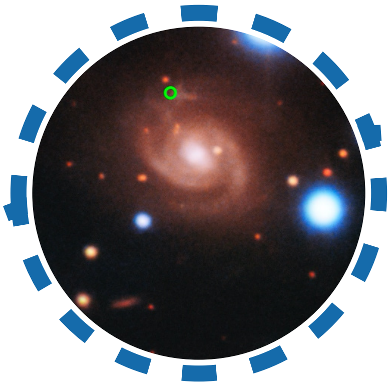
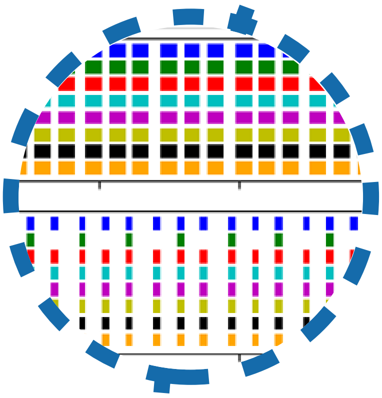
JIVE
Joint Institute for VLBI
ERIC





2020
ANNUAL REPORT

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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 2020, 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 Transportes, Movilidad y Agenda Urbana (MITMA)

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 2020:

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 2020 the extraordinary became commonplace for us all with the advent of the COVID-19 pandemic – which amongst other things revolutionised how many of us worked. JIVE was no exception – with the JIVE management and staff quickly adopting new work-from-home procedures that maintained high productivity while maximising the safety of the staff. These efforts of JIVE personnel, and of others around the EVN network supporting telescope operations, have ensured that the pandemic has only had minor impacts on the observing efficiency of the EVN; a remarkable result which was impossible to imagine at the start of the pandemic. I thank everyone involved in JIVE for their dedication and professionalism in adapting to pandemic conditions.

In the JIVE council the biggest areas of discussion during 2020 involved the future work plan and associated base future funding level for JIVE. By the end of the year JIVE member countries and collaborating organisations were able to agree on a 15% funding increase for the coming four-year period (2021-2024). This increase comes after many years of flat funding compared to gradually increasing costs. Achieving this funding increase against a background in which COVID was naturally the highest priority of national bureaucracies and budgets, required significant investment of effort and flexibility of approach on the part of JIVE's members. I thank all JIVE council members for their engagement in solving this issue. The achieved base funding increase together with other JIVE funding successes, in particular its participation in the new EU ORP project, establishes a firm stable financial basis for JIVE's work in the coming years.

This report outlines the very wide range of achievements of JIVE during 2020. These include direct involvement in very high impact, high visibility VLBI science projects such as following up the mystery of Fast Radio Bursts and supporting in various ways the Event Horizon Telescope and its science goal of imaging of Black Holes. Other notable science achievements to which JIVE has made significant contributions included studies of water maser super-bursts and the processing of orbiting VLBI data to obtain high-resolution images of galactic nuclei. Other supported non-standard VLBI projects included supporting EVN observations of the Insight Lander on the surface of Mars. JIVE's contributions to the EHT and other projects underlines that while the dominant task of JIVE is supporting the EVN, its software development and JIVE's in-house expertise also contributes more generally to the world VLBI 'ecosystem'. This global role also extends to organisational contributions, with the establishment during 2020 of the Global VLBI Alliance (GVA) to coordinate world astronomical VLBI being an important achievement which was largely realised by the personal efforts of the JIVE Director.

An important milestone during the year was the publication of the EVN Science Vision which outlined the prospects for high impact EVN science during the coming decade. The preparation of this comprehensive EVN science vision was supported by the EU-funded JUMPING-JIVE project and by JIVE's staff. Following on from this vision document JIVE personnel have been leaders in starting the development of the EVN's technical roadmap to convert the science vision into reality.

While the present achieved and future anticipated science results of VLBI are the ultimate fruits of JIVE's work, much of its day-to-day efforts concern making sure that the 'nuts and bolts' of the EVN both continue to operate and gradually improve. This work extends from providing correlation services to maintaining and developing various essential software packages. This annual report makes these background efforts visible. On behalf of the JIVE council and its members I thank everyone at JIVE involved for their work. Every contribution made, from bug fixes to organising logistics to developing new algorithms plays a vital role in JIVE's continued success.

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 stored 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 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 delivered with the final user product.

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 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 several 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.

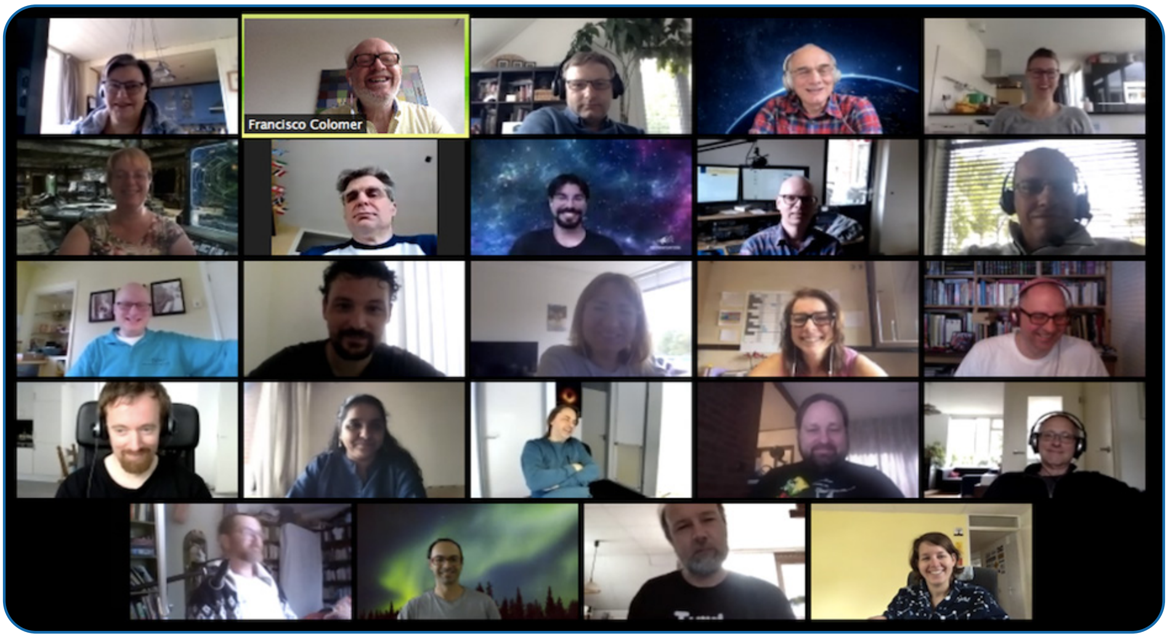
JIVE has developed a reputation to foster coordination, innovation and capacity building for European and global VLBI. In its role as central entity in the EVN, JIVE exploits the ERIC advantages to deal with EC projects, and provides support to services and activities of interest to the whole radio astronomy community, such as the Committee on Radio Astronomy Frequencies (CRAF).

1.2 JIVE IN 2020

The outbreak of the COVID-19 pandemic has had an enormous worldwide impact, causing abrupt changes in the plans of people and institutions. As of March 2020, the JIVE staff has been working mainly from home, and access to the offices in Dwingeloo has been very restricted. An important challenge in these circumstances is to guarantee the well-being of the staff and ensuring that everybody has adequate resources to perform their duties, while taking into consideration the difficulties that many people and their families experience. It is encouraging to note that all staff has remained healthy and safe during this time, and that the JIVE family has proved to be robust and resilient.

For more than a year now, and possibly for more months to come, travel has been absent from our agendas. Many events and activities have happened virtually. Even the regular Tuesday coffee meetings at JIVE are organized via Zoom. This new way of interacting has some clear advantages, like avoiding commutes and allowing events to be more inclusive, but also slows down some activities. We all hope that, once the pandemic is over, the best lessons learned will be incorporated into a more flexible and sustainable way to combine work and family life.

During 2020, some very important discussions on the sustainability of JIVE were concluded. As proposed previously, the JIVE Council approved the increase of the partners' financial contributions by 15%, starting in 2021. This is especially significant as it happened in the year of the pandemic, with many governments dealing with extreme challenges and it clearly demonstrates the interest and commitment of the JIVE partners. Another essential part of JIVE's sustainability is the acquisition of new projects. The approval by the European Commission of the OPTICON-RadioNet Pilot (ORP) project, in which JIVE is the partner receiving the largest share, will provide resources to maintain the highest standard of quality in supporting the EVN and its users. These resources will be essential after the successful completion in 2020 of the RadioNet project. The final aspect, namely increasing the number of JIVE partners, is continuously ongoing, and we anticipate the incorporation of Italy as full member in 2021. This is of course in line with the expectation that all the members of the EVN will eventually join the JIVE ERIC. The work of the European Union's Horizon 2020 project JUMPING JIVE (Joining up Users for Maximizing the Profile, the Innovation and Necessary Globalization of JIVE) has also provided an important contribution to the sustainability of JIVE, developing new capabilities for the EVN and working towards the future of VLBI. The project's activities are coordinated by JIVE and have continued in 2020 despite the limitation of the global pandemic.



JIVE Coffee via Zoom.

The focus of the JIVE mission is to provide expert support to the EVN and its users. To this purpose JIVE continuously strives to enhance the user experience, to support continuous innovation, and promote radio astronomy in Europe and beyond. An important event in 2020 was the publication of a new science vision for the EVN. Facilitated by the EC H2020 JUMPING JIVE project, it also served as the base for an EVN Technology Roadmap. Both scientific and technological developments in the EVN obviously should be compatible with those at other VLBI networks. A Global VLBI Alliance (GVA) has been formed to create a forum for discussion and transfer of information. The GVA includes representatives of the EVN, VLBA, EAVN, LBA, and their user and technical communities. The GVA is now formally recognized as a Working Group in the IAU Commission J (radio astronomy) and will help coordinate some of the opportunities identified in the new EVN science vision, particularly for joint observations with new facilities such as the SKA or for multi-messenger studies.

JIVE has facilitated or been directly involved in producing exciting science results using VLBI, like revealing the origin of a second repeating Fast Radio Burst (FRB), studying "super-bursts" of water maser emission, verifying the results of the Event Horizon Telescope (EHT) using AIPS and CASA, or obtaining the sharpest images of the quasar 3C 345 as part of the RadioAstron AGN collaboration. JIVE staff has also actively participated in the RadioNet project, as well as in the ESCAPE project (centered on the development of the European Open Science Cloud) and the ERIC Forum. The latter allows to exploit synergies between different ERICs and solve common challenges, while providing a voice for JIVE and other ERICs in the context of the new EC Horizon Europe program.

Communication and distribution of the EVN results are essential, and despite the challenges due to the cancellation of many events, JIVE has continued to produce the EVN Newsletter, maintain the EVN website and its presence in social networks. Support from the EVN institutes in this area is sought and of course much appreciated.

1.3 PERSONNEL

During this extraordinary year due to the COVID-19 pandemic the JIVE management and staff have ensured that the new conditions set by the public health rules, in particular the need to work from home, would only have minor impacts on the observing efficiency of the EVN.

Katharina Immer ended her contract as Support Scientist, and moved to ALLEGRO, the ALMA Regional Center in Leiden (the Netherlands).

Harro Verkouter is now Head of the Technical Operations and R&D department. Arpad Szomoru, who retired in 2019, still performs some advisory roles in JIVE.

Huib van Langevelde is Program Director of the Event Horizon Telescope (EHT).

02 SCIENCE HIGHLIGHTS

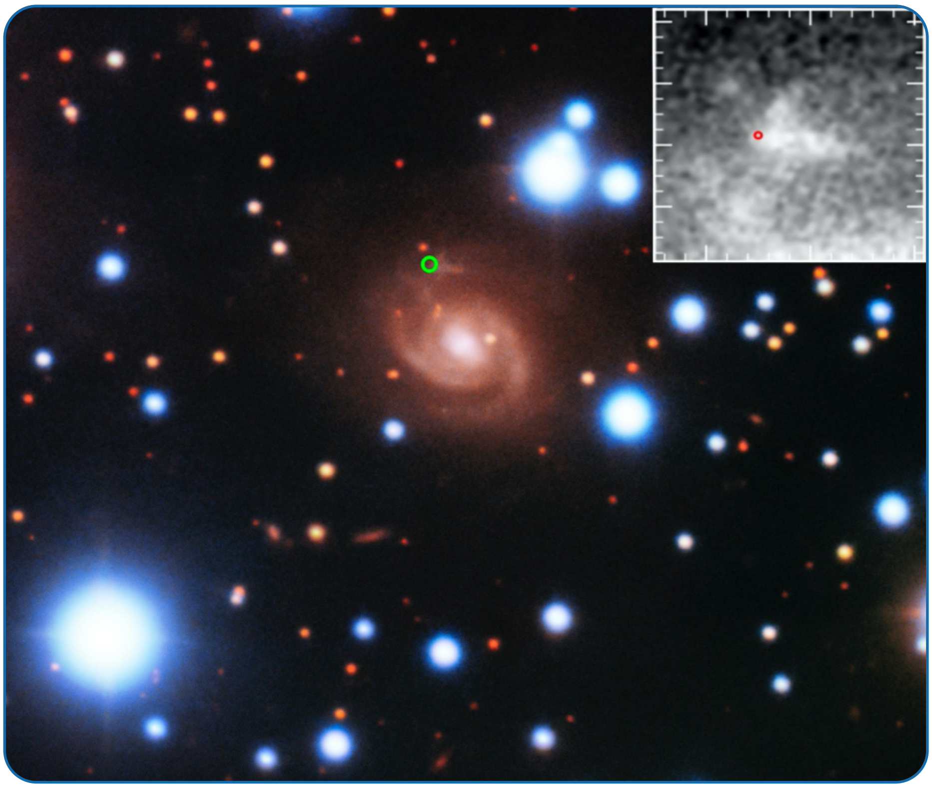
2.1 THE ENVIRONMENT OF A SECOND REPEATING FAST RADIO BURST REVEALED

Observations with the EVN revealed the origin of a second repeating Fast Radio Burst (FRB), whose bursts come from the inside of a spiral galaxy similar to our own. This FRB, 180916.J0158+65, is the closest extragalactic FRB to Earth ever localized and was found in a radically different environment to the first repeating FRB that was precisely localized, FRB 121102, also localized to the milliarcsecond level thanks to observations with the EVN. This discovery, that appeared in the issue of 6th of January of Nature (Marcote et al. 2020), once again, changes our assumptions on the origins of these mysterious extragalactic events.

