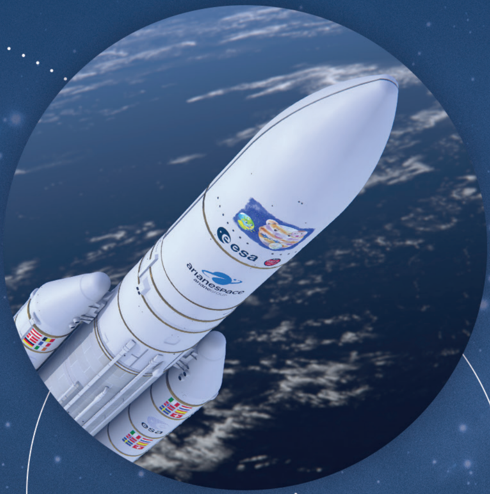
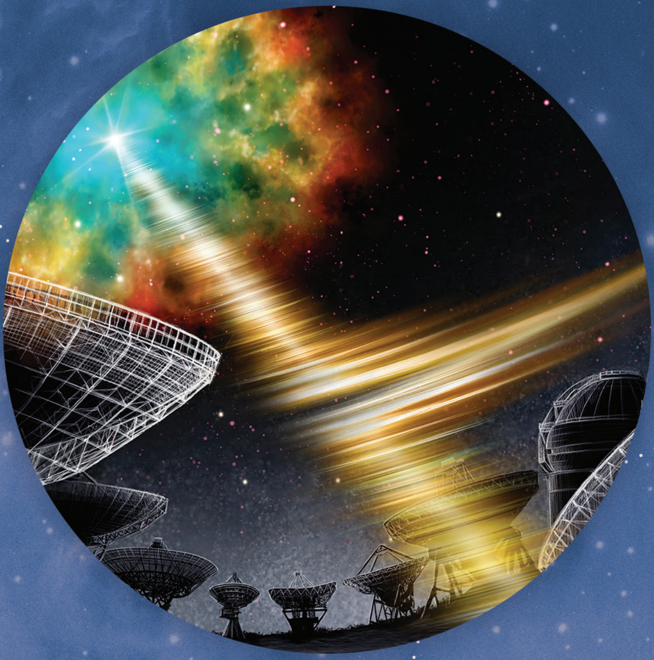
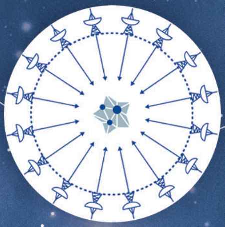
JIVE

Joint Institute for VLBI ERIC

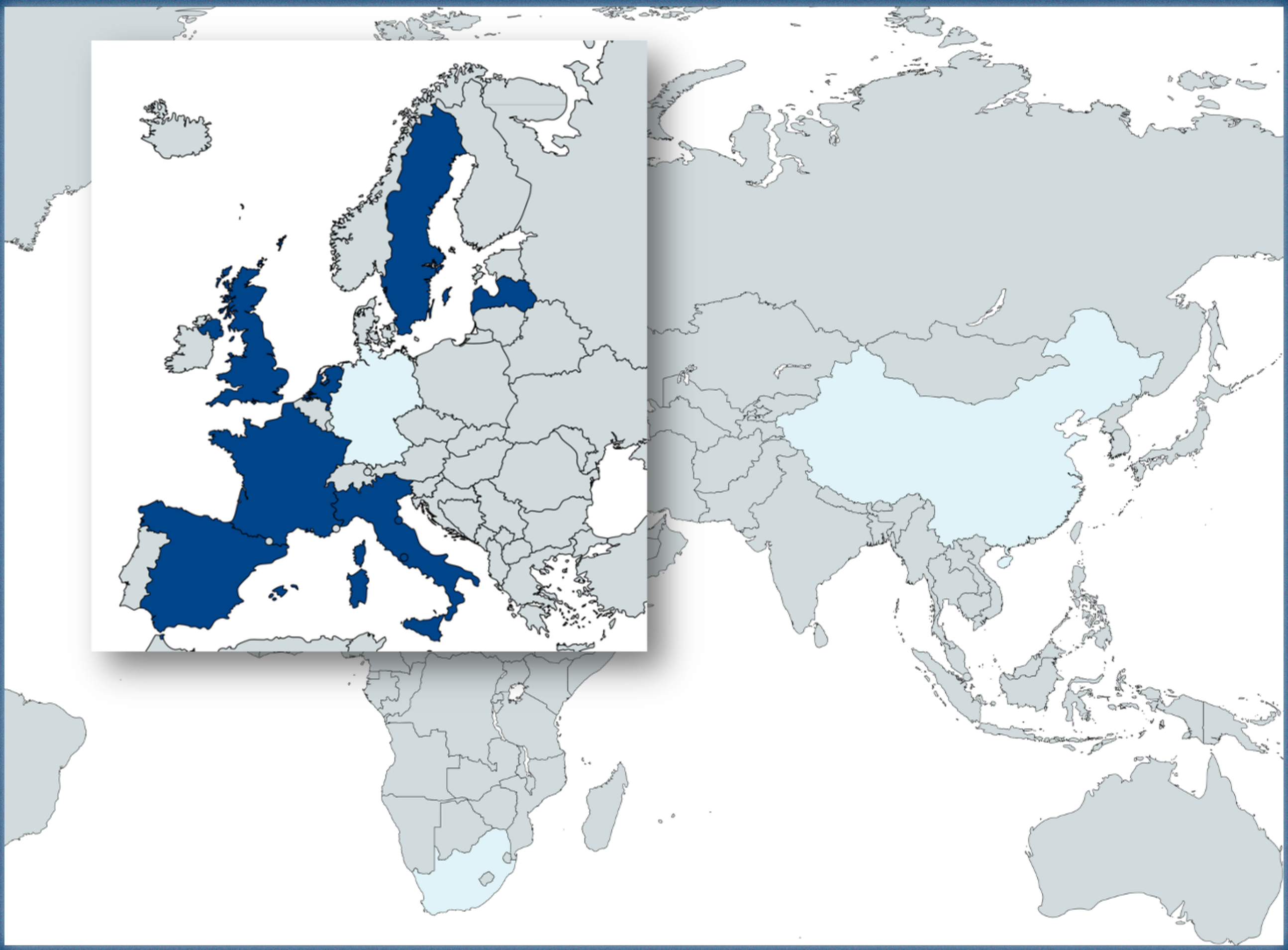






ANNUAL REPORT

2023



ANNUAL REPORT 2023

The Joint Institute for VLBI ERIC (JIVE) was established by a decision of the European Commission in December 2014. It 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 broadest sense.

