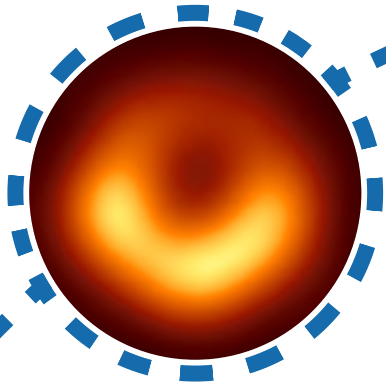
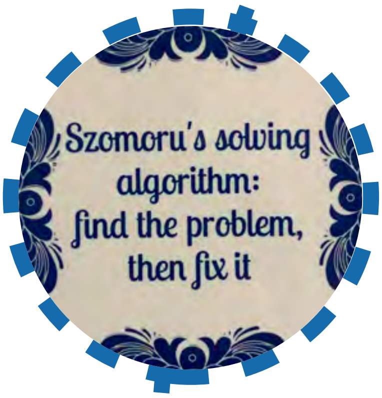
JIVE

Joint Institute for VLBI ERIC





2019 ANNUAL REPORT

ANNUAL REPORT 2019

The Joint Institute for VLBI ERIC (JIVE) was established by a decision of the European Commission in December 2014, and assumed the activities and responsibilities of the JIVE Foundation, which was established in December 1993. JIVE's mandate is to support the operations and users of the European VLBI Network (EVN), in the widest sense.

In 2019, JIVE had six members:

The Netherlands, represented by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) and the Netherlands Institute for Radio Astronomy (ASTRON)

France, represented by the Centre National de la Recherche Scientifique (CNRS)

Latvia, represented by the Latvijas Izglītības un zinātnes ministrija (IZM)

Spain, represented by the Ministerio de Fomento (MF)

Sweden, represented by the Vetenskapsrådet (VR)

The United Kingdom, represented by the Science & Technology Facilities Council (STFC)

JIVE was also supported by the following Participating Research Institutes in 2019:

National Astronomical Observatories of China (NAOC), China

Max Planck Institute for Radio Astronomy (MPIfR), Germany

Italian National Institute of Astrophysics (INAF), Italy

National Research Foundation (NRF), South Africa

FOREWORD

During my first year as the JIVE Council Chair it has been my pleasure to work closely with Paco Colomer as JIVE Director, members of the JIVE staff and other members of the JIVE council. As an EVN institute Director who also recently served as chair of the EVN Consortium Board of Directors I can only emphasize the absolutely central role that JIVE plays within the EVN. This role continues to expand significantly beyond JIVE's initial mission, when first established, to provide EVN correlation and user support, to now encompass a range of other activities that JIVE helps catalyse within the EVN community. These roles include helping with network technical and strategy development, nurturing potential new EVN partner telescopes and managing many of the internal and external communications of the EVN. A strong JIVE together with a large and active distributed EVN community, located both at its member telescopes and amongst its users, provides a unique recipe for the success of EVN/JIVE.

During 2019 JIVE celebrated the end of its first five years of existence as an ERIC. During the year the JIVE council concluded discussions on a long-term strategy and a recommended core programme for the coming years. These discussions built on the very positive external review of JIVE that was completed in 2018. An important part of the future JIVE strategy lies in attracting new partners to the EVN and JIVE. Significant progress on this front has occurred in 2019, including the signing of a collaboration MoU with NARIT for their 40m radio telescope under construction in Chiang Mai (Thailand).

During the year the EU H2020 project JUMPING JIVE project facilitated the development of an updated science vision for the EVN and global VLBI, demonstrating the enormous future potential for VLBI within the landscape of other large facilities. This EU project also has also continued supporting collaborations with several African nations for scientific and technical capacity building. Moreover, a similar initiative is growing in Latin America (IVIA). It is obvious that VLBI becomes ever more a truly global endeavour, in which appropriate coordination of developments is necessary; to this end JIVE is deeply involved in fostering a Global VLBI Alliance, a forum to analyse and optimise global astronomy VLBI developments, and which can also help support new projects such as SKA-VLBI or future space VLBI missions.

A number of impressive VLBI science results involving JIVE staff were produced during 2019 including JIVE involvement in making the first image of a shadow of a black hole, announced by the EHT collaboration in April 2019. JIVE scientists and engineers continue to push the technical capabilities and scientific applications of VLBI, developing broadband operations (including an upgrade of the fibre into Dwingeloo to 100 Gbps), new tools for data analysis (VLBI capabilities into CASA), and spreading this expertise to the community at large, via amongst other things training and user support that enables EVN users to focus on their scientific output. Communication of EVN and JIVE activities has seen a great boost during the past year, with a new website, many press releases, participation in events, plus a revamped EVN newsletter edited by JIVE staff. Presence in social networks is increasing as well.

In November 2019, Arpad Szomoru retired as Head of R&D at JIVE. Arpad has been instrumental in shaping what JIVE is today, leading the JIVE R&D group successfully for more than two decades. We appreciate Arpad both for his long commitment toward developing JIVE, but even more as a very dear colleague within European VLBI. We also welcome Harro Verkouter to his new role as he takes over Arpad's former responsibilities within the JIVE management team.

It is good to be reminded in this report of the achievements that are possible via the appliance of science by an international community working together towards common goals; as exemplified by JIVE and the EVN, especially at a time (June 2020) when the Coronavirus situation affects the world. I end by noting how impressive it has been to see the extent to which JIVE staff have adapted to Coronavirus restrictions, supporting the equally strong efforts at EVN stations, ensuring that most EVN observations and their correlation continue as planned. I thank everyone involved in these efforts.

John Conway

Chairman of the JIVE Council

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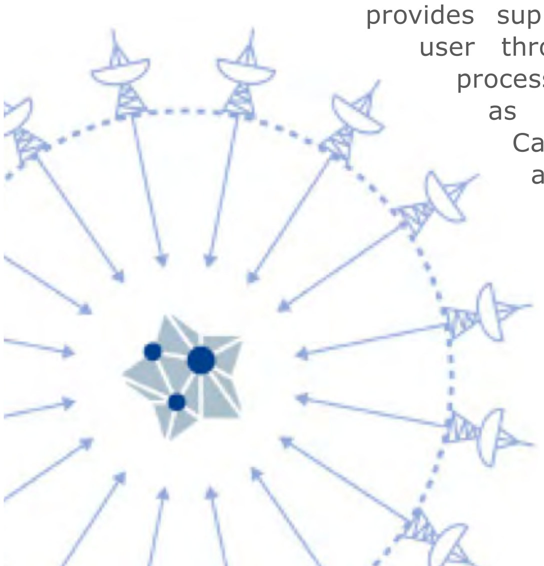
01 INTRODUCTION

1.1 JIVE MISSION

The Joint Institute for VLBI ERIC (JIVE) was established to support, progress and promote the use of Very Long Baseline Interferometry (VLBI). VLBI is a technique in which radio telescopes hundreds to thousands of kilometres apart observe the same radio source in the sky simultaneously. The observations from the telescopes are presented as digital signals, which are then combined at a central, dedicated data processor (the correlator). Astronomers can use the resulting data to produce an extremely high resolution image of the radio sky. Alongside making images, the technique can be used to measure positions of bright radio sources with very high accuracy.

In Europe, VLBI is organised through the European VLBI Network (EVN), a consortium that also includes members from other continents. JIVE hosts the correlator that provides the central data processing for the EVN and also supports most interactions with the astronomers who use the facility. The EVN is open to any astronomer who can write a competitive observation proposal.

JIVE receives the data from the telescope stations as computer hard disk recordings, or by direct streaming over fibre links (e-VLBI). The JIVE support team verifies the data quality, interacts with the staff at the telescopes, and provides support to the end user through subsequent processing and analysis as requested. Calibration data and images from a standard data pipeline are included in the final user product.



In order to keep the EVN and JIVE at the forefront of scientific research, JIVE harbours a team of scientists and engineers, who continually work on the development of new techniques and software to further the scientific capabilities of VLBI. The team's primary focus is to develop new observing modes by investigating new methods to record and transport data, in order to enhance the sensitivity and flexibility of the research infrastructure. Novel data processing techniques and platforms are also explored, and JIVE engineers work on various user interfaces, such as the software that astronomers use to schedule their observations and process their data. In addition, there is considerable expertise at JIVE in deploying VLBI for space applications.

The JIVE staff members also do scientific research themselves in a number of exciting areas, from active galactic nuclei at cosmological distances to star evolution in the Galaxy, which is considered essential to maintain appropriate expertise and provide excellent service to EVN stations and users.

JIVE has developed a reputation to foster coordination, innovation and capacity building for European and global VLBI. In its role as central entity in the EVN, JIVE exploits the ERIC advantages to deal with EC projects.

JIVE

1.2 JIVE IN 2019

As a consequence of the recommendations given by the review committee during its evaluation of JIVE in 2018, the JIVE strategy has been revised and approved by the JIVE Council. As indicated in the previous section, the JIVE mission still highlights on providing data and services by expert support to the EVN and users. In this sense, JIVE aims to enhance the user experience, support continuous innovation, and promote radio astronomy in Europe and beyond. An important task has been to facilitate the development of an updated science vision for the EVN, including its relation with other present and future large scientific facilities covering the whole multi-messenger landscape.

JIVE and partners have been busy in 2019 discussing the models to ensure its sustainability after its first five years of existence as a European Research Infrastructure Consortium (ERIC). As indicated in the statutes, the partners will commit for a new funding period starting in 2020. This is one of the main pillars of the sustainability strategy, which expects that all the members in the EVN will become members in JIVE.

The other main pillar is to keep a healthy portfolio of projects. In 2019, the main H2020 projects have continued: JUMPING JIVE, ESCAPE, RadioNet, and ERIC Forum. The first, JUMPING JIVE, has allowed to explore new partnerships to JIVE and the EVN, some technological applications (an upgraded VLBI scheduling program, pySCHED, and progress towards a robust monitoring system for the VLBI networks), many training activities in Africa, and a very strategic development to include the SKA in VLBI arrays (SKA-VLBI). ESCAPE works to include the EVN archive into the Virtual Observatory and EOSC, and develop VLBI processing tools in Jupyter notebooks. RadioNet provides essential resources to guarantee transnational access to the EVN and JIVE.

The ERIC Forum allows to exploit synergies and solve common challenges, also providing a voice to ERICs in the evolving scenario of EC financing as the new program Horizon Europe is being designed.

The concept of "Special programs" is now included in the JIVE strategy, as a possibility and means to expand its mission to areas of interest to the JIVE and EVN partners, such as geodetic and near-field VLBI applications of VLBI.

Discussions continue to set up a Global VLBI Alliance to ensure the flow of information on strategies and technological developments, as well as synergies and complementarities among the VLBI networks. Such alliance will be a great forum to coordinate some of the opportunities identified in the new EVN science vision, in particular for the joint observations with facilities such as the SKA.

JIVE has facilitated or been directly involved in the production of exciting science results using

Scientific workshop of the East Asian VLBI Network (EAVN) in Mito (Japan) in November 2019, forging the basis of a Global VLBI Alliance

VLBI, like the first even image of the shadow of a supermassive black hole in M87, its charismatic jet, high precision astrometry in our Galaxy, the observations of the afterglow of binary neutron star mergers producing gravitational waves in nearby galaxies, or studying planetary atmospheres.

“Science is not finished until it is communicated”. Last, but not least. On top of preparing press releases of the finest EVN results, preparing and maintaining the new EVN web, and presence in social networks, JIVE has taken the responsibility of producing the EVN Newsletter. Resources are however quite tight, and proper communication requires support from the EVN institutes.

1.3 PARTICIPATION IN WORKSHOPS IN SUPPORT OF POTENTIAL NEW EVN STATIONS

JIVE is very actively supporting the establishment and growth of new communities interested in VLBI. New partnerships in JIVE and EVN are very important, and a specific endeavour within JUMPING JIVE.

On February 25-28, a workshop in Mexico attracted participants from many countries in Latin America, Portugal and Spain, and set the grounds for an initiative for VLBI (Iniciativa VLBI Ibero-Americana, IVIA) which aims to refurbish unused 32-m communication antennas in these countries so they may be used as radio telescopes and also join the EVN.

One such antennas is in Sao Miguel (Azores, Portugal), part of a big effort in Portugal to support SKA, as discussed in the “Multi-messenger astronomy with SKA precursors and pathfinders” held in Aveiro on May 12-15, where the e-EVN was highlighted.

Future EVN stations may come from Thailand (Chiang Mai, workshop on November 5-10, and signature of a Memorandum of Agreement between NARIT and JIVE), Greece (Thermopylae Satellite Communication station, visited on May 30-31) and Ukraine (Zolochiv, workshop on October 2-5).

Signing of a Memorandum of Agreement between NARIT and JIVE in November 2019.

1.4 EVENTS

JIVE staff has participated in many conferences and workshop in 2019. Actually, the most efficient ways to share information and have impact in international projects is to meet colleagues in these events.

One of great tradition is the Bonn-Dwingeloo neighbours meeting which was organised by JIVE and ASTRON on June 6th in Dwingeloo, allowing the staff of two major VLBI centres in Europe to share ideas in science and technology.

Sponsored by JUMPING JIVE, the SKA-VLBI KSP meeting was held in Manchester (UK) on October 14-17, gathering 100 participants and demonstrating the huge interest and potential in VLBI observations with the SKA.

Co-organised by JIVE, the 29th annual international Astronomical Data Analysis Software & Systems (ADASS) conference was held in Groningen in October.

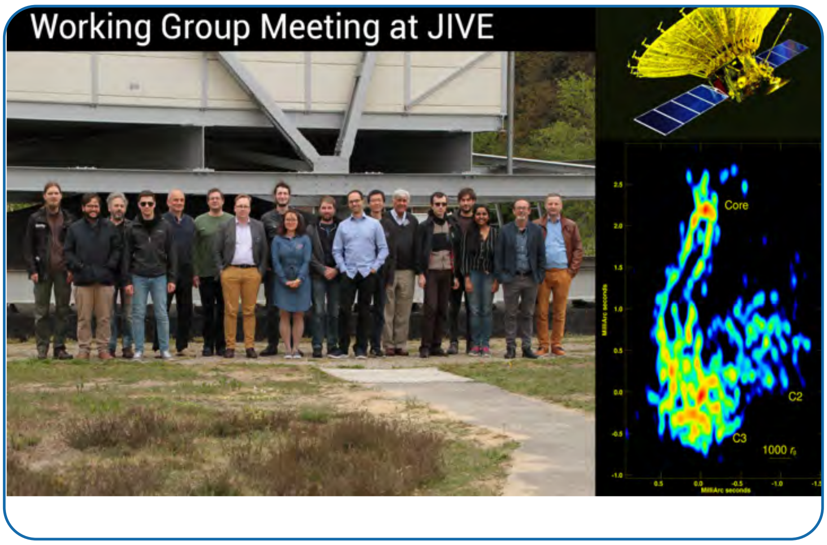
JIVE staff also participated in the SKA Engineering workshop "Concluding our past, realizing our future" in Shanghai (China) on November 25-28, and in the scientific workshop of the East Asia VLBI Network (EAVN) in Mito (Japan) on September 24-26, setting the basis of a Global VLBI Alliance.