One of the greatest mysteries in astronomy is where these short, dramatic bursts of radio light originate from. Although FRBs last only for a thousandth of a second, there are now hundreds of records of these enigmatic sources. However, from these records, the precise location is known for just a handful of FRBs - they are said to be ‘localised’. Furthermore, only a fraction of these FRBs has been observed to produce multiple bursts, the so-called repeating FRBs. The existence of a single population or two different populations of FRBs remains unclear.

On 19 June 2019, eight telescopes from the EVN simultaneously observed FRB 180916.J0158+65, which was originally discovered in 2018 by the CHIME telescope in Canada. During seven hours of observations the researchers, led by Benito Marcote (JIVE), detected four bursts, each lasting for less than two thousandths of a second. The EVN observations allowed the bursts to be precisely localised to a region of approximately only seven light years across. With this location the team were able to conduct observations with one of the world’s largest optical telescopes, the 8-m Gemini North on Mauna Kea in Hawaii. Examining the environment around the source revealed that the bursts originated from a spiral galaxy at redshift of 0.0337, specifically, from the apex of a prominent v-shaped star-forming region. The found location is radically different from the previously located repeating FRB, but also different from all previously studied FRBs.

The differences between repeating and non-repeating FRBs are thus less clear, suggesting that these events may not be linked to a particular type of galaxy or environment. It may be that FRBs are produced in a large zoo of locations across the Universe and just require some specific conditions to be visible. While the current study casts doubt on previous assumptions, this FRB is the closest to Earth ever localised, allowing us to study these events in unparalleled detail. An increasing number of precise localizations of FRBs will, ultimately, shed light on their origin and nature.



Optical image from Gemini North of the host galaxy of FRB 180916J0158+65 and a zoom-in of the star-forming region from where the bursts arise. The location of FRB 180916.J0158+65 is highlighted by the white cross and the red circle. The uncertainty in t the position of FRB 180916. J0158+65 derived from the EVN data is smaller than the resolution of the optical image. Marcote et al. 2020, Nature, 577, 190.

2.2 G25.65+1.05: A BURST AT THE MASER CROSSROADS

Cosmic masers were discovered nearly 50 years ago, and although great strides have been made in understanding the nature of these intriguing phenomena, they continue to present extraordinary behaviours. One such event is the ``super-bursts'' of water maser emission. Water masers are known to be variable, but only three Galactic water masers are known to flare to tens of thousands of Jy: Orion KL, W49N, and the recently discovered G25.65+1.05.

G25.65+1.05 (IRAS 18316−0602, hereafter "G25") is a massive star forming region that shows extreme maser activity. Long-term single-dish monitoring of H2O masers in G25 showed flares in 2002, 2010, and 2016 with flux densities of 4, 19, and 46 kJy, respectively (Lekht et al. 2018). The next powerful flare of 65 kJy was detected in September 2017 (Volvach et al. 2017, 2019). The most recent burst was found to be extremely short-lived: the peak flux density rose from about 20 kJy to 76 kJy within half a day on 20 November; the source then faded to about 20 kJy on 22 November (Ashimbaeva et al. 2017).

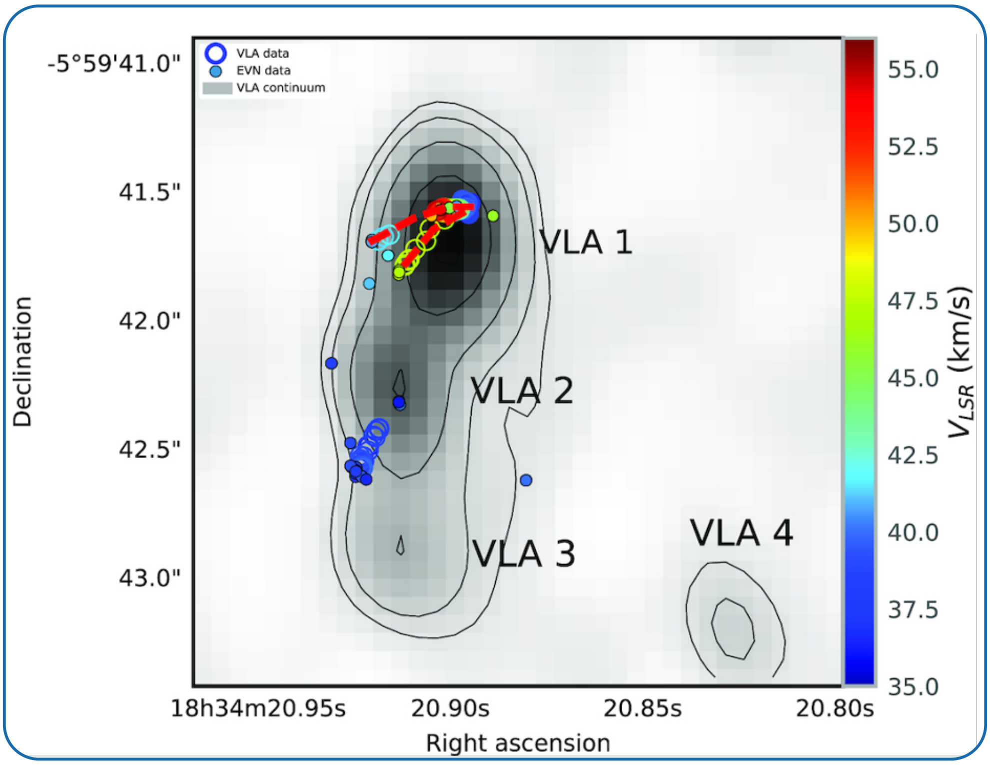
Moreover, G25 has reserved its place in history, not only as one of the exceptional "super-burst" sources, but also as the first target studied by the Maser Monitoring Organisation (M2O). The M2O is a global community of astronomers, observers and theorists collaborating to study the nature of astrophysical masers, their flaring behaviour and their uses as tracers of astrophysical phenomena. The organisation aims to bring together single-dish maser monitoring programs and manage follow-up VLBI observations of the detected flaring maser sources. The M2O team is led by Ross Burns (a former JIVE support scientist) and engages many other past and present JIVE employees, such as Francisco Colomer, Huib Jan van Langevelde, Olga Bayandina, and Katharina Immer.

In October 2017 one of the very first VLBI follow-up studies organised by the M2O took place. It was an e-VLBI observation of G25 conducted in response to the maser flare of September 2017. The array contained both short and long baselines, comprised of Effelsberg, Jodrell Bank (MkII), Onsala (20 m), Torún, Yebes and Hartebeesthoek.

The EVN data obtained for G25 revealed a complex distribution of maser emission in the region (Burns et al. 2020). H2O masers are found to trace two 'arcs' presumably associated with shocks in a protostellar jet or outflow. One of the arcs consists of two maser sheets delineating a large V-shape. The bursting maser is observed at the point where the two maser sheets intersect in the sky-plane of the observer.

The M2O team concluded that the superburst maser had occurred as a result of a rare spatial alignment of two maser cloudlets along the observer's line of sight associated with the intersecting sheets. Consequently, the background maser was subsequently amplified by the foreground maser. The two-stage amplification lead to a short-lived, spectacular surge in the measured flux density, most of which originates from a sub-milliarcsecond scale region.

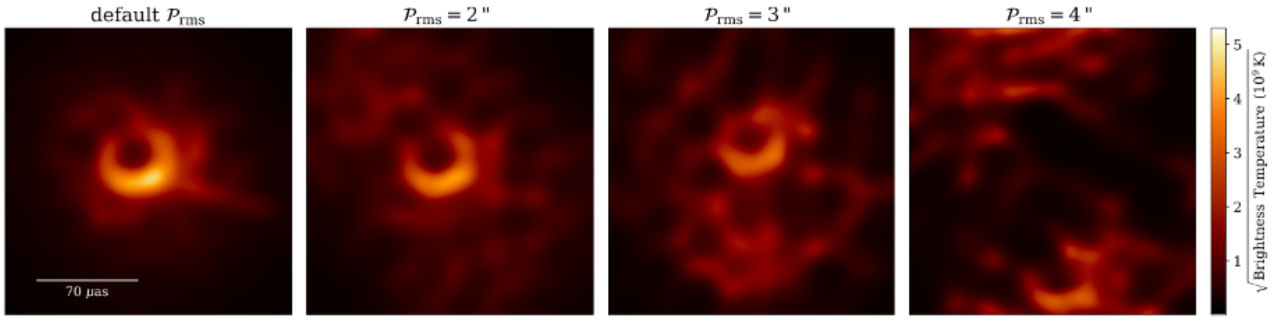
Several weeks after the EVN observations the G25.65+1.05 water maser had returned to its quiescent phase, only to go superburst yet again, reaching a flux density of 130,000 Jy and making it one of the most powerful sources of maser emission in our Galaxy. The EVN investigation gleaned essential insights into the mechanism of action of the superburst class of maser sources, of which only two other maser sources are known.



Visual summary of the water maser and 20 GHz continuum emission in G25.65+1.05, comparing EVN data (Burns et al. 2020, MNRAS, 491, 4069) with VLA data (Bayandina et al 2019, ApJ, 884, 140). Open circles indicate maser emission detected by the VLA while filled circles represent masers detected with the EVN. Colours indicate line of sight velocity and the red dashed line delineate the lateral 'V'.

2.3 EHT RELATED SCIENCE AND DEVELOPMENTS

As part of the efforts related to the Event Horizon Telescope (EHT), JIVE has invested in the development of VLBI data processing in the CASA package. The new VLBI functionality is maturing well, and has been broadly advertised to the community. It is at the basis of one of the main EHT data processing pipelines, and used for developing an EVN pipeline in the Jupyter notebook environment. It is also the basis of one of the main EHT data processing pipelines.



Images reconstructed from synthetic observations with all effects included under varying weather conditions. Roelofs et al. 2020, A&A, 636, A5.

The collaboration led by Iniyan Natarajan at Rhodes University in South Africa, and including several JIVE staff, has led to the development of a proto-type Bayesian fringe fitter. The Bayesian technique has significant benefits over the classical Schwab-Cotton method of fringe fitting, as it allows for including a source model in the prior, which leads to a better estimate and separation of the instrumental and source calibration parameters. The CASA fringe fitting task can also include a source model, but requires prior observations at similar spatial resolution and frequency, which are not always available.

The JIVE team was involved in the verification of the results using AIPS and CASA. The use of two different verification packages was a huge benefit in establishing the confidence in the Bayesian approach, as well as an excellent verification for the new CASA fringe fit task. The paper uses synthetic EHT data with different source models. The Bayesian approach outperforms the classical fringe fitting method in terms of calibration accuracy for the case of resolved asymmetric source structure. This would result in a significantly improved dynamic range in the final image. Though the method is still computationally intensive, it is a unique approach for new sources, and a powerful tool for identifying systematic errors in the calibration process.

Future work in this team will involve more complicated source models, such as rings and crescents, which will demonstrate the usefulness of Bayesian fringe fitting for EHT and ngEHT observations. The results were published in Natarajan et al. 2020, MNRAS 496, 801.

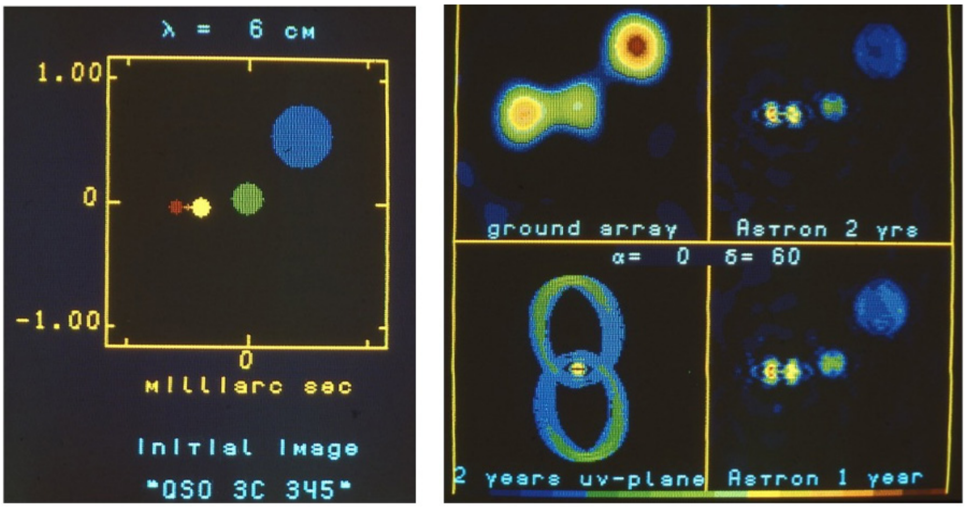
Synthetic data are invaluable to understand how source parameters can be derived from real observations, and to optimize observation and calibration strategies. They can also help to characterize new instruments and new modes of observation. The SYMBA package is a synthetic data generator for VLBI observations based on the MeqTrees descendant MeqSilhouette (Blecher et al 2017). For a given array of telescopes and observing parameters, it models realistic atmospheric and instrumental effects on top of an ideal source image, such as a GRMHD simulation (Roelofs et al. 2020).

The resulting synthetic data are calibrated with the rPicard pipeline, developed using the CASA-VLBI calibration functionality (Janssen et al 2019).