In 2023, JIVE had seven members:

— The French Republic: National Centre for Scientific Research (CNRS)
— The Kingdom of the Netherlands: Dutch Research Council (NWO) and the Netherlands Institute for Radio Astronomy (ASTRON)
— The Kingdom of Sweden: Swedish Research Council (VR)
— The Republic of Latvia: Ministry of Education and Science of the Republic of Latvia
— The Kingdom of Spain: Spanish National Geographic Institute (IGN)
— The United Kingdom of Great Britain and Northern Ireland: Science and Technology Facilities Council (STFC)
— The Italian Republic: National Institute for Astrophysics (INAF)

JIVE was also supported by the following participating research institutes in 2023:

— China: National Astronomical Observatories of the Chinese Academy of Sciences (NAOC)
— South Africa: National Research Foundation (NRF)
— Germany: Max Planck Institute for Radio Astronomy (MPIfR)

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FOREWORD

2023 was a unique year with several important milestones. Dr. Agnieszka Słowikowska, who was appointed Director of JIVE at the end of 2022, took up her new position in early 2023 and addressed several matters of great importance, some of which had been initiated by her predecessor, Dr. Francisco (Paco) Colomer.

During the year, JIVE underwent a review by an independent external committee, which assessed its performance over the past five years and made a series of recommendations to improve the operation and functionality of the infrastructure. This review is part of a regular process that takes place every five years.

The committee, selected by the JIVE Council, received full documentation of JIVE's activities and visited JIVE on 6-7 September, where they had the opportunity to meet staff and some scientific users and learn first-hand about the Institute's activities and the scientific use of the data. The committee produced a report, which was presented by the Director of JIVE to the JIVE Council at its meeting in November 2023. In the report, the committee rated JIVE's activities from exceptional and outstanding in four areas to exceeding expectations in one area. It was highlighted that JIVE is one of the most advanced organisations in terms of R&D in radio astronomy, its performance during the last 5 years was excellent and it showed an impressive efficiency despite the pandemic and the budgetary limitations. In view of the future challenges lying ahead and the rise of the profile of VLBI in astronomy, the panel recommended that the JIVE Council consider expanding the core activities of the infrastructure, taking advantage of the excellence and experience of its staff and the results of its R&D activities. In particular, there was a specific recommendation to include developments for the SKA-VLBI as a new core activity of JIVE and to maintain research in space-based sciences.

The Council was very pleased with the conclusions of the report and acknowledged the efforts of the JIVE staff and its director, congratulating them on their excellence, talent, and accumulated knowledge. I, on behalf of the Council, also take this opportunity to acknowledge the role of Francisco Colomer as the former Director of JIVE.

Another important milestone reached in 2023 was the launch of Radioblocks. This 4-year, 10 M€ project funded by the European Commission to develop shared building blocks for technological solutions beyond the state-of-the-art. This project will enable a wide range of new science and strengthen European scientific competitiveness in radio astronomy. It is coordinated by JIVE, which plays a central role as a research infrastructure in the field of radio astronomy and has proven expertise in coordinating several EC-funded projects in recent years, such as the H2020 JUMPING JIVE. The project started on 1 March 2023, and the kick-off meeting of Radioblocks took place on 29 March in Leiden, bringing together members of the 33 partners, including research institutes and industry.

During this year, JIVE returned to its normal activities after the pandemic and face-to-face meetings, workshops, conferences and daily interactions in the office resumed, the correlator had one of the highest numbers of hours processed in recent years and a new communications officer, Ioanna Kazakou, joined the JIVE staff for Radioblocks, ORP and JIVE/EVN.

I would like to congratulate the staff of JIVE and its director for their excellent work and commitment, which is fundamental to supporting the EVN and producing high-quality science in radio astronomy as shown in this report.

Pablo de Vicente

JIVE Council Chairperson

Introduction

01

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, located hundreds to thousands of kilometers apart, simultaneously observe the same radio source in the sky. These telescope observations are recorded as digital signals, which are then combined at a central, dedicated data processor known as the correlator. Astronomers use the resulting data to produce extremely high-resolution images of the radio sky and measure the 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 central data processing for the EVN and supports most interactions with astronomers who use the facility. The EVN is an open-sky facility that accepts observation proposals from anyone.

JIVE receives data from the telescope stations via computer hard disk recordings, offline downloads, or direct streaming over fiber links (e-VLBI). The JIVE support team verifies data quality, interacts with staff at the telescopes, and provides support to end users through subsequent processing and analysis as requested. The final user product includes calibration data and images from a standard data pipeline.

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

JIVE staff members also conduct scientific research in several exciting areas, ranging from active galactic nuclei at cosmological distances to star evolution in the Galaxy. This research is essential for maintaining expertise and providing excellent service to EVN stations and users.
JIVE has developed a reputation for fostering coordination, innovation, and capacity building for European and global VLBI. As a central entity in the EVN and through its status as an ERIC, JIVE shares these qualities with multiple institutes and European Commission (EC) projects.

1.2 JIVE IN 2023

The year 2023 marked a significant milestone as the first full year after the lifting of COVID-19 pandemic regulations. This allowed us to once again engage in face-to-face interactions, attend meetings, workshops, and conferences, and resume our presence in the office. The return to normalcy has been invigorating and has facilitated the strengthening of our collaborative efforts. Additionally, it was the first year under the leadership of our new JIVE director, Dr. Aga Słowikowska, who took over from Dr. Francisco Colomer.

One of the highlights of this year was the meeting held in Bologna to celebrate the 40th anniversary of VLBI, with the title "Bologna VLBI: Life begins at 40! New frontiers and scientific challenges for VLBI with enhanced frequency/time/space dynamic ranges" (https://vlbi-40.ira.inaf.it/). This event brought together many former JIVE employees, creating a vibrant environment for reflection and celebration. The discussions underscored the remarkable achievements of VLBI over the past four decades and highlighted the pivotal role that JIVE has played in its development. The gathering served as a testament to the enduring impact of our collective efforts and the importance of our continued collaboration.

