	254
Sardinia	360	350
Tianma	240	
Westerbork		202
Yebes	288	253
JIVE		1223
Total	2978	3503

the correlator using a new web tool. This tool allows to examine and evaluate the quality of the amplitude calibration at all observing frequencies and also of the performance of the different stations. This allows to generate statistics of the performance of the network and trends at individual stations. Figure 4.8 shows a snapshot of the web interface for evaluating the amplitude calibration quality.

Continuous calibration is a long time pursued goal and only half of the stations have adopted it. Software has been adapted to produce a correct amplitude calibration for such case and this item has been addressed along the TOG meetings.

Other issues which have been discussed at the TOG are related to the Field System, the control software for the backends and the antenna, the compatibility of different VLBI backends and the future usage of the DBBC3 (one of the future VLBI backends). New stations to VLBI have sent representatives to the meetings to get involved in the discussions and acquire experience that eases observations.

During the 2017-2018 period fringes at 5 and 22 GHz with e-Merlin where achieved for the first time. Kuntunse at Ghana took part in several observations and these also resulted in first fringes at 5 GHz.

Figure 4.8: *Snapshot of the web interface that allows to examine the amplitude calibration quality per station, frequency band and session.*

5 EVN observatory reports, full members

5.1 ASTRON, The Netherlands Foundation for Research in Astronomy, Dwingeloo, The Netherlands

The Westerbork Synthesis Radio Telescope (WSRT) participated in all EVN sessions of 2017-2018 with a single dish. Total observing hours 2017-2018, including VLBI and e-VLBI observations, are listed in Tab. 5.1.

In general observations were successful, only a small number of hours were lost due to front end and maser issues. The WSRT also participated in RadioAstron observations at L,C and P band. On average there were 40 observations per month. In 2017 RadioAstron observations were recorded on disk packs and full disk packs where shipped to Moscow. After a disk pack got lost during shipping software was developed to semi automatically upload data to an FTP server in Moscow. For VLBI and RadioAstron the WSRT has two circular Multi Frequency Front Ends (MFFE), which have cooled receivers at 3.6, 6, 13, and 18+21 cm, and uncooled receivers at 49 cm and 92 cm, Fig. 5.1a. The MFFEs were placed in the telescopes around 1997, and components are sometimes failing but despite their age they continue to function well.

The APERTIF (APERture Tile In Focus) Phased Array Feed (PAF) antennas and receivers have been installed in 12 telescopes, Fig. 5.1b. The other 2 telescopes continue to be used for VLBI and RadioAstron with a Multi Frequency Front End. The APERTIF commissioning phase is almost finished and Apertif is now entering its operational phase. In the future, there may be possibilities for APERTIF to participate in VLBI.

Table 5.1: Total observing hours 2017-2018, WSRT

Band	Hours
L	706.75
C	638.55
P	2.0
M	68.5
X	97.75
Total	1523.55

(a)   (b)
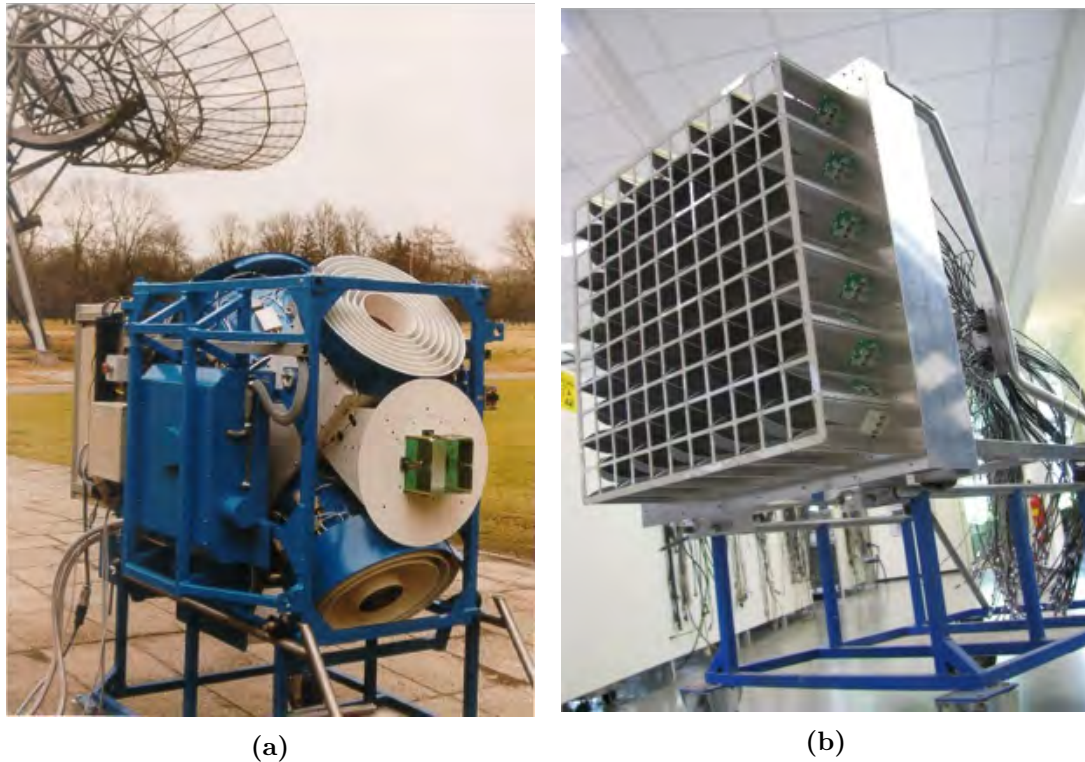
Figure 5.1: a.) *Multi Frequency Front End.* **b.)** *The APERTIF (APERture Tile In Focus) Phased Array Feed front end.*

Mid 2018 the maser went out of lock, Fig. 5.2. The manufacturer of the maser replaced the VCO. The maser was stable for a few months and then went out of lock again. Westerbork personnel is now trying to repair the maser themselves in consultation with the manufacture's system engineers.

Figure 5.2: *Inside of the maser and the signal (1.420405751GHz @-106dBm) from the physical part of the Maser.*

Since 2018 there is a FlexBuff installed at JIVE. Only one FlexBuff is needed since there is a direct fiber connection between Westerbork and Dwingeloo. In November 2017 and March 2018 Astron acquired 36 10 TB disks in order to upgrade JIVE FlexBuff

storage capacity. The DBBC was upgraded with two extra core2boards, it has now four core2boards. A Fila10g was installed to enable recording over fibre on the FlexBuff. The DBBC was also upgrade from Windows XP to Windows 7 for security reasons. EVN 2018-2 was the first session recorded on the FlexBuff.

5.2 Institute of Radio Astronomy (INAF IRA), Bologna, Italy

5.2.1 Medicina

Antenna

In the biennial 2017-18 antenna maintenance was carried out. In particular, the panels of the primary mirror were painted (see Fig. 5.3) and the rail track was replaced. Maintenance was done on the second driving wheel, too, the same maintenance of the first wheel being made in 2014. The air conditioning system of the rooms located on the antenna was substituted and the control rooms completely renovated.

Figure 5.3: *The 32 m Medicina antenna, October 2017.*

Receivers and observations

Medicina routinely observes in the 18, 21, 6, 5, 3.6, 1.3 cm bands. A dual- feed receiver is under construction in the 13.5-18 GHz band (2 cm band). A 6 cm receiver is ongoing for the SRT telescope. The receiver for Noto in the S, X and L band has been almost finalized.

VLBI back-end

The DBBC firmware versions currently in use are DDC V106 and V106E, PFB v16_11. The 2.8.1-p release of jiveab is currently installed. The FlexBuff system of Medicina has been upgraded with new disks. Now the capacity available is 360 TB. Medicina has also provided the same amount of TB for JIVE correlator.

e-VLBI

Medicina is routinely running e-VLBI experiments.

Space VLBI

Medicina participated in Radioastron observations (on average 24 experiments/month).

Field System

The workstation has been upgraded to FSL9. We?re running FS 9.11.19. The continuous calibration system is working for the Cassegrain receivers (6, 5, 1.3 cm). It was not possible to complete the same job for the Primary focus (21, 18, 13, 3.6 cm).

5.2.2 Noto

Since September 2018 the VLBI-friend is Andra Orlati.

Antenna

The telescope (see Fig. 5.4) now runs a new control software, the Enhanced Single-dish Control System (ESCS), developed in Medicina. It has been successfully tested and used for some VLBI experiment together with the Field System. The azimuth encoder was replaced. The telescope pointing has been verified and adjusted.

Receivers

The Noto antenna can, at the moment, observe at the frequencies of 2.3,5,6, and 22 GHz. The LNAs of each of the polarization of the 22 GHz receiver have been fixed. The SXL receiver on primary focus has been redesigned and under construction. We plan to mount it on antenna within the second EVN session 2019. At present the receiver at 43 GHz is under test, due to instability problems. A new cryogenic compressor has been purchased, and in the perspective to complete the frequency agility at least for C low, C high and K band new mechanical parts are planned to modify the Noto vertex room. Starting from session 3 of 2018 the hardware and the software for the continuous calibration has been installed and is now available for S, C, M and K bands.

During 2017-2018 the Noto antenna observed at the frequencies of 2.3, 5, 6, and 22 GHz. The LNAs of each of the polarization of the 22 GHz receiver were fixed. The SXL receiver on primary focus has been redesigned and under construction. We plan

to mount it on antenna within the second EVN session 2019. At present the receiver at 43 GHz is under test, due to instability problems. A new cryogenic compressor has been purchased, to complete the frequency agility at least for C low, C high and K band. Starting from session 3 of 2018 the hardware and the software for the continuous calibration has been installed and is now available for S, C, M and K bands.

Figure 5.4: *The 32 m Noto antenna.*

VLBI back-end

- The DBBC firmware version is currently DDC V105_1 and V106_E, PFB v16.

- FiLa10G firmware version 4.1.

- The Field System version is 9.11.18.

T&F

A frequency counter/timer (Keysight mod. 53230A) was purchased and installed. Software was created in order to handle the instrument and perform the measurements. The generated archive files are stored in a local disk and then transferred to the Bologna server.

RFI

A new system for RFI monitoring was developed. An Arduino card controls the rotor of a logarithmic antenna, then a LabView software acquires the power spectra in a completely automatic way. The data can be downloaded via the network, then the software plots the data in order to identify the signals that pollute the radio astronomy bands. The first measurement of the 300 MHz to 18 GHz spectrum was produced for the evaluation of the frequency bands assigned to radio astronomy

Feedback on VLBI Sessions

Session 3-2018: No fringes during C-low-band NME. The problem related to a 10 MHz cable was promptly solved during the session. The first stage LNA of the X-band receiver failed during the session. The receiver will not be available until the new one will be installed. Good fringes during K-band test and no other known problems.

- Session 2-2018: C-low-band session: good fringes and no known problems. S/X session: good fringes, no known problems. K-band session: weak fringes at the beginning of the NME, the cause was identified as being related to the positioning of the subreflector.

- Session 1-2018: C-low-band session: good fringes during the NME, C-high-band session: good fringes, no problems.

- Session 3-2017: S/X session: good fringes and no known problems. C-low-band session: good fringes. The 2 Gbps NME had a poor sampler statistics due to a wrong schedule version used at Nt. No known problems in other experiments. K-band session: Nt K-band receiver was under repair.

- Session 2-2017: FlexBuff used as primary recorder. C-high-band session: good fringes, but RCP fainter than LCP. No know problems in other experiments. Clow-band session: good fringes. EJ019A and EP103D lost in half due to a recorder problem.

- Session 1-2017: The last EVN session recorded on MK5. C-low-band session: incorrect behaviour of the recorder leads to no fringes. K-band session: good fringes but some issues related to recorder during some experiment.

5.2.3 Sardinia Radio Telescope (SRT)

Staff

From February 2017 to July 2018 the Head of Operation was Andrea Orlati. Since August 2018 to date the Head of Operation is Sergio Poppi. Since April 2017 to date the VLBI Friend at the station is Gabriele Surcis. Since April 2017 to date the VLBI Technical Friend is Carlo Migoni.

Antenna

From February 2017 to August 2017 the Sardinia Radio Telescope (SRT, see Fig. 5.5) was offline for the works on the primary mirror (painting) and active surface system. During this maintenance period the whole instrumentation, including the maser, the DBBC and the MARK5C, was moved into the new buildings and shielded room. The re-commissioning of the whole time-frequency apparatus was concluded successfully by the end of 2017. The system tests, calibration, and re-commissioning of the antenna after the heavy maintenance of the active surface system, started in September 2017, is still ongoing and its conclusion is planned by March 2019. The deployment of the 1 Gbps optical fiber cable was done in January 2018 and its extension to the 10 Gbps fiber link was done on the 29th of December 2018. A test has been planned for the beginning of January 2019. The FlexBuffs units (one at JIVE and one at SRT, of 360 Tb each) were purchased and delivered to JIVE (November 2018) and SRT (December 2018). We expect to have everything installed and fully operational in session 1/2019. The hardware required to implement continuous calibration (80 Hz) is ready. We plan to install and test the system sometime within next months. The first single-dish call of proposal after the maintenance of the active surface was released in September 2018 (deadline 9th of October 2018) and the observations started on the 11th of December 2018 and will finish in May 2019.

Figure 5.5: *The Sardinia Radio Telescope, SRT.*

Receivers

The L/P-, M-, and K-band receivers are fully operational. New receivers are now under development/construction:

- dual pol, single feed, C band. Advanced status.

- dual pol, 5 feeds, S band. Advanced status.

- dual pol, 19 feeds, Q band. Under development.

Firmware and softwares

- Field System: 9.11.19

- DBBC: DDC (106 and 106E), PFB (16)

- Fila10G: v4

- Jive5ab: 2.9.0

EVN session

The Sardinia Radio Telescope started again its participation into an EVN session from Session 01/2018, when it successfully took part to the Network Monitoring Experiments N18M1 and N18K1, and to all user experiments of the M-band block. The antenna fully took part to the EVN Sessions 02/2018 and 03/2018, at L- and K-bands (M-band was not scheduled during these two sessions).

e-VLBI

A successfully fiber connectivity test (max transmission at 800 Mbps) with the JIVE has been made in mid-April 2018, and the Sardinia Radio Telescope took part at 512 Mbps during the e-VLBI observing sessions: 18-19 September 2018 and 21-21 November 2018 (both at L-band).

RadioAstron

The observations were restored on June 2018, 1st. We regularly take part to the PI observations as monthly agreed at L-, P-, and K-band.

5.3 Institute of Applied Astronomy (IAA), St. Petersburg, Russia

The Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) has three radio astronomical observatories – Svetloe near St. Petersburg, Zelenchukskaya in the Northen Caucasus and Badary in the Eastern Siberia. These observatories with

the IAA Correlator Center in St.Petersburg form the Russian VLBI network "Quasar". The main purposes of the network is to conduct astrometric VLBI observations to obtain the Earth rotation parameters. Observatories also participate in joint and single astrophysical research. Each station equipped with at least three co-located techniques:

- 32 m radio telescope RT-32 (Sv, Zc, Bd);

- 13 m VGOS radio telescope (Sw, Zv, Bv);

- GNSS, SLR and DORIS (in Badary) systems.

Construction of the RT-13 radio telescope (Sw) in the Svetloe observatory was finished in late 2018, 5.6. Currently, the installation and configuration of the receiving equipment of the radio telescope is in progress. In 2019, test radio observations with three VGOS radio telescopes are planned.

Figure 5.6: *RT-13 radio telescope in the Svetloe observatory.*

5.3.1 Personnel

Dmitry Ivanov (Director), Alexey Melnikov (PC member), Andrey Mikhailov (Technical friend), Mikhail Kharinov (VLBI friend and Scheduler).

5.3.2 Observations

During the period 2017-2018 the "Quasar" network performs astrometric and astrophysical VLBI observations on domestic (IAA weekly 24 h EOP and daily e-VLBI 1 h UT sessions) and international programs.

The 32 m radio telescopes Sv, Zc and Bd participated in six EVN sessions at L, C, X and K bands with total duration about 126 days. In addition, the "Quasar" network radio telescopes has been used for 24h IVS experiments: Sv – 62, Zc – 78, Bd – 80 days. Also, a total of about 17 days of telescopes time was scheduled for RadioAstron observations, not included in EVN schedules. Observations on other programs took approximately Sv – 35, Zc – 30, Bd – 35 days.

5.3.3 Receivers

All RT-32 radio telescopes are equipped with the L, S, C, X and K bands receivers. At Bd the S-band receiver was replaced on a new one in February 2017. X-band LCP-channel and S-band LCP-channel receivers was recovered in June 2018. At Zc the new C-band two-channel receiver was installed in October 2017. At Sv the L-band receiver was replaced with a new one during 5-7 February 2017. C-band LCP-channel cryogenic system was replaced in 7 March 2017, after its fail.

5.3.4 Data recording and transport

IAA provides 160 TB (8 TB ×20)) for the EVN disk pool. A new 80 TB (10 TB ×8) was provided for the FlexBuff for JIVE correlator in October 2018. The network interfaces of Mark5B+ recording systems at Zelenchukskaya and Badary observatories have been updated to 10 Gbps in 2017. Today, data transfer rates between observatories and JIVE are 1.75 and 1.53 Gbps correspondingly.

5.3.5 IAA correlator center

The main goal of IAA Correlator Center is processing radio astrometric and astrophysical observations obtained at the "Quasar" network. At present, 3 correlators are involved in this processing: ARC, RASFX, and DiFX. The ARC is the main data processing instrument in the IAA Correlator Center for the domestic UT and EOP determination. The ARC was designed and built in the IAA RAS in 2009. The RASFX near-real time software correlator was developed in 2014 and used for regular VGOS data processing. The RASFX is capable of simultaneous processing data streams from six VGOS-compatible radio telescopes with a maximum data stream up to 96 Gbps. RASFX correlator has been performing data processing up to six 1 hour sessions from Zelenchykskaya-Badary RT-13 baseline for the UT1-UTC estimation for last two years. DiFX software correlator was installed in 2011 and is currently used for astronomical radio observations data processing.

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

Jodrell Bank Observatory performed a total of 151 regular EVN experiments during 2017-2018. Sixty-two experiments at 18/21 cm, 42 at 6 cm, 8 at 5 cm, 36 at 1.3 cm and 3 at 92 cm were scheduled to use Jodrell Bank's Lovell and Mk2 antennas. During this period, sixteen of the EVN experiments were joint e-MERLIN projects, although none were observed simultaneously due to the ongoing efforts to assimilate e-MERLIN into the EVN.

A total of 1075.5 h of telescope time was scheduled for regular EVN observations during 2017-2018. This consisted of 202 h on the Lovell and 873.5 h on the Mk2 telescope. In terms of waveband this was 488 h at 18/21 cm, 270.5 h at 6 cm, 60 h at 5 cm, 249 h at 1.3 cm and 8 h at 92 cm. The total reported data loss at the telescope for 2017-2018 was 40 h 20 m (3.7 %), i.e. a success rate of 96.3 %. JBO also contributed 272.5 h of observing time to out-of-session experiments (mostly EVN+RadioAstron observations) and a further 374.5 h of observing time for 20 regular e-VLBI observing sessions during 2017-2018.

Normal technical operations have run relatively smoothly during this reporting period. Common reasons for data loss during this period were high winds, disk recorder problems, failure of the OTCX antenna control computer, power glitches and servo faults.

During this reporting period Paul Burgess, our technical support specialist, retired from JBO. Eskil Varenius joined the National Facility support team and took over many of these responsibilities. Simon Garrington represented JBO at EVN CBD meetings and on the JIVE board. Throughout this period Tom Muxlow was the JBO representative on the EVN PC and Alastair Gunn continued to serve as the EVN Scheduler.

e-MERLIN stations are now available to routinely join the EVN in both recorded and real-time (e-VLBI) VDIF observations at 512 Mbps. The e-VLBI session in September 2018 was an important milestone where e-MERLIN stations participated in a full 24 h e-VLBI-run. Since then e-MERLIN stations have, for testing purposes, successfully taken part in multiple recorded and real-time science observations under shared-risk mode. Notable improvements during 2018 include hardware and software modifications to the WIDAR correlator, as well as development and testing of recording modes and observing procedures.