On April 10th 2019, the JIVE director was invited to present an update of the VLBI opportunities in Africa, at the Africa-Europe Radio Astronomy Platform (AERAP) meeting in Brussels, a forum to foster strategic cooperation in which JIVE promotes the development of the African VLBI Network (AVN) as a way to build human capacity in the SKA partner countries, a task in which JIVE is very involved thanks to resources provided by JUMPING JIVE.

In 2019, the RadioAstron space VLBI mission was completed. Over its whole operational period (2011–2019) RadioAstron, together with more than 40 Earth-based radio telescopes, conducted several hundred observations of AGN at wavelengths of 18, 6 and 1.3 cm. In May 2019, the RadioAstron AGN Working Group (WG) got together at JIVE.

Scientific highlights of their programme are multiple detections of extremely high brightness values in many AGN, hints on manifestations of refractive substructures in the cores of bright quasars, enigmatic properties of polarised radio emission of ultra-compact extragalactic radio sources. Work continues for publication of the results in 2020.

Left: RadioAstron AGN Working Group at JIVE, May 2019; *Upper right*: the RadioAstron Spektr-R spacecraft (credit: Lavochkin Scientific and Production Association); *Lower right*: Radio image of the source 3C 84 obtained with RadioAstron and a network of Earth-based radio telescopes at 1.3 cm (Giovannini et al. 2018, Nature Astronomy, volume 2, p. 472–477).



1.3 PERSONNEL

During 2019, new staff have joined JIVE. Two positions for support scientists were filled, Dr. Dhanya Nair (specialist in AGNs and high frequency VLBI) and Dr. Olga Bayandina (specialist in cosmic masers and space VLBI).

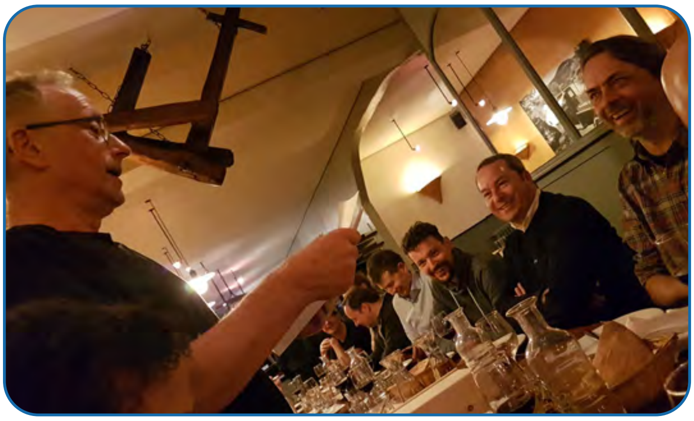
The H2020 JUMPING JIVE project allowed to bring Mrs. Cristina Garcia-Miró from the SKAO in Manchester to JIVE, in the role of SKA-VLBI scientist.

Finally, Dr. Waleed Madkour started as Frequency Manager for the Committee of Radio Astronomy Frequencies (CRAF), a service for the benefit of the EVN partners and the whole community in Europe.

In November 2019, Dr. Arpad Szomoru retired after 19 years of very successful service to JIVE. He will continue to be involved in some activities, such as the preparation of a technology roadmap for the EVN. His role as head of the R&D department is being filled (interim) by Harro Verkouter.



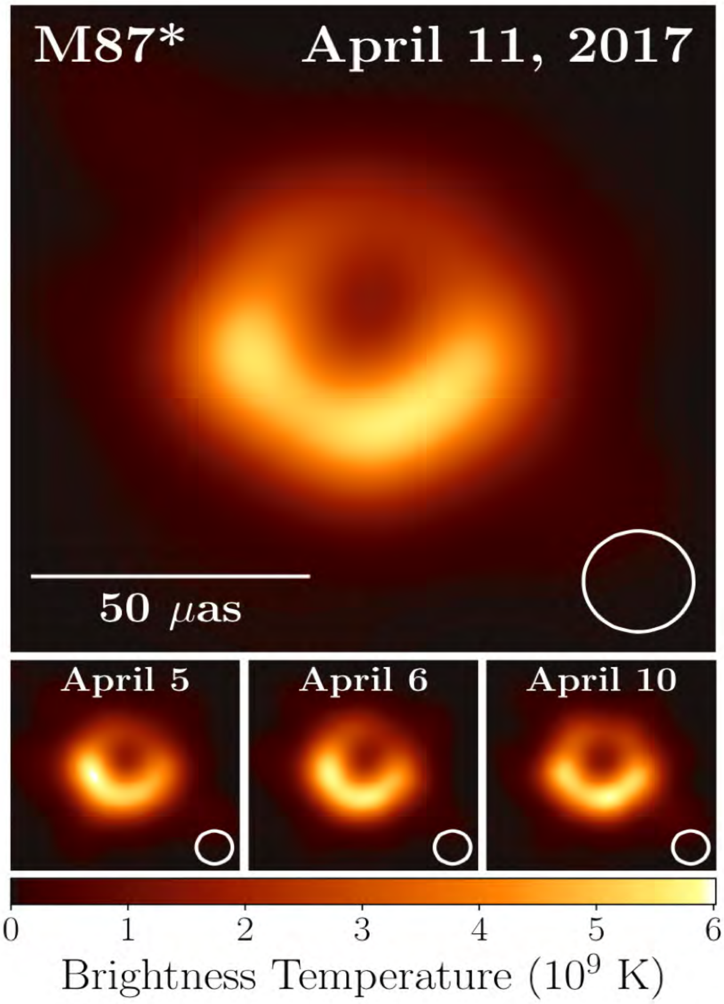

New JIVE staff in 2019, from left to right: Dhanya Nair, Olga Bayandina, Cristina Garcia-Miro, Waleed Madkour



Farewell Arpad Szomoru as Head of Technical Operations and R&D

02 SCIENCE HIGHLIGHTS

2.1 THE YEAR OF THE BLACK HOLE



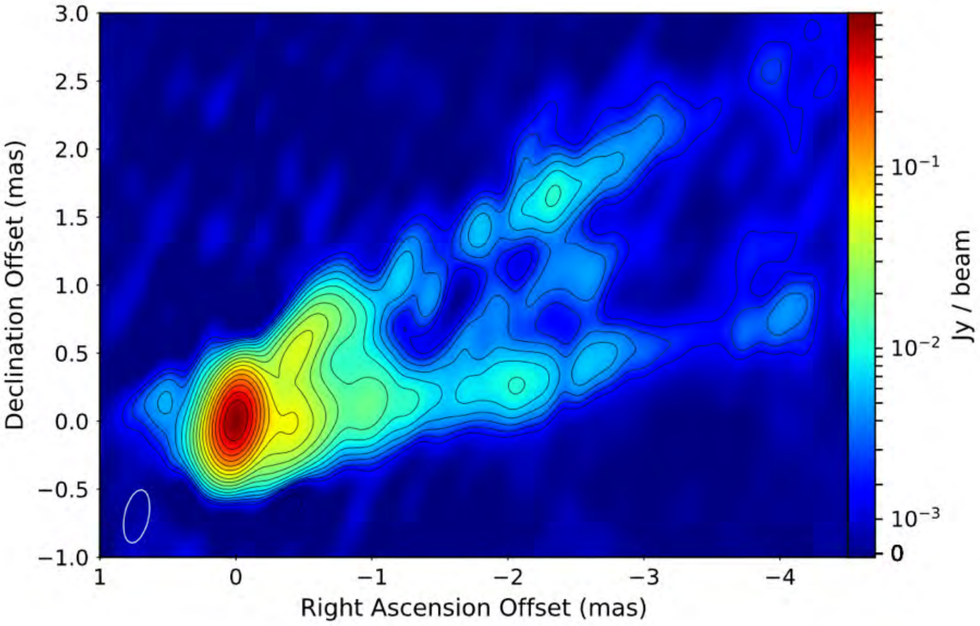
EHT images of the central supermassive black hole in the nearby galaxy Messier 87 (Akiyama et al. 2019, ApJ, 875, L1-L6).

The Event Horizon Collaboration has published a series of six papers in a special issue of the Astrophysical Journal Letters about very high-resolution imaging of the accretion flow around a supermassive black hole (SMBH) for the first time. The images reveal the gravitational light bending and photon capture at the event horizon, resulting in a ring-like emission structure around a dark region referred to as the "black hole shadow". The Event Horizon Telescope (EHT), an eighttelescope array spread around the globe, observed the SMBH candidate in M87 at 1.3mm wavelength (230 GHz frequency), with an angular resolution of just 25 microarcseconds. The measured size of the asymmetric ring is 42±3 microarcseconds, correponding to a black hole mass of M = (6.5±0.7) x 10^9 $M_\odot$ (EHT Collaboration, Akiyama et al. 2019).

The results were announced at press conferences in Europe and in the United States, and the images rapidly spread in social media. The EHT Collaboration received the prestigious Breakthrough Prize 2020 for their achievements. JIVE has played an important role in making the EHT efforts to image the central supermassive black hole of M87 a success. The JIVE team members Mark Kettenis, Des Small, Ilse van Bemmel and Huib van Langevelde have contributed to the calibration of data from the EHT observations, in particular by implementing new VLBI software together with the team at Radboud University.

The same JIVE-Radboud team has released an additional paper that describes rPICARD, a CASA-based calibration pipeline for VLBI data from different arrays (Janssen et al. 2019). This is an important step for the future of VLBI, as it allows to gradually move away from classic AIPS and use instead the CASA framework for data reduction. A particular feature of the pipeline is that it can apply different solution intervals to different antennas to aid fringe searching in the low signal-to-noise ratio regime. The pipeline is CPU scalable, ensuring that large bandwidth data from future arrays can be processed within reasonable computing times. The pipeline capabilities have been demonstrated by automated calibration and imaging of 7mm VLBA data on the inner jets of the SMBH in M87 .

Curiously, the jet shape itself may contain information about the physical properties of the central SMBH such as the mass and its spin. It has been suggested that the observed transition of a jet boundary shape from a parabolic to a conical form is associated with the flow transiting from the magnetically dominated regime to the energy equipartition between plasma bulk motion and magnetic field (Nokhrina et al. 2019). The team, including Leonid Gurvits showed, based on available observational data and comparisons to MHD simulations, that the SMBH in M87 is somewhat heavier than usually assumed - this has been fully confirmed by the above EHT results.



rPICARD image of the inner jets in M87. The complex collimation profile and the edge-brightened structure are in accordance with previous results (Janssen et al. 2019, A&A, 626, A75).

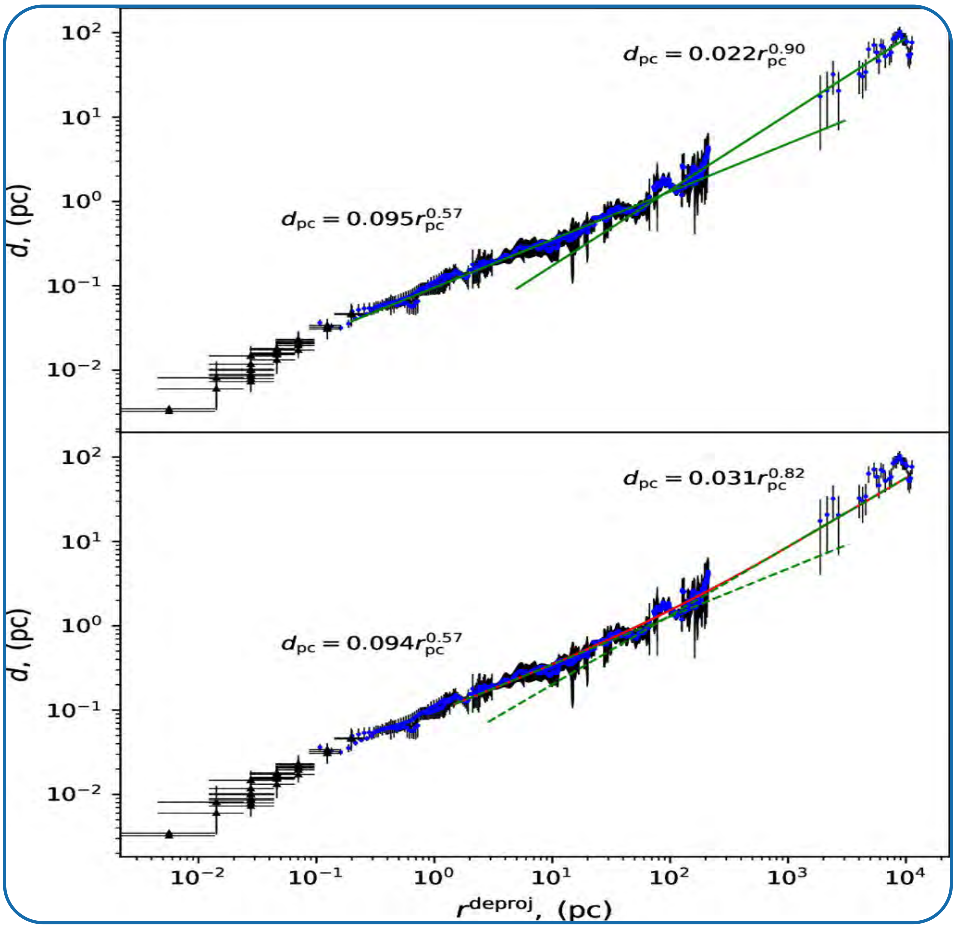
The central SMBH of our own galaxy should have a similar apparent angular size (probably smaller) than that of M87. It would thus require even higher angular resolutions to provide more detailed images of Sgr A*. This could be achieved by going to higher observing frequencies, or extend the baselines into space (Roelofs et al. 2019). The concept, called the Event Horizon Imager would have two satellites with a slightly different orbit, building up quite-well filled uv-coverage on a timescale of weeks. The simulated images demonstrate the level of detail one may expect to see in this arrangement.

Space mm-VLBI would certainly broaden our horizons to resolve the black hole shadow in other nearby SMBH, or to probe exotic massive black hole systems up to large redshifts. The various science cases are described in the ESA Voyage 2050 white paper compiled by Leonid Gurvits, Zsolt Paragi and several others from JIVE and EVN partner institutes (Gurvits et al. 2019).

2.2 THE CHARISMATIC JET IN THE GALAXY M87

In 1918, the American astronomer Heber Curtis, observing the galaxy M87, discovered what we call now a jet. A century later, in 2019, the nucleus of this galaxy took world center stage owing to the direct image of the shadow produced by the VLBI observation at 230 GHz by the Event Horizon Telescope.

However, VLBI studies of this cosmic laboratory were not limited to the EHT observations only. In a paper published in 2019, E. Nokhrina, L. Gurvits et al. (MNRAS, v. 489, p. 1197) presented results of their analysis of a large sample of VLBI data and demonstrated a new method of estimating parameters of the central supermassive black hole. The method is based on the accurate measurements of the jet cross-section in the close vicinity to the black hole. The method has potential of deepening our knowledge of the physics of the most powerful engines in the Universe – active galactic nuclei.



Cross-section of the jet versus distance along the jet in the central area of the radio galaxy M87 based on several years of VLBI monitoring (Nokhrina et al. 2019, MNRAS 489, 1197–1205).