In 2023, JIVE underwent a regular five-year review, involving eight panelists from various countries and institutes, including the Netherlands, France, UK, Germany, South Korea, South Africa, and the USA. The review panel's insights and recommendations were invaluable. We extend our heartfelt thanks to the panelists and the JIVE staff members who, under the leadership of former JIVE director Dr. Francisco Colomer, achieved outstanding results from 2018 to 2022. The review panel assessed JIVE's performance over the review period as uniformly excellent, highlighting strong operational support to the EVN, impressive efficiency despite pandemic and budget challenges, and strong scientific productivity. Additionally, it has emphasised JIVE's leading role in successful proposals for EC projects. Looking ahead, the panel notes the challenges JIVE faces but trusts it is well-positioned to seize exciting opportunities. Its recommendations aim to guide JIVE towards a bright future for the European VLBI community. The report of the Review Committee is publicly available and provides a comprehensive overview of our progress and recommendations for future directions (https://www.jive.eu/sites/default/files/shared/docs/JIV-ERIC_evaluation_report_2023_final.pdf).

In October the JIVE director visited Latvia to strengthen collaboration between Latvia, JIVE, and EVN. As an associate of EVN since 2016 and a full member of JIVE since 2017, Latvia plays a key role in this partnership. During her visit, Słowikowska toured the Irbene telescopes and met with key members of the Ventspils International Radio Astronomy Centre (VIRAC) to explore new collaboration opportunities. VIRAC, part of Ventspils University of Applied Sciences (VUAS), operates the historically significant 32-metre and 16-metre Irbene radio telescopes, which support 90% of EVN observations. These telescopes, equipped with advanced receivers, have made important contributions to astronomy and space technology research. Additionally, since January 2023, VIRAC has been involved in two new research projects focusing on solar and stellar flares and transient astrophysics. Słowikowska, together with VUAS Rector Prof. Adris Vaivads and VIRAC researcher Vladislavs Bezrukovs, concluded her trip with a visit to the Ministry of Education and Science of the Republic of Latvia, discussing the partnership's future with Jānis Paiders, Deputy State Secretary.

During her trip to Latvia, the JIVE director, accompanied by VUAS Rector Prof. Andris Vaivads (right) and VIRAC researcher Vladislavs Bezrukovs (taking the photo), met with Jānis Paiders (middle), Deputy State Secretary at the Ministry of Education and Science of the Republic of Latvia.

EC Projects

March 2023 saw the beginning of the EC INFRA-TECH project Radioblocks, aimed at significantly boosting the technical and digital development of European radio astronomy. This project, coordinated by JIVE, has received substantial funding of 9 million EUR from the European Commission and 3 million EUR from associated partners. With 32 partners from 13 countries, including prominent IGOs such as ESO and SKAO, Radioblocks is poised to enhance EU research infrastructures and unify European radio astronomy to remain competitive globally.

Additionally, the Opticon RadioNet Pilot (ORP) project underwent its second periodic report with very positive outcomes, further underscoring our commitment to advancing European electromagnetic ground-based optical and radio infrastructures. The ORP consortium meeting took place in Garching at the ESO headquarters in November. The agenda included a variety of sessions, such as parallel Working Group sessions, Executive/Board meetings, and the second project review, with key highlights being strategic discussions, presentations of two other pilot projects, ATMO-ACCESS and NFFA, and guest talks from AHEAD, EII, and RadioNet. The meeting successfully showcased progress across all work packages, positioning the project well for future planning and enhanced collaboration between communities.

ERIC Forum 2.0, the second implementation project for the ERIC Forum, was officially launched on September 1, 2023. Building on the guidelines and experiences from the project's first edition, ERIC Forum 2.0 aims to reinforce and standardise various practices across ERICs. These practices include discussing international collaboration, providing access to facilities and resources, upskilling ERIC staff and managing their contracts, enhancing resource management, and improving outreach and communication strategies. By focusing on these areas, ERIC Forum 2.0 strives

Dr. Paul Harrison from the University of Manchester presents the progress made on the development of the ORP proposal submission tool during the ORP Consortium Meeting in Garching.

to strengthen the overall functionality and cooperation within the ERIC community.

On this note, we would like to congratulate our colleagues who work on the low radio frequency network for becoming LOFAR ERIC in December 2023.

Science Operations and User Support

In 2023, JIVE continued to excel in its core mission of correlating astronomers' observations conducted with the EVN and global VLBI arrays. With 1157 correlator hours completed, it was the third-highest since adopting the SFXC correlator in 2011. Regarding annual EVN network hours, 2023 saw the second highest amount ever (1065.5) and the past three years have each been higher than any prior to 2021.

This impressive effort included contributions from visiting scientists and collaboration with various institutions to improve tools like PolConvert for better polarization correction in EVN data. Additionally, the EVN Archive grew significantly, reaching 185.31 TB of user-experiment FITS files by the end of 2023, reflecting an increase of around 3% over the year.

JIVE also coordinated various tests of new receivers and back-ends at EVN stations, addressing technical issues such as a quasi-periodic phase jitter at Toruń. These efforts included successful tests with the inclusion of Usuda (64 m) and Misasa (54 m) telescopes from Japan in the 3.6 cm NME, marking significant milestones for these stations' participation in EVN observations. Furthermore, JIVE supported seven first-time Principal Investigators (PIs) in 2023, with projects accounting for 202.5 network hours. Five of these PIs were female and three of them were students.

JIVE remained open to hosting data reduction visits and assisting with proposal development, welcoming several PIs and research groups throughout the year. These included visits of scientists and trainees from various universities and institutions. The institute's efforts ensured comprehensive user support from proposal definition to data analysis, maintaining its role as a central hub for EVN observations and advancing the scientific capabilities of VLBI.

The science output of JIVE in 2023 was impressive, with staff contributing to or leading numerous publications in prestigious journals. Decades of monitoring the nucleus of the M87 galaxy revealed a precessing relativistic jet, indicating a spinning supermassive black hole whose axis is tilted relative to the surrounding gas disc that feeds it (Ciu et al. 2023). These jets and winds from active galactic nuclei can expel gas from the central parts of a galaxy. In the 3C84 galaxy, it has been shown that the gas expelled by the supermassive black hole may eventually cool down and flow back, closing the feeding-feedback loop (Oosterloo, Morganti, and Murthy 2023). High-angular-resolution interferometric results using the RadioAstron telescope in space, in conjunction with radio telescopes on Earth, revealed a remarkable double-helix structure in the relativistic jets, challenging current models (Fuentes et al. 2023). Magnetic fields play a crucial role in both forming the jets and in the accreting environment, as demonstrated by the EHT team with the detection of circularly polarized radio emission from the central black hole in M87 (The Event Horizon Telescope Collaboration 2024). In the field of transients, JIVE scientists confirmed the association of the second Fast Radio Burst with a peculiar radio source, likely a „hypernebula" powered by either a magnetar or gravitational potential energy (Bhandari et al. 2023).