The impact of residual errors on the final scientific image can be assessed in detail, and can be traced through the entire process. This allows for improvement of the observation and calibration strategy, and establishes the hard limits to which accurate calibration is possible for given observational conditions.

The paper by Roelofs et al. demonstrates that atmospheric and instrumental corruptions cause significant errors in high-frequency EHT observations, which cannot always be fully corrected in calibration. Adding new stations to the EHT array at strategic locations would improve the calibration quality, resulting in higher angular resolution and dynamic range.

2.4 SPACE VLBI VIEW AT 3C 345 IN THE 1980S AND NOW



Simulation of imaging with the Radioastron mission of a source resembling the morphology of the quasar 3C 345 on the milliarcsecond scale. The left panel shows the model structure. The right panel contains reconstructed images obtained with the ground-only array and Radioastron images after 1 and 2 years (elapsed time) observations. The lower left quadrant in right panel shows the 2-year uv-coverage. Simulations of 1986 at the Space Research Institute, Moscow.

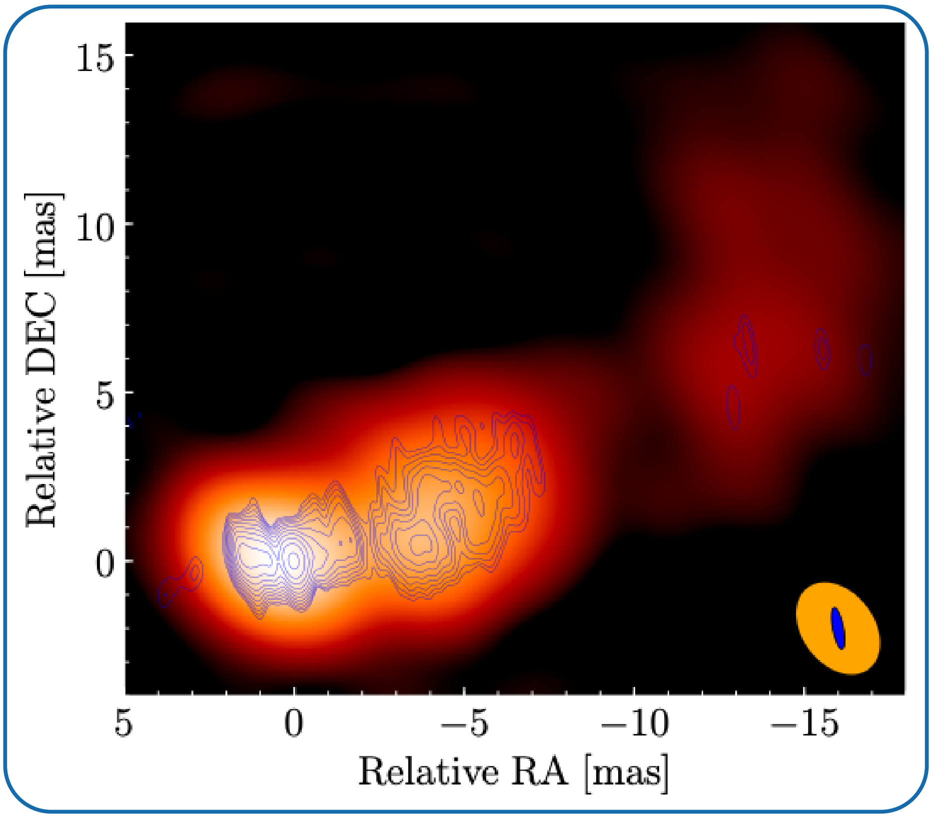
In 1985, the EVN Consortium Board of Directors (EVN CBD) began discussions with the leadership of the then Soviet Space VLBI project Radioastron. One of the points of attention was the expected performance of the mission in VLBI imaging experiments. The Radioastron imaging potential was investigated by intensive simulations conducted on analogues of the then mainstay computers PDP-11 by Digital Equipment Corporation (DEC). The figure above represents one of many simulation runs conducted in 1985-86. In that run, a hypothetic radio source qualitatively resembling the morphology of the well-studied quasar 3C 345 placed arbitrarily at the celestial coordinates RA = $0^h00^m00^s$, Dec = 60°00′00′′. The left panel shows the morphology of this 3C345-like source at the wavelength of 6 cm. The right panel presents the results of the simulation: the image, obtained with a ground-based array only, two Space VLBI images obtained with various integration times, and the full uv-coverage over the period of two years.

Among other things, these simulations paved the way for a Memorandum of Understanding on cooperation in the Space VLBI mission Radioastron, signed in December 1986 by the leader of the Radioastron project Nikolai Kardashev and the then Chairman of the EVN CBD Giancarlo Setti.

35 years later, the RadioAstron mission and EVN together produce top-notch results in studies of compact structures in celestial radio sources. Recently, the RadioAstron AGN collaboration obtained the sharpest images of the quasar 3C 345 at 1.6 GHz (Pötzl et al. 2021, A&A 648,A82).

This result exceeds the expectation of the 1980s. The paper by Pötzl et al. presents a plausible explanation of the apparent high brightness of the inner structure of the quasar 3C 345 and arguments against dominant impact on the brightness distribution of refractive substructure due on the galactic ISM.

Nikolai Kardashev (left) and Giancarlo Setti (right) sign the MoU on cooperation between the Radioastron mission and EVN at the Space Research Institute, Moscow, December 1986.



A total intensity RadioAstron image of 3C 345 at 1.6 GHz with the ground array data (orange scale) and all data including the space baselines (blue contours). The corresponding beam sizes are displayed in the bottom right corner. The RadioAstron angular resolution is 1.25x0.32 mas. The peak brightness is 0.39 Jy/beam. For the ground-only array, the resolution is 3.0x2.1 mas, and the peak brightness of 1.68 Jy. Pötzl et al. 2021, A&A 648, A82.

03 RESEARCH AND DEVELOPMENT

3.1 TECHNICAL OPERATIONS

During 2020 the COVID-19 pandemic has had impact on only a few select aspects of technical operations of the EVN at JIVE – but never to the effect of loss of observations. The correlator, storage, services, network and software remained operational throughout.

After the Dutch national lockdown and general Work-from-Home (WfH) came into action as of 16 March 2020 some time was spent in enabling remote access for the operators to the correlator control computer; previously not a high-priority situation. Several remote desktop applications and protocols were explored and a convenient WfH environment was created using Xming and PuTTY for setting up an encrypted point-to-point Virtual Private Network (VPN) between the home environment and the correlator control computer. Production correlation could be conducted as much as possible from home, limiting requests for exceptions to the ban of physical access to the building to e-VLBI/real-time observing days or service requests.

The main impact on technical operations was limited to delays in servicing requests (specifically hardware replacements) due to delayed delivery from suppliers and/or restricted access to the premises due to government and/or local regulations. Changing the purchase order workflow from a paper-based mechanism to an electronic submission and signing one took only about two months, after which no delays were incurred by this anymore.

3.1.1 Hardware

No new Mark5s, Mark6's or FlexBuffs were installed during 2020. The JIVE "datacentre" currently consists of more than 100 physical servers, 20 virtual and 12 switches/routers.

Approximately 30 hard disks failed during the course of the year and were replaced. Several machines required an upgrade to the amount of available disk space: archive, the off-site backup host and the CASA development host. Four Mark5s were outfitted with new Power Supply Units after these died as a result of an unscheduled power outage of the neighbourhood including the institute.

An LTO8 tape drive and a supply of LTO8 tapes (12 TB / tape) were ordered and installed to replace one of the failing LTO4 tape drives. Side effects of this upgrade are increased backup speed and capacity and much less tape changes required – certainly an advance during restricted access to the premises.

3.1.2 Network

The JIVE internal network and the shared redundant 100 Gbps external network link performed flawlessly during 2020. According to the original time line for the migration of host institute ASTRON's network configuration (assisted by JIVE staff) to using the shared 100 Gbps link was scheduled for Q4 2020, but this switchover was severely impacted by COVID-19 regulations and was still ongoing by the end of 2020. The sharing of the 100 Gbps link is expected to have no measurable impact on (real-time) EVN operations and data transfers. During 2020 JIVE staff was invited to take part in testing and sending feedback on the Dutch NREN SURFnet network management application.

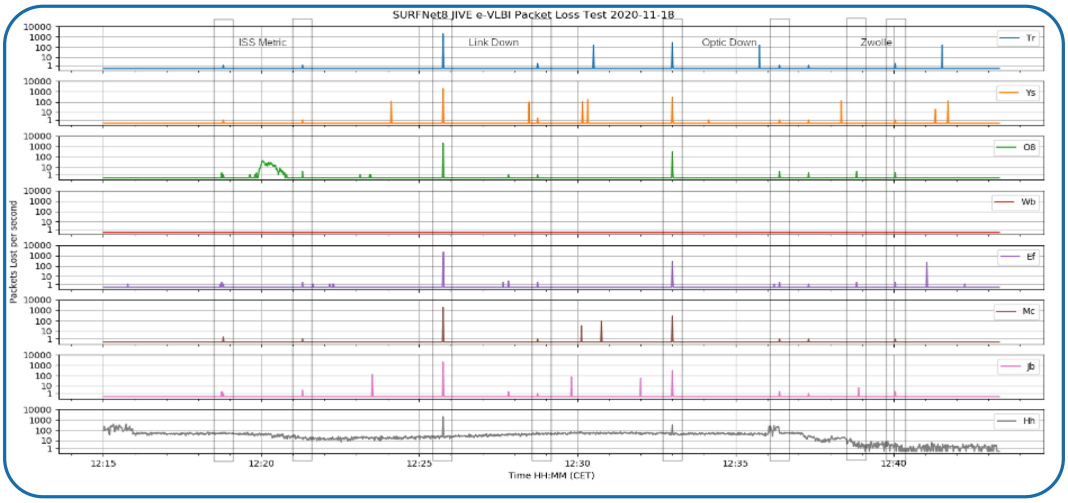
On 19 November 2020, following the regular 2 Gbps e-VLBI session, several EVN telescopes (Tr, Ys, O8, Wb, Ef, Mc, Jb and Hh) continued observing for a short network disruption test by SURF. Four tests were conducted: dynamic routing change, semi fibre cut simulation by disconnecting the Dwingeloo router, fibre cut simulation by turning a port's laser off and interrupting traffic into the Dutch city of Zwolle.

Packet loss at JIVE was monitored throughout the test period. The highest packet loss recorded across the tests was ≈ 4,000 packets per station for the "Link down" test on a data rate of 32,000 packets per station per second. The packet loss for the other tests was an order of magnitude smaller. Even the highest packet loss (12% of a single second) will not affect the scientific quality of the data. Finding the packet loss connected to the tests in the correlated data file was difficult and without guidance on where to look (time based) would likely have gone unnoticed.

3.1.3 High data rate (> 2 Gbps) (real-time) observations

During the test phase of the November 2020 e-VLBI session on 18 November a 4 Gbps real-time observation was conducted. The SFXC input nodes cannot handle more than ~ 3.5 Gbps of data in real-time, limited by CPU performance. In this test the approach to configure the FiLa10Gs at the stations to split 4 Gbps into 2 x 2 Gbps streams and route those to different SFXC input nodes was tested.

Ef, Hh, Ir, Tr, Mc and O8 took part in this test. No data was received from Hh; the data stream from Ef stopped sending reproducibly after ~5,000 packets sent when starting the observation (which, at 64,000 packets / second in this mode, translates to 78 ms); Tr did not have fringes in e-VLBI at all at that time. Fringes were observed between Mc, O8 and Ir.



Packet loss (logarithmic scale) per station as function of time on 19 Nov 2020. The tests are marked with vertical bars. There are two sets of bars for each test: the first when the change to the network was done, the second when the change was undone.

This observing mode explores a feature in the FiLa10G firmware that is not very common or well-tested. The firmware used at the stations was the same so the failure of Hh and Ef is currently unexplained, although after consultation with Bonn staff suspicions are that there may be a subtle hardware issue in the Ef FiLa10G triggering this (mis)behaviour of the firmware. The test indicates that 4 Gbps e-VLBI can be done but critically depends on correct functioning of hardware / firmware at the stations.

Several attempts were made to continuate the 32 Gbps observation tests. However, due to COVID-19 (no access to sites for observing), unavailability of DBBC3s at Ef and Ys/VGOS, and a cryogenic subsystem failure at one of the available VGOS twin telescopes (and no access to the site for timely repair) meant that insufficient stations remained: TianMa and one Onsala VGOS dish. There is just not enough high-bandwidth equipment available within the EVN – three out of the four stable "32 Gbps" stations are VGOS systems.

3.1.4 Software

Several tools (`runjob`, `log2vex`) were modified to support VEX2 data streams and automatic splitting of > 2 Gbps data streams into *n* x 2 Gbps for e-VLBI, including programming and configuring both the FiLa10Gs at the stations and the SFXC compute cluster accordingly.

The backup software was rewritten to support the new LTO8 tape drive and a backup-consolidation strategy was implemented. Previously three separate backup systems were active, linked to tape drives physically connected to a server. The new backup software consolidates the three backup systems into one, with the LTO8 tape drive reachable over the network.