2.3 OUR GALAXY

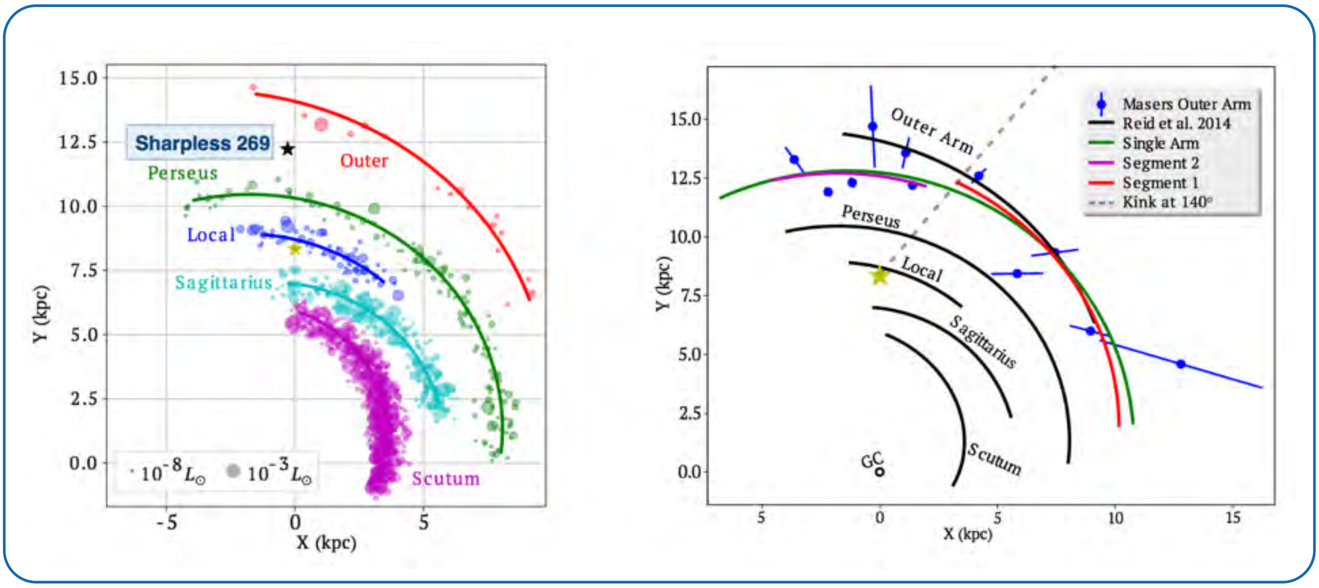
VLBI provides unique ways to probe the structure and kinematics of our Galaxy, through measuring proper motions and trigonometric parallaxes of molecular masers associated with very young high-mass stars. In the Galactic plane, where dust extinction blocks the view for optical instruments, this task is very challenging even for the Gaia mission.

The BeSSeL collaboration, including Katharina Immer, Luis Quiroga-Nuñez and Huib van Langevelde have determined and analysed trigonometric parallaxes and proper motions for approximately 200 high-mass star forming regions. These measurements strongly suggest that the Milky Way is a four-arm spiral, with some extra arm segments and spurs (Reid et al. 2019). The data allowed accurate measurement of the distance to the Galactic center to be R_0=8.15 ± 0.15 kpc, and the circular rotation speed at the Sun's position, Θ_0 = 236 ± 7 km s^{-1}.

It has been found that young, high-mass stars within 7 kpc of the Galactic center are narrowly distributed and therefore are very well suited to define the Galactic plane.

This data allows studies of individual objects as well as detailed investigation of the characteristics of certain arms/regions in the Milky Way. Objects (or groups of them) that apparently do not fit the current scheme of spiral arms are of particular interest. Sharpless 269 is star forming region with a debated distance, with differing values implying different structures for the Outer Arms.

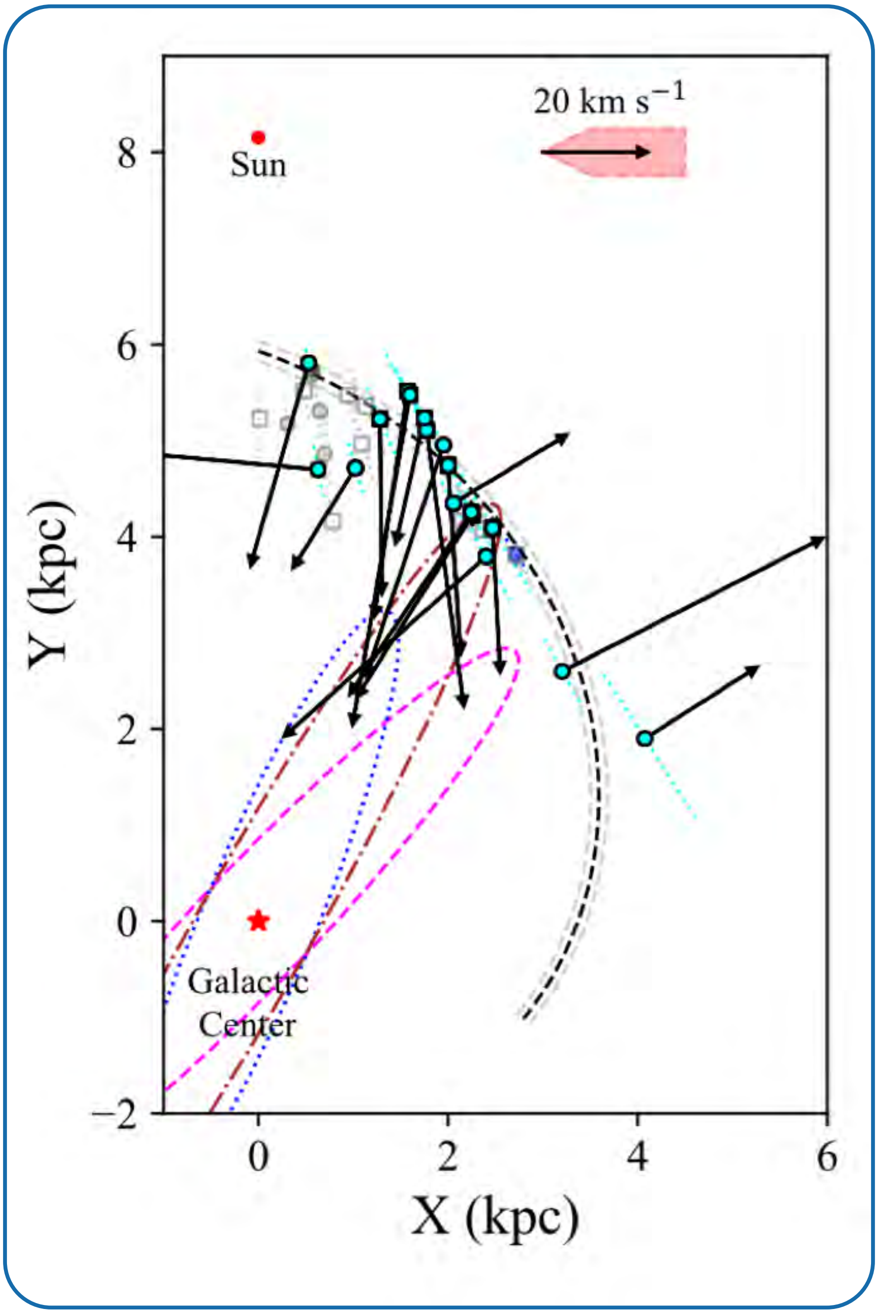
S269 is also special because it serves as an excellent probe to constrain the Galactic rotation curve at large radii. The controversy has been solved in a new study by Quiroga-Nuñez et al. (2019). The group targeted four water maser features in S269, and provided an accurate distance of 4.15 ± 0.2 kpc to the Sun. Using this number and observations of other massive young stars, Galactic kinematic simulations indicates there is a kink in the Outer Arm at a Galactic longitude ~140 degrees.



Spiral arms according to Reid et al. (2014) and the location of Sharpless 269 (black star). Right: Proposed new Outer Arm (green) and segments (red & purple; Quiroga-Nuñez 2019, A&A 625, A70)

Immer et al. (2019) studied the innermost Scutum Arm. They measured parallaxes and proper motions of water and methanol masers in sixteen high-mass star forming regions. Combining the data with other measurements, the group had a sample of 44 objects for kinematic studies.

They found sixteen sources with very large peculiar motions, of which thirteen were oriented toward the inner Galaxy. A likely explanation for these high peculiar motions is the combined gravitational potential of the spiral arm and the Galactic bar.



Peculiar motions in the Scutum Arm are oriented in the inner region of the Galaxy, where various studies indicate the presence of a bar structure (colored ellipses; Immer et al. 2019, A&A, 632, A123)

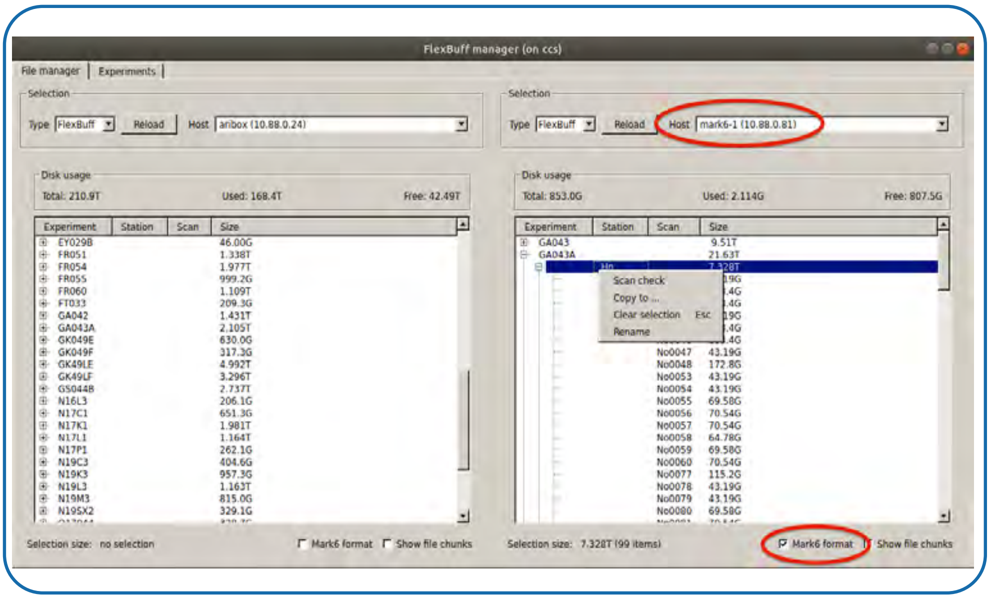
03 RESEARCH AND DEVELOPMENT

3.1 DATA RECORDING AND TRANSPORT

The equipment and data transfer tools at JIVE performed reliably over 2019. Minor issues were failing disks, most of which were replaced under warranty. The FlexBuff capacity grew to seventeen units (2019: Torún, SHAO) with a net total of 4.6 PB storage capacity and three Mark6 units (2019: SHAO). Production e-VLBI ran without noticeable data transport issues.

The internal network at JIVE was upgraded and reorganized for the upcoming SURFNet8 100 Gbps connection. Each FlexBuff and SFXC cluster node is now doubly connected to redundant internal core switches. In normal operating circumstances this doubles the bandwidth to each node and provides redundancy in case of fiber- or switch failures.

Two out of the three installed Mark6 units were made operational, requiring a substantial effort. As delivered by the manufacturer, the units can not read VLBA disk packs sent to JIVE (the only reason the EVN requires Mark6 units located at JIVE is to be able to read VLBA disk packs). After physical installation of the unit the operating system needs to be upgraded and the expensive network cards replaced with ones that support netboot .In order to manipulate Mark6 disk packs without requiring MIT Haystack cplane software, a command-line tool to mount, unmount or initialize modules was developed. To facilitate e-transfer of VLBA data from Mark6 disk packs, the FlexBuff manager GUI application was updated to support handling Mark6 formatted diskpacks and recordings.

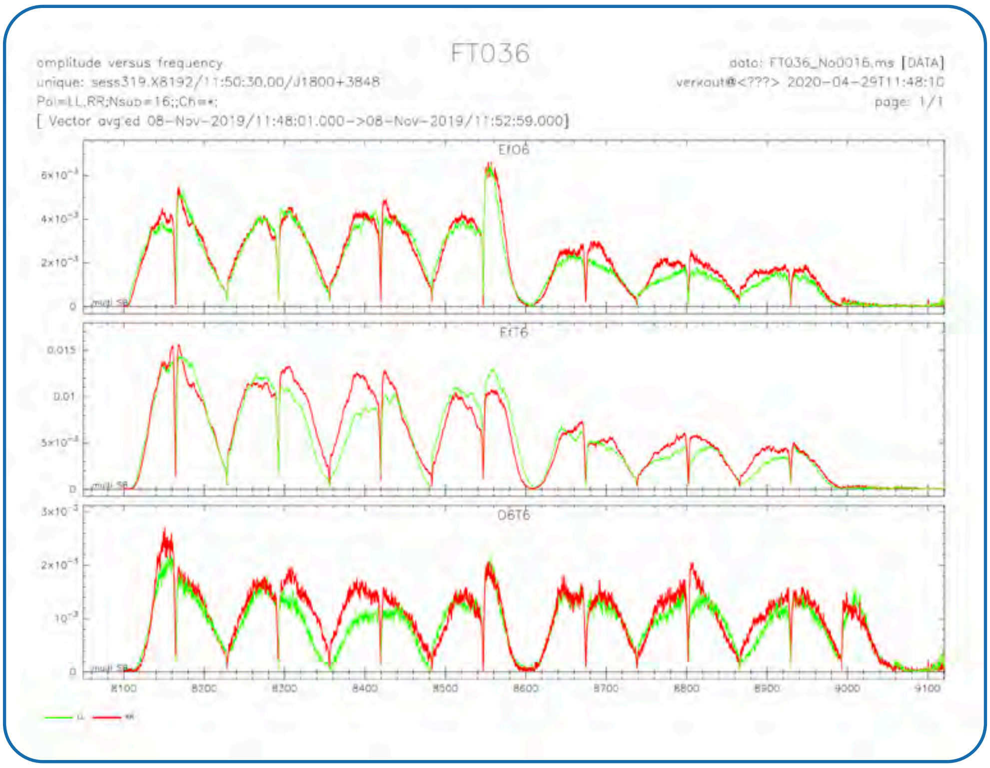


Screenshot of FlexBuff manager GUI with Mark6 support (highlighted) for convenient e-transfer

The jive5ab code was reorganized and brought under git version control and its build procedure was modernized to use CMake, improving cross-system support and enabling configuring optional extensions. In jive5ab it is now possible to flexibly group VDIF frames into separate recordings based on any combination of the VDIF frame header properties; VDIF frames can be automatically separated by VDIF thread ID and/or VDIF station. An optional e-transfer client can be compiled into jive5ab, allowing for direct transfer from jive5ab supported media (Mark5, Mark6, FlexBuff) into a running e-transfer server instance, as developed under ASTERICS WP5/Cleopatra. Both changes were tested in the field and will be integrated in future jive5ab releases in 2020.

Verkouter traveled to Arecibo Observatory to assist with the migration to an RDBE/Mark6 setup for VLBI observations. Together with the technical staff at Arecibo and experts from Effelsberg, NRAO and MIT Haystack a lot of progress was made, and first observations have taken place during the 6 and 18cm NMEs in session 3/2019 (along with one user experiment in each band). Amongst others a Python-based DRUDG replacement was created, and the Effelsberg local RDBE support code was integrated into the local support code for the Arecibo Field System. As a result of the upgraded system, AO can now participate in ftp fringe tests again and has started to use e-shipping for the transfer of EVN session data to JIVE.