Multiple changes in the RF signal chain feeding the Jodrell DBBC have resulted in significant improvements (approximately a factor of 3 in signal-to-noise) of Mk2 and Lovell VLBI data, as well as a more uniform response across the band. This new setup is used in all VLBI observations since May 2018.

Continuous system temperature monitoring has been commissioned for both the Mk2 and Lovell telescopes when controlled from the Field-System (FS). Following various developments, both telescopes have been verified to provide continuous values within the 10 % uncertainty desired in the EVN. E-MERLIN out-stations are not yet able to monitor system temperatures, but work is ongoing to enable this both for e-MERLIN-stand-alone and EVN+e-MERLIN data.

From EVN Session I 2018, JBO has moved from disk-pack recording to FlexBuff recording of all observations. This significantly simplifies data transport and enables faster transfer of data to JIVE for correlation. In addition to one machine with 202 TB RAID storage space at JIVE, we currently have 488 TB of available recording space at JBO, spread across three machines. This is sufficient to allow higher data rates for standard Mk2 and Lovell observing, as well as e-MERLIN out-station data for many experiments. Our investment in EVN storage is now directed solely towards FlexBuff storage.

The JBO-JIVE link has been upgraded to allow 4.5 Gbps real-time observations across a 10G fibre interface. This allows for standard EVN e-VLBI observations at 2 Gbps (and higher) bitrates, as well as data from e-MERLIN out-stations in e-VLBI mode.

Pointing accuracy has been improved significantly for all telescopes. The RMS pointing error across the sky is now 10-20 arcseconds at 6cm for all telescopes, including the Lovell Telescope. This significantly improves the signal quality for observations at wavelengths ¿18cm. In particular, the Lovell is now performing well in e-MERLIN and VLBI observations at 5cm and 6cm.

The VLBI timing system has been changed, with better reliability and logging of the JBO maser time as a result. In addition, a new maser has been delivered to the observatory which should, following final commissioning, further improve the quality of timing signals and logging.

5.5 Max-Planck Institut für Radioastronomie, Bonn, Germany

The Max-Planck Institut für Radioastronomie (MPIfR) was a founding member of the EVN and played a full role in all EVN activities in the period 2017–2018. Its 100 m telescope in Effelsberg is a crucial element of many EVN observations due to its very high sensitivity and wide range of observing frequencies (see section 5.5.3). The MPIfR Correlator Centre, a joint facility of the MPIfR and the German geodetic VLBI community (see section 5.5.4), continues to play a role for some EVN projects, notable those involving the Russian space–VLBI project RadioAstron.

5.5.1 MPIfR staff involvement in EVN activities

EVN CBD: Prof. J. Anton Zensus attended meetings. Uwe Bach attended the final meeting in November 2018 as incoming TOG Chair for 2019.

EVN PC: Andrei Lobanov attended meetings as the MPIfR representative, and was Secretary of the Committee.

EVN observations in Effelsberg: Uwe Bach was the "VLBI Friend" at Effelsberg, responsible for the execution of EVN observations.

EVN correlation at MPIfR: Walter Alef was Head of the MPIfR Division of VLBI Technology, which is responsible for the MPIfR Correlator Center and VLBI technical

developments. Helge Rottmann took over as Head of MPIfR Correlator Operations in 2018. Gabriele Bruni, Rebecca Azulay and Mikhail Lisakov were responsible for the correlation of EVN–RadioAstron projects. Jan Wagner modified the DiFX correlator software to support correlation of RadioAstron "closed–loop" observations made after the on–board H–maser failed in 2017.

EVN TOG: Walter Alef, Uwe Bach and Helge Rottmann attended TOG meetings. Uwe Bach becomes the new TOG Chair in 2019.

5.5.2 MPIfR staff involvement in other VLBI activities

VLBA, HSA and RadioAstron: Alex Kraus, as Effelsberg Scheduler, coordinates joint observations with these facilities. Olaf Wucknitz was a member of the RadioAstron Program Evaluation Committee (RPEC) in 2017 and 2018.

GMVA: The organization of the Global 3 mm VLBI Array (GMVA) is lead by MPIfR staff. Thomas Krichbaum, in conjunction with GMVA PIs, made the integrated, detailed observing schedule for each session, and organized observing support at Effelsberg and IRAM. Richard Porcas, as European GMVA Scheduler, organized the dates of observing sessions (including the participation of ALMA), administered GMVA proposal review, and planned the Block Schedule for sessions. (Eduardo Ros takes over this role in 2019.) Walter Alef, as Head of the GMVA Technical Group (GTG), was responsible for overseeing technical aspects of the GMVA, in particular issues of recording compatibilities between the GMVA and ALMA. Walter Alef and Helge Rottmann participated in the ALMA phasing project (APP). Helge Rottmann supported observations at Pico Veleta and ALMA. Alessandra Bertarini and Yurii Pidopryhora oversaw the correlation of GMVA data at the Bonn correlator.

EHT: Anton Zensus is Chair of the Event Horizon Telescope (EHT) Consortium. Eduardo Ros is the Executive Secretary of the Council. Thomas Krichbaum is a member of the EHT Science Council. Alan Roy lead the "VLBI at APEX" project, and was responsible for equipping the APEX telescope for VLBI observations with the EHT at 1 mm, and for making observations. Jan Wagner oversaw the correlation of EHT observations at the MPIfR correlator.

5.5.3 Effelsberg station report

Activities during 2017–2018

About 30 % of the observing time at Effelsberg is used for VLBI observations. Most are astronomical observations with the EVN, High Sensitivity Array (HSA), GMVA or other global networks, but a few geodetic VLBI observations for the IVS are also made. Since 2011 the Russian Astro Space Center has been operating a 10 m space radio antenna on board the satellite SPEKTR–R (RadioAstron project) to perform VLBI observations. Effelsberg is highly involved in the ground–based support of this mission.

In 2017 two long periods of downtime were caused by maintenance of both the azimuth track and the roll bearings of the azimuth wheels. The maintenance of the track had been planned for some time, after it had suffered a crack, originally in 2009. A provisional repair worked well, but the foundation suffered over the years and proper welding became necessary. The azimuth track was repaired between April 5th and May 11th, 2017 and caused operational restrictions; only a small number of observations could be performed in a limited azimuth range. After May 11th the observatory resumed normal operation. More unexpectedly, two of the roll bearings of the azimuth wheels broke, in July and September 2017. On both occasions an external company was needed to help with the repair. The repairs were completed within a few days with little down time, but only because the required tool provided by the company was available. The Effelsberg workshop has now bought its own tool for future repairs, so that they can be done independently and at any time. The bearings are about 30 years old; in total there are 64 (two for each of the 32 wheels). The bearings are now checked regularly for degradation.

After a long transition phase of about 2 years all receivers and frontend devices have been upgraded to a new control infrastructure, the so called InteRCoM (Integrated Receiver Controlling and Monitoring). The old receiver control system DÜSY (DigitalesÜbertragungsSYstem) was successfully used in Effelsberg for more than 40 years but discontinued components, new technologies in digital data communications and increasing requirements for control and monitoring receivers made it necessary to develop a replacement. The InteRCoM consists of a central server and controller cards that are installed in every frontend device. The server communicates to each device via Ethernet. Thereby all the controlling hardware has moved closer to the receiver and significantly reduces the signal path. The new components are RFI shielded, have real–time capabilities and the central server includes a timing generator which produces the blank/sync signal to switch noise diodes and calibration cycles in the backends. In addition the InteRCoM controller cards provide their own digital continuum backend for every receiver. Because of this modular and extendable concept, the integration could be done in parallel with full operation and new components can easily be integrated in the future. The local antenna control software was also upgraded and adapted to the InteRCoM. It now provides a large set of pre–defined settings for each receiver and observing mode to simplify access for the general observer.

In March 2018 a new Q–band receiver was installed in the secondary focus. It is a two horn system and provides a tunable frequency range of 33–50 GHz with an IF bandwidth of 4 GHz. Commissioning of the receiver is finished and the system performance is very good. It provides a factor two better SEFD than the old receiver, ranging from $\sim$100 Jy at 33 GHz to $\sim$150 Jy at 50 GHz. In Autumn 2018 a VLBI fringe test was organized between Effelsberg, KVN, Tianma (Shanghai) and Yebes to test the new Q–band receivers at Effelsberg and Tianma. Good fringes were found between all stations and proved that the new receivers work well. The new Q–band receiver at Effelsberg is now officially available for science observations (see Fig. 5.7).
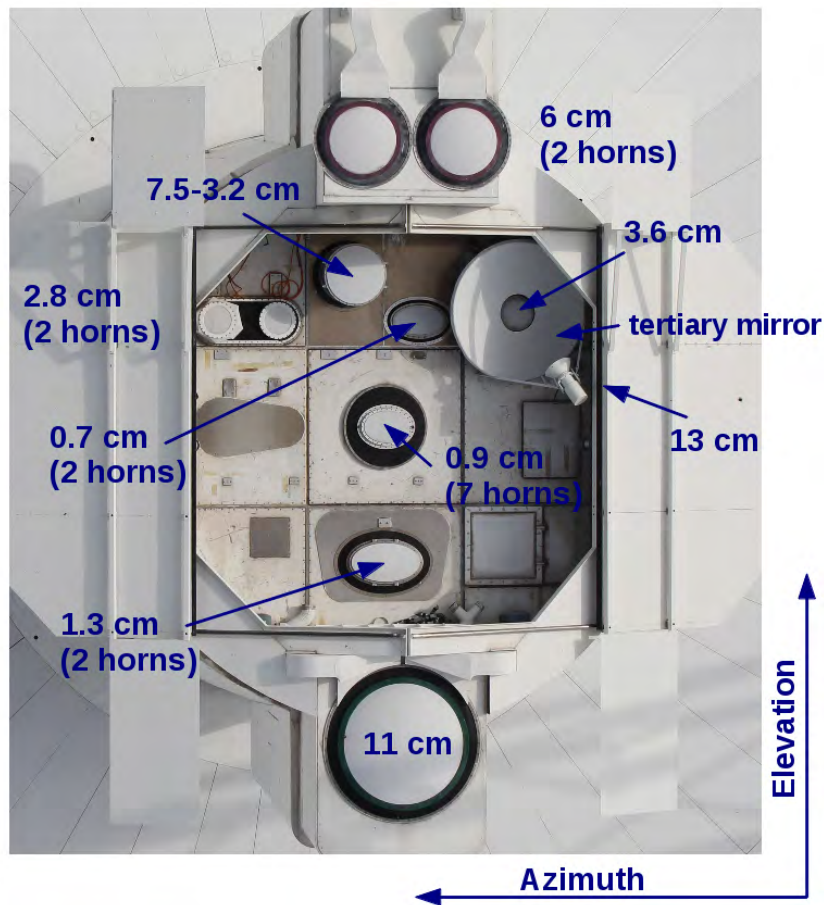
Figure 5.7: *Effelsberg secondary focus receivers. The new Q–band receiver is labelled "0.7 cm".*

Current VLBI Status

The equipment for VLBI data acquisition has reached a stable configuration and within the last two years only minor software development was performed. Observations to be correlated in Socorro are usually observed with the NRAO RDBE backends and recorded on a Mark5C recorder; the disks are then shipped to Socorro. All other VLBI observations are performed with the DBBC2 backend and recorded on Mark6 recorders. These are used in a RAID configuration and the diskpacks are not usually sent to the correlator; instead the recorded data is e–transferred via the e–VLBI network to the correlators in Bonn, at the ASC in Moscow, and JIVE. The two recorders currently provide a total local storage capacity of 390 TB. For storage of Effelsberg EVN data at JIVE the MPIfR also provided a 110 TB RAID system for JIVE.

Future Plans

For safety reasons the disk modules of one of the Mark6 recorders are currently configured as a RAID 5, so that a disk failure should not cause any loss of data. The performance is still being monitored, but the system seems to run stably with recording rates up to 8 Gbps.

NRAO is planning a VLBA upgrade in 2019 to allow 4 Gbps recording using Mark6 recorders; Effelsberg will then switch to using Mark6 recording for HSA observations. Because Effelsberg has two Mark6 recorders, using Mark6 for both disk module shipments and as a FlexBuff should not be a problem.

A new H–maser has been purchased for Effelsberg from T4 science. It is currently being commissioned and monitored against the old maser. Once the new housing and infrastructure to distribute the timing signals within the institute are completed it will become the standard time and frequency reference for Effelsberg. The new maser was necessary because the previous (much older) back–up maser broke down in 2017.

5.5.4 Bonn correlator report

The Bonn Correlator is operated jointly by the MPIfR and the German Federal Agency for Cartography and Geodesy (BKG). Correlator time is shared roughly equally between astronomical and geodetic projects. The main astronomical focus lies in the correlation of mm–VLBI observations made using the GMVA and EHT. The correlator is also used to process some EVN–RadioAstron observations (see Table 5.2).

DiFX

All VLBI observations are processed using the DiFX software correlator running the latest stable version (currently DiFX–2.5.2). A special branched version exists for correlation of RadioAstron observations (DiFX–RA–1.0.0). A number of new features were developed by the MPIfR during the reporting period, most notably the so–called "band–stitching" mode. This new mode allows correlation of non–matching sub–bands recorded at different stations, e.g. the overlapping 62.5 MHz–wide ALMA sub–bands. Band–stitching is now routinely used for correlation of GMVA+ALMA experiments. Implementation of the native Mark6 mode has now been completed, which allows direct correlation from Mark6 modules.

Correlation cluster

The correlation is performed on a HPC–cluster which consists of 68 nodes, each with 20 cores (= 1360 cores). Three head nodes allow execution of several correlation jobs in parallel. The cluster interconnect is realized via 56 Gbps Infiniband.

Data playback and storage

The number of Mark6 playback units has been increased to 9 to match the number of stations in the 2019 EHT array. 15 Mark5 units are available for playback of Mark5

Table 5.2: EVN–RadioAstron observations in 2017–2018 to be correlated in Bonn

EVN code	Project	λ	Observing date
GG081C	KSP AGN & Jets	1.3 cm	2017–03–07
GG081D	KSP AGN & Jets	1.3 cm	2017–03–08
GG081E	KSP AGN & Jets	1.3 cm	2017–03–08
GG081F	KSP AGN & Jets	1.3 cm	2017–03–08
GG081G	KSP AGN & Jets	1.3 cm	2017–03–09
GG081H	KSP AGN & Jets	1.3 cm	2017–03–09
GG081I	KSP AGN & Jets	1.3 cm	2017–03–09
GG081J	KSP AGN & Jets	1.3 cm	2017–03–09
GG081L	KSP AGN & Jets	1.3 cm	2017–03–13
GR039	GOT Gravitational lens S5 B0615+820	18 cm	2017–03–21
GG083A	KSP AGN & Jets	1.3 cm	2017–10–08
GG083B	KSP AGN & Jets	1.3 cm	2018–01–15
GG083C	KSP AGN & Jets	1.3 cm	2018–01–31
GG083D	KSP AGN & Jets	1.3 cm	2018–02–08
GG083E	KSP AGN & Jets	1.3 cm	2018–04–22
GG083F	KSP AGN & Jets	1.3 cm	2018–04–23
GG083G	KSP AGN & Jets	1.3 cm	2018–04–24
GG083I	KSP AGN & Jets	1.3 cm	2018–04–26
GG083J	KSP AGN & Jets	1.3 cm	2018–04–26
GS042	KSP M87	1.3 cm	2018–05–14
EB065	GOT Cygnus A	1.3 cm	2018–09–12

modules of all flavours (A,B,C). All Mark5 units are running SDK9.4. The correlation cluster has a total storage capacity of 1.3 PB, mostly used for storage of station data e–transferred over the internet. All cluster RAID servers were recently combined into a BeeGFS parallel file–system of 1.3 PB capacity. This has simplified the data access and has greatly reduced maintenance and bookkeeping efforts for the correlator staff.

E–transfer

E–transfers to and from the Bonn correlator are now realized via a central, single point–of–access e–portal server. The aim is to reduce the operational efforts at the stations, which previously were forced to first identify suitable storage areas on the various MPIfR RAID–servers and also maintain routes and logins to all these systems. The default transfer method is jive5ab; for exceptional cases tsunami can be used.

Data playback and storage

Due to the ongoing transition from Mark5 to Mark6 recorders at the stations, no additional Mark5 disk modules were purchased in 2017–2018. Instead 80 Mark6 modules were acquired by the MPIfR, mostly for EHT use.

5.5.5 Technical developments

DBBC2

The Digital Base–Band Converter VLBI backend DBBC2 has become the workhorse backend for the EVN and IVS. The DBBC2 was developed in a collaboration between the MPIfR and INAF/Noto and has been produced and sold by HAT–Lab, an INAF spin–off company.. About 30 units had been deployed in the field by the end of 2018.

The DBBC2 is one of the most important technical advances for the EVN in the last few years. The hardware, firmware and software have been enhanced continuously for improved reliability and increased performance. The most recent example is the 4 Gbps mode with 512 MHz contiguous bandwidth without sub–bands for GMVA compatibility with ALMA. The EVN move towards 2 and 4 Gbps recording and switching to stationary RAID recorders (FlexBuff) also depend on further parts and firmware developed in this project.

DBBC3

The main focus in the last two years for the development of the DBBC3 backend has been the DDC (Digital Down Conversion) and OCT (Octopus) observing modes. DDC allows the arbitrary selection of up to 16 tunable bands per IF with selectable bandwidths of 64, 32, 16, 8 and 4 MHz. With up to 8 IFs per system this allows up to 128 BBCs in one DBBC3. The DDC_V mode (VGOS) has been extensively tested by the MPIfR development team and by staff of the Onsala Space Observatory and is now used in the field for VGOS observations.

The OCT mode provides for the selection of up to two sub–bands per IF with bandwidths of 512, 1024 and 2048 MHz. The OCT_D (double filter) mode in the configuration with 0–2048 MHz and 2048–4096 MHz was developed to provide full compatibility with the R2DBE backend and was extensively tested for use in EHT observations.

Modifications to the analog conditioning modules of the DBBC3 have reduced the slope across the 4 GHz input band to less than 5 dBm, thus significantly increasing the sensitivity in the high frequency part of the band.

BRAND

The BRAND wide–band receiver is being developed with support from the European Union's Horizon 2020 research and innovation programme as a part of RadioNet. Its continuous frequency range from 1.5 to 15.5 GHz makes it a scientifically extremely interesting development for radio astronomy. It also covers the VGOS frequencies and even extends them to lower and higher frequencies. The project started in January 2017 and will end in summer 2020. It is a collaboration of INAF/Noto, MPIfR, OAN, OSO, ASTRON and VUC.

The BRAND prototype receiver will be installed at the Effelsberg 100 m telescope in 2020. The project will also research solutions for secondary–focus antennas, where

a promising candidate is the Japanese Ninja feed. The aim is to equip as many EVN telescopes as possible with a BRAND receiver in the next decade.

At the end of 2018 a feed horn, LNA, and HTSC filters were ready. Work on the digital part has been progressing well. 14 GHz–wide samplers have been procured and the FPGA processing boards have been designed. The firmware already consists of more than 100,000 lines of VHDL code for band reconstruction and band selection. In the first two years of the project no major obstacles were encountered.