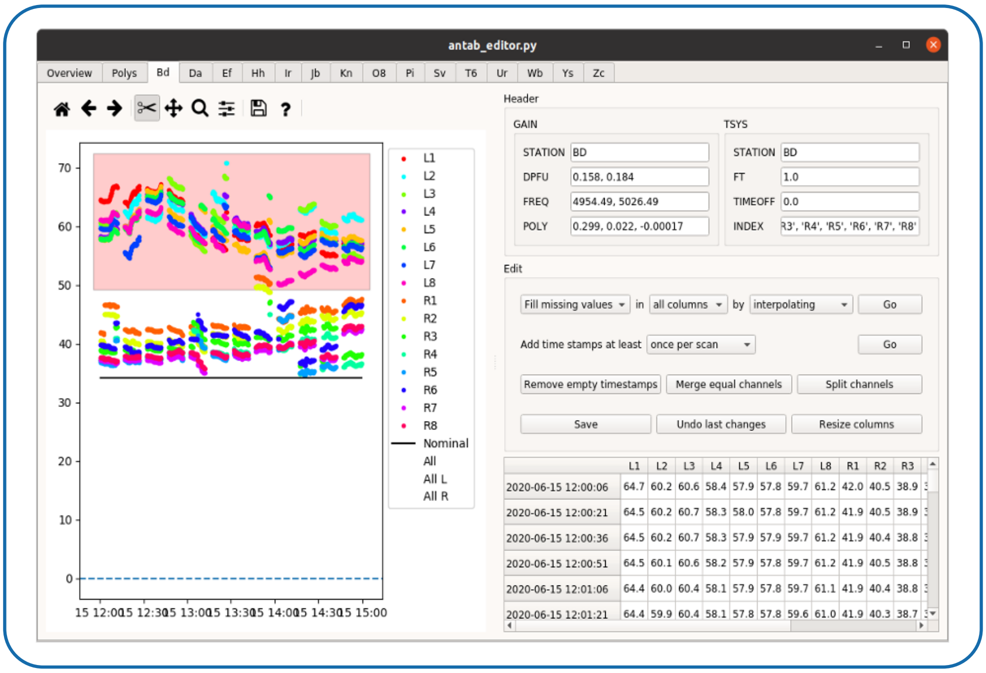
To improve open-sourcing and sharing code and scripts between the different groups, users, and developers of code relevant to the JIVE workflow or EVN data, a self-hosted `github`-like environment (using the open-source `gitea` project) was set up at https://code.jive.eu. Open projects can be explored and their documentation/issues can be browsed. Write access to the repository is presently limited to JIVE staff.

The NorthStar proposal tool, despite its age and difficulty of maintaining, needed to be updated a few times. A checkbox to have the proposer agree with the European General Data Protection Regulation (GDPR) was added. In order to properly support 4 Gbps observing mode proposals, data rate constraints per observing band were required to be implemented and remain correctly enforced under users changing back and forth between observing bands. Several other minor improvements were made to the tool.

A new program, `antab_editor.py`, was designed and implemented to help support scientists to process ANTAB files. Very often ANTAB file contain errors or inconsistencies and fixing them manually took an inordinate amount of time. The graphical user interface of the new `antab_editor.py` allows for quick detection and fixing most common ANTAB file issues. The source code and README are available from JIVE's own code repository at https://code.jive.eu/eldering/antab

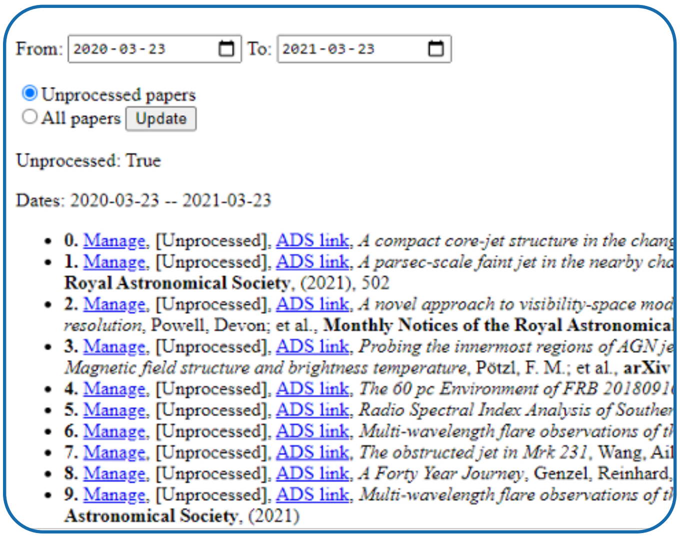
A database for linking EVN data sets to publications was designed. A feasibility study for a tool to automatically populate this database by mining EVN-related publications on the ADS was conducted. It turned out that even combining the heuristics of three separate manual solutions employed by various staff members was not enough to pursue this approach further. Less than 50% of publications referring EVN data could be automatically linked to project codes.

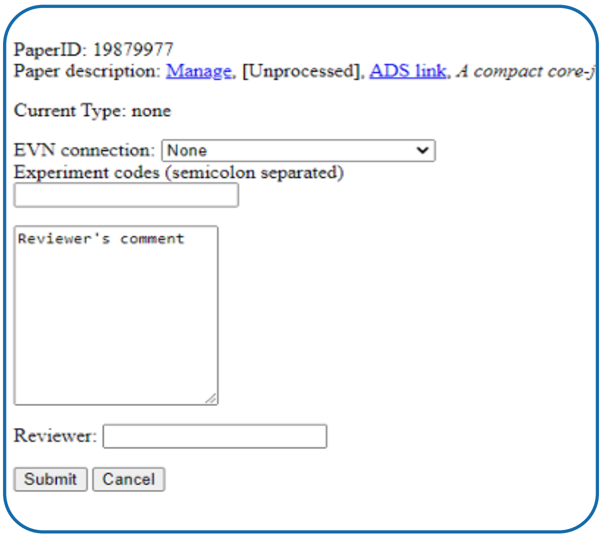
In order to make populating the database easier, a simple web-based tool was developed that provides the user with a list of new, as yet unclassified, papers that might be candidate papers for referring to EVN data. The user can read the PDF version and classify the specific linkage to EVN



Screenshot of the new `antab_editor.py` program showing a GUI based approach to finding and fixing common issues in ANTAB files.

data (several categories of linkage exist) or mark the paper as not related to EVN data at all (false positive) and optionally add an assessment – see the screenshots below. This is a first step towards providing a database structure allowing extraction of usage statistics using database queries instead of manually compiling these.





Screenshots of the web-based interface to the EVN data <–> publications linkage database
left: selection/overview of papers to review, right: manage the entry for a specific article.

3.2 RESEARCH AND DEVELOPMENT

A common comment heard amongst the software developers was that the prolonged WfH situation typically resulted into tasks taking longer than expected, and in one case even prevented the task from being undertaken as developing the code for that project turned out to be not feasible being located outside of the ASTRON/JIVE network.

The year 2020 saw a lot of progress in the areas addressed by the three work packages of the ESCAPE project that JIVE is involved in.

3.2.1 Open Source Software Repository (OSSR, ESCAPE WP3)

JIVE staff is involved in the high-level discussions and deliverables to create the OSSR as usable entity in the European Open Science Cloud (EOSC). Defining standards for common meta data for the software in the OSSR is in progress as well as appropriate and/or recommended licensing schemes for software to be included in the OSSR.

Regarding EVN specific work the Jupyter-CASA image was updated to be based on CASA 6.1 and the Docker image was updated to include commonly used packages such as AOFlagger (https://gitlab.com/aroffringa/aoflagger) WSClean (https://gitlab.com/aroffringa/wsclean), CARTA (https://cartavis.github.io/) and the JIVE VLBI tools. The Docker distribution was changed to Jupyterlab instead of a plain Jupyter notebook.

The useful `plotcal` task to plot various calibration tables was removed in the CASA 6 series. Because the `plotms` tool, which should absorb this functionality, does not integrate well with the Jupyter notebook environment and the `plotcal` tool being quite simple, a drop-in `plotcalng` Python + matplotlib (https://matplotlib.org/) based extension was developed and integrated with the Jupyter-CASA environment, see below. The seamless integration with the notebook environment comes "for free" for tools that are based on matplotlib.

3.2.2 Connecting ESFRI projects to EOSC through VO framework (ESCAPE WP4)

Several meetings were organized by the Centre des Données Astronomique de Strasbourg (CDS) involving ESCAPE partners as well as International Virtual Observatory Alliance (IVOA) experts to discuss standards for describing (radio-)visibility data in the VO framework.

Based on the outcomes of these discussions an experimental modified ObsCore (https://www.ivoa.net/documents/ObsCore/) data model was defined, allowing for visibility data to characterize the u,v-plane – an important property for letting users assess the scientific potential of the data set before e.g. downloading GBs of data to find out the u,v-coverage was (too) poor for imaging. These parameters are experimental and are tested by scientists to assess whether they are indeed meaningful as a selection criterion.

At JIVE scripts were generated to parse the FITS-IDI files from the EVN archive, extract and compute

Screenshot of the `plotcalng` task integrating seamlessly with the Jupyter-CASA notebook running on a Jupyterlab instance, displaying the results of a previously executed `fringefit` calibration. Effelsberg (Ef) was the reference antenna.

the relevant meta data for filling the ObsCore data base, including characterization of the u,v-plane. the figure on the next page illustrates the type of information used to transform a sparsely filled u,v-plane into a few numbers.

Dedicated hardware was purchased, installed and configured to run the production EVN VO ObsCore Table Access Protocol (TAP) service powered by the German Astrophysical Virtual Observatory (GAVO) DaCHS suite (https://docs.g-vo.org/DaCHS/). The decision to run the service on dedicated hardware is motivated by the fact that the EVN archive query service will eventually be registered in the global VO Registry-of-Registries and is expected to handle a non-trivial number of queries by the collective users of the VO.

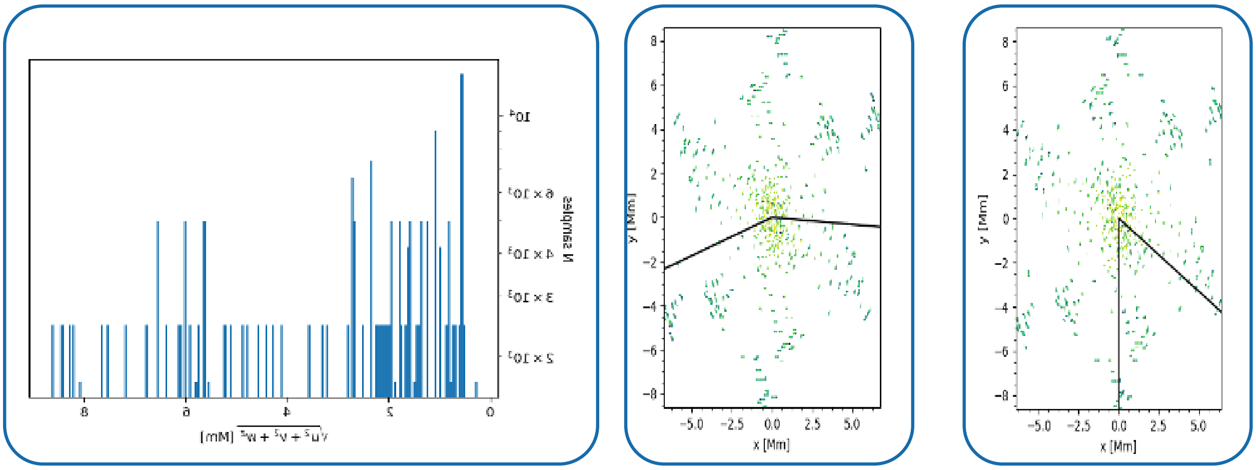
3.2.3 ESFRI Science Analysis Platform (ESCAPE WP5)

To experiment with science analysis platforms where the code is brought to the data, JIVE is setting up a Jupyterlab instance where the EVN CASA based continuum pipeline in Jupyternotebook format can run close to the EVN archive.

A development / demonstration Jupyterlab instance was set up on a virtual machine only reachable from the local network. Work on a Jupyterlab extension to interact with the EVN archive via its VO query interface was started. Currently the interface is limited to selection by experiment code.

The EVN continuum pipeline was analysed into its constituent steps such that a graphical representation of the workflow could be generated. This significantly helped in translating the pipeline into Jupyternotebook format. Some experiments with a Common Workflow Language representation of the pipeline were done but that approach did not seem viable for exposing to the PIs and was quickly dropped in favour of the Jupyter notebook interface.

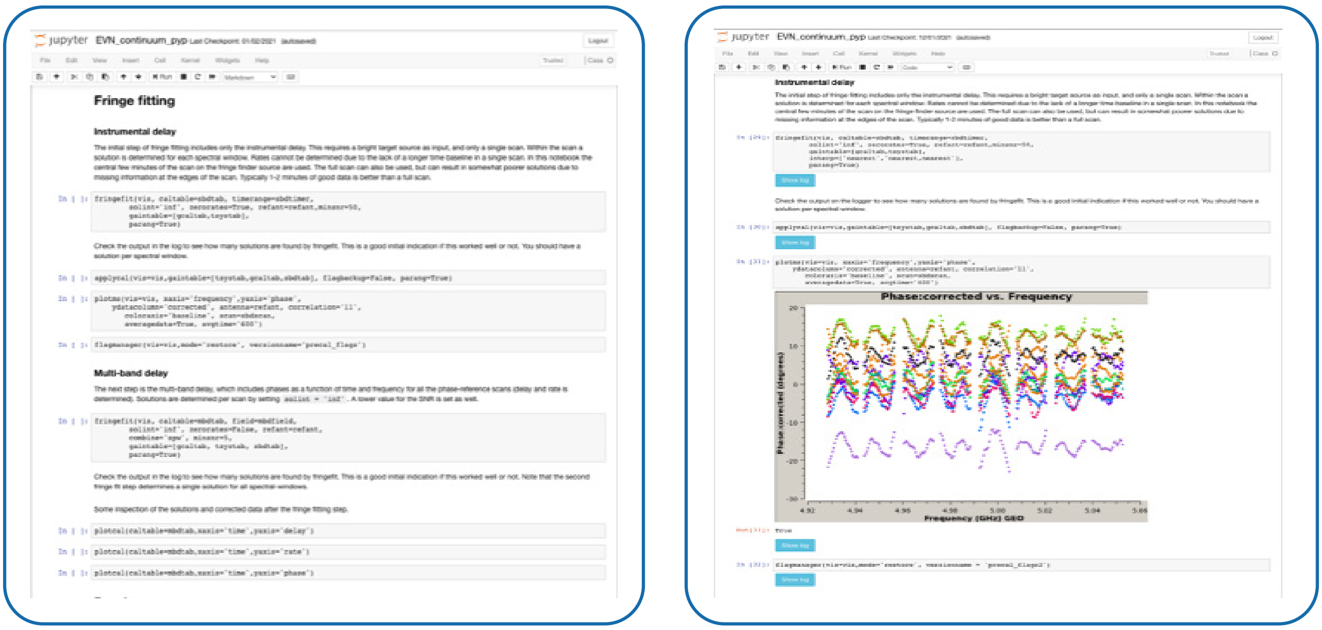
The proposed method is to let JIVE support staff generate a dedicated notebook with included preliminary calibration steps inserted per experiment. The user can download the notebook (or open it in the Jupyterlab environment) and start evaluating the cells. The images below



u,v-plane characterisation helper plots. left) the baseline histogram used to define a "filling factor" for the u,v-plane; middle) the raw u,v-coverage for the observation; and right) the rotated u,v-coverage to determine beam major and minor axis and the orientation of the ellipse.

show the comparison of the raw and an evaluated notebook.