8 Gbps fringes were observed on 8 November 2019. Effelsberg, Kunming, Onsala, and Shanghai observed the strong calibrator source J1800+3848 at X-band in dual circular polarisation. The observing bandwidth was split into 32 sub-bands of 64 MHz bandwidth by a DBBC2 in wastro mode at each station. Unfortunately the recording at Kunming failed without recording any data. The test clearly reveals IF video system bandwidth and receiver limitations, resulting in less than the full 1 GHz sky bandwidth being usable.



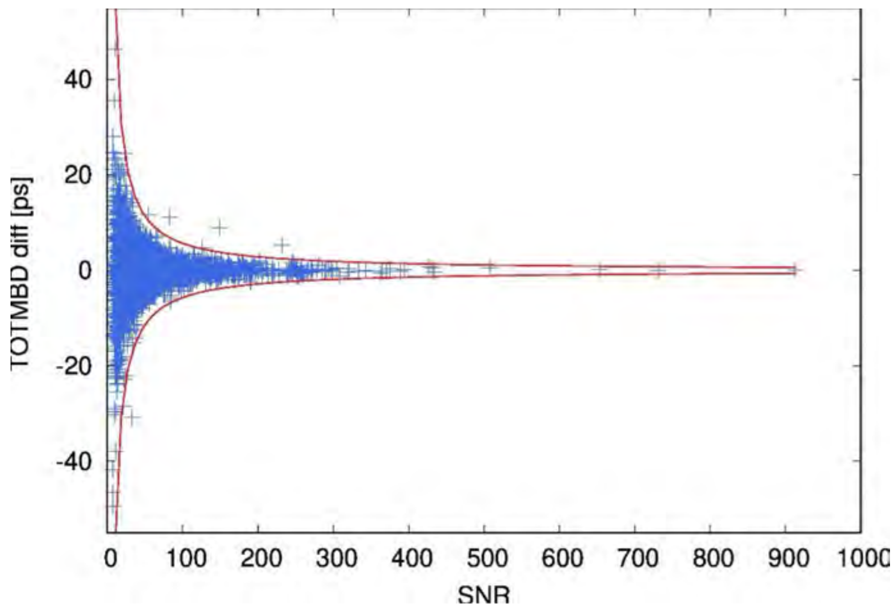
Bandpass plots for the 8 Gbps FT036 experiment. Note the fall-off of IF response towards the highest channels on several baselines

3.2 SOFTWARE CORRELATION

Development and maintenance of the SFXC software correlator at JIVE progressed over 2019; SFXC version 5.0 was released. This version supports "sliced" integrations where correlation of a single output accumulation period is split over multiple CPU cores. This reduces the time it takes for data to make it through the correlator, resulting in better "real-time" behavior during e-VLBI. It also reduces memory requirements, allowing larger integration times in mixed-bandwidth setups. SFXC's VEX2 support was improved and SFXC now also provides cross-polarization products for auto-correlations.

With the participation of e-MERLIN stations in EVN observations, complex mixed-bandwidth setups are now very common. The tools for producing plots for FTP fringe tests has been largely rewritten in Python, using the giza PGPLOT drop-in in replacement. This speeds up the generation of the plots considerably, lowering the turn-around time for providing feedback to the stations. At the moment it provides output that is almost indistinguishable from the old tool. Further improvements are planned, taking into account feedback and wishes from the JIVE support scientists and EVN station friends.

Further improvements to the geodetic (Mk4) output product have been made. The sfxc2mark4 conversion tool now produces proper ovex files that are required by some of the HOPS tools such as aedit. It is now possible to easily specify a mapping between two- and one-letter station codes. A comparison was made using the 24 hour geodetic IVS session R1872. It was correlated in Bonn using DiFX using a CALC9 model and in Dwingeloo using SFXC with a CALC10 model. The geodetic observable – total multi-band delay – was compared between the two data sets by M.-E. Gomez (Université de Bordeaux). The results show that with a few exceptions both systems produce "totals" that fall within ± 1σ of each other.



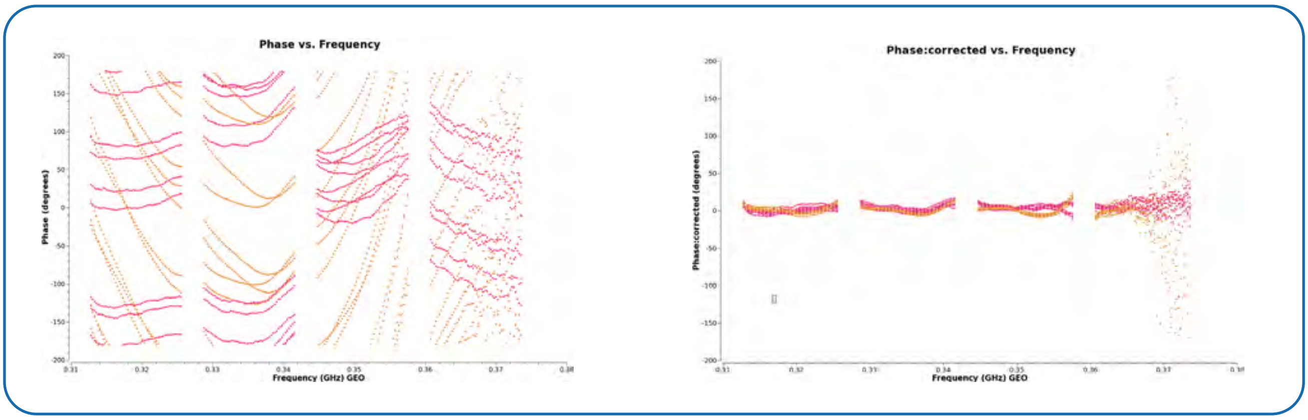
TOTMBD differences between DiFX and SFXC vs. SNR for X-band. The red curves represent ±1σ; it can be seen that with a few exceptions all of the differences are below this standard error.

3.3 USER SOFTWARE

The SCHED re-factoring project also continued to make good progress. It now has become extremely simple to install pySCHED using pip: pip install pythonSCHED suffices. The correlator control code has been modified to support both VEX1 and VEX2, which will be needed by the correlator to handle multiple data streams for 4 Gbps e-VLBI and e-MERLIN observations with more than one sub-band, or observations with multiple recordings per scan.

Other work on pySCHED led to the TSCAL keyword now also being allowed in the frequency catalog as well as in the station catalog. This allows Tsys measurement timing to be defined per frequency band and prevents the use of per band local copies of the station catalog. pySCHED was merged with the latest release of SCHED code and catalogs. A new allowed keyword was added to the input file: SCANEXP. This keyword is used to produce intent lines in the VEX2 output, expressing which set of experiments a scan belongs to. This will be used in the post-correlation proces of e.g. e-VLBI runs, where a calibration scan can be shared by multiple experiments.

Two Python-based fringefit prototype implementations -- the dispersive delay and the wide band fringe fit -- were rewritten in C++ for production and inclusion in a future CASA release. Both are now available as separate CASA5 packages. The dispersive delay version offers full control over which parameters to include in the least-squares estimation.
The novel wide-bands-with-gaps fringe fitter algorithm is documented and being tested on EHT data, awaiting data from the RadioNet BRAND project. A methodology for fringe fitting with a source model (from a FITS image's clean components) was developed as well. The code and its documentation were handed over to NRAO for production implementation.



The effect of fringe fitting with a despersive term. Left: raw, uncorrected EVN P-band data with clear curvature caused by ionospheric effects. Right: after fringe fit with a dispersive term the phases are flat. The highest frequencies are affected by noise and is not an artefact of the fringe fitter.

In the context of the ESCAPE project, development of a Jupyter kernel for the upcoming CASA6 release was started. While CASA6 is not yet ready for end users and many tasks are still missing, it is clear that NRAO is moving towards a different organization of the CASA suite and thus JIVE tooling needs to migrate with it. Other Jupyter related work concerned the implementation of a minimal re-computation framework for the Jupyter CASA kernel based on ASTERICS supported work published in 2018. Tasks run iteratively under the minimal re-computation framework only re-execute the tasks whose input parameters have changed from the previous iteration. Other effort spent on CASA and casacore concerned improved support for im- and exporting VLBI data in FITS-IDI and UVFITS format.

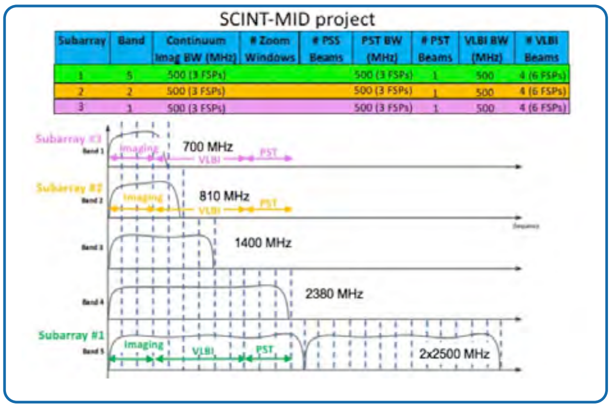
The code to do triggered observations at EVN stations was enhanced to produce triggers based on VOEvents, using code from A. Rawlinson, and integrated code written by Eldering to automatically produce schedules from such a trigger using pySCHED, exploiting its unique executable template-schedule feature.

Finally, primary beam correction is now part of the EVN pipeline.

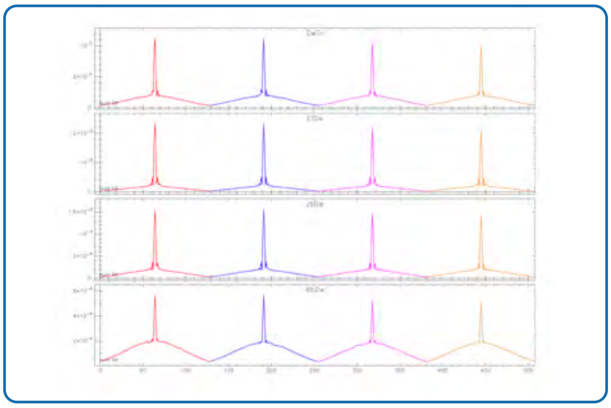
3.4 SKA AND VLBI

The JUMPING JIVE project WP10 "VLBI with the SKA" reached a number of milestones in 2019. The deliverable D10.3 "Portfolio of SKA-VLBI science cases" was submitted to the EC; these were further discussed at the SKA-VLBI Key Science Projects and Operations workshop between 14-17 October 2019, at the SKA HQ. This major event brought together 65 scientists from 18 countries. The JJ SKA-VLBI scientist (who formally moved from the SKA to JIVE during last year) participated in the CDRs for various SKA components and the SKA system CDR as well, where VLBI aspects were also discussed. Most notably, the first JJ WP10 deliverable D10.1 "Details on VLBI interfaces to SKA Consortia" was formally recognised as an SKA reference document.

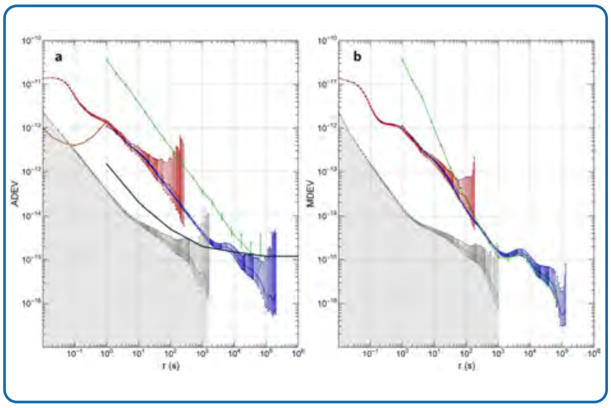
In the final year of the ASTERICS project, VLBI fringes between the Dwingeloo telescope (DWT) and several EVN stations (Sardinia, Effelsberg, Jodrell Bank and the WSRT) were demonstrated. This deliverable was for the SKA Signal And Data Transport consortium where JIVE was a member of. The VLBI fringes prove the viability of the White Rabbit time- and frequency transfer technology for use in the SKA telescopes by delivering a performance meeting the SKA standards. The DWT used a digital back end developed in-house by Boven and a White Rabbit (see front cover photo) link to the WSRT H-maser as its phase reference. The WSRT H-maser signal was propagated over 135 km of public, shared, fiber, using COTS equipment. The detection of VLBI fringes clearly demonstrates the ability to achieve a suffient level of clock stability over such links. The availability of two separate fiber links between WSRT and Dwingeloo (the public, shared route via Groningen and the dark fiber between WSRT and ASTRON) allowed the comparison of the effect of using a public, shared, network in stead of a private, dark, fiber. The results have been published as ASTERICS WP5/Cleopatra deliverable D5.14.



An example of how a proposed SKA-VLBI program would use SKA CSP resources. Figure 12 in JUMPING JIVE deliverable D10.3



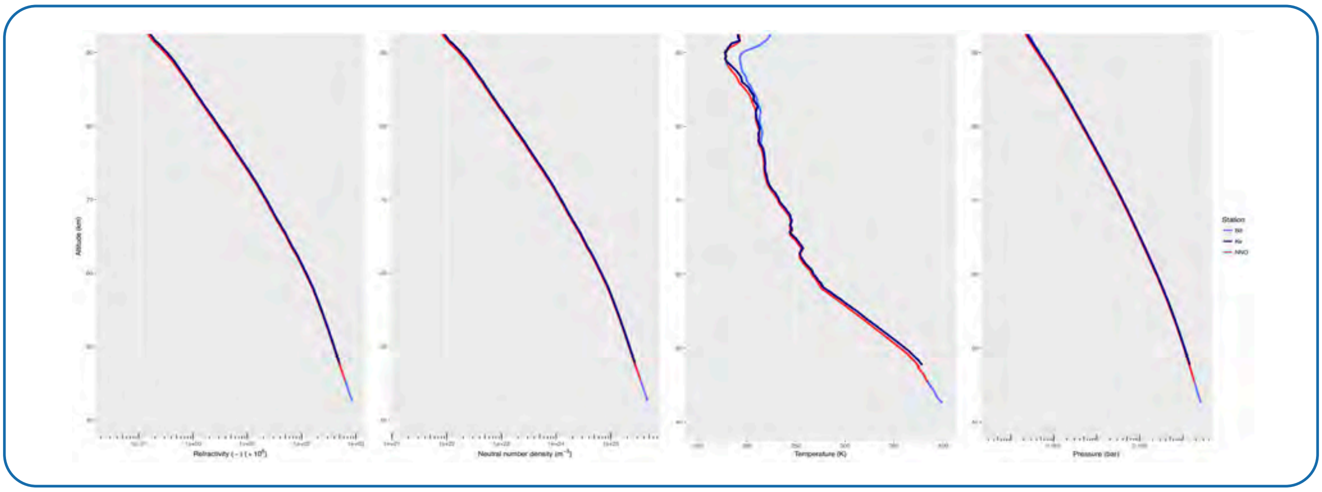
VLBI fringes between the Dwingeloo telescope (Dw) and EVN stations Sardinia, Effelsberg, Jodrell Bank and the WSRT in four 8 MHz channels of the N19L1 Network Monitoring Experiment at L-band.