5.6 National Astronomical Observatory (OAN), Instituto Geografico Nacional, Madrid, Spain

The Observatory of Yebes takes part in the EVN since the 90s but in 2008 its role became more important with the addition of the 40 m radio telescope to the network, Fig. 5.8. The 40 m radio telescope is the flagship of the Observatory which also runs the 13.2 m RAEGE radio telescopes, one of which is located at Yebes. The 40 m RT is a crucial element of the EVN due to its sensitivity and reliability. Below we summarize the status of the telescopes and the technical activities.

Figure 5.8: *The 40 m radio telescope observing at dawn*

5.6.1 Staff involved in EVN activities

- EVN CBD: Rafael Bachiller attends regularly to the board of directors on behalf of the IGN (Observatory of Yebes).

- EVN TOG: Pablo de Vicente has been the TOG chair between 2015 and 2018 and he has also been the technical VLBI representative of the Observatory of Yebes until mid 2018. Javier González has taken over this role since October 2018 (TOG meeting in Granada).

- EVN technical support. Pablo de Vicente, Javier González and Laura Barbas have formed the technical team to support VLBI operations at Yebes since many years ago until mid 2017. Since July 2017, the direction of the Observatory changed and this affected the VLBI operations management: the team was composed then by Javier González in charge of all VLBI operations, hardware and software, and Francisco Beltrán on general software related to the 40 m radio telescope and VLBI calibration (ANTAB scripting). There is also a team of engineers and operators who provide support on receivers and mechanics of the antenna.

5.6.2 VLBI observations at Yebes

The 40 m RT has devoted a total of 1893 h of its time to VLBI observations in 2018 and 2393 h in 2017. This is 39 % and 49 % of the observed time respectively. The time devoted to VLBI observations is distributed in different networks: EVN, GMVA, IVS, Radioastron, KVN and others. The number of hours and observations per network is summarized in Tab. 5.3.

- EVN. There are three periods per year three weeks each plus e-VLBI sessions, target of Opportunity observations and shared observations with Radioastron. Observations are performed at 2, 5, 6, 8, 22 and 43 GHz.

- Global Millimeter VLBA Array (GMVA). Two weekly sessions per year. These observations are performed at 86 GHz and use the same backends as the EVN. The current 86 GHz receiver only has one circular polarization and it will be replaced by a new wide band one with double polarization in early 2019.

- International VLBI System (IVS) observations. A large fraction of the telescope time is devoted to such observations at 2 and 8 GHz. Typically there are 24 sessions 24 hours each along the year. However every 3 years there is a CONT campaign which requires 14 contiguous days to be added to the standard schedule.

- KAVA: KVN + VERA. These observations are adhoc and happen during some days per year. They are performed at 22 and 43 GHz simultaneously, Fig. 5.9.

- Radioastron. These are observations at 5 and 22 GHz performed together with other VLBI stations and the Radioastron satellite to achieve a very high angular resolution. They are usually short (1 hour) but there are many of them along each

month, in some cases several within one day, but almost never contiguous. These are difficult to schedule to keep an efficient usage of the telescope.

- Others. The Observatory of Yebes receives requests for target of opportunities in which a set of EVN stations take part (usually 5 GHz) or in which the geodetic bands are used (S and X). This is the case for the RUA experiments in which Chinese, Russian and Australian stations usually take part.

Table 5.3: Distribution of VLBI observations at the 40 m along 2017 and 2018. Number of observations and observed hours per type of observation.

Network	2017		2018	
	# of obs.	(h)	# of obs.	(h)
EVN	76	576	83	621
GMVA	15	182	11	208
IVS	50	1200	29	768
Radioastron	178	225	95	108
KVN	6	32	11	68
Others	20	178	14	120
Total	342	2393	243	1893
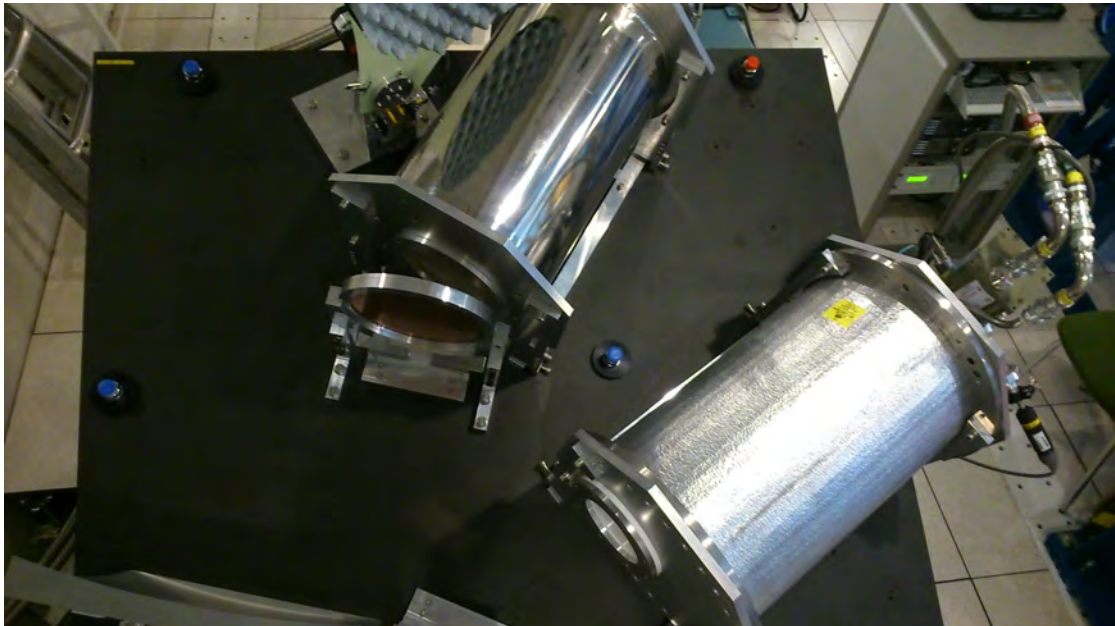
Figure 5.9: *The simultaneous 22 and 43 GHz receiver at the 40 m radio telescope receiver cabin*

VLBI observations with the 13.2 m radio telescope are restricted to VGOS project, Fig. 5.10. This telescope belongs to the small group of 5 stations that started VGOS observations in 2016 and which continued along 2017. In 2018, two more telescopes from Onsala Observatory joined the group and currently 7 telescopes take part in these observations. VGOS observations are typically 24 hours long and they are scheduled every 15 days. In the 2017-2018 period the Yebes 13.2 m telescope observed 50 VGOS sessions and 6 short EU-VGOS 4 hour sessions.

Figure 5.10: *View of the 13.2 m VGOS telescope with the 40 m RT behind.*

5.6.3 Technical activities

The technical activities related to VLBI observations are mainly devoted to receiver developments, software development, maintenance and operation of backends and correlation tests, Fig. 5.11.
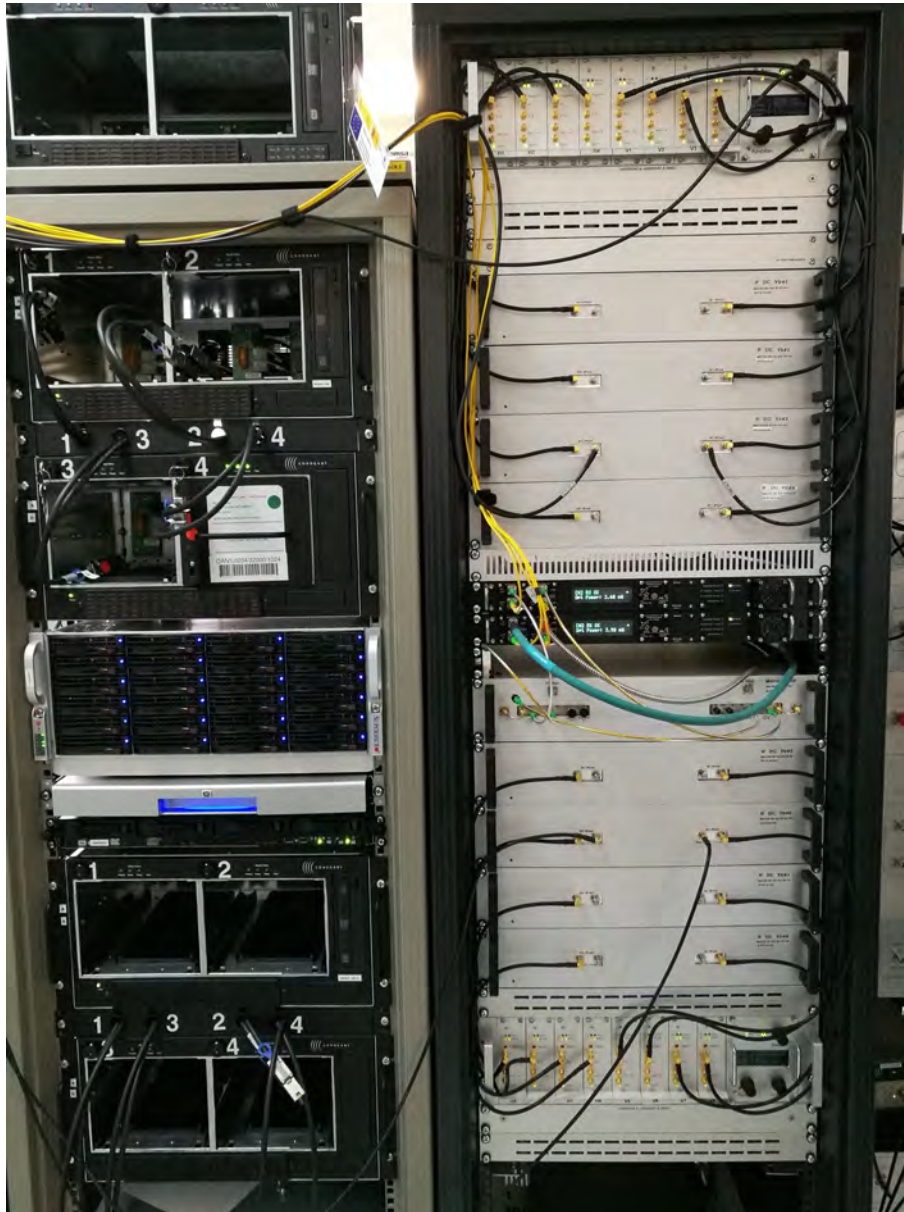
Figure 5.11: *Backends room at the 40 m radio telescope. Two Mark6 and 1 FlexBuff at the left rack. The IF for the 43 GHz and the 22 GHz together with the optical fibre receiver at the right rack.*

In 2017 the OY installed new Intermediate Frequencies (IFs) for the 22 and 43 GHz receivers which provide 2.5 GHz and 9 GHz instantaneous bandwidths respectively. The IF for both frequencies is transmitted via optical fiber to the backends room. During 2017 and 2018 the OY has been developing a 32-50 GHz receiver and a 72-90 GHz receiver within the Nanocosmos (EU funded) project. Such receiver will be commissioned by the beginning of 2019.

The OY takes part in two RadioNet JRAs since January 2017: BRAND and AETHRA. Within the first activity several tasks have been addressed, like the design and construction of a wide band balanced amplifier, RFI measurements at several EVN stations the feed design for a secondary focus wide band receiver. The second activity is devoted to technological research and developments for new millimeter and submillimeter receivers. In particular for Focal Plane Arrays for ALMA and NOEMA. The Observatory of Yebes takes part developing low noise wide band low consumption cryogenic amplifiers for the IFs of such receivers.

The OY also takes part in the TNA with the 40m being part of the EVN and in the NA sustainability package for TOG and GTG meetings. Work package 4.1 is led by the P. de Vicente (OY-IGN) and H. Rottman (MPIfR).

RadioNet has funded 2 short training missions (STM) of Yebes staff at MPIfR in Bonn and Effelsberg and it has hosted two people from Onsala Observatory and Ventspils (Irbene Observatory) within the same STM program. RadioNet has also funded an RFI workshop at Yebes in June 2017. This meeting was attended by more than 40 people from the EVN and other institutes.

The Observatory of Yebes also takes part in Jumping JIVE and leads WP 5 on new elements for the EVN. This package includes the analysis of new potential telescopes for the EVN and support to such telescopes. It also provides support for new receivers at the current EVN telescopes and addresses improvements in the feedback mechanism for the telescopes and in the data pipeline at JIVE correlator.

The 40 m RT has been using 2 DBBC2 for EVN observations and 2 FlexBuff units with a total storage space of 500 TB approximately. The connection to Internet for e-VLBI observations is 10 Gbps maximum. There is also a DBBC3 which has been partially and successfully tested. Four RDBEGs together with a Mark6 are used for VGOS observations at the 13.2 m radio telescope. A second backup Mark6 recorder is available. Tests after the installation of new firmware and software versions are performed at the station. These tests involve observations together with other EVN stations.

The Observatory of Yebes has gained experience on correlation using DifX as a powerful tool for debugging and solving problems. Currently we perform correlation tests between two antennas in astronomy and geodesy.

The OY also develops and maintains the ANTAB script used by EVN telescopes and which generates calibrated tables from the Field System Log files. It support calibration for hot/cold loads, fast switched noise diodes and standard noise diodes with the legacy ON/OFF mode.

Within the geodetic activities the OY has developed 3 phase cal and cable calibration units for BKG radio telescopes and it is currently constructing three wide band geodetic receivers for the NMA VGOS telescopes at Ny Alesund and for the future FGI VGOS telescope at Metsahovi. We have also installed a tri-band receiver at Ny Alesund, first at one telescope and later at the second one, the control system for both VGOS telescopes and we have provided technical assistance at the site to support geodetic VLBI observations and to install the receivers. As a consequence of such works the IVS considers the Observatory of Yebes an IVS technological development center.

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

5.7.1 Operations:

The Onsala Space Observatory (OSO) telescopes continued during 2017 and 2018 to play a full role within the global observing program for astronomical VLBI. In total 9 astronomical VLBI-sessions (6 EVN sessions and 3 global mm-VLBI sessions) were conducted. OSO is also regularly involved in e-VLBI sessions (typically ten 24 hour sessions per year) within the EVN. In addition, the Onsala 20 m telescope has been used for 51 (including CONT17) and 36 geodetic VLBI experiments in 2017 and 2018, respectively, as part of the observing program of the International VLBI Service for Geodesy and Astrometry (IVS).

John Conway was the CBD chair from July 2017-. Michael Lindqvist was chairman of the EVN Programme Committee from January 2015 to December 2017. Michael Lindqvist was the EVN Secretary from July 2017-.

5.7.2 Technical R&D:

OSO has successfully been involved in testing 4 Gbps (FR040). In addition, OSO has also been involved in real-time VLBI observations using the JIVE UniBoard correlator and thus contributed to its first real-time fringes.

OSO is involved in the RadioNet Joint Research Activity (JRA) BRoad bAND (BRAND) EVN. The aim of the project is to develop a very wide-band digital VLBI receiver for the EVN and also other telescopes. The frequency range of the BRAND receiver prototype will be from 1.5 GHz to 15.5 GHz. Until now, a radio astronomical receiver with a frequency ratio of 1:10 has never been realised. BRAND EVN is a truly European project with partners in Germany (MPIfR), Italy (INAF), Sweden (OSO), Spain (IGN), The Netherlands (ASTRON), and Latvia (VIRAC). OSO is leading the feed design for BRAND, with a first prototype currently under development for the primary focus of the Effelsberg 100 m telescope.

OSO is involved in the RadioNet JRA Radio Interferometry Next Generation Software (RINGS). The main objective for RINGS is to deliver advanced calibration algorithms for the next generation of radio astronomy facilities, characterized by a high sensitivity, a high bandwidth and long baselines. OSO has been working on the development and testing advanced algorithms for the polarization calibration of wide-band and long-baseline interferometric observations at both low frequencies (the case of LOFAR, EVN) and high frequencies (the case of mm-VLBI and ALMA). Additionally, OSO has also been working on the implementation of full polarization beam-modelling algorithms for the wide-band calibration software.

OSO is involved in the H2020 project JUMPING JIVE. OSO has mostly been involved in WP7 (The VLBI future). The main deliverable will be a document, in the form of a White Paper, that will address and explore several relevant points in setting the future priorities of VLBI science capabilities.

5.7.3 Instrument development and upgrades:

The Onsala Twin Telescopes were inaugurated 18 May 2017. The construction and installation of the Onsala Twin Telescopes has been funded by a generous grant from the Knut and Alice Wallenberg Foundation and Chalmers University of Technology.

5.8 Shanghai Astronomical Observatory

The Tianma station (TIANMA65) is located in Sheshan town, Songjiang district, the western suburbs of Shanghai, China. It is built and jointly funded by the Chinese Academy of Sciences (CAS), Shanghai Municipality, and the Chinese Lunar Exploration Program. The Tianma radio telescope with a diameter of 65 m, is a multifunction facility, conducting astrophysics, astrometry, geodesy, as well as space sciences researches with both single dish and VLBI observations. Besides of regular single dish observations on pulsars, spectral line and continuum sources, the telescope is a key member of the VLBI tracking system and spends a large amount of time on the Chinese Lunar Project, including the testing before the launch of the Chang'E satellites, and the tracking campaign after the launching. It is also actively involved in the international VLBI activities of astrometric, geodetic and astrophysical researches.

In 2017, Tianma 65 m radio telescope participated in fringe test observations in the EVN February, May and October sessions at 18, 6, 5 and 3.6 cm bands with the DBBC2 VLBI backend. Then it participated in the EVN February and October sessions of 2018 at 18, 6, 5, 3.6, 1.3, and 0.7 cm bands with DBBC2, and the newly installed FlexBuff was used in the fringe test observations with during the 2018 October session. Unfortunately, the EVN session II (in addition to ea059a, eg012e and ep112) in 2018 were missed due to the Chinese Lunar missions.

5.8.1 Receiver Maintenance in TIANMA65

All the seven sets of receivers (L, S/X, C, Ku, K, X/Ka, and Q band) of Tianma telescope are available for VLBI observation.

From the year of 2016, the TMRT L-band receiver has some polarization issue which might be caused by the phase difference in front of the 90 hybrid inside the warm electronics unit. Linear or circular polarization using the microwave switch can be chosen for the TMRT L-band receiver, which leads to the system complexity and instability. SHAO microwave technology lab will have some actions to the L-band receiver as follows: (1) Remove the linear polarization function to keep the system simple and robust. (2) Another next-generation compact L-band receiver with several narrow-bandwidth channels will also be considered to deal with the increasingly serious radio frequency interference problem. (3) The polarizer of the new L-band receiver will use an ortho-mode transducer and a 90 hybrid in front of the cryogenic LNA inside the cryostat. Currently, the TMRT L-band receiver works normally after the maintenance. We have got the fringe with RM015 in September 2018.

5.8.2 Antenna Maintenance with TIANMA65

The Tianma radio telescope conducted maintenance of mechanism in March 2018, including the greasing of the driving mechanism of azimuth and elevation, elevation bearing, the adjusting mechanism of sub-reflector and the rotating mechanism of the feed. We also checked the status of central pivot. Apart from the above annual maintenance, we greased the azimuth track and elevation gear per 3 months. All the maintenance work assured the antenna to be in a good status. In addition, we updated the wheels of protection cover of azimuth track, which shows good running state at present.

The primary reflector of the Tianma Radio Telescope (TMRT) distorts due to gravity, which dramatically reduces the aperture efficiency of high-frequency observations. In 2017-2018, we have acquired a model for the compensation of the gravitational deformation of the TMRT. After applying the model, there is a 150-400 % improvement in the aperture efficiency at low and high elevations. The model flattens the gain curve between $15 - 80°$ elevations with an aperture efficiency of approximately 50 %. The final weighted root-mean-square (RMS) error is approximately 270 μm. We also measured the thermal deformations when the backup and front structure were heated by the sun respectively, and then used the active surface system to correct the thermal deformations immediately to confirm the measurements. The thermal deformations when the backup structure is heated are larger than those when the front structure is heated. The values of half power beam width (HPBW) are related to the illumination weighted surface RMS, and can be used to check the thermal deformations. When the backup structure is heated, the aperture efficiencies can remain above 90 % of the maximum efficiency at 40 GHz for approximately two hours after one adjustment. While the front structure is heated, the aperture efficiencies can remain above 90 % of the maximum efficiency at 40 GHz, and above 95 % after one adjustment in approximately three hours.