The CASA based pipeline results were verified against EVN science data and an attempt was made to use AOFlagger for automated flagging. The result was not an immediate success; flagging EVN data in an automated fashion will require more investigation. The Python interface to the tool, required to seamlessly integrate with the Jupyternotebook environment, is still under development.



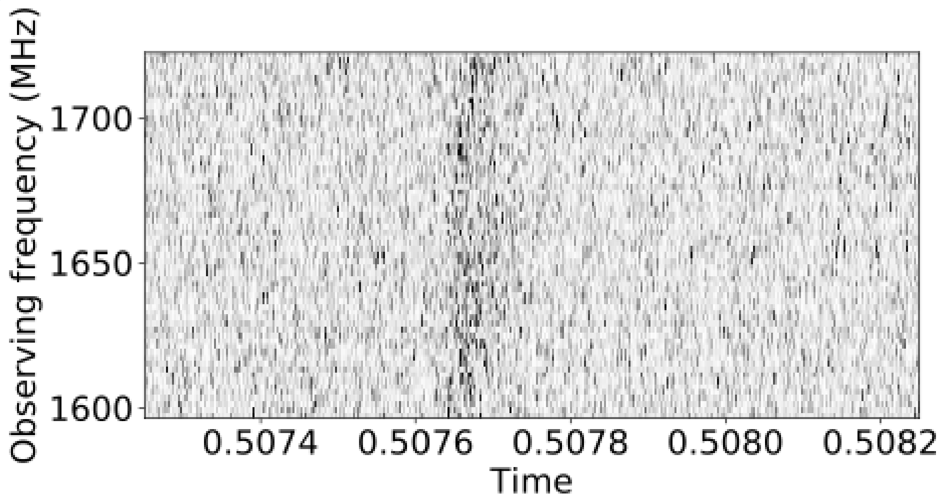
Left) Raw, unevaluated EVN continuum notebook as prepared by JIVE staff, showing mixed data reduction steps and documentation and Right) the same notebook now showing some evaluated cells, e.g. diagnostic plots to evaluate the quality of the calibration.

3.3 SOFTWARE CORRELATION

In 2020 the JIVE Software Correlator `sfxc` was updated to support 4 Gbps e-VLBI and tests were performed. In order to support geodetic and/or astrometric VLBI code was developed to append the model that was applied during correlation to the FITS-IDI files in the EVN archive.

A debugging infrastructure was implemented allowing the user to dump the full state of the `sfxc` processes (slightly less than a thousand are started in parallel for a typical EVN correlation) in machine-readable form. This has proven extremely useful to track hard to find deadlocks or difficult-to-reproduce bugs: at least two of those were found and fixed.

Support for sub-microsecond resolution coherently de-dispersed full-stokes filter bank output. These very high time-resolution data can give important constraints on the emission mechanism of Fast Radio Bursts (FRBs). The mode was used to probe the micro-second polarization structure of repeating FRB 20180916B.



Dynamic spectrum of FRB 20180916B at 0.25 μs time resolution.

3.4 USER SOFTWARE

3.4.1 CASA

The CASA fringe fitter task was refactored to allow runtime choice of regular or wide-band fringe fitting. The wide-band mode is being commissioned using EHT data whilst the dispersive fringe fitter was integrated in CASA release 5.7/6.1 and is underway to be demonstrated as production tool for LOFAR long baseline observations. High memory usage of the fringe fitter for certain data sets reported by users was investigated and a significantly reduced memory footprint version of the code is under test.

Full gain curve support is now available in CASA. Gain curves, when detected in FITS-IDI files, are imported into MeasurementSet (MS) format calibration tables (as non-standard but documented extension) and upon a MS split the appropriate gain curve data will be exported with it. The gain curves no longer need to be resampled.

Several bugs related to importing FITS-IDI data were fixed and the tools that add amplitude calibration meta-data to the FITS-IDI files were improved.

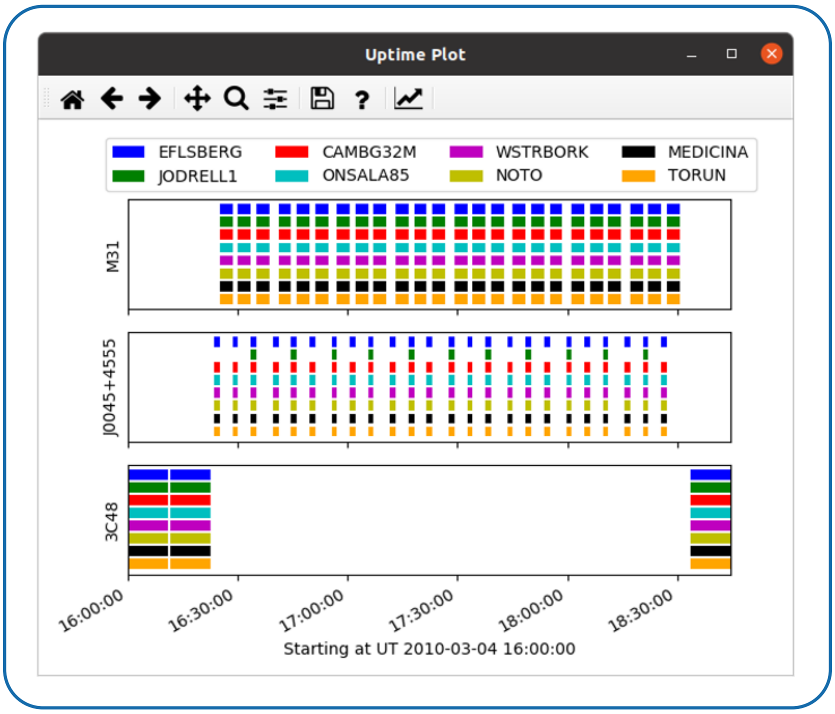
3.4.2 pySCHED

A runtime reduction of 30-50% was achieved by performing a code optimization pass where the amount of times the python to FORTRAN (and vice versa) memory writes were necessary was significantly reduced.

A version check at startup was added, allowing users to be informed that a new(er) version of the software is available for download/installation.

In order to ease keeping the pySCHED catalogue up-to-date with the latest EVN setups (contained in so-called `setini` files), a script was written to translate and normalize the `setinis` into new frequency catalogue entries.

Several user reports (bugs, feature requests) have to do with the matplotlib backend. Some plots required including extra information to provide more usability (see below). Another recurring issue is that the matplotlib Application Programming Interface is reasonably in flux, necessitating regular maintenance to keep the pySCHED plotting code in synchronisation with the matplotlib library.



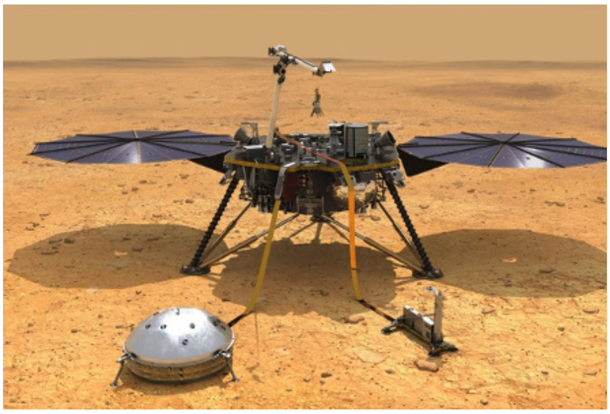
Improved usability of the Uptime plot: the legend was moved, more area is used for the actual plot and the title was clarified with "Starting at ...", which helps for observations crossing 00:00UT.

04 SPACE AND PLANETARY SCIENCE

VLBI developments with a space science "flavour" have been on the EVN and JIVE agenda for several decades. In the reporting year of 2020 their focus was on two themes: advancement of the near-field VLBI technique in the interests of planetary science and preparation for the next generation Space VLBI missions as a logical continuation of VLBI experiments in space and mm-wavelength VLBI on the ground.

4.1 FOCUS ON MARS WITH THOUGHTS ON JUPITER

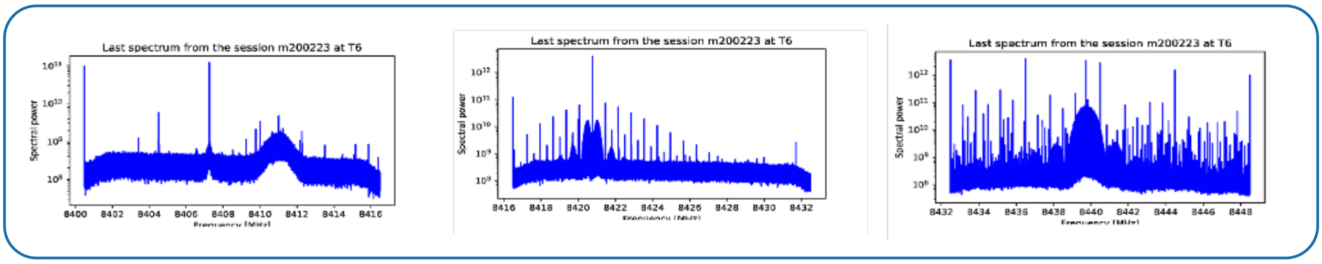
The countdown for the launch of the ESA's Jupiter Icy moons Explorer (JUICE) has almost started. The mission is scheduled to launch in the third quarter of 2022 and arrive in the Jovian system in the end of the decade. JIVE and partner organisations continue to prepare for the participation in this mission with PRIDE (Planetary Radio Interferometry and Doppler Experiment), one of eleven science experiments of JUICE. Meanwhile, another planetary mission, ExoMars, a joint project of ESA and the Russian space corporation Roscosmos is inching for the launch in the middle of 2022. One of the ExoMars experiments, LaRa, which aims to study the Mars interior, will benefit from an addition of PRIDE observations to its nominal measuring campaign (Dehant et al. 2020, Planetary and Space Sci. 180, 104776). In order to test PRIDE as a support to LaRa, an international collaboration led by D. Dirkx (Delft University of Technology, The Netherlands), including co-investigators from the leading LaRa organisation, the Royal Observatory of Belgium, and JIVE, conducted a series of observations as the EVN project ED045. Its target was the NASA lander InSight on the surface of Mars. The ED045 project comprise multi-epoch observations of the InSight lander signal in VLBI and Doppler modes at 8.4 GHz.



NASA Insight lander. Picture credit: NASA/JPL–Caltech.

The high spatial precision and multi-station Doppler data provided by PRIDE can reduce the estimated uncertainty of the Mars orientation parameters, which are strongly linked to the Martian interior. InSight is equipped with a radio transponder operating at the downlink X-band channel that coherently retransmits an uplink signal from a NASA Deep Space Network ground station, providing Doppler data with the precision of several tens of μm/s. These data are ideal for determining small variations in the Mars' rotation, from which properties of the Martian interior can be deduced.

The ED045 experiment serves as a fine-tuning exercise in preparation to more intense observations of the ExoMars mission and later – JUICE. The images below provide an example of spectra obtained in one of the ED045 observing runs. As Mars and its immediate vicinity is now densely populated by various operating spacecraft, one can see detections of five simultaneously emitting transmitters. The analysis of the ED045 results is ongoing.



The signal of several spacecraft is clearly visible in three channels of a single observation of 20 minutes with the Tianma 65-m radio telescope (China).

4.2 TOWARD SPACEBORNE SUB-MILLIMETER VLBI

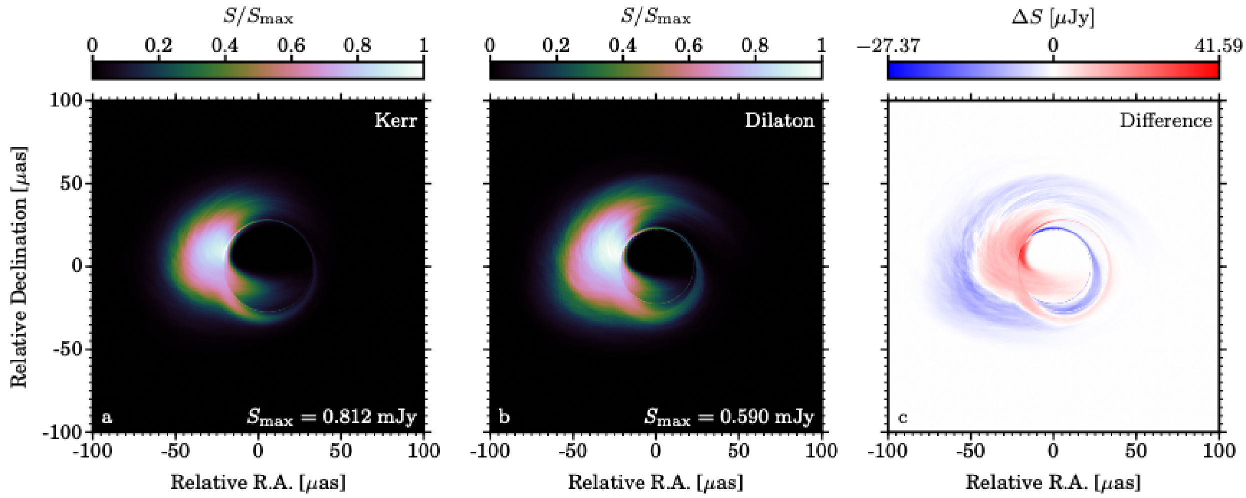
The case for future high-resolution radio interferometry in Space got a new boost in 2020. A conference entitled "Space VLBI 2020: Science and Technology Futures" was held in Charlottesville, VA, USA, 28–30 January 2020 (Lazio et al. 2020, arXiv:2005.12767). It was the second conference in the series that had started in Noordwijk, The Netherlands, in September 2018. The Charlottesville conference brought together about researchers from around the world for a brainstorming on the ways to create an interferometric system able to advance the results obtained by the EHT collaboration in imaging of the immediate vicinity of the SMBH in the nucleus of the radio galaxy M87.