JIVE and ASTRON jointly organised the summer student program for advanced master's students, who carried out research projects for 10-12 weeks at the institute. This program has been a tremendous success over the past decades. JIVE also organised the CASA VLBI School and participated in the ORP Proposal Writing School. The online EVN Seminars restarted, covering a wide range of topics relevant to VLBI. In-depth training and support for EVN users were offered, as in previous years, to visitors of JIVE. These visitors ranged from beginners to advanced users and had primary interests either in radio astronomy or other fields.

Technical Operations and R&D

The Technical Operations and R&D group worked on further improving the maintenance and monitoring of important aspects: failures, power consumption, and the current state) of the EVN compute-, service-, and storage clusters at JIVE (1100 CPU cores, >100 physical servers, 6+ PB online storage). Within the first nine months of the Radioblocks project very promising steps towards a GPU-based implementation of the SFXC software correlator algorithm and speeding up data decoding and distribution across the cluster nodes were already made. For SFXC a new normalisation scheme was implemented to remove mixed-bandwidth correlation amplitude correction discontinuities. An Earth-Orientation-Parameter adjustment task for CASA was verified and validated and should be included in one of the CASA releases in 2024. Other CASA work included an effort to produce a version of PolConvert as native CASA task operating on MeasurmentSet directly, with the goal of finalising in 2024. Additionally, JIVE introduced a web tool to track staff locations for improved collaboration and published the first official EVN DOI. Updates to various tools and systems continue to support JIVE and EVN operations.

Space

JIVE's space science activities aim to advocate for VLBI to new potential users beyond the traditional radio astronomical community. In 2023, JIVE continued this effort by establishing fruitful partnerships with various institutions, including NASA, the University of Tasmania, and Delft University of Technology, for the ESA's Jupiter Icy Moons Explorer (JUICE) mission launched in April 2023 to explore Jupiter and its moons. JIVE leads the PRIDE (Planetary Radio Interferometry and Doppler Experiment) for the JUICE mission, which uses VLBI techniques for precise measurements of spacecraft positions and velocities. The year 2023 has been marked by significant progress and achievements in the PRIDE development. JIVE's contributions to space science have been recognised with an ESA certificate of excellence awarded to three JIVE Space VLBI scientists, Leonid Gurvits, Mas Said, and Giuseppe Cimò.

CRAF and WRC-23

JIVE scientist and Frequency Manager of the Committee on Radio Astronomy Frequencies (CRAF), Waleed Madkour, took part in the International Telecommunication Union (ITU) World Radiocommunication Conference 2023 (WRC-23) in Dubai. The CRAF team is working diligently to protect our sky from radio interference and secure radio bands for astronomers, contributing to the efforts for Dark and Quiet Skies for Science and Society, as this crucial topic is known and discussed internationally.

The WRC-23 conference made decisions on several critical topics concerning the protection of the Radio Astronomy Service (RAS). These topics included mobile service operations in the upper 6 GHz band, safeguarding RAS from satellite constellations, reviewing the UHF band, recognising space weather sensors, and enhancing lunar communications. While the outcomes of WRC-23 for radio astronomy were generally positive, there are areas that will require follow-up actions.

Celebrating Three Decades of JIVE

On December 21, 2023, we celebrated the 30th anniversary of JIVE. This milestone is a testament to the dedication and hard work of all our former and current team members. As we look to the future, we are excited about the new era of radio astronomy that lies ahead and remain committed to pushing the boundaries of our field.

Congratulations to everyone for their efforts, and we wish JIVE continued success in the coming years. We look forward to the renaissance of radio astronomy and the exciting developments the next decade will bring.

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Joint Institute for VLBI ERIC

1.3 PERSONNEL

JIVE is organised into four departments: Science Operations, User Support, Technical Operations and R&D, Space Science and Innovative Applications. Additionally, there is a Coordination and Support Office that assists and facilitates the running of JIVE.

Dr. Giuseppe Cimò was appointed as the Head of the Space Science and Innovative Applications Group and took over the PI-ship of the PRIDE experiment of ESA's JUICE mission from Prof. Leonid Gurvits in November.

Dr. Giuseppe Cimò became the new PI of ESA's PRIDE-JUICE experiment in November 2023. Credit: Silvio Zangarini

We also welcomed Dr. Ioanna Kazakou as the new JIVE Communications Officer in September 2023. Ioanna's role is crucial in communicating the progress and achievements of EVN and JIVE, as well as the advancements in EC projects that JIVE contributes to, such as Opticon RadioNet Pilot (ORP), Radioblocks, and ERIC Forum 2.

Dr. Ioanna Kazakou on her first day as JIVE Communications Officer.