5.8.3 Update and current status of equipment

A new Fluxbuff has been installed in Tianma 65 m in June 2018, Fig. 5.12. The total capacity is 240 TB. We can work up to 2 Gbps that we use fila10g of the dbbc with FlexBuff. At the same time, we also upgraded FS from fs-9.11.8 to fs-9.11.19 for supporting the new devices.

Figure 5.12: *New FlexBuff hardware system at Tianma station.*

5.8.4 e-VLBI

More than ten e-VLBI experiments among the EVN have been carried out in 2017 at a data rate of 1024 Mbps for each e-VLBI session. With the network upgrading by CSTnet, Tianma 65 m has got the 2 Gbps bandwidth in this February. After testing our Fila10g in July, we found that we had some MTU problems with our light path from China to Europe. We are actively coordinating to solve problems.

5.8.5 TOG Meeting

The EVN Technical Operations Group Meeting 2018 has been held in Shanghai Astronomical Observatory, Chinese Academy of Sciences, on March 18-21, 2018, Shanghai, China, Fig. 5.13.

Figure 5.13: *Participants in the EVN TOG meeting, May 2018 in Shanghai.*

5.8.6 Prospects

For the session of 2019, Tianma 65 m will participate in L, C, S/X, K and Q bands observations of the EVN.

5.9 South African Radio Astronomy Observatory (Hartebeesthoek site)

On the 1st of April 2017, the Hartebeesthoek Radio Astronomy Observatory (HartRAO) merged with SKA South Africa to form the South African Radio Astronomy Observatory (SARAO). The HartRAO acting managing director, Prof Ludwig Combrinck, retired in December 2017. Dr Rob Adam is the SARAO managing director.

During the period covered by this report, Hartebeesthoek continued to operate its two VLBI capable antennas, the original 26 m equipped with multiple receivers ranging from L-band to K-band, and the newer 15 m with a co-axial S/X receiver, including the possibility of simultaneous operation. Both antennas are equipped with DBBC2 recording terminals and Mark5B+ recorders, with additional recording capability via integrated FiLa10G interfaces to a Mark5C recorder and a FlexBuff system, with the latter now being used for most EVN operations.

Despite the ongoing demand for higher bit-rates and its associated disk space requirements, the observatory was unable to contribute to the EVN pool. Fortunately the recent problems with 2 Gbps recording rates relieved some of the pressure on disk space.

Additionally the 26 m antenna continued to participate as a fully-fledged member of

the e-EVN array at up to 2048 Mbps via a dedicated layer-2 light-path over a 10GE fibre connection. It also continued to be quite heavily used in support of the RadioAstron survey program, typically switching frequency band in the middle of each observation. No new receivers have been added over this period.

Construction of the new 13.2 m ring-focus fast-moving VGOS compatible antenna (see Fig. 5.14) was fully completed by MT Mechatronics in early-2018, with only installation of the backup generation capacity remaining outstanding. A full VGOS receiver chain and associated equipment still remains to be installed. In the interim, a wide-band 7-9 GHz single polarisation receiver is being constructed to start the telescope commissioning process.

Figure 5.14: *The Hartebeesthoek VGOS antenna.*

Other SARAO VLBI activities during the reporting period included work towards the conversion of the Kutunse (Ghana) 32 m telecommunications antenna into a functioning radio observatory and part of the African VLBI Network (AVN). Kutunse participated in C-band EVN observations in February 2017 (N17C1), with fringes detected against stations in Europe and Hartebeesthoek. The telescope was inaugurated by the president of Ghana on August 24, 2017.

In addition, while SARAO's MeerKAT telescope (see Fig. 5.15 and 5.16) was under construction, one of its 64 antennas was used during EVN's Network Monitoring Experiment N18L1 in February 2018. Software was developed by JIVE staff to extract the recorded MeerKAT L-band linear polarisation data and reformat them into VDIF

format. VLBI fringes were then detected between one of MeerKAT's 13.5 m dishes, EVN stations in Europe more than 8000 km away, and Hartebeesthoek. The telescope was inaugurated by the deputy president of South Africa on July 13, 2018.

Figure 5.15: *SARAO's MeerKAT telescope in South Africa, credit SARAO.*

Figure 5.16: *MeerKAT under the Karoo night sky, credit SARAO.*

5.10 Toruǹ Centre for Astronomy, Nicolaus Copernicus University, Toruǹ, Poland

TRAO participated in the large majority of the EVN observations, Fig. 5.17. In 2017, TRAO observed for 727 hours during disk-based experiments and 342.5 hours during e-VLBI experiments, whereas in 2018, the respective numbers were: 735 hours and 209.5 hours. During the whole reporting period, the time and frequency (T&F) delivery to Tr was performed from a remote H-maser standard via the optical-fibre link. This method had been used at Tr for already three years and proved to be a very reliable solution. More details about it can be found in Krehlik et al. (2017).

Figure 5.17: *The Torun 32 m telescope.*

The receivers for 1.6, 6.6, and 22 GHz were overhauled in the reporting period and their performance has improved. Installation of FiLa10G, additional CORE boards, DBBC3, and 10 Gbps switch is underway owing to a substantial support granted in 2018 by Polish Ministry of Science and Higher Education. Two FlexBuffs one for the station and one for JIVE – with 360 TB disk capacity each were purchased. A new optical fibre cable from the Torun node to the observatory (about 15 km) was laid in 2018. Together with the above-mentioned switch, this will allow for higher data transfer rates during e-VLBI observations. Continuous calibration was implemented at the end of 2018. A campaign of laser scanning of the surface of Tr radio telescope was carried out in 2017 and 2018. The resulting data is still under scrutiny but the preliminary outcome of those measurements is that the shape of the 32 m dish is largely correct and only a relatively small number (less than 10 %) of its panels have to be adjusted.

5.11 Ventspils International Radio Astronomy Centre, Ventspils, Latvia

5.11.1 RT-32 radio telescope

Since last report, a new L-band receiver was developed and installed at RT-32. While still uncooled, in comparison to previous solution, sensitivity is improved at least 5 times (SEFD ~650 Jy). Dual circular polarization channels are available and frequency agility is greatly improved - switching between L band and C/M/X band receivers is matter of changing software scripts now. Second H maser is back from repairs. VLBI capability of L band and recently repaired maser was tested for the first time at January 23, 24 during e-VLBI EM135A and FR057. Fringes were obtained in both experiments. Regarding to C/M/X band receiver, it is again being repaired at manufacturer and it is estimated that it will be back in operation no sooner than April, 2019. It means that currently RT-32 at VLBI mode is available only at L band. During FR057 it was found that DBBC at RT-32 with firmware v107 gives much better results at 2 Gbps with less fringe SNR variations between channels in comparison to E-series firmware. We would prefer to use it during future sessions when possible.

5.11.2 RT-16 radio telescope

While RT-32 do not have C/M/X receiver available, RT-16 is still the main instrument for VLBI and single dish observations at these frequency bands. Receiver, H-maser and DBBC are working stable.

5.11.3 Both telescopes

Second FlexBuff unit is already sent to JIVE and currently both Irbene telescopes are fully using FlexBuff as main recorder for EVN since October, 2018. While going slowly, first successful tests of 80 Hz calibration functionality were carried out together with DBBC and Field System at L band. C/M/X implementation at RT-32 will be tested as soon as the receiver will be back from repair. In RT-16, new cable installation for 80 Hz signal is still required. Currently main activities regarding to VLBI systems are focused on:

- Implementation of 80 Hz calibration at RT-16 and RT-32

- Repair and installation of C/M/X band receiver at RT-32

- Calibration of RT-32 and RT-16 C/M/X receiver noise cal. diode with absorber.

- Further testing and improvement of RT-32 L band receiver

5.11.4 VLBI equipment status

RT-32 radio telescope

- Field System: fs-9.13.1-rc1

- DBBC: 4xADB3L, Internal Fila10g, DDC v106/v106E

- Mark5c + Glapper, jive5ab : 2.7.1 64bit, AMAZON,10GbE

RT-16 radio telescope

- Field System: fs-9.13.1-rc1

- DBBC: 4xADB2, External Fila10g (only one VSI connection right now), DDC v105_1/v105E_1

- Mark5c + Glapper, jive5ab : 2.7.1 64bit, AMAZON,10GbE

FlexBuffs:

- Capacity: 32 TB, jive5ab: 2.8.1 64bit on Ubuntu 16.04

- Capacity: 288 TB (36x8TB), jive5ab: 2.8.2-jet 64bit on Debian 9.3. Another 288 TB FlexBuff is already installed in Jive

5.12 Xinjiang Astronomical Observatory, Chinese Academy of Sciences

5.12.1 Antenna system

The Stewart platform for the sub-reflector manoeuvre on the Nanshan 26 m telescope has been upgraded in 2018, Fig. 5.18. The incremental rotary encoder of the actuator motor has been replaced with the absolute one. So the position measurement for the actuators is now more accurate and repeatable, which is crucial for the sub-reflector to have a stable reposition during the observation. The antenna roller bearings and motors have also been replaced or maintained.
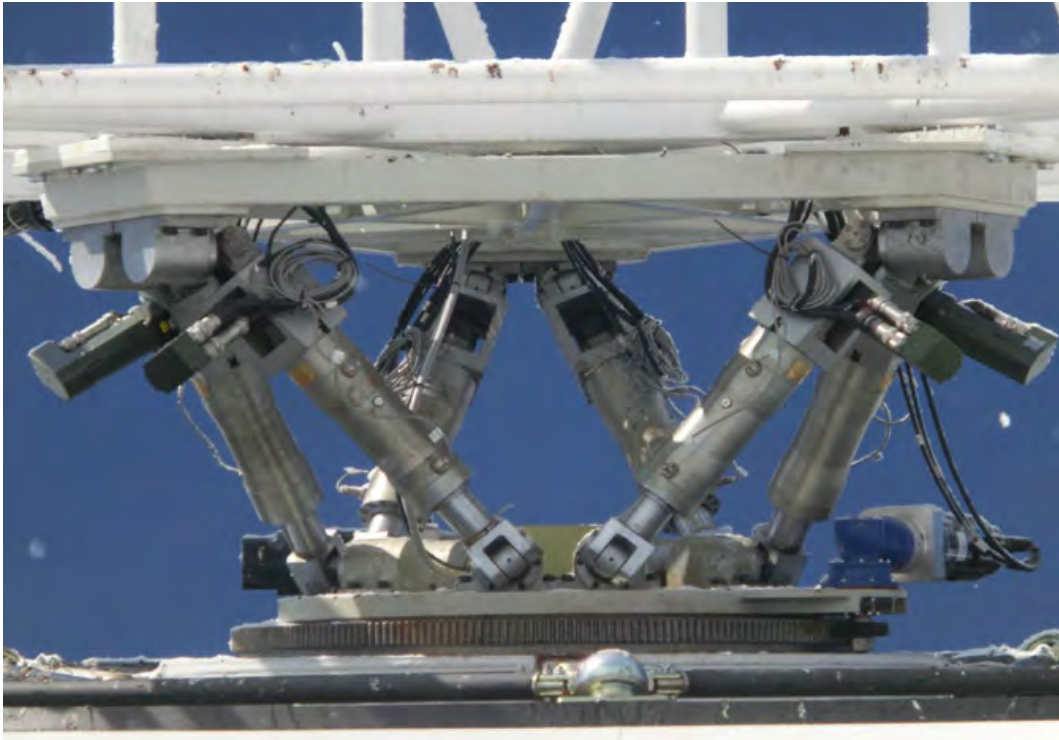
Figure 5.18: *The upgraded actuator motors on the Stewart platform of the Nanshan 26 m telescope.*

5.12.2 VLBI Backends and Recording Systems

The instalment of DBBC2 and CDAS2 and their system testing have been accomplished. They have been successfully used in the EVN, IVS and CVN joint observations since 2017. So the VLBI backends at Nanshan station is now fully digitalized. We are now preparing a firmware upgrade on DBBC2 from V.105 to V.107 to meet the new requirement for coming EVN observations. We have ordered 12 diskpacks with 32 TB storage per pack to enhance our capacity to participate high recording-rate observations. The

diskpacks will contribute the circulation pool from 2019.

5.12.3 Receiver Systems

The Q-band (7 mm) receiver has been tested and mounted in the RF cabin on the Nanshan 26 m telescope, Fig. 5.19. Currently the signal has been only down-converted to 4-12 GHz and a secondary down-coverting mixed is being shipped from the manufacturer to meet our digital IF backends. The Q -band system is expected to operate in 2019.
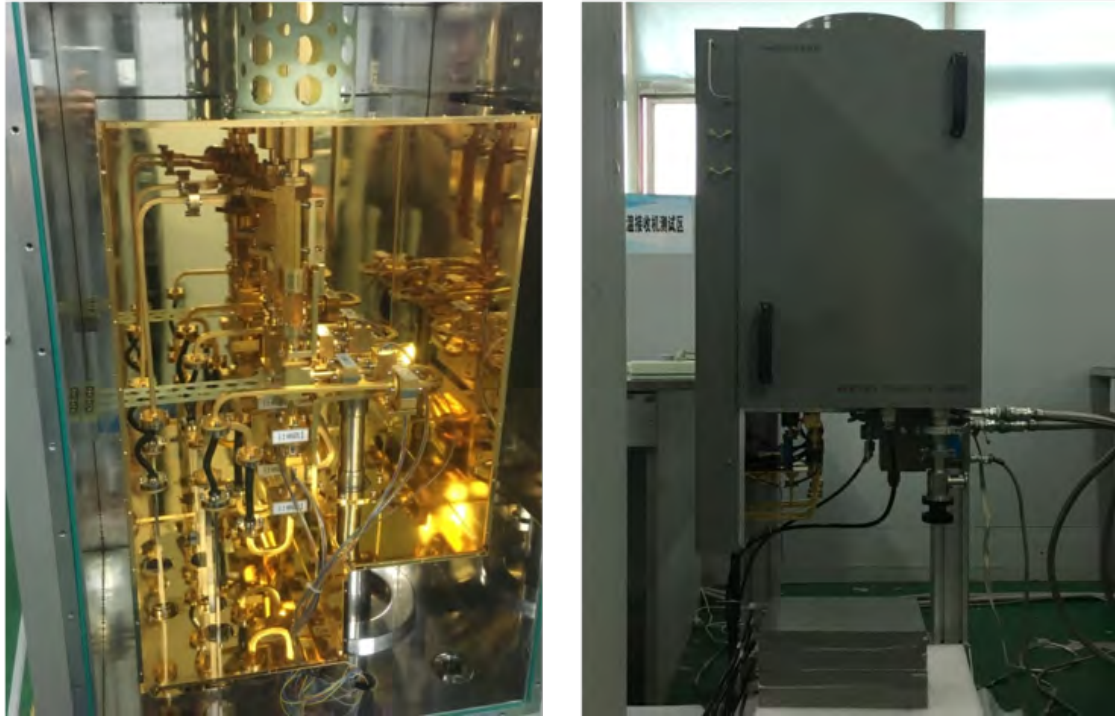
Figure 5.19: *The new Q-band receiver.*

5.12.4 Time-frequency Systems

The old H-maser clock MHM2010 purchased from the U.S. has expired and stopped work in 2018. Thereupon two domestic-made hydrogen maser clocks are now taking up the role to provide standard time-frequency service, the short-term frequency stability of which is now approaching 10^{-13}.

5.12.5 VLBI observations

In 2017, there were 154 experiments conducted by our Nanshan 26 m telescope as served in EVN, IVS and EAVN networks, with a total observing time about 1051 hours, including the lunar exploration observations; in 2018, 200 experiments were conducted and the total observing time is about 1500 hours.

6 EVN observatory reports, associated members

6.1 National Astronomy and Ionosphere Center, Arecibo Observatory, Puerto Rico, USA

Arecibo participated in a total of 19 global VLBI observations between January 2017 and December 2018. These include 7 EVN runs and 12 common observations with the Russian space antenna, RadioAstron.

Arecibo telescope was one of the stations of EVN network for the sub-arcsecond localization of the first known repeating burst source FRB 121102. These observations simultaneously detected both the bursts and the persistent radio emission at milliarcsecond angular scales. The data show that the burst and persistent radio emission are co-located to within a projected linear separation of < 40 pc (95 % confidence). The continuum spectrum of the persistent source is consistent with non-thermal emission and is likely to be a low-luminosity active galactic nucleus or a previously unknown type of extragalactic source. The high angular resolution observations also helped to establish the association of the persistent source with a faint (twenty-fifth magnitude) optical counterpart.

RadioAstron Space-ground interferometric observations involving Arecibo telescope and Westerbork telescope have determined the angular size of the scattering disk near 324 MHz toward a set of pulsars (B0823+26, B0834+06, B1237+25, B1929+10, and B2016+28). The measured scattering disks size range between 0.63 and 3.2 mas. Parabolic arcs were detected in the secondary spectra toward a subset of pulsars. Such structures indicate that the scattering is mainly produced by compact plasma layers thus ruling out the uniform model of inhomogeneities distribution.

Arecibo provides a maximum data recording rate of 2 Gbps using a RDBE/Mark5C system. This data rate allows processing of ~ 500 MHz bandwidth from each of the two polarizations and sampling the signal with 2 bit quantization. The regular EVN and RadioAstron observations are mostly carried out using the legacy VLBA4+Mark5A system. We are currently investigating upgrade options for the VLBI backend, which include increasing the recording rate by at least a factor of 2 as well as using the new Mark6 system.

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

The Geodetic Observatory Wettzell, Germany mainly contributed very successfully to the IVS observing program and to some observations of the EVN of the years 2017 and 2018. Technical changes, developments, improvements, and upgrades had been made to increase the reliability of the entire VLBI observing system. While the 20 m Radio Telescope Wettzell (RTW, Wz) and the 13.2 m Twin radio Telescope Wettzell North (TTW1, Wn) are in regular S/X sessions, the 13.2 m Twin radio Telescope Wettzell South (TTW2, Ws) is equipped with a VGOS receiving system and participates to all test and regular international and European VGOS session, Fig. 6.1.

Figure 6.1: *The Geodetic Observatory Wettzell with the two 13.2 m TWIN radio telescope antennas in the background on the right and the 20 m Radio Telescope Wettzell in the center.*

6.2.1 General information

The Geodetic Observatory Wettzell (GOW) is jointly operated by the Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG) and the Research Facility Satellite Geodesy (Forschungseinrichtung Satellitengeodäsie, FESG) of the Technical University of Munich (TUM). The 20-m Radio Telescope in Wettzell (RTW) has been an essential component of the IVS since the year 1983. Meanwhile, the 13.2 m Twin radio Telescope Wettzell North (TTW1, Wn) also produces S/X-data as a

regular station with up to three-fourth of the load of RTW in 2018. Doing observations with the second 13.2 m Twin radio Telescope Wettzell South (TTW2, Ws), which is the first complete VGOS-antenna at Wettzell, the observatory is prepared for future requirements in the IVS.

In addition to the VLBI, an ILRS laser ranging system, several IGS GNSS permanent stations, a large laser gyroscope G (ring laser) and the corresponding local techniques, e.g. time and frequency, meteorology and super conducting gravity meters, etc., are also operated. Wettzell also run a DORIS beacon as complete geodetic core site. Activities to monitor atmospheric parameters use a continuously growing number of equipment, including a Nubiscope, and weather balloons. Another project with external contractors is established to improve the timing system with compensated fiber-optic transfers and a frequency comb. The developments also need to meet the requirements for future operation strategies, so that projects to increase automation and remote control are ongoing.