Allan deviatian (ADEV) (a, left) and MDEV (b, right) frequency transfer link performance measurement of the 135 km White Rabbit link, measured with 50 Hz (blue) and 0.5 Hz (red) bandwidth. Also shown are commercial H-maser performance (black line) and measurement system noise limits (grey). The results show that coherence loss will be less than 2% for observing frequencies up to 10 GHz. For full details, see ASTERICS WP5/Cleopatra D5.7

04 SPACE AND PLANETARY SCIENCE

4.1 VENUSIAN ATMOSPHERE AS SEEN BY PRIDE

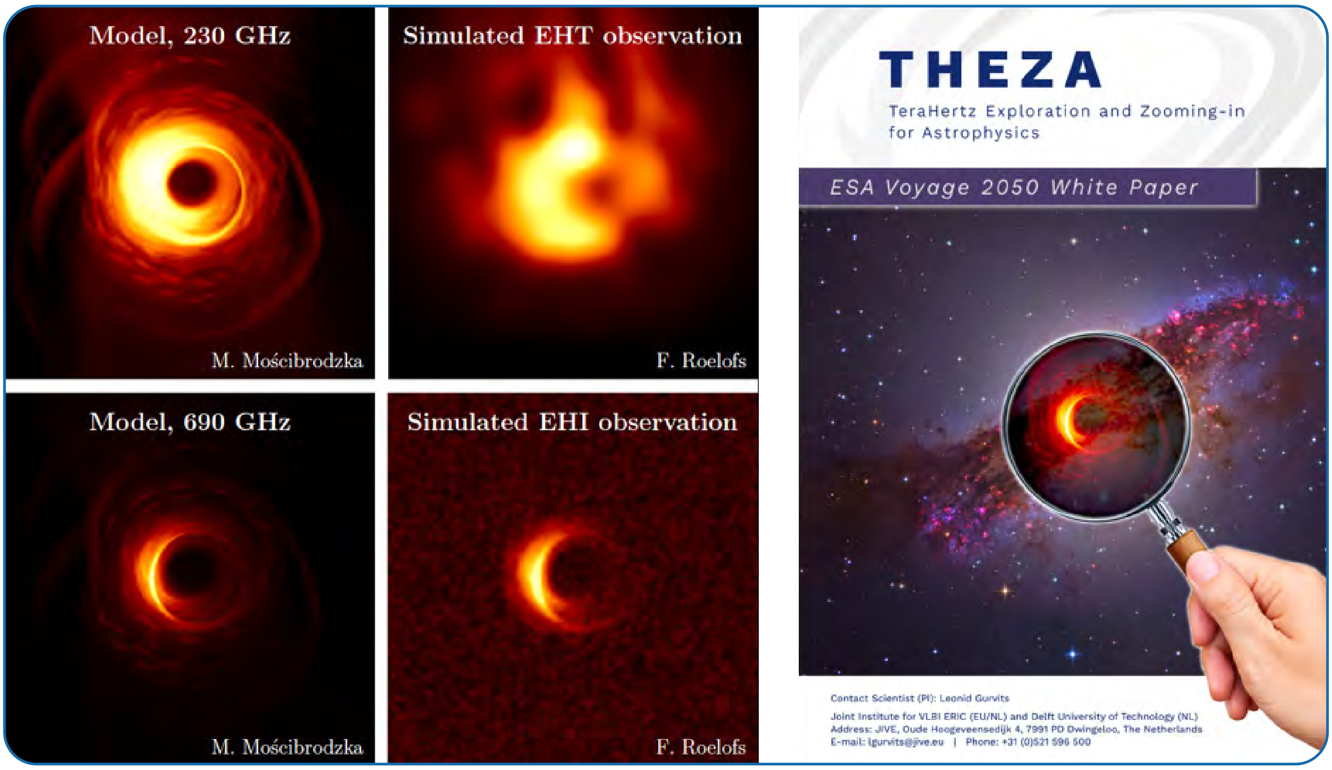


Refractivity, neutral number density, temperature and pressure profiles in the Venusian atmosphere during the session of 2012.04.29 (Bocanegra et al. 2019, A&A 624, A59).

The Planetary Radio Astronomy and Doppler Experiment (PRIDE) aims at being a major contribution to the ESA's Jupiter Icy Satellite Explorer (JUICE) scheduled for launch in 2022. Meanwhile, in preparation for JUICE, the technique is improved working with other planetary missions. A group of researchers led by JIVE scientists conducted a series of PRIDE observations of the ESA's Venus Express mission during several so called radio occultation events, in which the spacecraft was out of direct visibility from Earth for a fraction of its planetocentric orbit. The radio signal transmitted by the spacecraft in various phases of the occultation undergoes refraction in the Venusian atmosphere and ionosphere. Accurate evaluation of the properties of the refracted signals enables researchers to estimate parameters of the Venusian atmosphere. The group has demonstrated that PRIDE is at least as efficient as nominal instrumentation for radio measurements available to space agencies and sometimes can provide even better results, i.e. penetrating deeper in the Venusian atmosphere. These results have been presented in the paper by Bocanegra et al. (2019, Astronomy & Astrophysics 624, A59) and included in the PhD thesis by the leading author, Tatiana Bocanegra (see section 5).

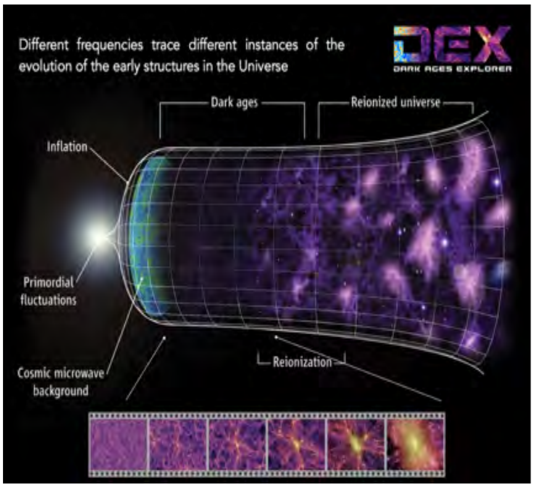
4.2 TOWARD SPACE-BORNE SUB-MILLIMETER VLBI

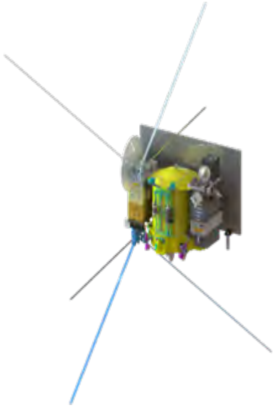
The year of 2019 marked the new beginning in VLBI science by presenting the first direct image of a supermassive black hole shadow in the nucleus of the galaxy M87 (see section 2 of this report) obtained by the Event Horizon Collaboration. But the geometrical size of Earth and radio signal propagation properties of the atmosphere make only two sources accessible for this type of studies, M87* and the source in the center of Milky Way, Sgr A*. To overcome these two principle limitations, one must place a sub-millimeter VLBI system in Space. In 2019, a collaboration led by the Radboud University and involving L. Gurvits published results of an investigation of a mission concept tentatively called Event Horizon Imager, EHI (Roelofs et al. 2019, A&A 625, A124). Implementation of this concept will make possible high fidelity imaging of the black hole shadow in the center of Milky Way as well as studies of other relativistic sources with microarcsecond angular resolution. In a parallel development, a collaboration co-led by L. Gurvits and Z. Paragi and involving representatives of many EVN and other institutes submitted a mission concept entitled TeraHertz Exploration and Zooming in for Astrophysics (THEZA) in response to the ESA's strategic call for future space science programmes Voyage-2050 (Gurvits et al., 2019, arXiv 1908.10767). Together, the EHI and THEZA studies form a platform for future major step toward space-borne sub-millimeter VLBI facilities which will revolutionise studies of relativistic processes in the immediate vicinity of super-massive black holes.



Four left square panels: models of 230 and 690 GHz structures and simulated images of these models obtained by the EHT and EHI, respectively (Roelofs et al. 2019, A&A 625, A124). Right: A cover-page of the ESA Voyage-2050 THEZA proposal (arXiv 1908.10767).

4.3 ULTRA-LONG-WAVELENGTH INTERFEROMETRY IN SPACE





Left: A schematic presentation of the evolution of the Universe to be addressed by the concept of an ULW facility proposed in response to the ESA Voyage-2050 call (Koopmans et al. 2019, arXiv 1908.04296). Right: A concept of a small satellite carrying instrumentation for ULW interferometry (Chen et al., 2019, arXiv:1907.10853).

The ultra-long wavelengths (ULW, corresponding to frequencies lower than the Earth's ionosphere cut-off value of about 20 MHz) remain the last almost unexplored range of the electromagnetic spectrum. It contains crucial information on the cosmological evolution of the Universe. Observations in this frequency regime require space-born radio telescopes which should be involved in interferometric systems for achieving the required angular resolution. Such a system has been proposed in response to the ESA's strategic call Voyage-2050 by a collaboration led by L.V.E. Koopmans (Groningen) and involving L. Gurvits (2019, arXiv 1908.04296). This proposal, entitled "Peering into the Dark (Ages) with Low-Frequency Space Interferometers" is synergistic to the Sino-European study conducted by the group of institutes involving JIVE "Discovering the Sky at Longest Wavelengths with a Small Satellites Constellation" (2019, arXiv:1907.10853). Together, these studies define a long-term roadmap for developments at the ULW regime for the coming decades.

05 COMMUNICATION AND TRAINING

5.1 COMMUNICATION AND OUTREACH

The new EVN web and EVN - JIVE Newsletter

"Science is not finished until it is communicated". In 2019, a number of initiatives have been developed to ensure that the results of the EVN and JIVE are widely known. Many such results were highlighted by press releases featured in the JIVE website. The EVN website is completely new, with modern style and updated information. Also since September, the EVN/JIVE Newsletter is produced at JIVE, featuring science and technology news as well as information on events and job opportunities.

Gina Maffey and Giuseppe Cimo presenting JIVE at the JIVE booth during the EWASS in Lyon

Huib van Langevelde at the Betweter Festival (credits Anna van Kooij)

JIVE staff attended many events to advocate for VLBI to colleagues and general public. Among others, in June, the EVN/JIVE booth was installed in the EWASS conference in Lyon, which attracted great interest by many participants. Gina Maffey attended the Public Awareness of Research Infrastructures (PARI) meeting "Communicating the importance of Science to Society" in Oxford (U.K), while Huib van Langevelde gave a public lecture "Zoom in into the black hole engines of radio galaxies" at the Astronomy on Tap event in Leiden.

In April 2019 Leonid Gurvits, representing JUMPING JIVE (Work Packages 3 and 9), participated in the public outreach campaign organised at middle and high schools in Ethiopia in conjunction with the IAU Symposium #356 "Nuclear Activity in Galaxies Across Cosmic Time" (Addis Ababa, Ethiopia, 7–11 October 2019).

Following the media attention for the first image of a Black Hole in M87, van Langevelde was invited to give a plenary talk at the Betweter festival on October 4 in Utrecht. This festival is a annual event in which cultural performances meet with science presentations and discussions. The presentation (in Dutch) was introduced by a well-known comedian and was very well received.

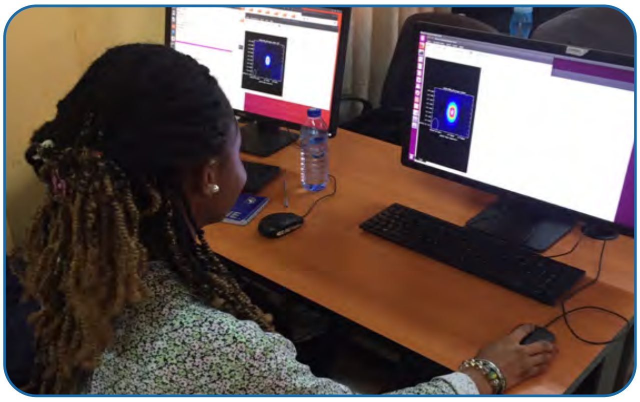
Several participants of the IAU Symposium #356 with students and teachers after an astronomy lesson at the Addis Ababa Public School no. 4, Ethiopia, October 2019

5.2 TRAINING

ASTRON/JIVE, together with ASTRON, continued in 2019 the traineeship program on large arrays, hosting two students from Africa in July with support from H2020 JUMPING JIVE.

The summer student program allowed John Hunter to learn, under supervision of Dhanya Nair, how to produce polarization maps of compact extragalactic radio sources, while Sophia Vaughan developed, under supervision with Huib van Langevelde, a calibration pipeline for spectral line sources.

With resources from JUMPING JIVE, many training activities have also been conducted in African countries. This has included schools and workshops on radio astronomy and VLBI (together with the UK program "Development in Africa by Radio Astronomy", DARA) where participants have hands-on experience on analysing real data, and also visits of African researchers and technical staff to JIVE and other European observatories. This initiative has been highlighted as one of the most impactful activities in JUMPING JIVE.



Training workshop on VLBI processing in CASA held in Ghana in July 2019.

For the past several years, JIVE and Delft University of Technology worked jointly on the development of the Planetary Radio Interferometry and Doppler Experiment technique – a multi-disciplinary enhancement of science return of planetary science missions. The essence of PRIDE is in combination of single-antenna Doppler and near-field VLBI measurements of spacecraft signal. An important effort in developing the PRIDE methodology was contributed by the TU Delft PhD student and former JIVE trainee Tatiana Bocanegra.

In March 2019, Tatiana successfully defended her PhD thesis "Planetary Radio Interferometry and Doppler Experiment (PRIDE) for radio occultation studies: a Venus Express test case" co-supervised by L.I. Gurvits and L.L.A. Vermeersen (TU Delft). Giovanni Granato, a MSc student at the Aerospace Faculty of the Delft University of Technology, worked on the simulations of the gravitational redshift experiment conducted with the instrumentation of the Space VLBI mission RadioAstron. Giovanni successfully defended his MSc thesis "Simulations of the RadioAstron Gravitational Redshift Experiment Accuracy" co-supervised by D. Dirkx (TU delft) and L. Gurvits in February 2019.

Left: Tatiana Bocanegra with members of the committee and assistants after her PhD defense, Delft University of Technology, 19 March 2019. Right: Giovanni Granato after defending his MSc thesis with his co-supervisors L. Gurvits and D. Dirkx, 20 February 2019.

06 OPERATIONS

6.1 CORRELATION

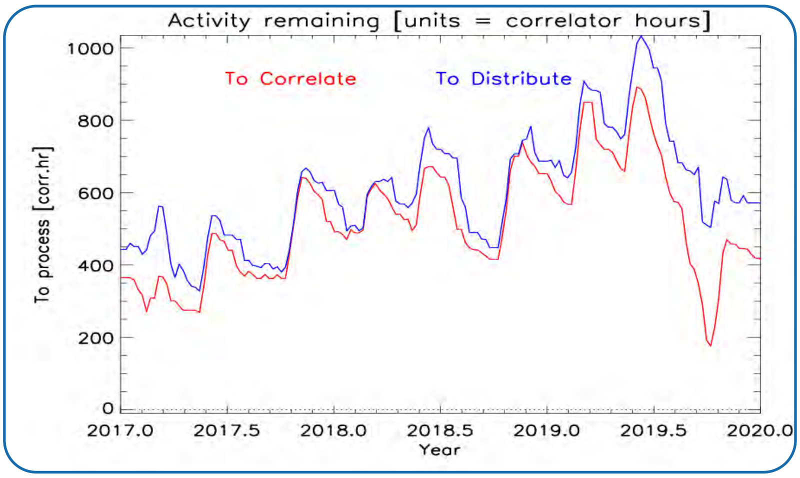
The core of JIVE's service is the processing of EVN data; the table below summarizes experiments that were correlated or distributed in 2019.