KEY FIGURES

7
Member Countries

3
Participating Research Institutes

25
JIVE Staff

USER EXPERIMENTS CORRELATED

117
Experiments

950
Network Hours

1157
Correlated Hours

2023

185.31

TB of total size user-experiments files in Archive

83

JIVE Staff Publications

3

EC Projects

OVER 600,000

People reached through our communication activities

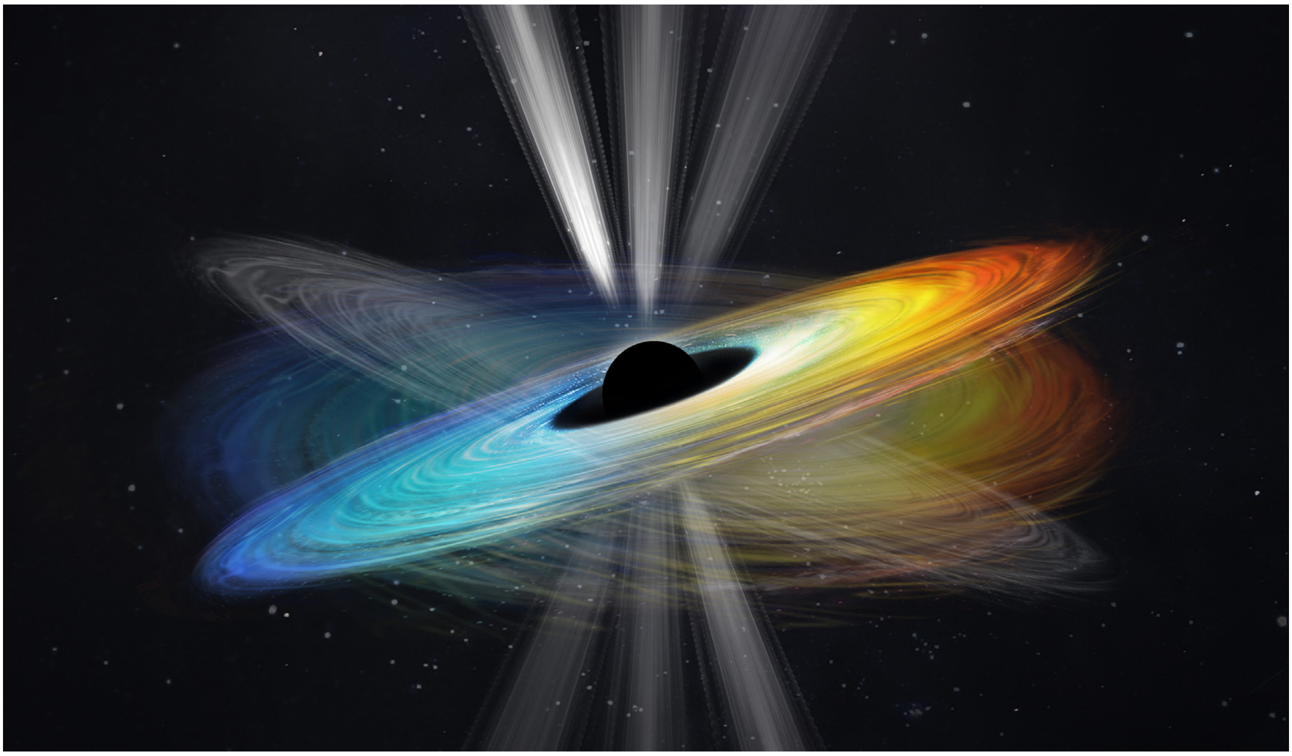
Science Highlights

02

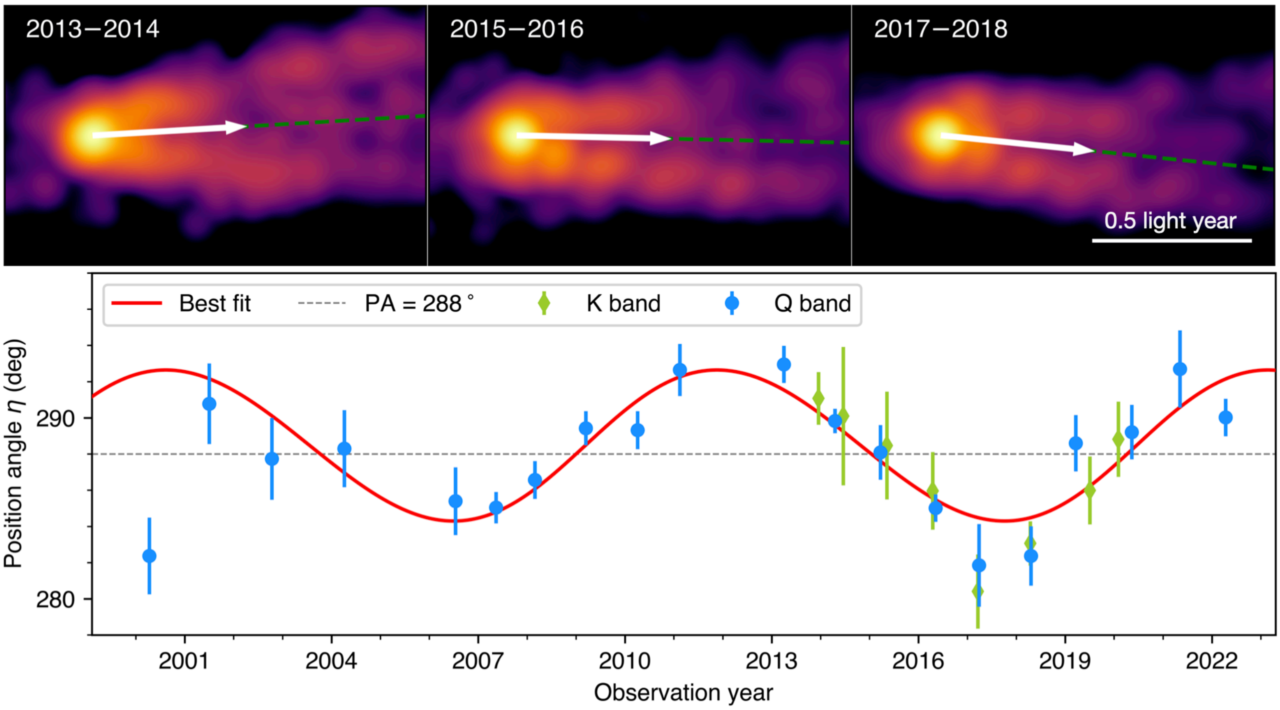
2.1 TWO-DECADE MONITORING OF M87 UNVEILS A PRECESSING JET CONNECTING TO A SPINNING BLACK HOLE

The nearby radio galaxy M87, located 55 million light-years from the Earth and harbouring a black hole 6.5 billion times more massive than the Sun, has recently been discovered to exhibit an oscillating jet. This investigation found the jet swinging up and down with an amplitude of about 10 degrees. Through the extensive analysis of data observed from 2000 to 2022 by various international networks of radio telescopes, the research team unveils a recurring 11-year cycle in the precessing motion of the jet base, as predicted by Einstein's general relativity. This work successfully linked the dynamics of the jet with the central supermassive black hole, offering the evidence for the existence of M87's black hole spin.

Supermassive Black Holes at the centre of active galaxies can accrete tremendous amounts of materials onto them due to the extraordinary gravitational force and power the plasma outflow like jets to nearly the speed of light extending to thousands of light-years away. The energy transfer mechanism among supermassive black holes, accretion disk, and relativistic jets has been puzzling physicists and astronomers for over a century. A prevailing theory suggests that energy can be extracted from a spinning black hole, allowing some materials surrounding the supermassive black hole to be ejected with great energy. However, the spin of supermassive black holes, a crucial factor in this process and the most fundamental parameter other than black hole



Schematic representation of the tilted accretion disk model. The black hole's spin axis is assumed to align vertically. The jet's direction stands almost perpendicular to the disk. The misalignment between black hole spin axis and disk rotation axis will trigger the precession of disk and jet. Credit: Yuzhu Cui et al. 2023, Intouchable Lab@Openverse and Zhejiang Lab



Top panel: M87 jet structure at 43 GHz after bi-yearly stacking data observed during 2013-2018. The corresponding years are indicated at the left-top corner. The white arrows indicate the jet position angle in each subplot. Bottom panel: Best fitting results based on the yearly-stacked image from 2000 to 2022. The green and blue points are obtained from observations at 22 GHz and 43 GHz, respectively. The red line represents the best fit according to the precession model. Credit: Yuzhu Cui et al. 2023

mass, has not been directly observed.