An advanced interferometric system able to meet the scientific challenge of advancing the EHT results must operate at sub-millimeter wavelengths, and must be spaceborne. Several initiatives around the world address this task. In Europe, a collaboration

Participants of the conference "Space VLBI 2020: Science and Technology Futures", Charlottesville, VA, USA, 29 January 2020.

co-led by L. Gurvits and Z. Paragi (both JIVE staff) and involving representatives of many EVN and other institutes work on a mission concept entitled TeraHertz Exploration and Zooming in for Astrophysics (THEZA). A White Paper describing this concept is under consideration by ESA as input into its strategic call for future space science programmes Voyage 2050 (Gurvits et al. 2021, Experimental Astronomy, in press). As demonstrated in this White Paper, the concept would provide means of investigating astrophysical phenomena which are beyond reach by any other techniques. For example, this is the case for direct investigation of accretion onto a Kerr black hole.

The coming years will see activation of a number of science case investigations and pre-design studies aiming to develop a space-borne facility for transformational science in the domain of high-resolution sub-millimeter radio astronomy.



Left: simulated image at 230 GHz from a GRMHD simulation of accretion onto a Kerr black hole. Middle: the same for a non-rotating dilaton black hole. Right: the difference between the two images.
Further details in Gurvits et al. 2021, Experimental Astronomy, in press; the original figure from Mizuno et al., 2018, Nature Astronomy 2, 585-590.

05 COMMUNICATION AND TRAINING

5.1 COMMUNICATION AND OUTREACH

JIVE coordinates and hosts several initiatives to visualize the results of the European VLBI Network. Within the scope of H2020 JUMPING JIVE (WP2), dedicated to outreach and advocacy for JIVE and the EVN, the focus has been on attracting new users and increasing global visibility of the EVN and services of JIVE.

COVID-19 has caused many events to be postponed or even cancelled in 2020. Some of them have taken place online.

With the support of JUMPING JIVE, a Special Session at the European Astronomical Society (EAS) conference, which was online-only in 2020, was organized: "Registering the Universe at the highest angular resolution" (EAS SS16) was dedicated to advocate the use of VLBI, especially to non-experienced users, in a wide range of science topics. The session lasted one day, consisting of 3 blocks of 1.5 hours each. The attendance was satisfactory with about 100 participants connected remotely to listen to the talks and to discuss in the dedicated Slack channels. A proposal for a Special Session at the EAS in 2021 has been submitted and already approved. The session will focus on the synergies between the Event Horizon Telescope, high-energy and multi-messenger astronomy.

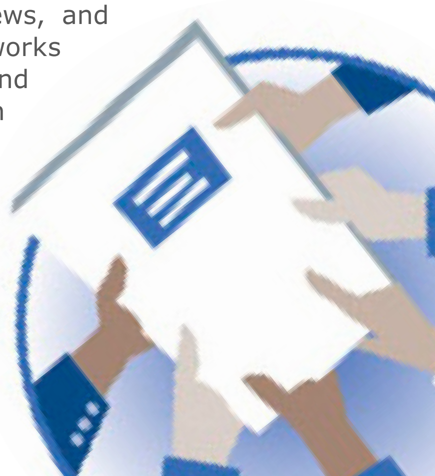
Unfortunately, the ASTRON/JIVE Summer Student program could not be organised in 2020.

Special highlights are the maintentance of the EVN website and the production and distribution of the EVN Newsletter quarterly in January, May and August).

In 2020, due to the cancellation of the EVN Symposium, a series of online seminars started under the title "The sharpest view of the Radio Universe. VLBI: Connecting astronomers

worldwide" ("7 speakers on 7 science topics every 7 weeks"), to bring together the VLBI community and highlight the results of the EVN and VLBI in general. The EVN e-seminars are recorded, and can be accessed in the JIVE/EVN YouTube channel, being watched already thousands of times. The success of the EVN e-seminars justify that the activity will continue on a regular basis.

Other activities, like the preparation of press releases and news, and activity in social networks (Twitter, Facebook and Linkedin have continued in 2020.



06 OPERATIONS

6.1 CORRELATION

The core of JIVE's service is the correlation of astronomers' observations conducted with the EVN and global VLBI arrays; the table below summarizes experiments that were correlated or distributed in 2020. 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	118	959.5	1121.5	22	60	60
Distributed	124	1041.5	1227.5	24	67	67
e-EVN experiments	24	191.5	191.5			
e-EVN ToOs	5	41.5	41.5			

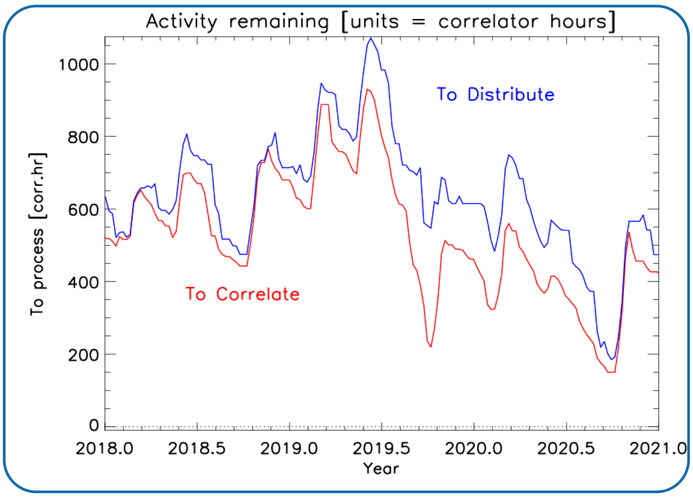
Summary of projects correlated or distributed in 2020. Here, "network hours" sum the total duration of experiments, and "correlator hours" are the network hours multiplied by any multiple correlation passes required -- the actual time to correlate can be several times larger for the more complex correlations.

COVID-19 restrictions left footprints in all aspects of correlator operations in 2020. Large-scale working from home began on 16 March. During the first three months, access to the building remained possible for specifically defined tasks as approved on a case-by-case basis. Operators performed correlation remotely, with authorization for an operator to be on-site arranged for the days of real-time e-EVN observations and for handling disk-packs (receiving incoming packs, preparing shipments of outgoing packs, and mounting as many packs from a session as possible into playback units at once to maximize options for switching among observations when correlating remotely). When restrictions were relaxed starting from June, one operator was in Dwingeloo 2-3 days per week, providing a more normal regime for logistics and routine maintenance. In October, COVID-19 measures were tightened up again, but this quasi-regular operator presence continued. Since March, support scientists have worked entirely remotely.

Resiliency has naturally suffered somewhat in this environment. Nonetheless, the number of correlator hours completed in 2020 was the second highest since shifting to SFXC starting in 2011. The number of correlator hours in the queue to correlate was 7.6% lower at the end of 2020 than it was at the beginning. As can be seen in the figure on the top of the next page.

In the two figures on the next page side by side, the figure on the left traces the evolution of the annual EVN network hours. This fell somewhat in 2020, reflecting the choice of some PIs to defer their experiments from the May/June session because of reduced array composition, given that COVID-19 restrictions at some stations precluded their participation (Medicina, Noto, Sardinia, and Torún missed the entire session; Tianma, Yebes, and the e-MERLIN out-stations missed various portions of it). The figure on the right focuses on e-EVN experiments, showing the break-down into individual proposal categories.

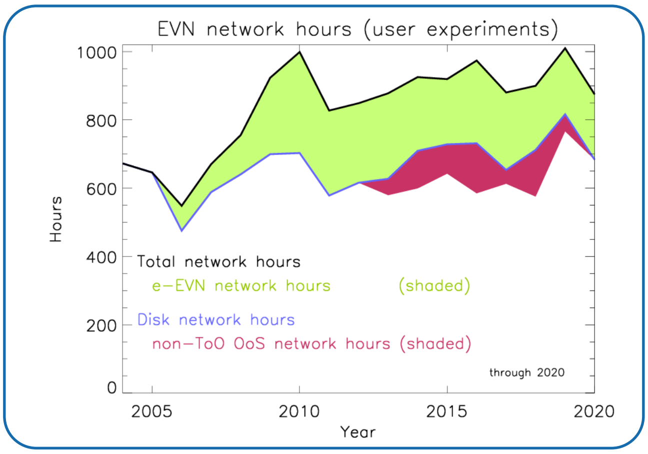
The size of the correlator queue at different stages in the processing cycle. The red line shows the number of correlator hours that remain to be correlated. The blue line shows the number of correlator hours in experiments whose data remain to be distributed to the PI.



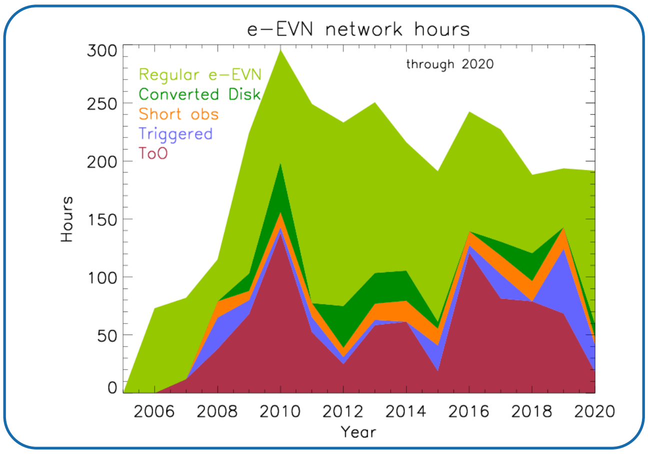
A sampling of highlights from 2020:

• GA043 was the first SiO spectral-line observation at 43 GHz to be correlated at JIVE.

• ER047 is a long project, broken up into six 12-hour epochs, investigating the contributions of AGN and star formation across a large redshift range via the faint (~few μJy) population of radio sources in the COSMOS two square-degree field. This holds the current record for the most phase centers output in a single correlation at 761. Through the first four epochs, each 12-hr observation has required 102-137 hours to correlate, depending on the number of successfully participating stations. The first two epochs were distributed in 2020, together amounting to 19.5 TB (subsequent epochs with a larger number of stations could reach around 14 TB per epoch).



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).



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.

• There were seven EVN target of opportunity observations (two via e-EVN) and three e-EVN trigger observations, arising from eight proposals. Scientific topics covered fast-radio bursts (FRBs), blazars from which neutrinos were detected by IceCube, monitoring a short gamma-ray burst, maser outbursts in young massive stars, a new type Ia supernova, and an extra-galactic transient.

• The first FRB-burst trigger from the on-going correlation-only project based on observations shadowing CHIME occurred in April.

• The team of ET036, a 72-hr project seeking redshift dependence in the scaling of observed VLBI delays, became the first external users to receive correlated data from SFXC exported in mark4 format. This capability was developed under JUMPING JIVE/WP6 and validated via the K-band EVN geodesy project EC065 led by WP6 members.

• Three 18cm RadioAstron user experiments have been correlated and distributed. Fringes to RadioAstron from the more sensitive ground stations were seen in most scans, with weakening detections as the (non-projected) baseline-length increased -- similar to the behavior seen in the previous 18cm observation with fringes. These experiments brought in Australian and Japanese ground stations. Another 18 cm observation was prepared and clock-searched, but with no fringes to RadioAstron seen in any scan.

6.2 EVN SUPPORT

4 Gbps modes were tested in various network monitoring experiments (NMEs) within 2020, in order to check empirically the front-end/IF ranges and the tunability of the LOs at the DBBC stations in terms of providing a common 512 MHz frequency range. Wavelength bands tested were 6 cm, 5 cm, and 1.3 cm. All used 32 channels of 32 MHz, except for 5 cm where Effelsberg had a limit of 16 channels in their current DBBC configuration. So that used instead 64 MHz filters, whose pass-band shapes are not as rectangular as are other filter-widths in the current DBBC firmware.

By the end of 2020, only the three QUASAR antennas, Urumqi, and Robledo provided data on Mark5 packs; the rest e-ship to FlexBuffs at JIVE, either via the automatic-retrieval process or manually via off-line arrangements. NRAO stations continue to send their data on Mark6 packs, which are promptly copied onto local FlexBuffs in order to be able to recycle the packs back to them in time to meet their logistical requirements.

Prior to the February/March session, JIVE arranged and conducted a couple fringe-test observations for Arecibo in their two-RDBE back-end configuration. During observations within the session itself, there were large delay offsets (>200 microsec) between channels containing the two different polarizations. The user experiment with Arecibo (ER047D) was correlated with a special version of SFXC having compensation for this delay difference built in. Arecibo had repaired this condition by the May/June session.

JIVE also arranged and conducted fringe-test observations for investigating the stability of the Westerbork maser prior to the October/November session. The 6cm network monitoring experiment in this session saw the first attempt to get fringes to the 32m telescope at Zolochiv, Ukraine, observing two dual-pol 8 MHz subbands within the larger 2 Gbps NME. Problems recording data at the station precluded seeing fringes here. Initial discussions with JPL began about how JIVE can assist in validating aspects of the new DSN digital backend currently under development.