For a detailed list of the user experiments, see Section 8.5, "Correlator Activity".

	User Experiments			Test and Network Monitoring		
	N	Ntwk_hr	Corr_hr	N	Ntwk_hr	Corr_hr
Correlated	146	1169	1370	28	84.5	88.5
Distributed	138	1074	1251	27	85.5	89.5
e-EVN experiments	33	193.5	193.5			
e-EVN ToOs	10	68.5	68.5			

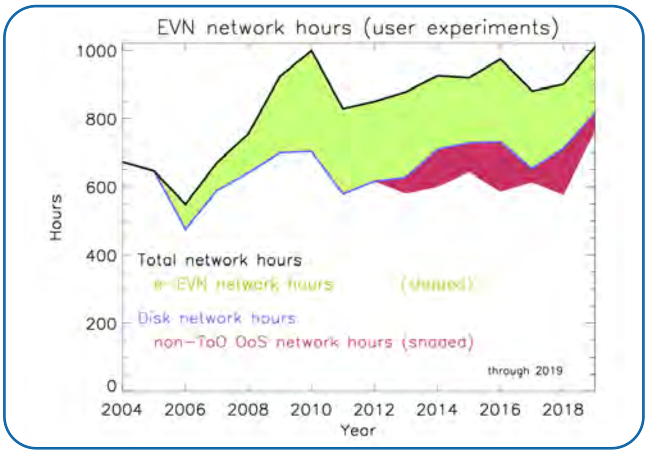
Table:Summary of projects correlated or distributed in 2019. Here, "network hours" sum the total duration of experiments, and "correlator hours" are simply network hours multiplied by any multiple correlation passes required -- the actual time to correlate can in the more complex correlations, be up to several times larger.

A concerted effort, especially over the summer and autumn, was directed towards reducing the size of the correlation queue. The ability to maintain such a focus arose to a large extent from a lull in project reporting and proposing activity over that time-frame, as well as having just completed earlier in the year the actions to recover from the E-series DBBC firmware problems of 2018. From peak to trough (from just after session 2 to just before session 3), the queue to correlate went from 892 to 176 correlator hours. The number of network and correlator hours correlated in 2019 were up by 76% and 71%, respectively, compared to those from 2018.

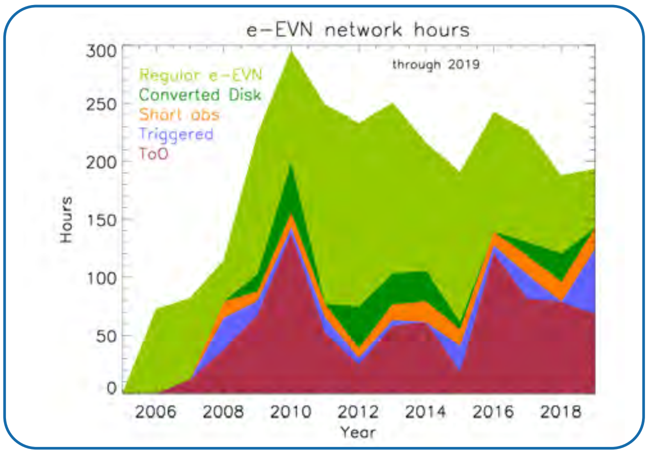


The size of the correlator queue at different stages in the processing cycle. The red line shows the number of correlator hours that remain to be correlated. The blue line shows the number of correlator hours in experiments whose data remain to be distributed to the PI.

2019 also saw some records fall for the size of observing: the first time there has been over 1000 network hours of user experiments in a calendar year (1010) and the most disk-based network hours (816.5, previous high was 733.5). The figure on the left traces the evolution of the annual EVN network hours. The figure on the right focuses on e-EVN experiments, showing the break-down into individual proposal categories.



Annual EVN network hours, with separate color-coded areas for different user-experiment categories, from top to bottom: real-time e-EVN (light green), non-ToO out-of-session disk-based (dark red), and "traditional" disk-based (white). (Note that the 2018 totals have been adjusted down compared to the 2018 Annual Report to reflect observations that decided subsequently to re-join the observing queue because of the E-series firmware problems.)



e-EVN network hours, with separate color-coded areas for different proposal categories, from bottom to top: target-of-opportunity, triggered, short observations, converted from disk, and regular.

The year 2019 continued to see new ground broken in various experiments:

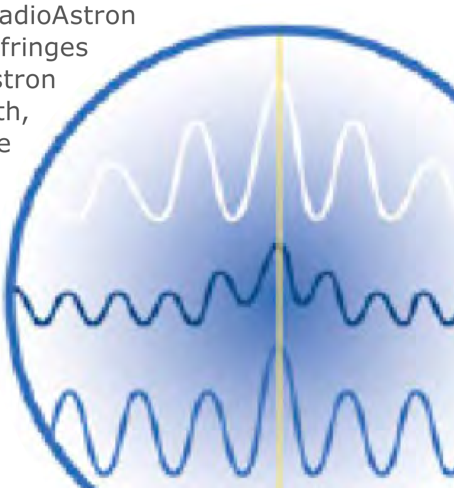
- 2Gbps observations returned by the March e-EVN day and session 2 for disk observations. This marked the end of a period in which bit-rates were limited to 1Gbps stretching back to session 2/2018, because of the E-series DBBC firmware problems.

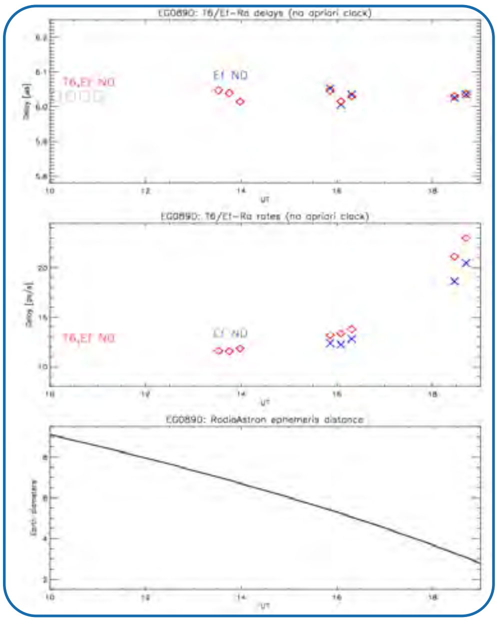
- By the autumn there were the first user e-EVN experiments including all three of the Russian QUASAR antennas and the Chinese Kunming antenna, all able to maintain 1Gbps real-time transfer rates.

- There were ten e-EVN ToO and seven e-EVN trigger observations (arising from 11 proposals), covering fast-radio-burst localization (4), extra-galactic nuclear transients (3), X-ray binary transients (2), tracing the expansion of gamma-ray bursts (3 epochs), accretion bursts in a young massive star (in 3 different molecular species), shocks in a recurrent nova, and ionization in the coma of an interstellar-visitor comet. 2019 saw a record for the most triggered e-EVN network hours (56; the previous high was 27).

- GM074 was the first joint Global + LBA observation at 3.6cm, and observing over three days with a rotating overlap among the geographical sub-networks, required building a single 76-hour correlation schedule file from the three separate daily schedules, including reconstituting physically present baselines that did not appear in any of the daily schedules. The resulting 2612 scans, all less than two minutes, also brought attention to some inefficiencies in starting sub-jobs within SFXC, which led to various speed-ups being developed.

- The first RadioAstron user experiment at L-band was correlated using the normal production system; standard clock-searching saw fringes directly using a null a priori clock model for RadioAstron, without need for an acceleration term. Interestingly, more baselines showed fringes towards the end of the observation, and as one went earlier, fewer and fewer did. Comparison to the RadioAstron ephemeris showed that fringes went away as RadioAstron moved farther from Earth, suggesting that the source was being resolved on such baselines.





Residual delay and rates on baselines from Effelsberg and Tianma to RadioAstron for EG089D (18 cm), with the ephemeris distance of the satellite over the same time range. ("ND" denotes a non-detection.)

6.2 EVN SUPPORT

Extensive testing occurred early in the year to validate the DBBC firmware v107 that would provide 2Gbps observing capability lost when the problems with the older E-series firmware arose in 2018. This firmware became operational starting from the March e-EVN day and the May/June disk session. Loading the firmware seems more robust, and the band-passes for the 32MHz filters are also flatter out to both edges, as opposed to the truncation in the outer ~10% on both sides of the maximum-width filters in the earlier firmware.

Initial testing began with some stations for 4Gbps configurations using tunable BBCs with the same v107 firmware, using modes with 64MHz filters and modes with 32 channels of 32MHz filters. Both approaches have issues (band-pass shape for the 64MHz filters; interaction with scheduling software for 32 channels) for further investigation, as does identifying possible LO settings across the full set of EVN stations to maximize overlap in the resulting 512MHz frequency range.

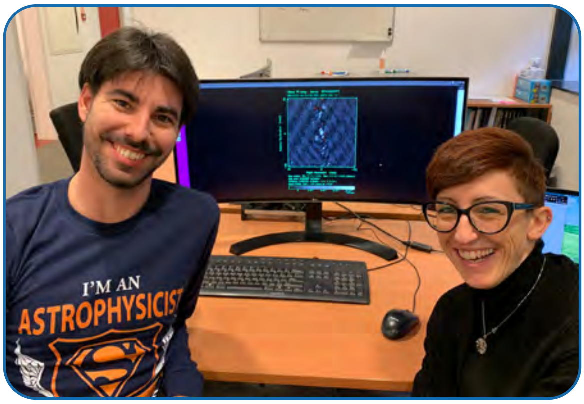
The cause of the occasional delay jumps of ~1 ns in data from e-MERLIN out-stations was identified as the width of the tracking window for fibre delays. Such jumps complicate phase-referencing observations, and this tracking feature was turned off for subsequent VLBI observations.

By the end of 2019, 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 QUASAR stations and Chinese stations, although activity towards making the transition to FlexBuff operations is underway there as well. There continues to be "unbudgeted" use of FlexBuffs at JIVE for special circumstances (e.g., data from the Australian LBA stations); so far the FlexBuffs at JIVE have been able to accommodate such instances without creating operational bottle-necks. In session 3, NRAO stations sent their data on Mark6 packs, which were also copied onto FlexBuffs in order to be able to recycle the packs timely enough for their logistical requirements.

In the 2019 edition of the biennial IVS Technical Operations Workshop, held at Haystack Observatory northwest of Boston, JIVE personnel taught two seminars, with three recitations each: VLBI Data Acquisition, Formats, Transfers, and Tools, and Pointing and Amplitude Calibration Theory and Practice. In the post-workshop evaluation, each seminar received three votes as the "best" class (only one other class got more such votes).

6.3 USER SUPPORT

JIVE provides support in all stages of a user's EVN observation, from proposal definition to data analysis. There were fifteen first-time PIs in 2019 observations, including five students — triple the overall number for first-time PIs in 2018, and almost double the number of first-time student-PIs. A list of visitors to JIVE can be found in section 8.4.



JIVE support scientist Benito Marcote with visitor Sara Motta

JIVE continued to provide PIs with experiment-specific scheduling templates to track the evolving configurations of equipment at EVN stations.

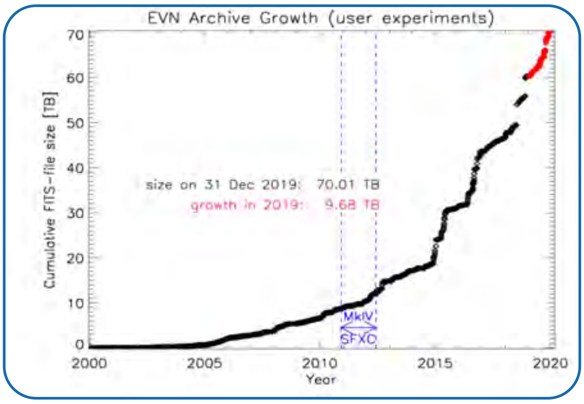
A new tactic in 2019 was the creation of a set of band-specific station catalogs to provide a snapshot of the continuous-calibration situation across the stations, as their development proceeds at their own pace.

Observations at 18- and 5cm now regularly have linear-polarization stations. We now correlate all of these with cross-hand polarization products, to enable post-correlation transformation of these linear polarizations back to circular via polConvert. The EVN pipeline now contains the primary-beam correction that fits Gaussians to primary-beam maps provided by the stations (although the collection of such maps remains incomplete).

The EVN Data Reduction Guide on the new EVN web page has been cast into parallel guides, covering both the AIPS and CASA analysis packages, and placed side-by-side in columns to facilitate comparison of how each handles the various conceptual stages of analyzing EVN data.

The EVN Archive remains the entry point for users to retrieve their correlated EVN data, and provides open access to others following the one-year proprietary period (six months for ToO projects).

The total size of user-experiment FITS files in the Archive reached 70TB by the end of 2019, an increase of 16% in the year.



Growth of user experiments in the EVN Archive. Experiments archived in 2019 are plotted in red. Vertical dashed lines show the transition period between the MkIV and SFXC correlators.

07 FINANCES

7.1 JIVE FINANCIAL REPORT 2019

Balance [after allocation of results]

ASSETS	2019 in €	2018 in €
Tangible fixed Assets		
Tangible fixed Assets	104,766	153,028
Total of Tangible fixed Assets	104,766	153,028
Current Assets		
Work in process	0	0
Receivables	918,250	986,209
Cash at bank	2,528,662	3,752,992
Total of Current Assets	3,446,912	4,739,201
Total Assets	**3,551,678**	**4,892,229**

LIABILITIES	In €	In €
Capital		
General reserve	1,796,620	1,270,450
Designated funds	142,367	299,678
Total capital	1,938,987	1,570,128
Other Liabilities		
Short term debts	1,612,691	3,322,101
Total Other Liabilities	1,612,691	3,322,101
Total Liabilities	**3,551,678**	**4,892,229**

Statement of profit and loss

REVENUES	2019 BUDGET in €	2019 ACTUAL in €	2019 DIFFERENCE in €	2018 ACTUAL in €
Income				
Contributions/subsidies third parties	2,741,802	2,771,263	29,461	2,470,517
Interest	0	0	0	0
Other	114,000	154,574	40,574	192,739
Total Income	2,855,802	2,925,837	70,035	2,663,257
Total Revenues	**2,855,802**	**2,925,837**	**70,035**	**2,663,257**

EXPENDITURES	in €	in €	in €	in €
Operations				
Grants/Expenditures	2,848,433	2,556,978	-291,455	2,728,004
Total Operations	2,848,433	2,556,978	-291,455	2,728,004
Total Expenditures	**2,848,433**	**2,556,978**	**-291,455**	**2,728,004**

RESULT	7,369	368,859	361,490	-64,747

7.2 JIVE PROJECTS

Project & Work Packages	Dates	JIVE role
BlackHoleCam (EC)	01.10.14 - 30.09.20	BlackHoleCam is an ERC synergy project to enable sub-mm VLBI in which JIVE contributes to the real-time data verification and user software.
ASTERICS (EC)	01.05.15 - 01.09.19	ASTERICS is a collaboration to provide common tools and interfaces for ESFRI-listed astronomy projects.
JUMPING JIVE (EC)	01.12.16 - 31.01.21	JIVE coordinates the Joining up Users for Maximizing the Profile, the Innovation and Necessary Globalization of JIVE (JUMPING JIVE) project. JUMPING JIVE aims to take VLBI into the next decade, with JIVE and the EVN as globally recognized centres of excellence in radio astronomy.
AENEAS (EC)	01.01.17 - 31.12.19	AENEAS (Advanced European Network of E-infrastructures for Astronomy with the SKA) is an EC funded study to develop a concept and design for a federated data science centre for the SKA.
RadioNet4 (EC)	01.01.17 - 31.12.20	RadioNet supports the collaboration of major radio astronomy facilities in Europe. JIVE is involved in the RINGS workpackage and receives trans-national access funds.
ESCAPE (EC)	01.02.19 - 31.07.22	ESCAPE builds of the ASTERICS project to support the implementation of EOSC, developing joint multiwavelength/multi-messenger capabilities in astronomy, astrophysics and particle astrophysics communities.