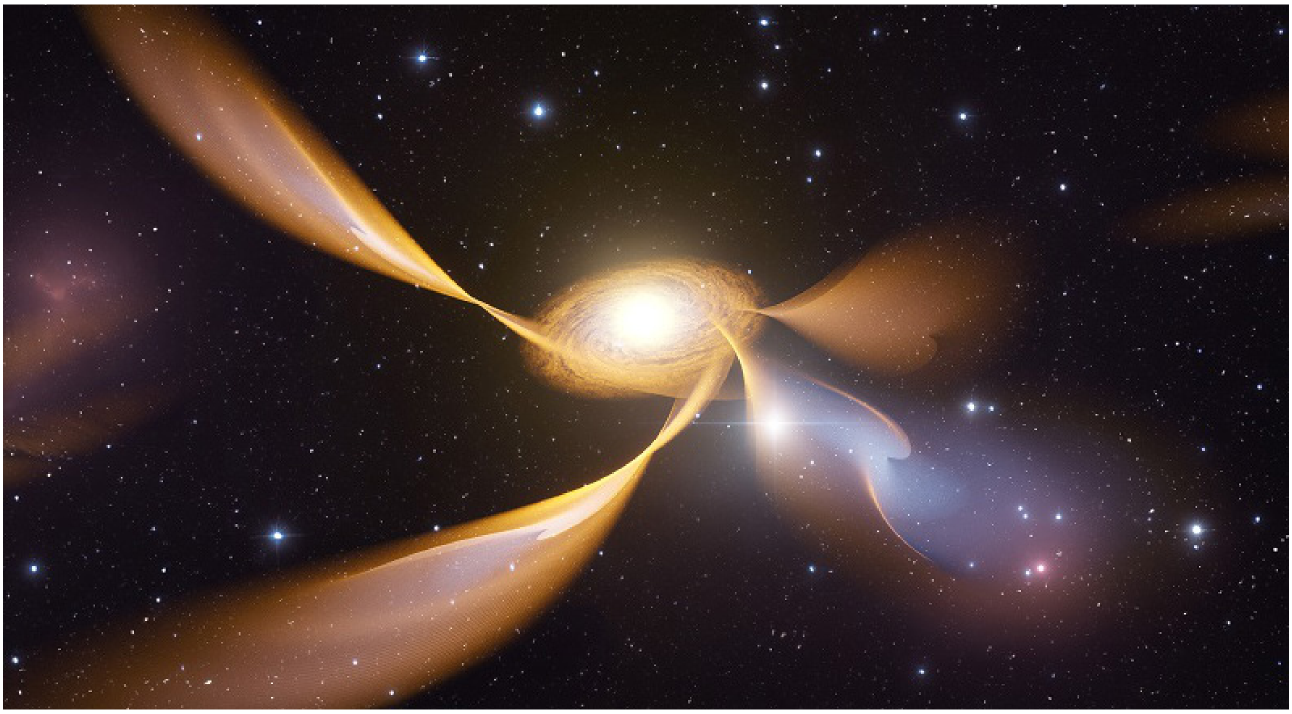
The research team, including Junghwan Oh from JIVE, analysed a vast amount of data and compared it to state-of-the-art theoretical simulations using a supercomputer. The study indicated that the rotation axis of the accretion disk misaligns with the black hole's spin axis, leading to a precessing jet. Detecting this precession served as a compelling support, providing unequivocal evidence that the supermassive black hole inside M87 is indeed spinning, unlocking new dimensions in our understanding of the nature of supermassive black holes.

Cui et al. 2023,
Nature, Volume 621, 711-715

2.2 DISCOVERY CLOSES THE SUPERMASSIVE BLACK HOLE FEEDING-FEEDBACK LOOP

Supermassive black holes at the centres of galaxies have long been known to emit enormous amounts of energy. This causes the surrounding gas to heat up and flow far away from the centre. As a result, this depletes the gas reservoir feeding the black hole and makes the galactic nucleus less active. Theory predicts that the gas expelled to the outskirts of the galaxy will cool down and may eventually fall back to the centre. There has been indirect evidence for this theory, but cooled gas moving toward the central black hole has never been observed.

Researchers from ASTRON and the University of Groningen, as well as Suma Murthy from JIVE, have shown that this process is indeed in action in active galactic nuclei. They observed cold molecular gas (traced by carbon monoxide) in a nearby galaxy and found that cold gas may indeed flow back after cooling. The team used data collected by the ALMA observatory from the iconic galaxy 3C 84 (also referred to as NGC 1275 or Perseus A). This galaxy is located 235 million light years away in the northern constellation of Perseus. It is the textbook example of what astronomers call „AGN feedback" or the recirculation of gas near a black hole. It had been known for decades that plasma jets from the supermassive black hole disrupt the hot gas around 3C 84 and that filaments of colder gas float in and around the system. And it had long been assumed that those filaments fall back toward the black hole, but it had never been proven.