The GOW is also responsible for the AGGO system in La Plata, Argentina (which is the former station TIGO in Concepción, Chile), and the German Antarctic Research Station (GARS) O-Higgins on the Antarctic Peninsula.

6.2.2 20 m Radio Telescope Wettzell (RTW, Wz)

The 20 m RTW (see Fig. 6.2) has been supporting geodetic VLBI activities of the IVS and partly other partners, such as the EVN, for over 35 years now. Operational hours in the reporting period are plotted in Fig. 6.3 (also see Tab. 6.1). The telescope is still in a very good and stable state. The main priority was laid to the participation in all daily one hour INTENSIVE-sessions (INT/K) in order to determine UT1-UTC. Increasing the know-how, sessions can now also be scheduled, correlated, and analysed by staff of the Wettzell observatory. Therefore, several own local and global sessions were operated, including a 10 day lasting local CONT session testing the stability of all Wettzell antennas at the end of 2018. Using the Field System extension for remote control, weekend INTENSIVEs were partly done from remote. The antenna supported all main IVS 24h sessions and is still one of the main components of the IVS. Up to 94 percent of the operations were IVS schedules in 2017, and up to 86 percent in 2018. About max. 1 percent of the observation load was for EVN in 2018. Local sessions increased in 2018 to over 13 percent of the operations. In 2017, IVS again scheduled a CONT session (CONT17) where a continuous operation over 15 days was supported.

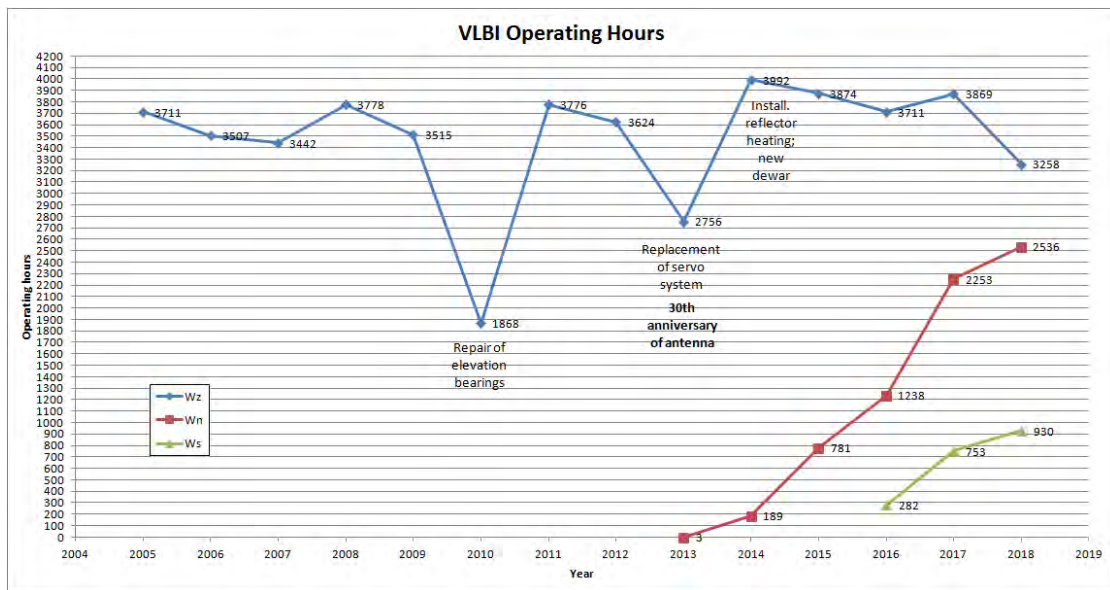**Figure 6.2:** *20 m Radio Telescope Wettzell during sun set.*

Figure 6.3: *Annual hours of operation of the Wettzell antennas since 2005.*

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Table 6.1: Annual participation of the 20 m Radio Telescope Wettzell to services

Network	**2017**			**2018**		
	# of obs.	hours of obs.	% of obs.	# of obs.	hours of obs.	% of obs.
IVS	510	3627	93.75	470	2797	85.85
EVN	0	0	0.00	3	28	0.86
Local	30	198	5.12	52	433	13.29
Survey	0	0	0.00	0	0	0.00
Others	2	44	1.14	0	0	0.00

All VLBI data from the 20 m RTW is transferred with e-VLBI techniques to Bonn, Tsukuba, Haystack, Washington, and Socorro, using TSUNAMI or now only jive5ab anymore on the 1 Gbps connection of the Wettzell observatory. Meanwhile, Bonn and Washington correlator fetch sessions from FlexBuff systems at the Wettzell observatory. Most of the sessions are recorded on Mark5B+ systems and later on transferred to the local FlexBuff servers. But also direct recording is possible. Mainly weekend INTENSIVES are directly recorded as VDIF streams on the FlexBuff systems. Additionally, 24 h sessions were recorded with this technique to evaluate the stability in parallel to the classic recording. About 5 percent of all sessions at 20m RTW were directly recorded on FlexBuff in 2018 (0.36 percent in 2017).

The 20 m antenna together with the northern twin telescope Wn also supported the final Wettzell high-speed VLBI session (WHISP) sessions in 2017, planned by colleagues of the Bonn University. WHISP sessions schedule a large number of observations to validate turbulence models in a local application. During WHISP, common clock tests were made where all telescopes were connected to maser EFOS-60. These tests were quite interesting to find issues in technical solutions for stable frequency transfers over hundreds of meters using classic techniques. Found problems should be obsolete after using a new optical time distribution system with active phase compensation.

Monthly maintenance days were scheduled to give enough time to maintain the systems. Additionally, service periods were necessary to finalize the cleaning and coating of the antenna tower, the back structure, and the cabins by an external contractor. Using a replacement dewar, built by IVS Centro de Desarrollos Tecnológicos de Yebes, Spain enabled short maintenance times for the cryo-systems, because the complete dewar hardware can be replaced and the repair can be done in the workshop while keeping the antenna operative. The NASA Field System is now on version 9.11.19. All DBBC2s use now firmware DDC v106 and are connected or integrate a FILA10G to stream data over 10 Gbps networks. A main change was the switching from the Mark4 rack to the digital DBBC recording. All sessions are now recorded using DBBC2 and a Mark5B (partly FlexBuff). On October 1st, 2017, the conformity declaration to follow the EC Machinery Directive was signed, so that now all VLBI antennas ensure legal certainty in the sense of European right. Open issues are an oil leakage in two elevation gears, the upgrade of the IF or maybe RF distribution, and an improvement of control structure.

6.2.3 13.2 m Twin Telescope Wettzell North (TTW1, Wn)

The Twin Telescope Wettzell project (see Fig. 6.4) is Wettzell's realization of a complete VGOS conformity. Currently, the northern antenna Wn is still equipped with an S/X/Ka receiving system to support the standard S/X sessions of the IVS and of local performance tests and research questions. The northern antenna was the first available antenna supporting fast slewing modes in the IVS and uses now a DBBC2 (firmware DDC v105_1) in combination with a Mark5B+. It is used in sessions like the 20 m antenna. Its performance in operating hours can be found in Fig. 6.3 (also see Tab. 6.2). It mainly participates in IVS sessions where it also supported a separate network in CONT17 session in 2017. EVN uses about 1 percent of the time. Locally scheduled and analysed sessions increased up to about 18 percent. Missing partners for Ka sessions reduce the possibilities to demonstrate geodetic Ka session. All recorded data is transferred with e-VLBI techniques.

Figure 6.4: *The Wettzell Twin Telescope with its two 13.2 m antennas (Wn in the front) and the control building.*

Table 6.2: Annual participation of TTW1 to services

	2017			2018		
Network	# of obs.	hours of obs.	% of obs.	# of obs.	hours of obs.	% of obs.
IVS	129	1956	86.82	160	2017	79.53
EVN	0	0	0.00	3	29	1.14
Local	39	207	9.19	58	448	17.67
Survey	5	46	2.04	4	42	1.66
Others	2	44	1.95	0	0	0.00

The Wn antenna runs quite stable and reliable. It is controlled with the NASA Field System version 9.11.19. Minor changes were made. It is now additionally equipped with a cable calibration system built by IVS Centro de Desarrollos Tecnológicos de Yebes, Spain.

6.2.4 13.2 m Twin Telescope Wettzell South (TTW2, Ws)

The southern antenna Ws of the twin telescope is Wettzells first VGOS compliant antenna using a broadband feed (Elevenfeed). It uses a tuneable up-downconverter, two DBBC2, and a Mark6 to record 4 bands in both polarizations. Meanwhile, Ws is a regular part of the IVS VGOS network doing bi-weekly observations. Its performance in operating hours can be found in Fig. 6.3 (also see Tab. 6.3). In 2017, main part of the work was to find issues and to stabilize the system. After some tests it was able to be integrated in the Wettzell telescope array, so that all three telescopes can be used and correlated for local sessions. Data of the VGOS sessions is shipped to Haystack for correlation because of the huge data amount of about 16 or 32 TB per day. Local sessions are correlated at Wettzell and take about a quarter of the operation time.

Table 6.3: Annual participation of TTW2 to services

	2017			2018		
Network	# of obs.	hours of obs.	% of obs.	# of obs.	hours of obs.	% of obs.
IVS	21	476	63.21	25	590	63.44
EVN	0	0	0.00	0	0	0.00
Local	15	194	25.76	12	263	28.28
Survey	8	83	11.02	4	41	4.41
Others	0	0	0.00	9	36	3.87

The staff at Wettzell does continuous upgrades, implementations, and tests of the backend system. DBBC2 got new firmware of PFB v106. A DBBC3 was installed and will be tested. Ws now uses also the same cable calibration system like Wn installed in 2018. Ws uses the VGOS branch of the NASA Field System version 9.12.7.

6.2.5 Other VLBI relevant activities

To improve the e-VLBI capacities, three FlexBuff systems with 21 TB, 72 Tb, and 102 TB were installed. Main sytems behind are extendable DELL PowerVault MD3460 Storage Arrays connected to a DELL PowerEdge R730 server. All systems are accessible with Jive5ab, while the use of Tsunami will fade out.

To connect all FlexBuff, Mark6, and FILA10G systems and to support a flexible, selectable recording, a new 10 Gbps network was installed using fiber links between the telescopes and suitable network switches. The network supports a direct recording of VDIF streams from different FILA10G sources.

A cluster with 10 nodes (including one head node) and each with 4 cores was installed for correlation of local sessions at Wettzell using the software correlator DiFX and hardware from the previous Bonn correlator. The installation was supported by Bonn colleagues. Additionally, all necessary software for scheduling (Sked, VieVs), fringe fitting (fourfit etc.), and analysis (VieVS, nuSolve) was installed, so that staff at Wettzell is now able to do the whole observation chain from scheduling to analysis. A local software LEVIKA is used for planning observation times and also for analysing of local sessions. To exchange latest news about correlation with a software correlator, 12th DiFX Users and Developers Meeting was held at Wettzell from September 3rd to 7th, 2018.

For a better overview of antenna parameters and for emergency detections, a monitoring system was installed as central data archive using ZABBIX software. Data from the NASA Field System, the recording systems, but also from antenna control unit, UPS systems or meteorological sensors are collected and evaluated to generate triggers showing alerts according to different severity levels. The TUM at Wettzell also joined the project JUMPING JIVE) to implement a monitoring infrastructure for the whole EVN network coordinated by Joint Institute for VLBI ERIC, Dwingeloo, The Netherlands. JUMPING JIVE is funded by the Horizon 2020 program of the European Union. Part of the local Wettzell development and installation was a web based remote monitoring web page for the NASA Field System (see Fig. 6.5) which can be used to retrieve about 110 parameters. Additionally, data collectors and web screens were implemented for Mark6 systems and different other hardware. The guard of the Wettzell observatory got a monitoring tablet showing current problems and alarms as central monitoring point.
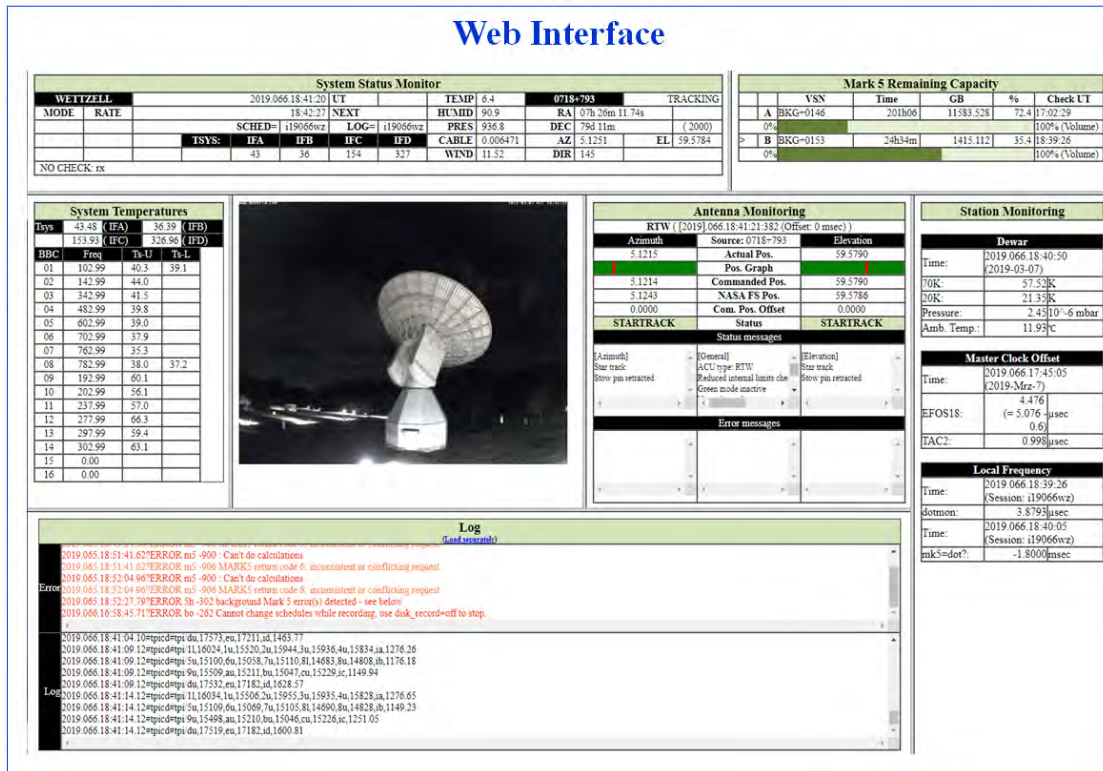
Figure 6.5: *Web interface of the NASA Field System for the 20 m radio telescope Wettzell.*

The permanent survey of the reference point of the twin antennas was continued using total stations on different pillars and 20 to 30 reflectors in the back structure of the antenna. With about 4 sessions per year, a continuous monitoring of the reference point over the year is possible.

6.2.6 Future Plans

Dedicated plans for the next reporting period are:

- Establishing automated observations

- Study about future use of the 20m radio telescope

- Implementing VGOS-compatibility for TTW1 using a QRFH feed

- Continuous improvements with the VGOS broadband system at TTW2

- Install a DBBC3 and further FlexBuff systems

- Establish a monitoring of atmospheric parameters

- Increase the correlation capabilities

6.3 Korea Astronomy and Space Science Institute (KASI), Korea VLBI Network (KVN), Korea

6.3.1 VLBI Staff

The director of KVN is Jongsoo Kim as also a Director of Radio Astronomy Division at Korea Astronomy and Space Science Institute (KASI). The representative of KVN at the EVN CBD is Taehyun Jung as a Principal Investigator of KVN project. The technical VLBI friend is Do-Young Byun.

6.3.2 VLBI Observations

The Korean VLBI Network (KVN; http://kvn.kasi.re.kr) is a dedicated mm-VLBI network, operated by the KASI. Its three 21 m radio telescopes are located around South Korea in Seoul, Ulsan, and Jeju Island and has a simultaneous multi-frequency (22, 43, 86 and 129 GHz) receiving system.

KVN operates 10 months a year except during the summer maintenance period (mid-June mid August). Every year the total time of VLBI observations is more than 3500 hours. KVN mainly shares 1000 hours observing time with VERA a year as a 'KaVA (KVN and VERA Array; http://kava.kasi.re.kr)' and also participates EVN, GMVA, and RadioAstron (RA) sessions at 22, 43 and 86 GHz.

In 2018, we officially started the operation of East Asian VLBI Network (EAVN; http://eavn.kasi.re.kr) as the international collaborative VLBI array operated by KASI, National Astronomical Observatory of Japan (NAOJ), Shanghai Astronomical Observatory (SHAO; China), and Xinjiang Astronomical Observatory (XAO; China). The statistics of KVN operation is summarized in Tab. 6.4. In 2018, the EVN, GMVA and EAVN observations were dramatically increased due to RA, EAVN and Sejong (geodesy VLBI station in Korea) observations.

6.3.3 KVN Operation, 2017-2018

In March 2018, there was simultaneous 22 and 43 GHz VLBI observations among KVN, VERA and Yebes. Total 8 radio telescopes were participated in this campaign and successful fringes at 22 and 43 GHz among all baselines were successfully detected as shown below.

6.3.4 Technical Developments

K- and W-band Receiver Upgrade: During 2017 and 2018, all three K-band receivers of KVN was upgraded to support wider frequency range (18-26 GHz) compared to old one (21.25-23.25 GHz). This new receiver has a compact feed horn and a wideband polarizer. The T_{rx} is ~ 25 K. In addition, one W-band receiver of KVN Ulsan radio telescope was also upgraded, which has the frequency ranges from 85 to 116 GHz. Other two W-band receivers at KVN Yonsei and Tamna radio telescopes will be upgraded by August 2019.

Table 6.4: KVN Operation, 2017-2018

	2017 #	2017 Hours	2018 Obs	2018 Hours	Note
KVN	37	303	38	370	KVN open call obs.
KVN KSP	81	1375	138	1079	KVN key science program
KVN TestObs	56	249	57	459	KVN test obs.
KaVA	63	473	54	450	KaVA open call obs.
KaVA LP	48	533	72	458	KaVA large program
KaVA Geodesy	14	240	12	194	KaVA K-band geodesy
EAVN, Sejong, EVN, GMVA	40	335	75	914	EVN incl. RadioAstron obs.
VLBI Total	339	3508	446	3924	
Single Dish	121	787	62	313	

Compact Triple-band Receiver (CTR): A compact triple-band receiver (CTR) was developed for KVN and the first light was successfully detected. The current KVN quasi-optical system has a larger optical bench (2600 mm x 2300 mm) in order to incorporate individual cryogenic receivers in separate cryostats, but this CRT has an integrated quasi-optical circuit in single cryostat, in which frequencies range from 18 to 115 GHz with a size of 600 mm x 980 mm. Three frequencies are K (18-26 GHz), Q (35-50 GHz), and W(85-115 GHz) bands and the following figures show the CTR and its first light observed at KVN Yonsei radio telescope on 5 September 2018. Three spectral lines of CO (^{12}CO at 115.27 GHz) and methanol (CH_3OH at 19.97 and 36.17 GHz) were detected simultaneously.

OCTAD Backend System: The current KVN backend system (KDAS) is limited up to 2 Gbps data rate per single frequency band for a single polarization. A new backend system of KVN, OCTAD (Optically Connected Transmission System for Analog-to-Digital Conversion) manufactured by ELECS company, was introduced and tested for supporting KVN wideband observations (i.e., 8, 16 and 32 Gbps), eventually simultaneous four frequency band (22, 43, 86 and 129 GHz) observations with a full polarization support. Both 16 and 32 Gbps data streams via OCTAD were successfully recorded onto Mark6 and the 16 Gbps fringes were detected.