08 TABLES AND METRICS

8.1 JIVE COUNCIL

Representatives of Members

Dr. Patrick Charlot – Laboratoire d'Astrophysique de Bordeaux, Pessac, France

Dr. Guy Perrin – National Centre for Scientific Research, Paris, France

Dr. Indra Dedze – Ventspils University of Applied Sciences, Ventspils, Latvia

Mr. Dimitrijs Stepanovs - Ministry of Education and Science, Latvia

Prof. Carole Jackson – ASTRON, Dwingeloo, the Netherlands

Mrs. Saskia Matheussen – NWO, Den Haag, the Netherlands

Dr. José Antonio López Fernández – Instituto Geográfico Nacional, Madrid, Spain (Vice chair)

Mrs. Monica Groba Lopéz – Instituto Geográfico Nacional, Madrid, Spain

Prof. John Conway – representing the EVN Board of Directors, Onsala Space Observatory, Onsala, Sweden (Chair)

Mr. Mathias Hamberg – Vetenskapsrådet / Swedish Research Council, Stockholm, Sweden

Prof. Simon Garrington – Jodrell Bank Centre for Astrophysics, Manchester, UK

Dr. Colin Vincent – Science and Technology Facilities Council, Swindon, UK

Representatives of Associated Research Institutes

Dr. Fernando Camilo – National Research Foundation, South African Radio Astronomy Observatory, Cape Town, South Africa

Prof. Zhinqiang Shen – NAOC, Shanghai Astronomical Observatory, Shanghai, China

Dr. Tiziana Venturi – INAF-IRA, Bologna, Italy

Prof. Anton Zensus – MPIfR, Bonn, Germany

8.2 JIVE PERSONNEL

Dr. Jay Blanchard	Support Scientist (until 1 March 2019)
Dr. Olga Bayandina	Support Scientist (since 15 April 2019)
Mr. Paul Boven	Network Systems Engineer
Dr. Bob Campbell*	Head of Science Operations
Dr. Giuseppe Cimò	Space VLBI Scientist
Dr. Francisco Colomer Sanmartín*	Director
Drs. Bob Eldering	Software Engineer
Mrs. Cristina Garcia-Miro	SKA-VLBI Scientist (since 11 October 2019)
Prof. Leonid Gurvits*	Head of Space Science & Innovative Applications Group
Mr. Bert Harms	Chief Operator
Dr. Katharina Immer	Support Scientist
Dr. Ing. Aard Keimpema	Scientific Software Engineer
Dr. Ir. Mark Kettenis	Software Project Scientist
Mrs. Yvonne Kool-Boeser	Senior Secretary
Mr. Martin Leeuwinga	Hardware Support Engineer
Dr. Gina Maffey	Science Communication Officer
Dr. Waleed Madkour	CRAF Frequency Manager (since 15 August 2019)
Dr. Benito Marcote Martin	Support Scientist
Dr. Dhanya G. Nair	Support Scientist (since 1 Februrary 2019)
Dr. Zsolt Paragi*	Head of User Support
Mr. Luis Henry Quiroga-Nuñez	Support Scientist (since 1 September 2019)
Dr. Des Small	Scientific Software Engineer
Dr. Arpad Szomoru*	Head of Technical Operations and R&D (retired 21 November 2019)
Dr. Ilse van Bemmel	Project Scientist
Drs. Aukelien van den Poll	Finance and Project Officer
Prof. Huib Jan van Langevelde*	Chief Scientist
Drs. Harro Verkouter	Senior Software Engineer (until 21 November 2019)
Drs. Harro Verkouter*	Interim Head Technical Operations and R&D (since 22 November 2019)

* - JIVE MT member

8.3 EDUCATIONAL RESPONSIBILITIES

MSc project supervision

Giovanni Granato - by L. Gurvits and D. Dirkx, TU Delft (completed and defended in February 2019)

Máté Krezinger - by Z. Paragi, ELTE University, Budapest

Keith Tirimba – by L.H.Quiroga Nuñez & H.J. van Langevelde, Leiden University

PhD project supervision

Tatiana Bocanegra-Bahamón – by L.I. Gurvits and L.L.A. Vermeersen, TU Delft (completed and defended in March 2019)

Luis Henry Quiroga-Nuñez – by H.J. van Langevelde, Leiden University (completion in 2020)

Paul Boven - by H.J. van Langevelde, Leiden University (completion in 2023)

Lecturing

Praktische Sterrenkunde (1st year Bachelor course), Leiden University, by H.J. van Langevelde (spring 2019)

Secondary affiliations:

Giuseppe Cimò – affiliated with ASTRON, the Netherlands (until 30.04.2019)

Francisco Colomer-Sanmartin - affiliated with Instituto Geográfico Nacional, Madrid, Spain

Leonid Gurvits – affiliated with the Department of Astrodynamics and Space Missions, Delft University of Technology, the Netherlands

Leonid Gurvits – affiliated with the CSIRO Astronomy and Space Science, Australia (since 21.11.2019)

Huib Jan van Langevelde – affiliated with Sterrewacht Leiden, Leiden University, the Netherlands

Luis Henry Quiroga-Nuñez – affiliated with Sterrewacht Leiden, Leiden University, the Netherlands

8.4 VISITORS TO JIVE

Name	Institute	Period	Host
C. Phillips	CSIRO, Australia	10-15 February	Szomoru
S. Frey	Konkoly Observatory, Hungary	10-22 February	Paragi
K. Gabanyi	Konkoly Observatory, Hungary	10-22 February	Paragi
K. Perger	Konkoly Observatory, Hungary	10-22 February	Paragi
R. Burns	EACOA (East Asia Core Observatories Association), Japan	15-30 March	Paragi

Name	Institute	Period	Host
M. Ma	Shanghai Astronomical Observatory, China	31 March - 28 September	Gurvits
A. Plavin	Moscow Institute of Physics and Technology, Russia	5-16 May	Paragi
B. Woode	University of Ghana, Ghana	20-24 May	Campbell
N. Lumbwe Chanka	Rhodes University, South Africa	20-24 May	Campbell
S. Jaiswal	Shanghai Astronomical Observatory, China	20-24 May	Campbell
Z. Modak	University of Bonn, Germany	20-24 May	Campbell
J. Hunter	Boston University, USA	3 June - 10 August	Nair
J.M. Rodriguez-Espinosa	Instituto de Astrofisica de Canarias, Spain	17-19 June	Marcote
S. Jin	Instituto de Astrofisica de Canarias, Spain	17-19 June	Marcote
S. Vaughan	Oxford University, UK	24 June - 31 August	van Langevelde
I. Natarayan	SARAO / RARG, South Africa	10-12 July	van Langevelde
D. Klindzic	Croatian Astronomical Society, Croatia	10-24 July	Gurvits
M.E. Gomez	CNRS, France	22-26 July	Campbell
D. Duev	Caltech, USA	11-16 August	Gurvits
L. Chen	NAO-CAS, China	4 September	Gurvits
G. Moellenbrock	NRAO, USA	10-16 October	Kettenis
T. An	Shanghai Astronomical Observatory, China	18-22 October	Paragi
P. Atri	ICRAR-Curtin, Australia	21-23 October	Nair
D. Williams	University of Oxford, UK	28 October - 1 December	Bayandina
E. Chiaraluce	INAF, Italy	27 October - 1 November	Bayandina
J. Wu	National Space Science Center, CAS, China	10-11 November	Gurvits
L. Deng	National Space Science Center, CAS, China	10-11 November	Gurvits
X. Li	National Space Science Center, CAS, China	10-11 November	Gurvits
L. Wu	National Space Science Center, CAS, China	10-11 November	Gurvits
J. Yan	National Space Science Center, CAS, China	10-11 November	Gurvits
M. Durjasz	Nicolaus Copernicus University, Poland	18-27 November	Immer
S. Motta	University of Oxford, UK	2-14 December	Marcote
K. Rygl	Italian ALMA Regional Centre, INAF, Italy	11-13 December	van Bemmel

Name	Institute	Period	Host
M. Janssen	Radboud Universiteit Nijmegen, the Netherlands	12 December	van Bemmel

8.5 CORRELATOR ACTIVITY

User experiments with correlation, distribution, or release activity in 2019.

Project code	Observation Date/ Session	Principal Investigator	User Experiments
BC246A	Dec.18	Cimo	MRO-TGO-MEX tracking
C246B-C	Jan.19	Cimo	MRO-TGO-MEX tracking
A059A-B	s.2/18	An	A sub-pc-separation SMBH binary in a spiral galaxy NGC 7674?
EA062C	Mar.19	Atri	A parallax measurement for the black hole XRB MAXI J1820+070
B064C-D	s.3/18	Bach	Does Cygnus A harbor a binary black hole?
B064E-F	s.2/19	Bach	Does Cygnus A harbor a binary black hole?
B066A-B	s.3/18	Bietenholz	SN 2014C Evidence for anistotropic mass loss
EB068	s.1/19	Baan	Formaldehyde Absorption and Emission in NGC3079
EB069	s.3/18	Biggs	Determining H0 from the new time-delay lens B1030+074
EB070	s.1/19	Boven	Radio Flare Star Ross 867
EB072	s.1/19	Burns	Jet onset in S255: the accretion-ejection relation in massive stars
EB073	s.2/19	Bartkiewicz	Gas properties in the environments of HMYSOs using the methanol and excited-OH masers
C063A-D	s.1/19	Cheng	Proper motion determination of a sample of FR 0 galaxies
EC064	s.2/18	Cimo	In-beam phase referencing observations of two Mars orbiters
EC065	s.2/18	Charlot	Improved positions of non-geodetic EVN telescopes from 22 GHz VLBI
C066A-B	s.3/18	Caccianiga	A VLBI survey of high redshift blazar candidates
C067A-D	s.1/19	Climent	Probing the nature of radio emission from Ultracool Dwarfs
C070A-B	s.3/19	Chiaraluce	Resolving the radio cores of high luminosity AGN
ED044	s.1/19	Durjasz	Methanol maser variability as a tracer of episodic accretion Pilot study
EG089D	s.1/16	Gurvits	Second-epoch Space VLBI visit into core-jet laboratories in the distant Univers
G100C-D	s.2/19	Giovannini	EVN Observations to Solve the Puzzle of FR0 Radio Galaxies
EG102F	Jan.19	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample
EG102G	Feb.19	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample
EG102H	Mar.19	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample

Project code	Observation Date/ Session	Principal Investigator	User Experiments
EG102I	May.19	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample
G103A-B	s.2/19	Gurvits	A Core-jet laboratory at z~4
G104A-B	s.3/18	Guirado	Uncovering the radio emission of the substellar triple system VHS1256-1257
H035A-C	s.2/18	Hartley	Cosmic telescopes: witnessing the emission mechanism of radio quiet quasars
H036A-H	s.2/19	Hartley	Cosmic telescopes: witnessing the emission mechanisms of radio quiet quasars
K038C-D	s.2/19	Koay	Inclination Dependences of Optical-UV Broad Emission Line Profiles in Quasars
K040A-B	s.2/19	Karska	Particle acceleration in protostellar jets: the case of Ser-emb 8N
EK047	s.3/19	Kutkin	Probing the new extreme intrahour variable with VLBI
EL056B	s.2/19	Landoni	SDSS 0040-0915: a z 5 BL Lacertae, a blue FSRQ, or a weak emission line QSO?
EM132B	s.2/18	Marcote	Unveiling the origin of the radio emission in the gamma-ray binary LS I +61 303
M133A-C	s.3/18	Marcote	Markarian 622: a curious example of a binary AGN
EM135A	Jan.19	Marcote	Precise localizations of Fast Radio Bursts and their persistent counterparts
EM135B	Apr.19	Marcote	Precise localizations of Fast Radio Bursts and their persistent counterparts
EM135C	Jun.19	Marcote	Precise localizations of Fast Radio Bursts and their persistent counterparts
EM135D	Dec.19	Marcote	Precise localizations of Fast Radio Bursts and their persistent counterparts
EM137	s.2/19	Mohan	Proper motion of AT2018cow radio afterglow to constrain its physical nature
EN005A	Dec.19	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EO016A	s.2/19	Olech	Relative motions and structure evolution in periodic 6.7GHz methanol masers
P106D-E	s.3/18	Perez-Torres	Mrk1018: Ignition of accretion onto a companion supermassive black hole?
P106F-G	s.1/19	Perez-Torres	Mrk1018: Ignition of accretion onto a companion supermassive black hole?
P111A-C	s.3/18	Baan	OH gas in megamaser galaxies
EP112	s.2/18	Petrov	Probing mas-level optical structure with VLBI observations of Gaia detected AGNs
P113A-B	s.3/18	Panessa	The variable VLBI core of NGC 4151
P113C-D	s.1/19	Panessa	The variable VLBI core of NGC 4151
EP113E-F	s.2/19	Panessa	The variable VLBI core of NGC 4151
EP114A	Jun.19	Perez-Torres	Understanding the nature of extragalactic nuclear transients
EP115	s.1/19	Perger	Zooming into the centre of the mysterious high-redshift quasar PMN J0909+0354
EP118A	Sep.19	Perez-Torres	Understanding the nature of extragalactic nuclear transients
ER047A	s.1/19	Radcliffe	EVN-COSMOS - Taming AGN star-formation across cosmic time