6.3 USER SUPPORT

JIVE provides support in all stages of a user's EVN observation, from proposal definition to data analysis. There were eight first-time PIs in 2020 observations, including two students. A list of visitors to JIVE, prior to the COVID-19 lockdown can be found in section 8.4.

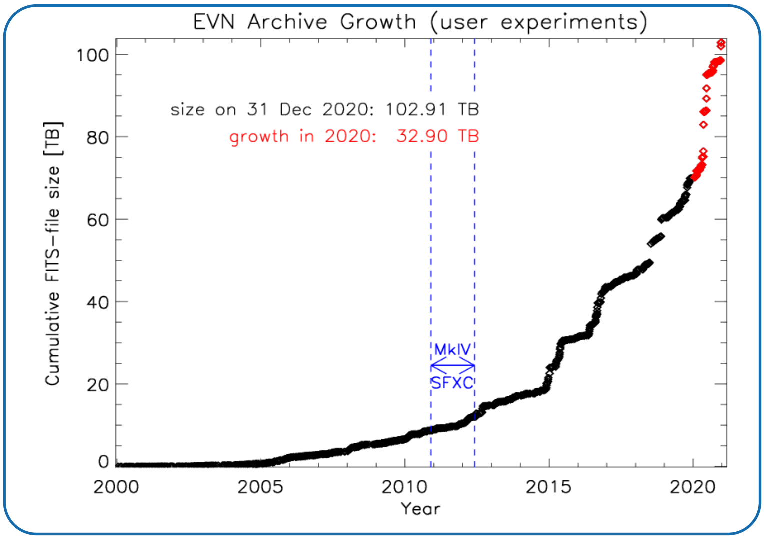
Due to the travel restrictions worldwide in most of 2020, there were not many data reduction visits at JIVE in this period. In cases when inexperienced users require, we provide support through Zoom and other remote collaboration tools. Sharing screens is an excellent way to monitor their progress, explain certain steps in detail, and easily spot errors. As from October the "usersupport@jive.eu" address is operational; to facilitate the communication between support scientists and the users in a transparent way for everybody. The R&D and the support groups join efforts in developing software that aid production correlation, and user support.

Data calibration issues reported by users to JIVE are usually related to amplitude calibration, and phase-reference imaging. The former was addressed earlier in 2020 by implementing strict rules in spotting formal errors in ANTAB tables. The issue of poor initial gain values will have to be addressed at both the stations and at JIVE. The experience is that some PIs (especially the young ones with less experience) cannot always deal with poor stations gains on their own, therefore support scientists will keep monitor this issue, along with phase-referencing performance.

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

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 passed the 100 TB mark by the end of 2020, increasing by 47% during the year.

The EVN Programme Committee will authorize, upon request, a three-month extension to the one-year proprietary period for PIs who encountered delays in being able to process their data because of COVID-19 restrictions in their countries. JIVE contacted PIs who had already received their one-month warning and whose proprietary period overlapped with such restrictions (different time-ranges for China and Europe), and added new text to this effect to the template of the one-month warnings that JIVE sends out. This policy has remained in effect throughout 2020.



Growth of user experiments in the EVN Archive. Experiments archived in 2020 are plotted in red. Vertical dashed lines show the transition period between the MkIV and SFXC correlators.

07 FINANCES

7.1 JIVE FINANCIAL REPORT 2020

Balance [after allocation of results]

ASSETS	2020 in €	2019 in €
Tangible fixed Assets		
Tangible fixed Assets	53,912	104,766
Total of Tangible fixed Assets	53,912	104,766
Current Assets		
Work in process	0	0
Receivables	1,073,694	918,250
Cash at bank	2,014,973	2,528,662
Total of Current Assets	3,088,667	3,446,912
Total Assets	**3,142,579**	**3,551,678**

LIABILITIES	In €	In €
Capital		
General reserve	1,952,533	1,796,620
Designated funds	82,932	142,367
Total capital	2,035,465	1,938,987
Other Liabilities		
Short term debts	1,107,114	1,612,691
Total Other Liabilities	1,107,114	1,612,691
Total Liabilities	**3,142,579**	**3,551,678**

Statement of profit and loss

	2020 BUDGET	2020 ACTUAL	2020 DIFFERENCE	2019 ACTUAL
REVENUES	**in €**	**in €**	**in €**	**in €**
Income				
Contributions/subsidies third parties	2,507,274	2,364,580	-5,545	2,771,263
Interest	0	0	0	0
Other	113,560	256,893	86,894	154,574
Total Income	2,620,834	2,621,473	81,349	2,925,837
Total Revenues	**2,620,834**	**2,621,473**	**81,349**	**2,925,837**
EXPENDITURES	**in €**	**in €**	**in €**	**in €**
Operations				
Grants/Expenditures	2,626,248	2,524,995	-101,253	2,556,978
Total Operations	2,626,248	2,524,995	-101,253	2,556,978
Total Expenditures	**2,626,248**	**2,524,995**	**-101,253**	**2,556,978**
RESULT	**-5,414**	**96,478**	**182,602**	**368,859**

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.
JUMPING JIVE (EC)	01.12.16 - 31.07.21	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.
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.
ERIC Forum	01.01.19 - 31.12.22	ERIC Forum brings together all established and upcoming ERICs.
ESCAPE (EC)	01.02.19 - 31.01.23	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

Member Representatives

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

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

Dr. Aleksejs Klokovs – Ventspils University of Applied Sciences, Latvia

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

Prof. Carole Jackson – ASTRON, the Netherlands

Dr. Marco de Vos - ASTRON, the Netherlands

Mrs. Saskia Matheussen – NWO, the Netherlands

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

Mrs. Monica Groba Lopéz – Instituto Geográfico Nacional, Spain

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

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

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

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

Associated Research Institutes Representatives

Dr. Fernando Camilo – NRF, SARAO, South Africa

Prof. Zhinqiang Shen – NAOC, SHAO, China

Dr. Tiziana Venturi – INAF-IRA, Italy

Prof. Anton Zensus – MPIfR, Germany

8.2 JIVE PERSONNEL

Dr. Olga Bayandina	Support Scientist
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
Prof. Leonid Gurvits*	Head of Space Science & Innovative Applications Group
Mr. Bert Harms	Chief Operator
Dr. Katharina Immer	Support Scientist (until 1 September 2020)
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
Dr. Benito Marcote Martin	Support Scientist
Dr. Dhanya G. Nair	Support Scientist
Dr. Zsolt Paragi*	Head of User Support
Dr. Des Small	Scientific Software Engineer
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*	Head Technical Operations and R&D (since 21 May 2020)

* - JIVE MT member

8.3 EDUCATIONAL RESPONSIBILITIES

MSc project supervision

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

PhD project supervision

Luis Henry Quiroga-Nuñez – by H.J. van Langevelde, Leiden University (thesis sucessfully defended on 12 March 2020)

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

Kenzie Nimmo - by Z. Paragi and B. Marcote, UvA (main supervisor J.Hessels) (start in 2020)

Lecturing

Praktische Sterrenkunde (1st year Bachelor course), Leiden University, by H.J. van Langevelde (spring 2020)

Secondary affiliations:

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 (through May 2020)

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

8.4 VISITORS TO JIVE

Name	Institute	Period	Host
R. Burns	National Observatory of Japan in Tokyo, Japan	9-10 January	Campbell
K. Nimmo	Amsterdam University, the Netherlands	20-24 January	Marcote
H. Kobayashi	National Observatory of Japan in Tokyo, Japan	17-21 February	Colomer
Y. Kono	National Observatory of Japan in Tokyo, Japan	17-21 February	Colomer
T. Oyama	National Observatory of Japan in Tokyo, Japan	17-21 February	Colomer
J. Kallunki	Aalto University, Finland	19-20 February	Madkour
A. Aberfelds	VIRAC, Latvia	23-29 February	Immer
L. Frans	University of Namibia, Namibia	29 February - 6 March	Colomer

8.5 CORRELATOR ACTIVITY

User experiments with correlation, distribution, or release activity in 2020.

Project code	Observation Date/ Session	Principal Investigator	User Experiments
EA063	s.3/19	Aberfelds	Imaging variable sources from Irbene monitoring program
EB064G-H	s.2/20	Bach	Does Cygnus A harbor a binary black hole?
EB070	s.1/19	Boven	Radio Flare Star Ross 867
EB074A-B	s.3/19	Bruni	Zooming into the cores of restarted giant radio galaxies
EB079	s.3/20	Bartkiewicz	Gas properties around HMYSOs II: Methanol and excited OH masers at a mas scale
EB080	s.2/20	Aramowicz	Methanol masers in W49N
EB081A	s.2/20	Boven	Astrometry Ross 867
EC070A-D	s.3/19	Chiaraluce	Resolving the radio cores of high luminosity AGN
EC070E-L	s.1/20	Chiaraluce	Resolving the radio cores of high luminosity AGN
EC070M-N	s.3/20	Chiaraluce	Resolving the radio cores of high luminosity AGN
EC071A-B	s.3/19	Casadio	Search for 10^6 to 10^{10} solar masses gravitational lenses
EC071C-E	s.1/20	Casadio	Search for 10^6 to 10^{10} solar masses gravitational lenses
EC071F,H	s.3/20	Casadio	Search for 10^6 to 10^{10} solar masses gravitational lenses
EC075	s.3/20	Chen	Imaging the most distant radio QSO J0903+5012
ED045B	s.1/20	Dirxx	Observations of Mars landers - Enhancing knowledge of Martian interior
ED045D	s.2/20	Dirxx	Observations of Mars landers - Enhancing knowledge of Martian interior
ED045F	s.3/20	Dirxx	Observations of Mars landers - Enhancing knowledge of Martian interior
ED046A-C	s.2/20	Durjasz	Multi-frequency maser observations in a bursting high-mass protostar
ED048A-B	s.3/20	Durjasz	Observations of bursting methanol maser sources
EG097A	Jan.16	Gurvits	Space VLBI visit into core-jet labs in the distant Universe
EG097B	Feb.16	Gurvits	Space VLBI visit into core-jet labs in the distant Universe
EG097C	Feb.16	Gurvits	Space VLBI visit into core-jet labs in the distant Universe
EG102J	Jun.20	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample
EG102K	Oct.20	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample
EG102L	Nov.20	Gabanyi	Towards solving the puzzle of high-z radio sources: extending the VLBI sample
EG108	Dec.20	Giroletti	Are gamma-ray blazars associated with IceCube neutrinos?
EG109A-B	s.1/20	Gabanyi	A dual AGN candidate with 0.13 arcsec separation
EK043A	Mar.20	Kirsten	Correlation of an ad-hoc VLBI array shadowing CHIME FRBs

Project code	Observation Date/ Session	Principal Investigator	User Experiments
EK044	s.1/20	Kravchenko	Tracing structural changes and variability of a jet collimation profile in M87
EK045A-C	s.3/19	D-J.Kim	Spectral line VLBI study of circum-nuclear gas in obscured AGN
EK046A-D	s.3/19	Kovalev	Resolving the mystery of large VLBI-Gaia offsets
EK046E-H	s.1/20	Kovalev	Resolving the mystery of large VLBI-Gaia offsets
EK047	s.3/19	Kutkin	Probing the new extreme intrahour variable with VLBI
EM117O-P	s.1/20	Moscadelli	A 3-D View of high-mass star formation: gas Kinematics and Magnetic Fields
EM131D-F	s.3/19	Marcote	Unveiling the existence of wind collision regions on massive binary stars
EM140A	s.3/19	Mohan	EVN monitoring observations of transient AT2019dsg
EM140B	s.1/20	Mohan	EVN monitoring observations of transient AT2019dsg
EM141A-B	s.1/20	Mezcua	A Candidate Intermediate Mass Black Hole in an Extremely Metal PoorDwarf Galaxy
EM143A	s.1/20	Mus	Proper motions and the quest for the thirds image in PKS1830
EN004	s.3/19	Njeri	Exploring the resolving microJy radio source population with EVN+e-MERLIN
EN005B	Jan.20	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EN005C	Mar.20	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EN005D	Apr.20	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EN005E	May.20	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EN005F	Jun.20	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EN005G	Oct.20	Nimmo	A repeating FRB survey: precise localization and radio counterparts
EN006A-B	s.1/20	Nimmo	Observations of a possible extragalactic pulsar wind nebula
EN006C-D	s.2/20	Nimmo	Observations of a possible extragalactic pulsar wind nebula
EO016B	s./319	Olech	Relative motions and structure evolution in periodic 6.7GHz methanol masers
EO016C	s./120	Olech	Relative motions and structure evolution in periodic 6.7GHz methanol masers
EP117A	Apr.20	Purkayastha	A multi-scale analysis of kpc outflows in Seyfert Galaxies
EP117B	Jun.20	Purkayastha	A multi-scale analysis of kpc outflows in Seyfert Galaxies
EP118B	Feb.20	Perez-Torres	Understanding the nature of extragalactic nuclear transients
EP119	s.1/20	Perez-Torres	Testing the jet-outflow connection in the nearby radio-quiet AGN HE0040-1105
EP120	s.2/20	Perez-Torres	Unveiling the progenitor scenarios of Type Ia supernovae
ER047A	s.1/19	Radcliffe	EVN-COSMOS - Taming AGN star-formation across cosmic time
ER047B	s.2/19	Radcliffe	EVN-COSMOS - Taming AGN star-formation across cosmic time
ER047C	s.3/19	Radcliffe	EVN-COSMOS - Taming AGN star-formation across cosmic time
ER047D	s./120	Radcliffe	EVN-COSMOS - Taming AGN star-formation across cosmic time