Artist's impression of the filaments of gas flowing toward the accretion disc of 3C 84. Credit: Luca Oosterloo (whoislvca.com)

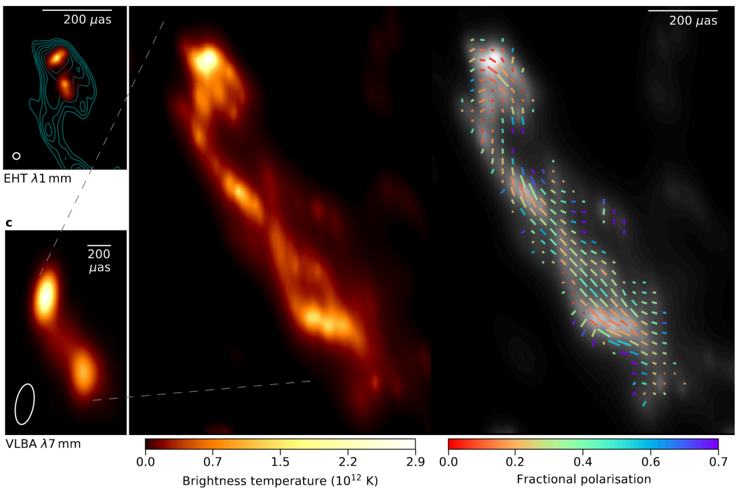
Oosterloo, Morganti, and Murthy 2023, Nature Astronomy, Volume 8, 256-262

2.3 SPACE INTERFEROMETRY REVEALS HELICAL FILAMENTS WITHIN A SUPERMASSIVE BLACK HOLE'S JET

Blazars are the most powerful continuous sources of radiation in the universe. Like other active galaxies, they exhibit a structure consisting of a central supermassive black hole surrounded by a feeding material disk. However, they belong to the 10% of active galaxies that display high-speed plasma jets emerging from both poles and to an even smaller percentage of cases allows us to observe these jets almost head-on. A group of researchers led by the Institute of Astrophysics of Andalusia (IAA-CSIC) and including Leonid Gurvits from JIVE has observed the jet of the galaxy 3C 279 with unprecedented resolution and has discovered large filaments with a double helix structure that requires an update to the theoretical models used until now.

The results have been obtained using RadioAstron, a space radio telescope capable of reaching distances close to the Moon, and a network of twenty-three radio telescopes distributed throughout the Earth. The images reveal that the jet in 3C 279 displays a complex structure composed of at least two helical filaments extending from near the core to over 570 light-years away. This is an unprecedented structure and builds upon a previous result: in 2020, the Event Horizon Telescope (EHT) that captured the first image of a black hole in 2019, revealed unexpected structures in the core of 3C 279. However, EHT's sensitivity was insufficient to observe the filaments.

The properties of the helical filaments led the team to conclude that they are caused by instabilities in the plasma that makes up the jets. Taking all the elements into account, it was found that the model used for four decades to explain the radio variability associated with the jets does not apply in this case. Therefore, they proposed an alternative model that takes into account the newly observed structures. Furthermore, the study suggests the presence of a helical magnetic field that confines the jet. Therefore, it is the magnetic field, which in 3C 279 rotates clockwise around the jet, that channels the material travelling along it at a speed of 0.997 times the speed of light.



High resolution images of the relativistic jet in the balzar 3C279. The images reveal a complex structure within the jet with several parsec-scale filaments forming a helix shape. Credit: RadioAstron/Fuentes et al.

Fuentes et al. 2023,
Nature Astronomy, Volume 7, 1359

2.4 EVN LINKS SECOND FRB TO A POTENTIAL HYPERNEBULA

Artist's impression of FRBs emitted by a source called FRB 20190520B, and originating in a hypernebula Credit: Daniëlle Futselaar/ASTRON

FRBs—fast radio bursts—are brief but intense flashes of radio waves, which last less than the blink of an eye and originate from distant galaxies. While some FRBs are one-off events and are never detected again, others have been observed to repeat. Repeating FRBs are comparatively easy to catch and provide a wealth of information about the objects that produce them. FRB 20121102A is the first-known repeating FRB and was until recently the only repeating FRB known to be associated with a potential hypernebula.

Now, a team led by Shivani Bhandari and including Benito Marcote and Zsolt Paragi from JIVE have confirmed the association of a second FRB source, called FRB 20190520B, with a potential hypernebula. This FRB was discovered using the 500-m FAST telescope in China and appeared to be associated with a constant source of radio waves in addition to the repeating flares. This more constant source of radio waves hints at a hypernebula powered by the same object that makes the bright radio bursts.

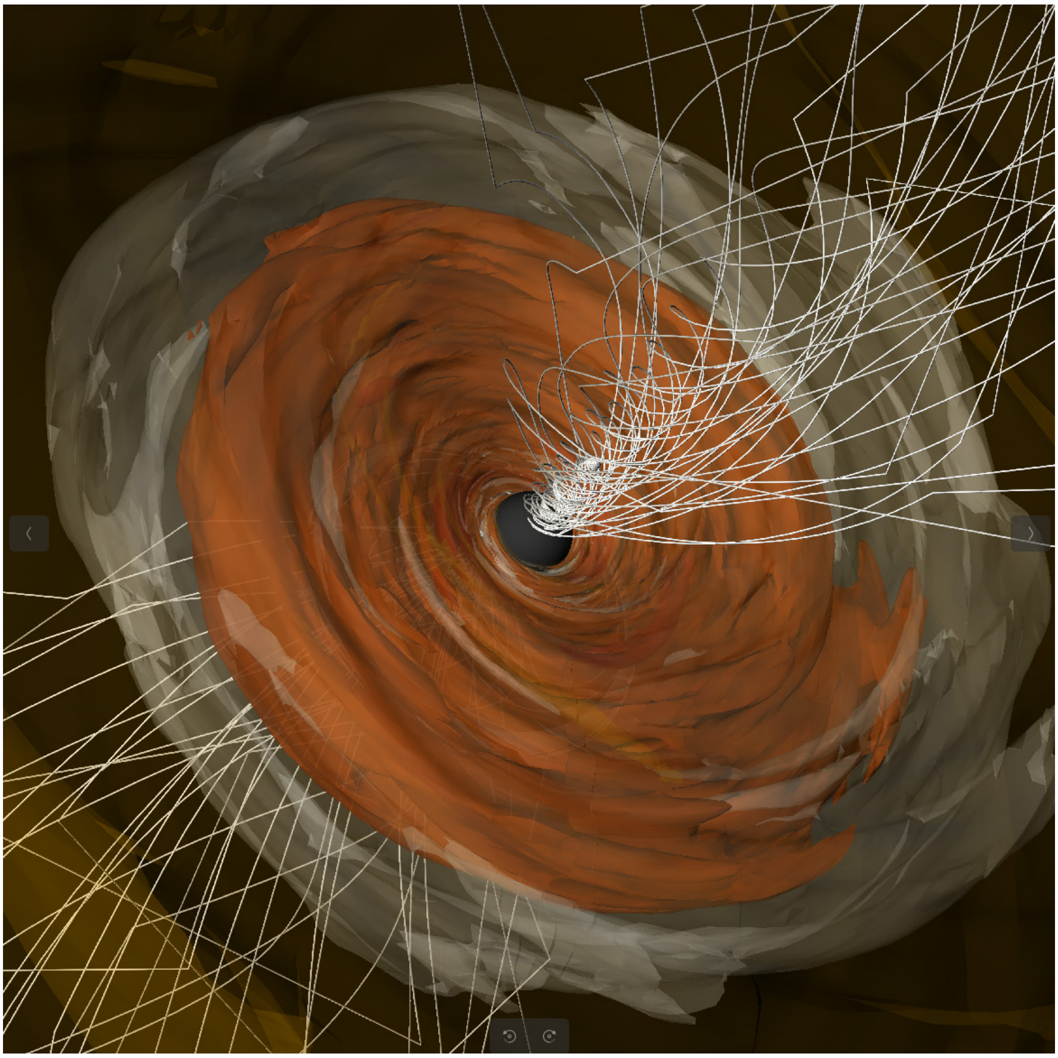
The team observed FRB 20190520B using the European VLBI Network. Evidence has been found earlier that some FRBs are produced by extremely magnetic neutron stars called „magnetars". The persistent radio emission around FRB 20190520B likely arises due to powerful winds of charged particles from the central magnetar that creates a nebulous region surrounding the source. Thanks to the newly obtained data, the age of this putative magnetar was constrained to be between only 4 to 1,900 years old and that of the nebula to be at least 900 years old. This observation suggests that there may be a sub-population of young FRB sources embedded in luminous nebulae.