Project code	Observation Date/ Session	Principal Investigator	User Experiments
ER047B	s.2/19	Radcliffe	EVN-COSMOS - Taming AGN star-formation across cosmic time
ES074C	s.2/18	Surcis	Monitoring of the magnetic field and of the outflows expansion in W75N-VLA2
ES084B	s.2/18	Surcis	A detailed study of the H2O 'gigamaser', and of its polarization, in TXS2226-184
ES088D	Dec.19	Schulz	The parsec-scale view of the last Westerbork HI absorption survey
S090A-C	s.3/18	Schulz	The origin of the radio jets in the young radio galaxy 4C 52. 37
ET036A	s.2/18	Titov	Cosmological imprint in the VLBI astrometry data
ET036B	s.3/18	Titov	Cosmological imprint in the VLBI astrometry data
ET036C	s.1/19	Titov	Cosmological imprint in the VLBI astrometry data
T038A-D	s.2/18	Tarchi	H2O megamaser VLBI: a powerful tool to study ejection and accretion in Seyferts
T038E-H	s.3/18	Tarchi	H2O megamaser VLBI: a powerful tool to study ejection and accretion in Seyferts
ET042A	May.19	Tudose	EVN observations of X-ray binary transients
EX008	s.2/18	Xu	VLBI Astrometry of HD 179821: Supergiant or post-AGB star?
Y033A-C	s.1/19	Yang	Observing mildly relativistic expansion in nearby luminous transient AT2018cow
EY034	s.2/19	Yang	Milliarcsecond imaging of a hyperluminous obscured quasar at z~4.6
Z028A-C	s.2/18	An	The magnetic fields of jets at early ages of the Universe
Z029A-C	s.2/19	Zhang	Verify Gaia Astrometric Results using radio stars
GG084B	s.2/18	Ghirlanda	Do binary neutron star mergers always produce a jet?
M074A-C	s.1/19	Motta	Probing the disc-jet coupling in the neutron star binary Sco X-1
S045A-B	s.2/19	Schulz	Mapping jet-driven outflows of atomic hydrogen in radio galaxies
GV025	s.1/19	Varenius	What is powering IC 860?
RA003	s.2/19	Atri	Astrometry of the high Galactic latitude black hole X-ray binary Swift J1357.2-0933
RB005	s.1/19	Burns	Accretion burst in G358.93-0.03
RB006A	Sep.19	Burns	Accretion burst in G24.33+0.14
RB006B	Oct.19	Burns	Accretion burst in G24.33+0.14
RB007	Nov.19	Burns	Hydroxyl maser burst in G24.33+0.14
RG010A	Sep.19	Ghirlanda	Radio imaging of the close-by long GRB 190829A
RG010B	Oct.19	Ghirlanda	Radio imaging of the close-by long GRB 190829A
RG010C	Nov.19	Ghirlanda	Radio imaging of the close-by long GRB 190829A
RM012C	Aug.17	Ma	VLBI observation of turbulence in inner solar wind
RP028B	Feb.19	Perez-Torres	ToO EVN observations of the nuclear transient in IRAS 23436+5 257
SB02A-B	s.3/19	Bruni	Giant radio galaxy¬†PBC J2333.9-2343
RSC04	Jan.19	R.R.Chen	Candidate in-beam reference sources for FAST-discovered pulsars

Project code	Observation Date/ Session	Principal Investigator	User Experiments
RSC05	Feb.19	W.Chen	A new Galactic transient source Swift J1858.6-0814
RSG09B	Jan.19	Gabanyi	A candidate triple AGN
RSG13	Jun.19	Gawronski	Gaia19axp - next Trakhtenbrot's type event?
RSK04	Nov.19	Kunert	CSS galaxy 1321+045 in an X-ray cluster
RSM03	s.1/19	Marcote	Exploring the mas structure of a new and unique gamma-ray binary
RSM04	Nov.19	Mohan	The newly discovered tidal disruption event candidate AT2019dsg
RSM05	Sep.19	Mohan	Recently detected tidal disruption event AT2019ehz
RSO03	Feb.19	Orienti	Compact mas-scale structure in the hotspot 3C 227 West
RT014	May.19	Tudose	Cyg X-3 in outburst
RV002	Sep.19	Vedantham	Astrometric shifts induced by the ionized coma of the interstellar visitor comet C/2019 Q4
RY008	Oct.19	Sokolovsky	Imaging shocks in the symbiotic recurrent nova V3890 Sgr

8.6 JIVE STAFF PUBLICATIONS

Journal Articles

D. A. Ladeyschikov, **O. S. Bayandina**, A. M. Sobolev: Online Database of Class I Methanol Masers, 2019, The Astronomical Journal, 158, id. 233

K. Immer, J. Li, **L. H. Quiroga-Nuñez**, M. J. Reid, B. Zhang, L. Moscadelli, K. L. J. Rygl: Anomalous peculiar motions of high-mass young stars in the Scutum spiral arm, 2019, Astronomy and Astrophysics, 632, id.A123

D. Dirkx, I. Prochazka, S. Bauer, P. Visser, R. Noomen, **L. I. Gurvits**, B. Vermeersen: Laser and radio tracking for planetary science missions—a comparison, 2019, Journal of Geodesy, 93, 2405-2420

M. J. Reid, K. M. Menten, A. Brunthaler, et al. (including **K. Immer**, **L. H. Quiroga-Nuñez**, **H. J. van Langevelde**): Trigonometric Parallaxes of High-mass Star-forming Regions: Our View of the Milky Way, 2019, The Astrophysical Journal, 885, id. 131

A. Coutens, H. B. Liu, I. Jiménez-Serra, et al. (including **H. J. van Langevelde**): VLA cm-wave survey of young stellar objects in the Oph A cluster: constraining extreme UV- and X-ray-driven disk photoevaporation. A pathfinder for Square Kilometre Array studies, 2019, Astronomy and Astrophysics, 631, id.A58

N. Koide, H. Nakanishi, N. Sakai, et al. (including **R. A. Burns**): Outer rotation curve of the Galaxy with VERA. IV. Astrometry of IRAS 01123+6430 and the possibility of cloud-cloud collision, 2019, Publications of the Astronomical Society of Japan, 71, id.113

R. A. Burns, T. Handa, T. Omodaka, et al.: NH3 observations of the S235 star-forming region: Dense gas in inter-core bridges, 2019, Publications of the Astronomical Society of Japan, 71, id.91

E. E. Nokhrina, **L. I. Gurvits**, V. S. Beskin, et al.: M87 black hole mass and spin estimate through the position of the jet boundary shape break, 2019, Monthly Notices of the Royal Astronomical Society, 489, 1197-1205

O. S. Bayandina, **R. A. Burns**, S. E. Kurtz, N. N. Shakhvorostova, I. E. Val'tts: VLA Overview of the Bursting H2O Maser Source G25.65+1.05, 2019, The Astrophysical Journal, 884, id. 140

L. M. Gindilis, **L. I. Gurvits**: SETI in Russia, USSR and the post-Soviet space: a century of research, 2019, Acta Astronautica, 162, 1-13

O. Porth,et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**): The Event Horizon General Relativistic Magnetohydrodynamic Code Comparison Project, 2019, The Astrophysical Journal Supplement Series, 243, id. 26

B. Marcote, Y. Maan, **Z. Paragi**, **A. Keimpema**: Probing the origin of the off-pulse emission from the pulsars B0525+21 and B2045-16, 2019, Astronomy and Astrophysics, 627, id. L14

M. Janssen, C. Goddi, **I. M. van Bemmel**, et al. (including **M. Kettenis**, **D. Small**): rPICARD: A CASA-based calibration pipeline for VLBI data. Calibration and imaging of 7 mm VLBA observations of the AGN jet in M 87, 2019, Astronomy and Astrophysics, 626, id.A75

D. Dall'Olio, W. H. T. Vlemmings, M. V. Persson, et al. (including **H. J. Van Langevelde**): ALMA reveals the magnetic field evolution in the high-mass star forming complex G9.62+0.19, 2019, Astronomy and Astrophysics, 626, id.A36

J. W. T. Hessels, L. G. Spitler, A. D. Seymour, et al. (including **A. Keimpema**, **B. Marcote**, **Z. Paragi**): FRB 121102 Bursts Show Complex Time-Frequency Structure, 2019, The Astrophysical Journal, 876, id. L23

B. Marcote, K. Nimmo, O. S. Salafia, et al. (including **Z. Paragi**): Resolving the Decades-long Transient FIRST J141918.9+394036: An Orphan Long Gamma-Ray Burst or a Young Magnetar Nebula?, 2019, The Astrophysical Journal, 876, id. L14

J. F. Radcliffe, M. A. Garrett, T. W. B. Muxlow, et al. (including **A. Keimpema**, **R. M. Campbell**): Nowhere to Hide: Radio-faint AGN in GOODS-N field. I. Initial catalogue and radio properties (Corrigendum), 2019, Astronomy and Astrophysics, 625, id.C1

F. Roelofs, H. Falcke, C. Brinkerink, et al. (including **L. I. Gurvits**): Simulations of imaging the event horizon of Sagittarius A* from space, 2019, Astronomy and Astrophysics, 625, id.A124

L. H. Quiroga-Nuñez, **K. Immer**, **H. J. van Langevelde**, M. J. Reid, **R. A. Burns**: Resolving the distance controversy for Sharpless 269. A possible kink in the outer arm, 2019, Astronomy and Astrophysics, 625, id.A70

J. M. D. Kruijssen, J. E. Dale, S. N. Longmore, et al. (including **K. Immer**): The dynamical evolution of molecular clouds near the Galactic Centre - II. Spatial structure and kinematics of simulated clouds, 2019, Monthly Notices of the Royal Astronomical Society, 484, 5734-5754

K. Akiyama, et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**) : First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole, 2019, The Astrophysical Journal, 875, id. L6

K. Akiyama, et al (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**): First M87 Event Horizon Telescope Results. V. Physical Origin of the Asymmetric Ring, 2019, The Astrophysical Journal, 875, id. L5

K. Akiyama, et al (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**): First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole, 2019, The Astrophysical Journal, 875, id. L4

K. Akiyama, et al (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**): First M87 Event Horizon Telescope Results. III. Data Processing and Calibration, 2019, The Astrophysical Journal, 875, id. L3

K. Akiyama, et al (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**): First M87 Event Horizon Telescope Results. II. Array and Instrumentation, 2019, The Astrophysical Journal, 875, id. L2

K. Akiyama, et al (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H. J. van Langevelde**): First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole, 2019, The Astrophysical Journal, 875, id. L1

T. M. Bocanegra-Bahamón, G. Molera Calvés, **L. I. Gurvits**, et al. (including **G. Cimò**): Venus Express radio occultation observed by PRIDE, 2019, Astronomy and Astrophysics, 624, id.A59

G. Ghirlanda, O. S. Salafia, **Z. Paragi**, et al. (including **B. Marcote**, **J. Blanchard**, **L. I. Gurvits**, **H. J. van Langevelde**): Compact radio emission indicates a structured jet was produced by a binary neutron star merger, 2019, Science, 363, 968-971

G. Surcis, W. H. T. Vlemmings, **H. J. van Langevelde**, B. Hutawarakorn Kramer, A. Bartkiewicz: EVN observations of 6.7 GHz methanol maser polarization in massive star-forming regions. IV. Magnetic field strength limits and structure for seven additional sources, 2019, Astronomy and Astrophysics, 623, id.A130

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09 ACRONYMS AND ABBREVIATIONS

AENEAS	Advanced European Network of E-infrastructures for Astrononmy with the SKA
AERAP	Africa-Europe Radio Astronomy Platform
ADASS	Astronomical Data Analysis Software and Systems
AGB	Asymptotic Giant Branch
AGN	Active Galactic Nuclei
AIPS	Astronomical Image Processing System
ALMA	Atacama Large Millimeter/submillimetre Array
ASTERICS	Astronomy ESFRI & Research Infrastructure Cluster
ASTRON	Netherlands Institute for Radio Astronomy, the Netherlands
AO	Arecibo Observatory
AVN	African VLBI Network
BRAND EVN	BroadBAND EVN
CBD	Council Board of Directors
CASA	Common Astronomy Software Applications
CDR	Critical Design Review
CM	Centimetre
CNRS	Centre National de la Recherche Scientifique National Center for Scientific Research, France
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
CRAF	Committee of Radio Astronomy Frequencies
DARA	Development in Africa with Radio Astronomy
DBBC	Digital Base Band Converter
DiFX	Distributed FX software correlator
EAVN	East Asia VLBI Network
EC	European Commission
Ef	Effelsberg station, Germany
e-EVN	electronic (realtime) European VLBI Network
EHT	Event Horizon Telescope
EHI	Event Horizon Imager
e-MERLIN	enhanced Multi-Element Radio Linked Interferometer Network
EOSC	European Open Science Cloud
ERIC	European Research Infrastructure Consortium
ESA	European Space Agency
ESCAPE	European Science Cluster of Astronomy and Particle physics ESFRI research infrastructure
ESFRI	European Strategy Foum on Research Infrastructures
ESO	European Southern Observatory

e-VLBI	electronic Very Long Baseline Interferometry
EVN	European VLBI Network
EWASS	European Week of Astronomy and Space Science
FITS	Flexible Image Transport System
FITS-IDI	Flexible Image Transport System - Interferometry Data Interchange
FRB	Fast Radio Burst
FTP	File Transfer Protocol
Gb	Gigabit
Gbps	Gigabit per second
GHz	Gigahertz
GPS	Global Positioning System
GRB	Gamma Ray Burst
GW	Gravitational Wave
H2020	Horizon 2020 EC Funding Program
Hh	Hartebeesthoek station, South Africa
HOPS	Haystack Observatory Processing Suite
IAU	International Astronomical Union
IF	Intermediate Frequence
IGN	Istituto Geográfico Nacional
	National Geographic Institute, Spain
INAF	Istituto Nazionale di Astrofisica
	Italian National Institute of Astrophysics, Italy
IRA	Istituo di Radio Astronomia
	Institute of Radio Astronomy, Italy
IVIA	Iniciativa VLBI Iberico-Americana
IVS	International VLBI Service for Geodesy and Astrometry
JIVE	Joint Institute for VLBI ERIC
JUICE	JUpiter ICy satellites Explorer
JUMPING JIVE (JJ)	Joining up Users for the Maximising the Profile, the Innovation and the Necessary Globalisation of JIVE
LBA	Long Baseline Array, Australia
LOFAR	Low Frequency Array
Maser	Maser amplification through simulated emission of radiation
Mbps	Megabit per second
Me	Meerkat dish, South Africa
MF	Ministerio de Fomento
MHz	Megahertz
MNRAS	Monthly Notices of the Astronomical Society
MoU	Memorandum of Understanding
MPIfR	Max Planck Institute for Radio Astronomy
MT	Management Team
NAOC	National Astronomical Observatories of China
NARIT	National Astronomical Research Institute of Thailand
ND	Non-detection
NL	The Netherlands
NME	Network Monitoring Experiment
NRAO	National Radio Astronomy Observatory
NRF	National Research Foundation (South Africa)
NWO	Nederlandse Organisatie voor Wetenschappelijk Onderzoek
	Netherlands Organisation for Scientific Research, the Netherlands

PI	Principal Investigator
PN	Planetary Nebula
PRIDE	Planetary Radio Interferometry and Doppler Experiment
pySCHED	python SCHEDuling software
R&D	Research and Development
RDBE	ROACH Digital Back End
RINGS	Radio Interferometry Next Generation Software
rPICARD	Radboud PIpeline for the Calibration of high Angular Resolution Data
SARAO	South Africa Radio Astronomy Observatory
SCHED	VLBI Scheduling software
SFXC	EVN Software Correlator
SHAO	Shanghai Astronomical Observatory
SKA	Square Kilometre Array
SKA-NL	Square Kilometre Array Netherlands
SMBH	Super Massive Black Hole
SNR	Signal to Noise ratio
STFC	Science and Technologies Facilities Research Council, United Kingdom
TB	Terabyte
THEZA	TeraHerz Exploration and Zooming in for Astrophysics
ToO	Target of Opportunity
TOTMDB	Total Multi-Band Delay
UK	United Kingdom
ULW	Ultra Long Wavelength
USA	The United States of America
UTC	Coordinated Universal Time
VDIF	VLBI Data Interchange Format
VeA	Ventspils Augstskola Ventspils University College, Latvia
VLA	Very Large Array, United States of America
VLBA	Very Long Baseline Array, United States of America
VLBI	Very Long Baseline Interferometry
VO	Virtual Observatory
VR	Vetenskapsrådet Swedish Research Council, Sweden
WG	Working Group
WP	Work Package
WSRT	Westerbork Synthesis Radio Telescope, the Netherlands
YERAC	Young European Radio Astronomers Conference
Ys	Yebes observatory, Spain

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