6.3.5 Workshops and Meetings

The Radio Telescope User's Meeting for domestic users of KVN, TRAO and JCMT/ALMA is held every year in Korea, supported by the projects of KASI Radio Astronomy Division. In 2017, the KaVA/EAVN Joint Science Working Group Meeting was held at KASI in order to promote Face-to-face discussion in each science working group (AGN, Evolved Stars, Galactic Astrometry and Star-Forming Regions), exchanging information between SWGs, and introducing the latest results obtained with KaVA and other VLBI arrays. The East Asian VLBI Workshop (EAVW) is held annually among four countries in East Asia (China, Japan, Taiwan and Korea) by turns. In 2018, the 11th EAVW was

held in PyeongChang, Korea, hosted by the KASI. During the workshop, the Memorandum of Understanding on the EAVN operation and scientific collaboration among four institutes of KASI, NAOJ, SHAO and XAO was made.

6.3.6 Extended KVN Project

The KVN is planning to install one more radio telescope in South Korea, which is name as the "Extended KVN (EKVN) project". In 2017 the A planning study of EKVN was conducted. The new telescope will be the same as current KVN telescopes, but it is expected to have much wider radio frequency coverages such as C/X(6-8), K(18-26), Q(35-50), W(85-115) and 230 GHz. If it is successful, the EKVN project will start from 2020 and the construction will be completed in 2023.

6.4 Metsähovi Radio Observatory (MRO), Aalto University, Metsähovi, Finland

Metsähovi Radio Observatory (MRO) is located on the premises of Aalto University at Metshovi, Kylml, Finland, about 35km from the university campus. MRO has operated a 13.7 m radio telescope since 1974, and several smaller antennas mainly for solar observations have been added since then, Fig. 6.6.

Observations are scheduled ?24/7/365?. Metshovi is known for its long-term quasar and solar monitoring, and these programmes take most of the telescope time. The main radio telescope is used to observe hundreds of active galactic nuclei (AGN) and a few galactic microquasars at 37 GHz daily; many light-curves extend over four decades, to the early 1980s. Likewise, the year 2018 marked the 40th anniversary of solar radio observations at MRO: the main radio telescope has been used to create solar radio intensity maps mainly at 37 GHz since 1978.

The telescope radome and surface panels were replaced in 1992-1994 (the current surface accuracy is 0.1 mm rms, and the drive speed is 1.2 degrees per second). In early 2020 the steering system will be upgraded, and in mid-2020 the radome will be renewed.

Astronomical VLBI observations are carried out with receivers at 22, 43 and 86 GHz. Furthermore, the telescope is used for Geodetic VLBI by the Finnish Geospatial Research Institute, with a 2/8 GHz receiver.

Figure 6.6: *The Metsähovi Radio Observatory, Finland.*

7 Joint Institute for VLBI ERIC

7.1 Institute news

JIVE has experienced an active two years, with new projects beginning; exciting technical developments and the continuation of high profile science. It was a fitting time for the ERIC to celebrate both 50 years of VLBI in 2017 and 25 years of JIVE in 2018, Fig. 7.1

Figure 7.1: *Celebrating 25 years of JIVE with JIVE staff and alumni.*
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JIVE coordinates the EC H2020 JUMPING JIVE project, which began in December 2016 and provides an opportunity for JIVE as an ERIC to profile itself with its potential partners, the user base and the international radio astronomy community. In practice, it means that JIVE can enhance its effort in outreach, in particular to advocate its relevance for European and global science. It also offers a possibility to address some key operational interfaces that will be important in the foreseen globalisation of VLBI. One of the highlights from this project is to facilitate the production of an updated science vision for VLBI (and the EVN in particular) – an effort in which the whole community is involved. JUMPING JIVE also supports the development of tools (e.g. pySCHED for scheduling of global-VLBI observations) and new capabilities for the JIVE correlator

(geodetic modes). Moreover, it has also supported development and capacity building of radio astronomy in Africa, where the new station of Kuntunse (Ghana) delivered its first results in 2017. The project was successfully reviewed by the EC in November 2018. An additional product of JUMPING JIVE is the development of VLBI capabilities for the Square Kilometer Array. In this respect, JIVE is leading the definition of the "SKA-VLBI" modes and science cases, which will enable the participation of SKA-MID phase-1 (without long baselines) into a VLBI network such as the EVN.

The EC RadioNet project, coordinated by JIVE's partner the Max Planck Institute for Radio Astronomy (MPIfR, in Bonn, Germany) began in January 2017. As with previous RadioNet programmes, JIVE was able to implement adequate user support due to transnational access funding for the EVN provided by this EC integrating activity. Alongside the training, engineering and science networks that RadioNet helps to maintain, many of the RadioNet activities are also of great relevance to JIVE. For example, the EVN benefits from a work package on next generation receivers (BRAND EVN) and JIVE contributes directly to a project to provide new data processing tools, notably for fringe fitting VLBI data in the RINGS work package.

JIVE continued to contribute to the EC funded ASTERICS effort, pioneering data processing techniques and showcasing, for example, the use of Jupyter (an open source web application) for data handling in the software package CASA. As part of the ASTERICS project, JIVE also collaborated with ASTRON, SURFnet and OPNT to allow the Dwingeloo telescope to participate in VLBI observations with the EVN.

Due to the commencement of the JUMPING JIVE project in 2017, JIVE has also begun to focus on communicating the excellent work ongoing at the EVN. The largest investment, time wise, came in 2018 at the European Week of Astronomy and Space Science (EWASS 2018). JIVE hosted a booth featuring highlights of research conducted with the EVN and materials to attract new users to the EVN. This was regarded as a successful endeavour, with plans to repeat this exercise in the future. Throughout 2017 and 2018 important EVN results were shared as press releases among a new and growing network of outreach officers and scientists, ensuring all EVN partners have access to key pieces of news associated institutes. The close of 2018 also brought with it an overhaul of the EVN website. Currently in the first phase of transition it is hoped that this will provide an attractive platform for new and existing users.

7.1.1 Personnel

New projects commencing at JIVE brought with them new positions and new faces. During 2017, Dr. Gina Maffey joined as Science Communication Officer, working with both JIVE and the EVN. Dr. Katharina Immer from ESO arrived as the newest Support Scientist. The end of 2017 saw the departure of JIVE's Digital Engineer, Dr. Jonathan Hargreaves, who moved to ASTRON, but remains a familiar face at JIVE.

Notably, 2018 began with a change for the Director of JIVE. After 10 years of leading the team Prof. Huib van Langevelde took the decision to step down (Fig. 7.2) and was replaced by Dr. Francisco Colomer. Colomer had joined JIVE earlier in 2017, from IGN in Spain, as the Policy Officer and Project Manager for the JUMPING JIVE project.

Van Langevelde will continue as a Senior Scientist at JIVE and has adopted new teaching responsibilities at Leiden University.

Figure 7.2: *Huib van Langevelde receives the appreciation of his colleagues in the EVN Consortium Board of Directors.*

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7.2 Research and development

7.2.1 Data recording and transport

During 2017 and 2018 many EVN stations added new FlexBuffs (the EVN-developed commercial off-the-shelf (COTS) based high-capacity data recorders) to the storage pool at JIVE. As 10 TB disks started to become affordable, the capacity of the individual units increased to 250 TB. Some of the early contributing stations also started upgrading their units by replacing the original 4 TB disks with 10 TB disks, using the freed-up disks to populate Mark5 disk packs. As a result, it became necessary to re-inforce the floor in the JIVE correlator room, to cope with the extra load of the new SFXC cluster and the racks with an increasing number of storage units. In 2018, two Mark6 recording units plus expansion chassis were purchased and installed at JIVE as part of the NWO-Dome project – which aims to enable VLBI observations between the EVN and the KAT7/MeerKAT arrays in South Africa. Throughout the reporting period, all the control code developed at JIVE, including the jive5ab recording and data transfer program, continued to function smoothly and reliably, requiring relatively few bug fixes and upgrades.

7.2.2 JIVE hardware upgrade

A massive upgrade of the SFXC cluster, as well as a complete overhaul of the local network, was set in motion in early 2017, Fig. 7.3. After a careful evaluation of various options, a design was completed after the summer and hardware was procured. The choice was made to purchase three SuperMicro MicroBlades, containing 14 servers each, and on each server 20 2.2 GHz cores, 128 GB RAM, 120 GB SSD storage and 2x10G Ethernet. 840 Cores were added to the existing 512 cores, while 128 of the oldest cores were decommissioned, as they would actually slow down the correlation. In all, the SFXC cluster now has a total of 1224 cores. The network was designed around four Mellanox SN2100 16-port 100G/40G switches, connected in pairs. All machines that can be are interconnected at two times 10 Gbps, those that cannot are connected to the old switches, which remain in use. This upgrade means that JIVE is very well prepared for a future with many more stations and higher bandwidths.

Figure 7.3: *New correlator and network hardware during installation at JIVE.*
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7.2.3 Software correlation

Development of the features, and upgrades, of the EVN software correlator (SFXC) continued throughout 2017 and 2018. A Polyphase Filter Bank (PFB) mode was implemented. The advantage of a PFB compared to the default windowed FFT is a much lower spectral leakage and a higher spectral resolution. This in turn gives a major improvement in data quality for spectral line observations. In the context of the JUMPING JIVE project, for geodetic purposes a conversion of SFXC output to Mk4 format was implemented, which is the native data format in the geodetic data processing suite HOPS. Support for multiple data streams per station (based on the soon-to-be-released VEX2 standard experiment description) was also built in.

7.2.4 Hardware correlation and digital engineering

The JIVE UniBoard Correlator (JUC) – originally developed as a part of a Joint Research Activity in RadioNet FP7 – was tested extensively and results were compared in great detail with the EVN software correlator (SFXC), Fig. 7.4. Further improvements were made to the control code and methods were implemented to fine-tune the playback speed, in order to prevent outbursts and packet loss inside the local network. In principle, the JUC is now an operational correlator, capable of correlating 16 stations at a full 4 Gbps, once all four UniBoards are connected through the new network.
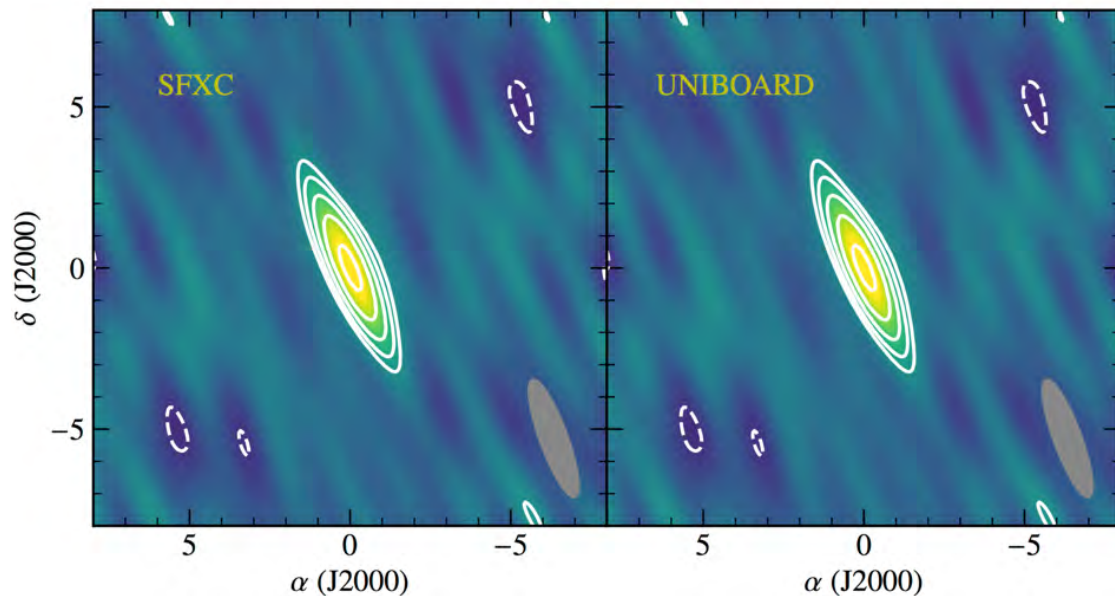

Figure 7.4: *First light with JIVE UniBoard Correlator: single 2.5-min scan of J1955+5131 from a EVN observation at 6 cm with seven stations: Effelsberg, Medicina, Noto, Onsala, Tianma, Zelenchukskaya, and Badary, correlated with both SFXC and JUC.*

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Following discussions with the JUC hardware designer and a rewrite of the control code, the first successful real-time transfer of data from the telescopes to the correlator occurred at the end of 2017. As generated test data were used no fringes could be obtained, however the JUC kept up with the real-time processing without any problems. Real time tests were repeated several times in 2018, during which remaining issues were solved. A complete EVN experiment targeting a resolved source was correlated in parallel with the SFXC by one of the JIVE support scientists and the results were found to agree to a high level of accuracy.

7.2.5 User software

The CASA software suite is widely used to process radio astronomical data. However, VLBI has continued to rely on legacy code because fringe fitting was not a part of CASA. A VLBI fringe fitter, written at JIVE and initially supported by the Black Hole Cam project, followed by the RadioNet RINGS work package, was finally included in CASA release 5.3, making this the first CASA release ever capable of handling VLBI data.

Two workshops were organised at JIVE in 2017 and one during the EVN symposium in 2018, which gave participants the chance to test the new code. The aim of the EVN symposium workshop was to get people up to speed with the new CASA tasks, and several participants managed to complete the entire tutorial. The workshop was viewed as a success and constructive feedback was received for further developments of the software. The JIVE effort to enable remote data processing, bringing the computer to the data instead of the other way around, attracted much attention in the field. In 2017, a Jupyter kernel was created specifically for CASA, which was then improved throughout 2018. An online tutorial is available at http://jupyter.jive.nl. Users connecting to the service can access a Jupyter notebook in which they can reduce an entire VLA dataset from start to finish.

Much work went into the re-factoring of SCHED, the time-honoured scheduling software used by many VLBI networks around the world. This code was developed in the eighties and written in Fortran, and is not easy to modify or even to maintain. The use of digital baseband converters (DBBC) is now supported by pySCHED, and many updates and improvements were made following feedback from the JIVE support scientists.

7.2.6 Time and Frequency distribution

For the ASTERICS project, JIVE collaborated with ASTRON, SURFnet and OPNT to connect the H-maser reference located at the Westerbork Synthesis Radio Telescope (WSRT) to the Dwingeloo telescope via a link WSRT-Groningen-Dwingeloo, together with a direct dark-fibre link for calibration. The aim is to use this reference signal, transported via public fibre, as a local clock, allowing the Dwingeloo telescope to participate in VLBI observations with the EVN. As with the SKA design, extensive use was made of White Rabbit equipment, an open-source technology initiated by CERN and further developed sustained by a large engineering community.
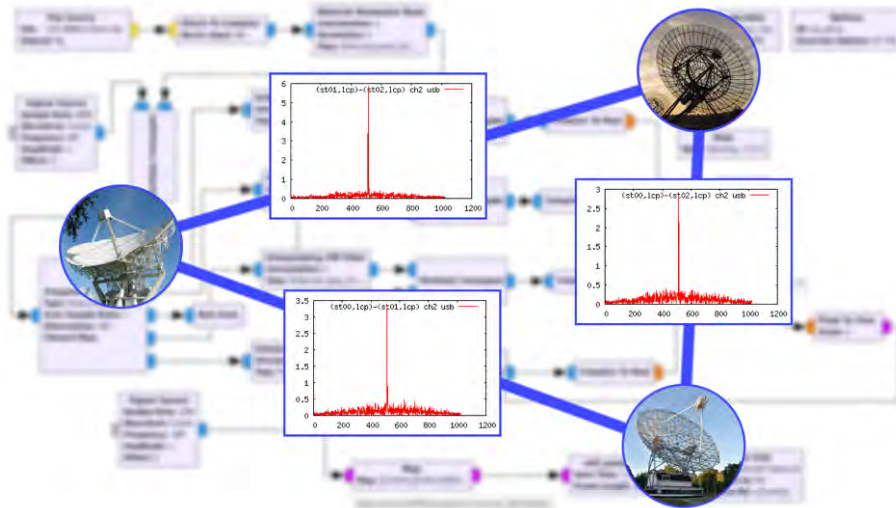
Figure 7.5: *ASTRON-JIVE daily image showing the return of the Dwingeloo Radio Telescope to VLBI with fringes between Dwingeloo, WSRT and Jodrell Bank MK2.*

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As a first step, a VLBI session with Dwingeloo, the WSRT and the MK2 at Jodrell Bank yielded fringes to the Dwingeloo telescope for the first time in about 40 years, Fig. 7.5. For this test, a local Rubidium clock was used, not yet the WSRT maser; this will be attempted in the beginning of 2019. Eventually, the H-maser signal will also be transported from Groningen to the LOFAR array in the East of the Netherlands.

7.2.7 SKA

The main contribution of JIVE to the SKA effort consisted of providing the Synchronisation and Timing (SAT) architect in the Signal and Data Transport (SaDT) consortium. In 2018, detailed designs for the SaDT design and UTC distribution of the SKA successfully passed the Critical Design Review – with the official announcement to appear in 2019.

Verifying the UTC Distribution design for the SKA required extensive testing, both in the field on long fibre runs, and in the climate chamber and EMI facilities at ASTRON. The result of this effort is a complete description of the systematic and random error contributions on the link performance down to the pico-second level. The model shows that the completed design meets the SKA timing accuracy requirements, even on the longest links and in the harsh climatic environments of the future SKA sites.

An SKA-VLBI scientist position was established at the SKA headquarters in Jodrell Bank in 2017 by JIVE and the SKAO, under the framework of the EC funded JUMPING JIVE project (under work package 10 - 'VLBI with the SKA'). The main responsibilities of the SKA-VLBI scientist are to assist with the SKA design process to ensure that all VLBI requirements are fulfilled, to work towards establishing an operational model for SKA-VLBI, and to support the SKA-VLBI focus group.