Project code	Observation Date/ Session	Principal Investigator	User Experiments
ER051	s.3/19	Riseley	Resolving the core/jet structure of the Giant Radio Galaxy ESO422-G028
ES074D	s.3/20	Surcis	Monitoring of the magnetic field and of the outflows expansion in W75N-VLA2
ES091A-B	s./120	X.Shu	Milliarcsecond structure of transient radio emission from mid-IR burst galaxies
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
EV022	s.2/20	Vaddi	Investigating twin-jet evolution in Dual AGNs
EX009	sep.20	Xu	Validate Gaia Stellar Reference Frame via VLBI Astrometry of Radio Stars
EY027B	Jan.20	Yang	Imaging the pc-scale radio structure of Eddington accreting source PDS 456
EY029B	Mar.20	Yang	Is there violent jet activity at the early stage of black hole growth?
EY037	Nov.20	Wang	Nature of the nuclear radio source in I Zwicky 1
GA043A-B	s.1/20	Alcolea	Observations of two AGB binary systems: R Aqr and Mira
GS044A-B	s.3/19	Spingola	Confirming the first detection of a merging dual SMBH system at high-z
RD001	s.1/20	Durjasz	Mapping of 6.7 GHz maser in accretion burst HMYSO: Observations of very early phase of burst
RD002	s.2/20	Durjasz	Mapping of reappeared 6.7 GHz maser emission in HYMSO
RG011	s.1/20	Giroletti	Are gamma-ray blazars associated with IceCube ŒΩ‚Äôs? The case of IC 200109A
RM016A	s.3/20	Marcote	GRB 201015A: an extreme short gamma-ray burst with a luminous radio afterglow?
RM016B	Dec.20	Marcote	GRB 201015A: an extreme short gamma-ray burst with a luminous radio afterglow?
RN001A	May.20	Nimmo	A Potential Galactic FRB Source
RN001B	s.2/20	Nimmo	A Potential Galactic FRB Source
RSB02A-B	s.3/19	Bruni	Multi-epoch observations of the giant radio galaxy¬†PBC J2333.9-2343
RSC06	Jan.20	Cao	Compactness of the high-redshift quasar J1156+4443
RSC07	s.3/20	Cao	A newly reported radio-weak BL Lac candidate J0435+5522
RSG12	s.3/19	Garrett	Potential calibrators in the Kepler field
RSG15	Jan.20	Gawronski	Gaia alert source Gaia19ceq
RSP14	Jan.20	Perez-Torres	Short observations on ASASSN-18jd

8.6 JIVE STAFF PUBLICATIONS

Journal Articles

O. S. Bayandina, P. Colom, S. E. Kurtz, et al: Probing GLIMPSE Extended Green Objects (EGOs) with hydroxyl masers, 2020, Monthly Notices of the Royal Astronomical Society, 499, 3961

M. Blanc, O. Prieto-Ballesteros, N. André, et al (inlcuding **L.I. Gurvits**) : Joint Europa Mission (JEM): a multi-scale study of Europa to characterize its habitability and search for extant life, 2020, Planetary and Space Science, 193, 104960

Y. Han, P. G. Tuthill, R. M. Lau, et al (including **B. Marcote**): The extreme colliding-wind system Apep: resolved imagery of the central binary and dust plume in the infrared, 2020, Monthly Notices of the Royal Astronomical Society, 498, 5604

L.H. Quiroga-Nuñez, **H.J. van Langevelde**, L. O. Sjouwerman, et al.: Characterizing the Evolved Stellar Population in the Galactic Foreground. I. Bolometric Magnitudes, Spatial Distribution and Period-Luminosity Relations, 2020, The Astrophysical Journal, 904, 82

D. A. Ladeyschikov, J. S. Urquhart, A. M. Sobolev, S. L. Breen, **O. S. Bayandina**: The Physical Parameters of Clumps Associated with Class I Methanol Masers, 2020, The Astrophysical Journal, 160, 213

M. Galametz, A. Schruba, C. De Breuck et al. (including **K. Immer**): Dense Gas Survey in the Magellanic Clouds. I. An APEX survey of HCO⁺ and HCN(2-1) toward the LMC and SMC, 2020, Astronomy and Astrophysics, 643, A63

D. Psaltis, L. Medeiros, P. Christian et al. (including **M. Kettenis, D. Small, I. van Bemmel, H.J. van Langevelde**): Gravitational Test beyond the First Post-Newtonian Order with the Shadow of the M87 Black Hole, 2020, Physical Review Letters, 125, 141104

P. Scholz, A. Cook, M. Cruces, et al. (including **B. Marcote**): Simultaneous X-Ray and Radio Observations of the Repeating Fast Radio Burst FRB ˜ 180916.J0158+65, 2020, The Astrophysical Journal, 901, 165

M. Wielgus, K. Akiyama, L. Blackburn et al. (including **M. Kettenis, D. Small, I. van Bemmel, H.J. van Langevelde**): Monitoring the Morphology of M87* in 2009-2017 with the Event Horizon Telescope, 2020, The Astrophysical Journal, 901, 67

A. Rodríguez-Kamenetzky, C. Carrasco-González, J. M. Torrelles, et al. (including **H. J. van Langevelde**): Characterizing the radio continuum nature of sources in the massive star-forming region W75N (B), 2020, Monthly Notices of the Royal Astronomical Society, 496, 3128

J-Y. Kim, T.P. Kirchbaum, A.E. Broderick et al. (including **M. Kettenis, D. Small, I. van Bemmel, H.J. van Langevelde**): Event Horizon Telescope imaging of the archetypal blazar 3C 279 at an extreme 20 microarcsecond resolution, 2020, Astronomy and Astrophysics, 640, A69

I. Natarajan, R. Deane, **I. van Bemmel**, et al. (including **H. J. van Langevelde, D. Small, M. Kettenis, Z. Paragi, A. Szomoru**): A probabilistic approach to phase calibration - I. Effects of source structure on fringe-fitting, 2020, Monthly Notices of the Royal Astronomical Society, 496, 801

J. R. Callingham, P. A. Crowther, P. M. Williams, et al. (including **B. Marcote**): Two Wolf-Rayet stars at the heart of colliding-wind binary Apep, 2020, Monthly Notices of the Royal Astronomical Society, 495, 3323

R. Gold, A.E. Broderick, Z. Younsi et al. (including **M. Kettenis, D. Small, H.J. van Langevelde, I. van Bemmel**): Verification of Radiative Transfer Schemes for the EHT, 2020, The Astrophysical Journal, 897, 148

A.E. Broderick, R. Gold, M. Karami (including **M. Kettenis, D. Small, I. van Bemmel, H.J. van Langevelde**): THEMIS: A Parameter Estimation Framework for the Event Horizon Telescope, 2020, The Astrophysical Journal, 897, 139

B. Husemann, J. Heidt, A. De Rosa, et al. (including **Z. Paragi**): Revisiting dual AGN candidates with spatially resolved LBT spectroscopy. The impact of spillover light contamination, 2020, Astronomy and Astrophysics, 639, A117

M. Amiri, B. C. Andersen, K. M. Bandura, et al. (including **A. Keimpema, B. Marcote, Z. Paragi**): Periodic activity from a fast radio burst source, 2020, Nature, 582, 351

J. Yang, **L.I. Gurvits, Z. Paragi**, S. Frey, J.E. Conway, X. Liu, L. Cui: A parsec-scale radio jet launched by the central intermediate-mass black hole in the dwarf galaxy SDSS J090613.77+561015.2, 2020, Monthly Notices of the Royal Astronomical Society, 495, L71

J. Yang, **Z. Paragi**, T. An, W.A. Baan, P. Mohan, X. Liu: A two-sided but significantly beamed jet in the supercritical accretion quasar IRAS F11119+3257, 2020, Monthly Notices of the Royal Astronomical Society, 494, 1744

A. Bartkiewicz, A. Sanna, M. Szymczak, L. Moscadelli, **H. J. van Langevelde**, P. Wolak: The nature of the methanol maser ring G23.657-00.127. II. Expansion of the maser structure, 2020, Astronomy and Astrophysics, 637, A15

R. A. Fallows, B. Forte, I. Astin, et al. (including **I. M. van Bemmel**): A LOFAR observation of ionospheric scintillation from two simultaneous travelling ionospheric disturbances, 2020, Journal of Space Weather and Space Climate, 10, 10

P. Kharb, D. Lena, **Z. Paragi**, S. Subramanian, S. Vaddi, M. Das, R. Khatun: The Intriguing Parsec-scale Radio Structure in the "Offset AGN" KISSR 102, 2020, The Astrophysical Journal, 890, 40

V. Dehant, S. Le Maistre, R.-M. Baland, et al. (including **L.I. Gurvits**): The radioscience LaRa instrument onboard ExoMars 2020 to investigate the rotation and interior of mars, 2020, Planetary and Space Science, 180, 104776

B. Marcote, K. Nimmo, J. W. T. Hessels, et al. (including **Z. Paragi, A. Keimpema**): A repeating fast radio burst source localized to a nearby spiral galaxy, 2020, Nature, 577, 190

T. An, P. Mohan, Y. Zhang, et al. (including **L.I. Gurvits, Z. Paragi**): Evolving parsec-scale radio structure in the most distant blazar known, 2020, Nature Communications, 11, 143

R. A. Burns, G. Orosz, O. Bayandina, et al. (including **K. Immer, B. Marcote, H. J. van Langevelde**): VLBI observations of the G25.65+1.05 water maser superburst, 2020, Monthly Notices of the Royal Astronomical Society, 491, 4069

L.I. Gurvits: Space VLBI: from first ideas to operational missions, 2020, Advances in Space Research, 65, 868

M. J. Bentum, M. K. Verma, R. T. Rajan, et al. (including **L. I. Gurvits**): A roadmap towards a space-based radio telescope for ultra-low frequency radio astronomy, 2020, Advances in Space Research, 65, 856

N. V. Nunes, N. Bartel, M. F. Bietenholz, et al. (including **L.I. Gurvits**): The gravitational redshift monitored with RadioAstron from near Earth up to 350,000 km, 2020, Advances in Space Research, 65, 790

O. S. Bayandina, N. N. Shakhvorostova, A. V. Alakoz, R. A. Burns, S. E. Kurtz, I. E. Val'tts: RadioAstron reveals super-compact structures in the bursting H₂O maser source G25.65+1.05, 2020, Advances in Space Research, 65, 763

Y. Y. Kovalev, N. S. Kardashev, K. V. Sokolovsky, et al. (including **C. García-Miró, L. I. Gurvits**): Detection statistics of the RadioAstron AGN survey, 2020, Advances in Space Research, 65, 705

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09 ACRONYMS AND ABBREVIATIONS

AGN	Active Galactic Nuclei
AIPS	Astronomical Image Processing System
ALLEGRO	ALMA Regional Center node the Netherlands
ALMA	Atacama Large Millimeter/submillimetre Array
ASTRON	Netherlands Institute for Radio Astronomy
AO	Arecibo Observatory
CBD	Consortium Board of Directors
CARTA	Cube Analysis and Rendering Tool for Astronomy
CASA	Common Astronomy Software Applications
CHIME	Canadian Hydrogen Intensity Mapping Experiment
CNRS	Centre National de la Recherche Scientifique National Center for Scientific Research, France
COVID-19	COrona VIrus Disease 2019
CPU	Central Processing Unit
CRAF	Committee on Radio Astronomy Frequencies
DEC	Digital Equipment Corporation
DBBC	Digital Base Band Converter
EAVN	East Asia VLBI Network
EC	European Commission
Ef	Effelsberg station, Germany
e-EVN	electronic (realtime) European VLBI Network
EHT	Event Horizon Telescope
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
FITS	Flexible Image Transport System
FITS-IDI	Flexible Image Transport System - Interferometry Data Interchange
FRB	Fast Radio Burst
GAVO	German Astrophysical Virtual Observatory
Gb	Gigabit
Gbps	Gigabit per second

GDPR	General Data Protection Regulation
GHz	Gigahertz
GRB	Gamma Ray Burst
GRMHD	General-Relativistic Magnetohydrodynamic
H2020	Horizon 2020 EC Funding Program
Hh	Hartebeesthoek station, South Africa
IAU	International Astronomical Union
IF	Intermediate Frequency
IGN	Istituto Geográfico Nacional
	National Geographic Institute, Spain
INAF	Istituto Nazionale di Astrofisica
	Italian National Institute of Astrophysics
IRA	Istituo di Radio Astronomia
	Institute of Radio Astronomy, Italy
IRAS	Infrared Astronomical Satellite
ISM	Interstellar Medium
IVS	International VLBI Service for Geodesy and Astrometry
JIVE	Joint Institute for VLBI ERIC
JUICE	JUpiter ICy moons 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 Royal Astronomical Society
MoU	Memorandum of Understanding
MPIfR	Max Planck Institute for Radio Astronomy
MT	Management Team
NAOC	National Astronomical Observatories of China
NL	The Netherlands
NRAO	National Radio Astronomy Observatory
NREN	National Research and Education Network
NRF	National Research Foundation (South Africa)
NWO	Nederlandse Organisatie voor Wetenschappelijk Onderzoek
	Netherlands Organisation for Scientific Research
OSSR	Open Source Software Repository
OPTICON	Optical Infrared Coordination Network for Astronomy
ORP	OPTICON RadioNet Project
PDP	Programmed Data Processor
PI	Principal Investigator
PN	Planetary Nebula
PRIDE	Planetary Radio Interferometry and Doppler Experiment
pySCHED	python SCHEDuling software
R&D	Research and Development
RA	Right Ascension
RDBE	ROACH Digital Back End

rPICARD	Radboud PIpeline for the Calibration of high Angular Resolution Data
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
SYMBA	SYnthetic Measurement creator for long Baseline Arrays
TB	Terabyte
THEZA	TeraHerz Exploration and Zooming in for Astrophysics
ToO	Target of Opportunity
TOTMBD	Total Multi-Band Delay
UK	United Kingdom
USA	The United States of America
UTC	Coordinated Universal Time
VeA	Ventspils Augstskola
	Ventspils University College, Latvia
VGOS	VLBI Global Observing System
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
VPN	Virtual Private Network
VR	Vetenskapsrådet
	Swedish Research Council
WfH	Work from Home
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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