7.2.8 VLBI with South Africa

JIVE spent considerable effort on enabling VLBI between the EVN and the prototype KAT7 array, to be followed by MeerKAT and, eventually, the SKA. This work was supported by funding from NWO and the South African NRF, through a collaboration that was initiated several years ago. Eventually the decision was made to skip attempts to use KAT7 for VLBI, and instead to concentrate on MeerKAT. As MeerKAT's sampling rate and data formats are not yet VLBI compatible, software was developed by JIVE staff to extract and resample 2×32 MHz, overlapping with the 8×8 MHz bands observed by the EVN stations, and reformat it to the VLBI Data Interchange Format (VDIF), de facto a complete signal processing chain to convert MeerKAT native beamformer output to VLBI compatible VDIF. This led to fringes being detected during two NMEs in 2018, both to a single MeerKAT dish and a phased-up array of 16 MeerKAT dishes, Fig. 7.6. The tests also revealed a subtle issue with the beamformer signal processing, which was in fact of much interest to the MeerKAT engineers. Finding VLBI fringes using a single 13.5 m MeerKAT dish on an 8000+ km baseline clearly demonstrates the excellent quality of the dish and receiver system. The above results and other MeerKAT-VLBI aspects will be reported in a South-African-led White Paper that will be distributed amongst the community in the near term.
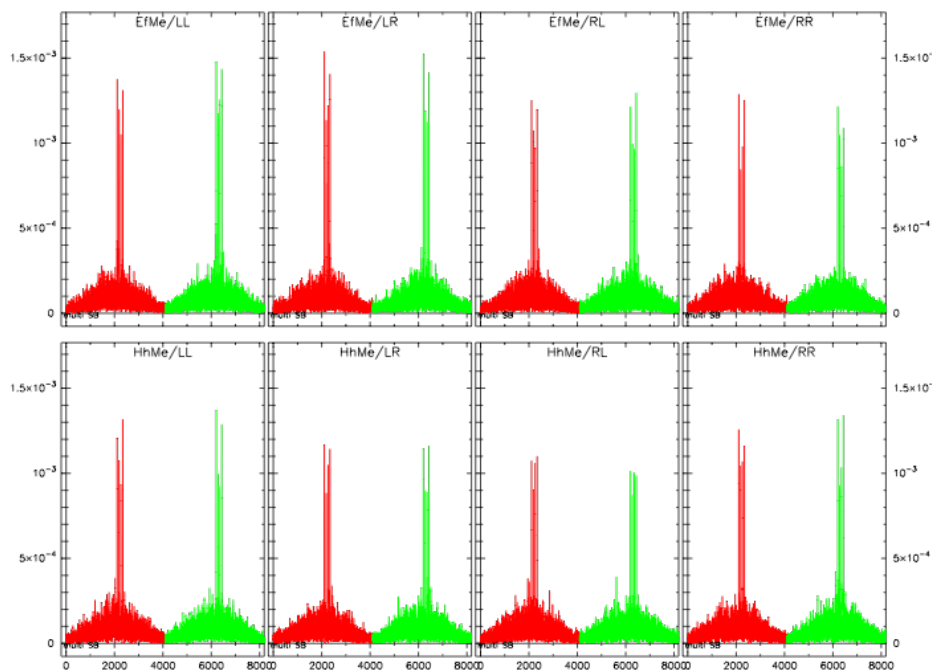

Figure 7.6: *Fringes in two subbands between beamformed MeerKAT and the EVN telescopes Hartebeesthoek and Effelsberg.*

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7.2.9 Space and Planetary Science

The Planetary Radio Astronomy and Doppler Experiment (PRIDE) developed at JIVE and aimed at multi-disciplinary enhancement of the science output of planetary and space science missions was accepted as one of the eleven experiments of the ESA's Jupiter Icy Satellites Explorer (JUICE) mission. It is scheduled for lift-off in May 2022. PRIDE will address and enhance science tasks of the JUICE mission by providing measurements for improvement of the Jovian system ephemerides as well as measuring parameters of the propagation medium penetrated by the spacecraft radio transmission. The experimental potential of PRIDE in radio occultations was demonstrated with several observations of the ESA's Venus Express using the EVN and global VLBI arrays conducted between 2012-2014. In this work, the propagation of the ESA's Venus Express orbiter radio emission was explored in various geometries (ingress, egress, total eclipse) as well as radio communication configurations (open and closed loops). The investigation demonstrated the potential of the PRIDE methodology in measuring parameters of the planetary atmosphere at altitudes and pleasures unreachable by other available techniques. The results of these studies were included in the PhD dissertation by Tatiana Bocanegra; the PhD defense will occur in March 2019.

Dora Klindžić, a student of the Department of Physics of the University of Zagreb (Croatia), worked at JIVE in 2017-2018 as an Erasmus trainee on the applications of PRIDE to studies of the Mars interior and atmosphere. The project focused on radio occultations of the ESA's Mars Express spacecraft observed with the EVN in 2012-2016, and Dora successfully defended her MSc thesis in September 2018.

7.3 EVN Operations

7.3.1 Correlation

The core of JIVE's service is the processing of data from the European VLBI Network (EVN); Tab. 7.1) and 7.1 summarises experiments that were correlated at JIVE during 2017 and 2018.

Table 7.1: Experiments that were correlated at JIVE during 2017

	User Experiments			Test and Network Monitoring		
	N	Ntwk (hr)	Corr (hr)	N	Ntwk (hr)	Corr (hr)
Correlated	97	706.0	759.0	26	88	88
Distributed	95	691.0	751.0	25	86	86
Released	84	614.5	674.5	23	81	81
e-EVN experiments	36	227.0	227.0			
e-EVN ToOs	9	81.5	81.5			

Table 7.2: Experiments that were correlated at JIVE during 2018

	User Experiments			Test and Network Monitoring		
	N	Ntwk (hr)	Corr (hr)	N	Ntwk (hr)	Corr (hr)
Correlated	79	664.5	802.5	35	111	111
Distributed	85	695.5	854.5	36	109	109
Released	84	648.5	764.5	31	93	93
e-EVN experiments	32	188.0	188.0			
e-EVN ToOs	12	79.0	79.0			

2017 and 2018 saw a lot of 'firsts' in EVN experiments:

- First e-EVN observation to use pulsar gating/binning (EM128A, January 2017);

- First 2 Gbps e-EVN observation including Arecibo, which is limited to 16 MHz subbands (mark4). Centring 16 MHz USB BBCs in the 2 Gbps stations' 32 MHz subbands avoided the copying implicit in standard mixed-BW correlation (two 16MHz subbands packed into a 32 MHz subband), which might not have been able to keep up with real-time correlation with the 12-station array. (RP027, March 2017);

- First use of simultaneous real-time correlation and recording onto FlexBuffs at JIVE for a 2 Gbps observation (RM013, September 2017);

- First user e-EVN experiments including e-MERLIN out-stations in September 2018. Three out-stations participated at 512 Mbps to fit, together with a Jodrell Bank antenna at 1 Gbps, within the current network bandwidth limitation from the UK of 3000 Mbps. SFXC was able to keep up with the mixed-bandwidth correlation in real-time (each out-station uses 64 MHz channels which in this experiment needed to be split into 16 MHz channels to match the other stations).

- First successful participation of the Sardinia Radio Telescope in e-EVN user experiments (September 2018).

- First joint Global + LBA observation at 18 cm (GS039, May 2017) and 6 cm (GG084A, March 2018).

- First fringes from a RadioAstron user experiment using the normal production system; the ephemeris was good enough to keep residual delays and rates within standard clock-search windows over the course of the experiment, and not require estimation of an acceleration term. This is consistent with previous "off-line" tests using test observations and scans of experiments correlated in Bonn - suggesting that lack of fringes via the normal production system in other user experiments may have been target-related rather than production-system-related.

In total, there were 21 e-EVN ToO observations (arising from 13 proposals), covering a range of targets including E-M counterparts and their structural evolution; gravitational wave events; X-ray binaries; the (only yet known) repeating fast radio burst; other transients (including giant bursts from stellar masers); tracing the expansion of gamma-ray bursts (2 different ones); investigating a possible association between a gamma-ray burst and fast-radio bursters; seeking jet components in a gamma-ray detected nova; and, an unusual transient in the nuclear region of a narrow-line. In addition, there were 4 e-EVN triggered observations (arising from 3 proposals), covering targets ranging from SWIFT-detected Gamma-ray Bursts, X-ray binaries, to gravitational-wave event counterparts. Three of the triggered observations belonged to the relatively new class of 'generic triggers'.

User e-EVN experiments at 6 cm now routinely run at 2 Gbps for most stations (Ef, Mc, Nt, On, Ys, Hh, Ir); with four others currently at 1 Gbps (Jb, Wb, Tr, T6) and perhaps Ar at 512 Mbps, a total of 18.5 Gbps streaming into JIVE for real-time correlation is similarly routine. During the November 2017 e-EVN day clock-search/test period, real-time correlation of a new record of 20 Gbps was sustained (On sent two back-ends'-worth of 2 Gbps).

It has occurred that a station observes using linear rather than circular polarizations. JIVE have made scripts to wrap around the CASA PolConvert program (I. Marti-Vidal) in order to reconstruct circular polarizations for such stations, both in continuum and spectral-line observations, within the FITS files prior to distribution to the PI.

The "E-series" firmware for the DBBC enabled 2 Gbps observing via tunable 32 MHz channels had been deployed for user experiments since session 3/2015, but a new version of this showed amplitude variations across channels, most notably in session 1/2018. However, a quick succession of tests showed that the behaviour could persist even for a station reverting back to earlier version, but was not necessarily entirely reproducible. The CBD decided in May to revert to the non-E-series firmware, at the expense of 2 Gbps bit-rates. This change was carried out, which required JIVE to make last-minute revisions to the schedules for ∼85 % of the session 2/2018 user experiments. The rest of 2018 remained at 1 Gbps while new firmware was being developed and tested to re-attain higher bit-rates. Detailed per-station/frequency-band summaries of the effects of this firmware problem were presented at the Users' Meeting during the EVN Symposium in Granada, and targeted summaries were sent to PIs of possibly affected observations, along a description of their re-queuing options.

7.3.2 EVN Support

The Kuntunse telescope in Ghana (just to the north of Accra) participated in 6 cm Network Monitoring Experiments (NME) in session 1/2017 (N17C1) and session 1/2018 (N18C1). This is the first of the future AVN telescopes to join an EVN observation. During the first NME fringes were detected, with phase stability limited by the current rubidium frequency standard. However. This was improved upon in the subsequent NME in 2018 with fringes obtained in the ftp fringe-test segments. Support scientists from JIVE taught at training events in 2017 and 2018 hosted by the Development in

Africa with Radio Astronomy (DARA) training programme in Ghana. In 2018, two African VLBI Network visitors spent a week at JIVE where they were introduced to how the EVN and JIVE work, under the aegis of an ASTRON/JIVE traineeship programme supported by JUMPING JIVE.

The first compelling fringes from e-MERLIN out-stations came in the 6 cm NME in session 2/2017 (N17C2). This comprised 4 out-stations, each observing at a bit-rate of 512 Mbps. The sampler statistics were not good (essentially 1-bit sampling with a ∼20 % asymmetry around 0), and some of the out-stations had occasional jumps in phase(time). By the 6 cm NME of session 3/2017 (N17C3), the behaviours had noticeably improved. e-MERLIN out-stations also participated in five 18 cm user experiments in session 3/2017 (not yet correlated). The short baselines provided by being able to include e-MERLIN out-stations as individual telescopes in an EVN correlation has been a long standing desire expressed by users, in order to improve sensitivity to more diffuse emission and help wide-field mapping.

In session 1/2018, good e-MERLIN out-station fringes were seen at 1.3 cm, completing the bands having overlap with the EVN. During 2018, data quality continued to improve, such that it was possible to permit detection of model-based effects. Residual phases/delays from phase-referencing observations led to the realization that the tropospheric model was being applied in the e-MERLIN correlation (and thus doubly-applied after the EVN correlation) – it is now turned off for e-MERLIN correlation when out-stations participate in EVN observations, and the effect in earlier data can largely be compensated via CLCOR/ATMO in AIPS using a nominal zenith delay of 220 cm.

The Kunming telescope in Yunnan (southwest China) participated in NMEs and some user experiments at 5 cm and 6 cm in session 2/2017, and in the entire 3.6/13 cm block of session 3/2017. No significant problems have arisen. The Urumqi telescope recorded in parallel using their existing (mark4) and new (DBBC) back-ends in the initial 18 cm and 5 cm blocks of session 2/2017, using specially prepared schedules. Upon reliable success with the DBBC, they shifted to entirely-DBBC operation for the following 6 cm block of that session. Fringes from the RAEGE Santa Maria telescope (Azores) were found in a single-baseline test using a geodetic S/X set-up in February 2018. Test observations were conducted for the new 7 mm receivers at Effelsberg and Tianma, with fringes seen to both.

e-shipping, in which JIVE pulls data from the telescopes to FlexBuffs at JIVE, continued to grow in importance. By the end of 2018, the majority of EVN stations used the FlexBuff system to record data and e-shipping to transfer the data to JIVE. Those yet to make this transition include the KVAZAR stations, Chinese stations, and Torun, although some activity in the direction of FlexBuff operations is underway at these stations as well. There has been "unbudgeted" use of FlexBuffs at JIVE for special circumstances (e.g., data from the Australian LBA, inter-correlator transfers); so far there has been enough slack in the FlexBuffs at JIVE to accommodate such instances.

Under the aegis of JUMPING JIVE WP5, central database structures for station feedback and amplitude calibration, which hitherto have been stored purely in an experiment-based fashion. The new SQL structures permit stations to search across all experiments by various quantities and create their own custom plots and tables. The new structures

are presented using a web-based Grafana graphical interface. Station feedback has been back-loaded through 2002, and amplitude calibration through 2006.

JIVE has also installed a Mattermost server to handle real-time communication with stations during e-VLBI, ftp fringe-tests, and the like. Mattermost was found to overcome some recently arising limitations with skype and slack – all EVN stations retain access and conversation history is preserved.

7.3.3 EVN User Support

JIVE provides support at all stages of a user's EVN observation, from proposal definition to data analysis. There were 19 first-time PIs in 2017 and 2018 observations, including seven students. Six of these first-time PIs had an e-EVN observation (two of them students). JIVE continued to provide PIs with experiment-specific scheduling templates to track the evolving configurations of equipment at EVN stations. About 85 % of the schedules for session 2/2018 had to be re-made at JIVE after the PIs had already submitted them, in order to enact the reversion back to non-E-series DBBC firmware as directed by the CBD.

The EVN Archive is a vital user service, which is openly accessible following the expiry of the proprietary period (one year, but six months for ToO projects). The total size of user-experiment FITS files in the Archive at the end of 2018 was 60.32 TB. Figure 7.7 shows the growth of the Archive with time.
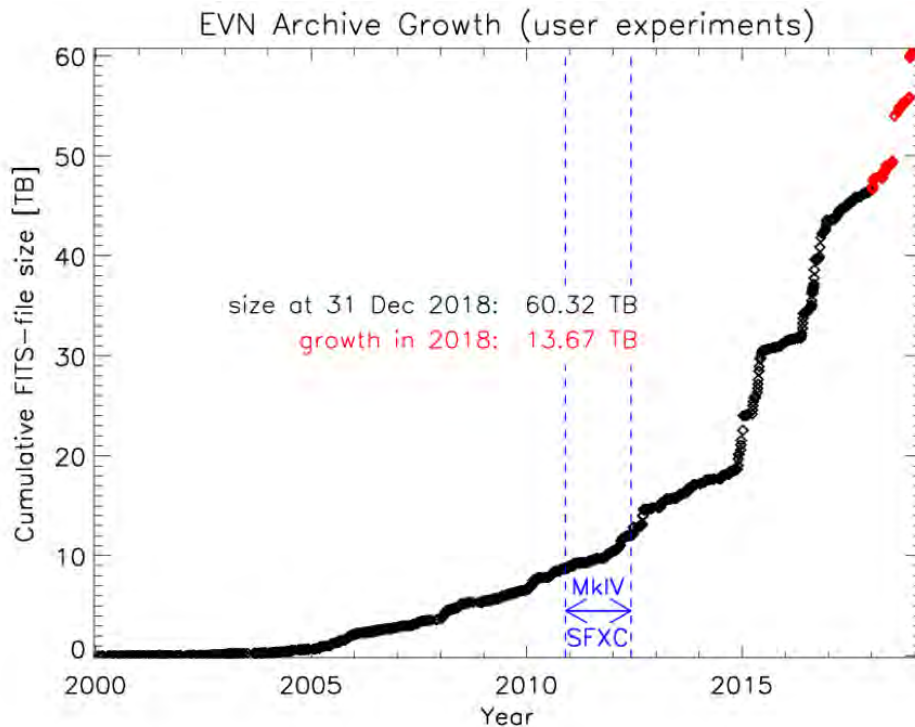

Figure 7.7: *The growth of the EVN archive with time.*

The EVN Archive has been adjusted at JIVE and supporting utilities in order to host FITS files resulting from EVN observations correlated at Bonn. The fitsfinder utility, which databases information from the archived FITS files to permit searching the Archive across a variety of query parameters, was modified to also work on FITS files from Bonn. Thus, the first experiment correlated at Bonn is now fully incorporated into the EVN Archive. The main 'tabs' of the EVN Archive (e.g., FITS files, standard plots, pipeline results) have also been adjusted to include a separate tab for proposal abstracts, which will be populated for observations resulting from proposals submitted on or after the October 2017 deadline. Abstracts from proposals submitted via the NorthStar tool are extracted automatically from the NorthStar database; those from ToO or short-observation proposals are extracted manually from the proposal and passed via the standard archiving script.

The EVN Archive is now listed in re3data.org, a registry of research data repositories, searchable by discipline, country (European Union for the EVN Archive), or content type. There are currently 24 repositories listed under astrophysics.

The script that provides primary-beam corrections into the FITS files received its first application by users in their own observations in 2018. It fits Gaussians to beam maps provided by stations; most of the large stations (who typically taper their sensitivity to the outer reaches of their antennas) have provided such maps, smaller stations that have not receive nominal-diameter models.

8 VLBI related meetings with significant participation by EVN institutes

8.1 European Week of Astronomy and Space Science, Prague, Czech Republic, June 26-30, 2017

Today, both radio and optical astrometry can reach absolute accuracies of the order of $100\,\mu$as, while achieving differential astrometry uncertainties of the order of $10\,\mu$as. This gives rise to a wealth of new and interesting scientific studies from tracing the orbits of nearby binary stars, measuring distances of star-forming regions across the Milky Way, to imaging the base of the AGN jet. Currently, several systematic radio astrometry programs are being carried out, such as the VLBI-Exploration-of-Radio-Astrometry, the Bar-and-Spiral-Structure-Legacy survey and the Gould's-Belt-Distances survey. In 2018, the third realization of the International Celestial Reference Frame (ICRF3) is expected. From 2016, optical astrometry has seen a boom with the publication of the first Gaia catalogue DR1, of which the final catalogue is foreseen in the early 2020s. Given the impact both radio and optical astrometry will have on the scientific community, Kazi Rygl (INAF-IRA), Teresa Antoja (ICCUB), Geraldine Bourda (LAB), Francois Mignard (OCA), Nobuyuki Sakai (NAOJ), Alberto Sanna (MPIfR) and Huib van Langevelde (JIVE/Sterrewacht Leiden) organized a "Synergies with Radio Astrometry" session within the Gaia symposium at the 2017 EWASS conference in Prague, opening a dialog between these two communities for discussing and starting new collaborations. In particular, the session aimed to emphasize the scientific merit from the combination of radio and optical astrometry. For a summary see EVN Newsletter 48.

8.2 Astrophysical Masers: Unlocking the Mysteries of the Universe, Cagliari, Italy, September 4-8, 2017

IAU Symposium 336 "Astrophysical Masers: Unlocking the Mysteries of the Universe" was held in Cagliari (Sardinia, Italy) on 4-8 September, 2017, Fig. 8.1. This was the sixth of a series organised every 5 years, where scientists from around the world gather to discuss the latest advancements in the field. The program includes many aspects of maser research, with a strong presence of VLBI results. Since the last meeting in South Africa in 2012, there has been an explosion of work on masers, especially related to the cosmic distance scale, the structure of the Milky Way, star formation and evolution, and the masses of (AGN) black holes. The very high resolution VLBI results provide key information, complementary to that of other astronomical techniques. For a summary of the meeting see EVN Newsletter 49.
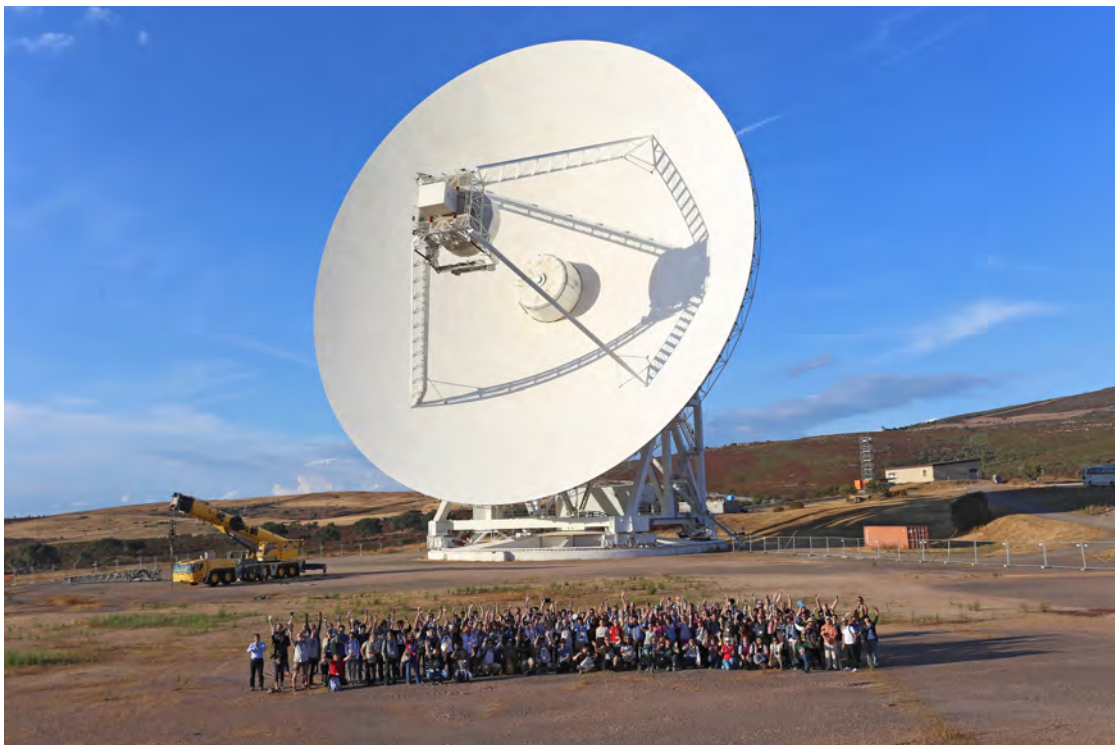

Figure 8.1: *Participants in "Astrophysical Masers: Unlocking the Mysteries of the Universe" meeting in Cagliari, September 4-8, 2017.*

8.3 Young European Radio Astronomers Conference, Bologna, Italy, September 18-21, 2017

The Istituto di Radioastronomia (INAF) organized the YERAC in 1972, 1980 and 1996 and the 47th YERAC on September 18-21, 2017 in Bologna. The scientific topics ranged from filaments in the Cosmic Web to the Sun, from theoretical astrophysics to software and technological development. The meeting gathered a total of 34 students coming from about 28 institutes throughout Europe, South Africa and Korea, Fig. 8.2. The gender distribution was almost equally split between men and women, with 19 females and 15 males. For a summary of the meeting see RadioNet report – YERAC 2017.

Figure 8.2: *Participants in the YERAC, Bologna, Italy, September 18-21, 2017.*

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8.4 CASA-VLBI Workshop, Dwingeloo, the Netherlands, October 2-6, 2017

For some time now JIVE (Des Small, Mark Kettenis and Ilse van Bemmel) have been working on making VLBI data reduction with CASA possible. The main motivation is that AIPS is no longer the dominant software package for doing radio astronomy. Learning to use it, just to be able to reduce VLBI data is becoming somewhat of a hurdle. The first CASA VLBI workshop was organised by JIVE during the first week of October, Fig. 8.3. During this workshop experts on VLBI, e-MERLIN and long-baseline LOFAR from all over the world spent a week working with a pre-release of our software on their own data. This helped a lot in identifying remaining bugs and missing functionality. The overall verdict seems to be that JIVE is very close to having usable (but basic) VLBI support in CASA. This work was funded through the BlackHoleCam ERC grant and the SKA-NL project. Work continues in the RadioNet RINGS work package, where JIVE is working on adding support for dispersive terms (to correct for the effect of the ionosphere) and support for wide bands. For a summary of the meeting see RadioNet report – Introducing VLBI tools in CASA.

Figure 8.3: *Participants in the CASA-VLBI workshop at JIVE, October 2-6, 2017.*

8.5 6th International VLBI Technological Workshop, Bologna, Italy, October 9-11, 2017

The 6th International VLBI Technological Workshop (IVTW) meeting took place in Bologna in October 2017 and gathered more than 65 people from many institutions involved in VLBI across the world, Fig. 8.4. The workshop was focused on developments at stations and correlators. The agenda of the meetings and presentations are available at the web page. For a summary of the meeting see EVN Newsletter 49 and RadioNet report – IVTW 6.

Figure 8.4: *The sixth International VLBI Technological Workshop meeting in Bologna, October 9-11, 2017.*

8.6 European Radio Interferometry School (ERIS), Dwingeloo, the Netherlands, October 16-20, 2017.

The seventh European Radio Interferometry School (ERIS) was organised jointly between the Netherlands Institute for Radio Astronomy (ASTRON) and the Joint Institute for VLBI ERIC (JIVE) at ASTRON headquarters in Dwingeloo from 2017 October 16-20. It is a bi-annual graduate level school that forms a fundamental part of the training and development of young radio astronomers primarily from Europe, but also from RadioNet partner countries throughout the world. The school has both lectures and practical tutorials that are given by invited specialists in interferometry who have the expertise and experience in using the main European radio astronomy facilities, which include the Atacama Large Millimetre/Sub-millimetre Array (ALMA), the e-Multi-Element Remotely Linked Interferometry Network (e-MERLIN), the European VLBI Network (EVN), the Low Frequency Array (LOFAR) and the Northern Extended Millimetre Array (NOEMA).

ERIS is open to all regardless of their ethnicity, gender and academic position. In total, 73 participants attended the school from 21 countries, Fig. 8.5. The vast majority of the participants were at graduate level (Masters/PhD) with a few staff members and a few at bachelor level. The number that was female was 35, giving a gender ratio between meal and female of 1:0.92. For a summary of the meeting see RadioNet report – ERIS 2017.

Figure 8.5: *Participants in the ERIS 2017, Dwingeloo.*

8.7 European Week of Astronomy and Space Science, Liverpool, April 3-6, 2018

The EC H2020 JUMPING JIVE project organised a strategic presence of VLBI in the 2018 edition of the European Week of Astronomy and Space Science (EWASS), which took place in Liverpool (UK) on April 3-6 2018, Fig. 8.6. The most focused activity was the Special Session "Exploring the Universe: A European vision for the future of VLBI" (SS11) organised by Tiziana Venturi (INAF), Michael Lindqvist (OSO) and Zsolt Paragi (JIVE), in the context of JUMPING JIVE WP7. The main objective within JUMPING JIVE WP2 ("Outreach and advocacy") was to bring the VLBI technique and unique science conducted to the attention of a broader astronomical audience. In addition, expert VLBI users showed their successful research examples and included information on JIVE and the EVN in their presentations across a number of symposia and special sessions. For a summary of the meeting see EVN Newsletter 50.

Figure 8.6: *Photos from the EWASS in Liverpool, April 3-6, 2018.*

8.8 The 14th EVN Symposium and Users Meeting, Granada, Spain, October 8-11, 2018

The 14th EVN Symposium and Users Meeting (evnsymp2018.iaa.es) was hosted by the Instituto de Astrofsica de Andaluca-CSIC (IAA-CSIC) in Granada (Spain) on behalf of the EVN Consortium Board of Directors. The meeting took place on October 8-11, 2018 at the main auditorium of the 'Parque de las Ciencias' of Granada, the science museum of the city. This biennial meeting is the main forum for discussion of the latest VLBI scientific results and technical and technological developments within the EVN member countries. At this 14th EVN Symposium there was also a chance for user input into the future Science Vision for the EVN and, as usual, an EVN User's Meeting was organised within the scientific program.

Topics discussed during this edition of the symposium included:

- Powerful active galactic nuclei science

- Starburst galaxies, extragalactic masers, and supernovae

- Stellar evolution and stellar masers

- Transient sources and pulsars

- Astrometric, geodetic & space applications

- VLBI technology developments

- Current and future VLBI facilities and international cooperation

On this occasion, the EVN Symposium was also focused on the role of EVN on:

- Very-high sensitivity VLBI with SKA

- Future multi-wavelength and multi-messenger astronomy including high angular-resolution astronomy at other wavelengths

As a parallel activity of the EVN Symposium, a CASA-VLBI tutorial with over 80 participants was organised by JIVE for the late afternoon of October 11th, 2018 on the premises of the IAA-CSIC. A visit to the IRAM 30 m millimetre radio telescope, in the Sierra Nevada Mountains close to Granada, was also organised.

There were 170 registered participants from 25 countries world-wide, Fig. 8.7. There was a more than significant participation from South Korean colleagues (24 attendees), followed by Spain (23), Russia (17), Italy (15), Germany (14), and the Netherlands (13). About 21 % of attendees were women, and a significant fraction of participants were young researchers and students. There were 91 oral presentations (including 11 reviews) that were distributed in 11 sessions, of which four of them had to be organised in parallel sessions (AGN/Stellar Evolution) for the first time in an EVN Symposium. This was needed in this occasion to alleviate the large pressure to obtain time for contributed

talks. Almost 80 posters were also presented during the Symposium. As usual, the EVN Users Meeting gave attending astronomers the opportunity to provide feedback about EVN proposal evaluation, operations, correlation and data distribution and archiving.

The large number of attendees, and the variety of results presented on new astrophysical topics that are far from traditional for the VLBI community, especially with regard to astrophysics of transient phenomena, multi-messenger science and synergies with observations at other spectral ranges, indicates that the EVN community is evolving and growing.

Figure 8.7: *Conference group picture taken at the hall of the 'Parque de las Ciencias' of Granada.*

8.9 The 7th International VLBI Technology Workshop, Krabi, Thailand, November 12-15, 2018

The 7th International VLBI Technology Workshop was hosted by NARIT, the National Astronomical Research Institute of Thailand, in Krabi, Thailand, from 12 to 15 November 2018. There were 40 registered participants, Fig. 8.8. The International VLBI Technology Workshops have evolved from the highly successful 10 year series of International e-VLBI workshops. The scope of the technology workshops is to encompass all areas of hardware and software development relevant to VLBI. NARIT is in the process of establishing the Thai Radio AstronomyObservatory (TNRO) in Chiang Mai, which will host a new 40 m RadioTelescope and a 13.2 m VGOS station on the same site, expected to seefirst light in early 2020. With the ambition to become an active participant in VLBI, hosting the IVTW provided a perfect opportunity for the Thai and international VLBI astronomy communities to meet and discuss. For a summary of the meeting see EVN Newsletter 52.

Figure 8.8: *Participants in the 7th International VLBI Technology Workshop in Krabi, Thailand.*

8.10 Young European Radio Astronomers Conference, Dwingeloo, the Netherlands, 4-6 September, 2018

The Young European Radio Astronomers Conference (YERAC) 2018 took place from 4-6 September, 2018, Fig. 8.9. Host institutes were JIVE (JIV-ERIC) and ASTRON (NWO-I). Selection was done using the letter of reference (no letter implied no participation), and suitability of the candidates (early career and radio astronomical research). This resulted in 30 participants. The group contained over 1/3 women and several native African astronomers. Participants nationalities spanned the entire globe, their current institutes being well distributed within Europe. For a summary of the meeting see RadioNet report – YERAC 2018.

Figure 8.9: *Participants in the YERAC 2018, Dwingeloo.*

9 EVN publications

9.1 EVN related referred publications (in alphabetical order) 2017

1. Abbott, B.P., Abbott, R., Abbott, T.D., et al. 2017. *Multi-messenger Observations of a Binary Neutron Star Merger.* ApJ 848, L12. (RP029A-B)

2. Ahnen, M.L., Ansoldi, S., Antonelli, L.A., et al. 2017. *First multi-wavelength campaign on the gamma-ray-loud active galaxy IC 310.* A&A 603, A25. (EE009A-B; EE009C-D)

3. Azulay, R., Guirado J.C., Marcaide, J.M., et al. 2017. *Young, active radio stars in the AB Doradus moving group.* A&A 602, A57. (EG062A-F; EG084A-B)

4. Bogdán, Á., Kraft R.P., Evans D.A., et al. 2017. *Probing the Hot X-Ray Gas in the Narrow-line Region of Mrk 3.* ApJ 848, 61.

5. Bruni, G., Gómez, J.L., Casadio, C., et al. 2017. *Probing the innermost regions of AGN jets and their magnetic fields with RadioAstron. II. Observations of 3C 273 at minimum activity.* A&A 604, A111. (GA030C)

6. Caccianiga, A., Dallacasa, D., Antón, S., et al. 2017. *SDSSJ143244.91+301435.3 at VLBI: a compact radio galaxy in a narrow-line Seyfert 1.* MNRAS 464, 1474. (EC048)

7. Cao, H.-M., Frey, S., Gabányi, K.É., et al. 2017. *VLBI observations of four radio quasars at $z > 4$: blazars or not?.* MNRAS 467, 950. (EGC054A-B; EC054C-D)

8. Chatterjee, S., Law, C.J., Wharton, R.S., et al. 2017. *A direct localization of a fast radio burst and its host.* Nat 541, 58. (RP024A-E; RP026A-C)

9. Etoka, S., Gérard, E., Richards, A.M.S., et al. 2017. *Recurring OH Flares towards o Ceti - I. Location and structure of the 1990s' and 2010s' events.* MNRAS 468, 1703. (RE001)

10. Herrero-Illana, R., Alberdi, A., Pérez-Torres, M.Á., et al. 2017. *No AGN evidence in NGC 1614 from deep radio VLBI observations.* MNRAS 470, L112. (EH030A-B)

11. Krehlik, P., Buczek, Ł., Kołodzeij, J., et al. 2017. *Fibre-optic delivery of time and frequency to VLBI station.* A&A 603, A48.

12. Kundu, E., Lundqvist, P., Pérez-Torres, M.Á., et al. 2017. *Constraining Magnetic Field Amplification in SN Shocks Using Radio Observations of SNe 2011fe and 2014J.* ApJ 842, 17. (EP092A-B)

13. Marcote, B., Paragi, Z., Hessels, J.W.T., et al. 2017. *The Repeating Fast Radio Burst FRB 121102 as Seen on Milliarcsecond Angular Scales.* ApJ 834, L8. (RP024A-E; RP026A-C)

14. Moscadelli, L., Sanna, A., Goddi, C., et al. 2017. *Extended CH_3OH maser flare excited by a bursting massive YSO.* A&A 600, L8. (RS002; EL032)

15. Nappo, F., Pescalli, A., Oganesyan, G., et al. 2017. *The 999th Swift gamma-ray burst: Some like it thermal. A multiwavelength study of GRB 151027A.* A&A 598, A23. (RG007A; RG007B)

16. Natarajan, I., Paragi, Z., Zwart, J., et al. 2017. *Resolving the blazar CGRaBS J0809+5341 in the presence of telescope systematics.* MNRAS 464, 4306. (RSC02)

17. Nyland, K., Davis, T.A., Nguyen, D.D., et al. 2017. *A Multi-wavelength Study of the Turbulent Central Engine of the Low-mass AGN Hosted by NGC 404.* ApJ 845, 50.

18. Park, S., Yang, J., Oonk, J.B.R., et al. 2017. *Discovery of five low-luminosity active galactic nuclei at the centre of the Perseus cluster.* MNRAS 465, 3943. (EO009)

19. Petrov, L., Kovalev, Y.Y., 2017. *On significance of VLBI/Gaia position offsets.* MNRAS 467, L71. (GC030; GC034A; BCD; EF)

20. Petrov, L., Kovalev, Y.Y., 2017. *Observational consequences of optical band milliarcsec-scale structure in active galactic nuclei discovered by Gaia.* MNRAS 471, 3775. (GC030; GC034A; BCD; EF)

21. Prandoni, I., Murgia, M., Tarchi., A., et al. 2017. *The Sardinia Radio Telescope. From a technological project to a radio observatory.* A&A 608, A40.

22. Quiroga-Nuñez, L.H., van Langevelde, H.J., Reid, M.J., et al. 2017. *Simulated Galactic methanol maser distribution to constrain Milky Way parameters.* A&A 604, A72. (RP026A-C)

23. Rushton, A.P., Miller-Jones, J.C.A., Curran, P.A., et al. 2017. *Resolved, expanding jets in the Galactic black hole candidate XTE J1908+094.* MNRAS 468, 2788. (RR007A-B; RR009)

24. Sanna, A., Moscadelli, L., Surcis, G., et al. 2017. *Planar infall of CH_3OH gas around Cepheus A HW2.* A&A 603, A94. (ES071A; ES071B; ES071C)

25. Yang, X., Yang, J., Paragi, Z., et al. 2017. *NGC 5252: a pair of radio-emitting active galactic nuclei?* MNRAS 464, L70. (RSY03)

9.2 EVN related referred publications (in alphabetical order) 2018

1. An, T., Sohn, B.W., Imai, H., 2018. *Capabilities and prospects of the East Asia Very Long Baseline Interferometry Network.* Nat Astron 2, 118.

2. Atemkeng, M., Smirnov, O., Tasse, C., et al. 2018. *Baseline-dependent sampling and windowing for radio interferometry: data compression, field-of-interest shaping, and outer field suppression.* MNRAS 477, 4511.

3. Bocanegra-Bahamón, T. M., Molera Calvés, G., Gurvits, L. I., et al. 2018. *Planetary Radio Interferometry and Doppler Experiment (PRIDE) technique: A test case of the Mars Express Phobos Flyby. II. Doppler tracking: Formulation of observed and computed values, and noise budget.* A&A 609, 11.

4. Bright, J.S., Fender, R.P., Motta, S.E., et al. 2018. *Long-term radio and X-ray evolution of the tidal disruption event ASASSN-14li.* MNRAS 475, 4011. (EP096)

5. Gabányi, K.É., Frey, S., An, T. 2018. *Is 4C+29.48 a γ-ray source?* A&A 612, 10. (EL034A)

6. Gabányi, K.É., Frey, S., Gurvits, L.I., et al. 2018. *High-resolution Radio Image of a Candidate Radio Galaxy at z = 5.72.* RNAAS 2, 200. (RSG11)

7. Gabányi, K.É., Frey, S., Paragi, Z., et al. 2018. *The radio structure of the peculiar narrow-line Seyfert 1 galaxy candidate J1100+4421.* MNRAS 473, 1554. (EG087)

8. Gawroński, M. P., Goździewski, K., Katarzyński, K., et al. 2018. *Another look at AM Herculis - radio-astrometric campaign with the e-EVN at 6 cm.* MNRAS 475, 1399. (EG069A-B; EG069D-F)

9. Giovannini, G., Savolainen, T., Orienti, M., et al. 2018. *A wide and collimated radio jet in 3C84 on the scale of a few hundred gravitational radii.* Nat Astron 2, 472. (GS032A; GS032B)

10. Guirado, J.C., Azulay, R., Gauza, B., et al. 2018. *Radio emission in ultracool dwarfs: The nearby substellar triple system VHS 1256-1257.* A&A 610, A23. (EG092A-C)

11. Gupta, N., Srianand, R., Farnes, J.S., et al. 2018. *Revealing H I gas in emission and absorption on pc to kpc scales in a galaxy at z $\sim$ 0.017.* MNRAS 476, 2432. (GG074)

12. Kool, E.C., Ryder, S., Kankare, E., et al. 2018. *First results from GeMS/GSAOI for project SUNBIRD: Supernovae UNmasked By Infra-Red Detection.* MNRAS 473, 5641.

13. Kutkin, A.M., Pashchenko, I.N., Lisakov, M.M., et al. 2018. *The extreme blazar AO 0235+164 as seen by extensive ground and space radio observations.* MNRAS 475, 4994. (EK028)

14. Lew, B. 2018. *Improving pointing of Toruń 32-m radio telescope: effects of rail surface irregularities.* Exp. Astron. 45, 81.

15. Litvinov, D.A., Rudenko, V.N., Alakoz, A.V., et al. 2018. *Probing the gravitational redshift with an Earth-orbiting satellite.* Physics Lett. A 382, 2192. (EL053; EL057)

16. Mattila, S., Pérez-Torres, M.Á., Efstathiou, A., et al. 2018. *A dust-enshrouded tidal disruption event with a resolved radio jet in a galaxy merger.* Sci 361, 482. (EP063, EP068; EP075; EP087; GP053)

17. Michałowskl, M.J., Xu, D., Stevens, J., et al. 2018. *The second-closest gamma-ray burst: sub-luminous GRB 111005A with no supernova in a super-solar metallicity environment.* A&A 616, 15. (RP018)

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