Another hypothesis is that the hypernebula is powered by gravitational potential energy, instead of magnetic decay of a magnetar. In this scenario, the bursts are produced within the powerful outflows of a black hole or a neutron star that is „eating" matter from a nearby companion star at devilishly high rates.

Bhandari et al. 2023,
Astrophysical Journal Letters, Volume 958(2), L19

2.5 A SUPERMASSIVE BLACK HOLE'S STRONG MAGNETIC FIELDS ARE REVEALED IN A NEW LIGHT

The Event Horizon Telescope (EHT) collaboration, including JIVE's researchers Huib van Langevelde, Ilse van Bemmel, Mark Kettenis, and Des Small, has shown for the first time how light from the edge of the supermassive black hole M87* spirals as it escapes the black hole's intense gravity, a signature known as circular polarisation. The way light's electric field prefers to rotate clockwise or counterclockwise as it travels carries information about the magnetic field and types of high-energy particles around the black hole. The results support earlier findings from the EHT that the magnetic field near the M87* black hole is strong enough to occasionally stop the black hole from swallowing up nearby matter.



A computer simulation of a disk of plasma around the supermassive black hole at the centre of the M87 galaxy. Analysis of the circularly polarised, or spiralling light, in EHT observations shows that magnetic fields near the black hole are strong. These magnetic fields push back on infalling matter and help launch jets of matter at velocities near the speed of light out. Credit: George Wong

In 2019, the EHT released its first image of a ring of hot plasma close to the event horizon of M87*. In 2021, EHT scientists released an image showing the directions of the oscillating electric fields across the image. Known as linear polarisation, this result was the first sign that the magnetic fields close to the black hole were ordered and strong. The measurements of the circular polarisation, although very weak, provide yet more conclusive evidence for these strong magnetic fields.

The team performed different tests on the data and all of them found unambiguous evidence that circularly polarised light exists close to the event horizon. In the end, because the EHT's measurements of circular polarisation were much weaker than the earlier datasets, the team was unable to come up with an unambiguous image of the „handedness" of the spiralling light. Instead, the team was able to determine that the circularly polarised or spiralling part of the light could only be a small fraction of the total light making up the black hole image. These results allowed them to test different theories for the shape and movement of the plasma and magnetic field around the black hole, including a set of state-of-the-art supercomputer simulations.

The Event Horizon Telescope Collaboration 2024, Astrophysical Journal Letters, Volume 957(2), L20

Research and Development

03

3.1 TECHNICAL OPERATIONS

From a hardware and personnel perspective, 2023 was a reasonably uneventful year with few surprises or changes. The production storage-, compute-, and network environments performed steadily. Also, the biggest issue encountered did not cause data loss or loss of correlator capacity.

Several tasks that started in the previous year were carried over into this year and are still ongoing. The group's staff continued to work on upgrades related to the operating system, firmware, BIOS, security and software, and on maintenance and improvements thereof. One of the group's senior staff members spent three months at NRAO for an extended science visit supporting his PhD thesis. This had no immediate impact on day-to-day operations but meant that certain (ongoing, future-looking) projects were delayed or affected.

3.1.1 HARDWARE

The Korean VLBI Network sent 16 x 18 TB hard-disk drives (HDDs), enabling JIVE to fill twelve of the eighteen remaining free slots in the On/Nt/Mc/Sr-*PetaBuff* that was installed in 2022.

The remaining disks are kept as spares. The number of failed HDDs, as well as the fraction of those replaced outside (or under) warranty, is identical to last year's within 3%. This is a recurring unbudgeted cost for the Technical Operations/R&D group and is approximately equal to the group's total annual desktop computer investment budget. Some statistics to investigate quality of the disks, such as average lifetime versus spread in lifetime per type of disk, were tried but the number of disks for a statistically meaningful result is still too low.

Due to a complete replacement of the cooling system and bringing (significant) parts of the electrical system and construction in the host institute's building to comply with current safety regulation standards, the JIVE storage- and compute clusters had to be shut down on at least four days. A few more short-term outages are expected in 2024 as the process nears completion. One of the days without central cooling coincided with e-VLBI. Powering down all equipment that was not strictly necessary to run the e-VLBI, combined with using outside air and fans, was enough to conduct the observations and prevent the equipment from overheating. JIVE Technical Operations/R&D staff is involved in the renovation process to combine the construction works with the operations of the EVN and JIVE.

Following an announcement to the MIT Haystack/Conduant Mark6 user community regarding the discovery of a potential wire overheating problem in Mark6 expansion chassis, the four Mark6 units at JIVE were inspected and modified according to the instructions in Mark6 Memo #10.

By far the largest issue started in mid-February, when, after approximately two months of service, within a period of twenty-four hours, sixteen of the thirty-six new, larger, HDDs (upgraded from 8→18TB) recently installed in the WSRT flexbuff failed. The RAID configuration at JIVE allows for lossless single disk failures in each pool of six disks (note: only one pool of data, ~30 TB, was completely lost since the move to the flexbuff system, starting from ~2018), implying that sixteen failed HDDs would have caused a total, irrecoverable loss of all data on the system, i.e. 400 TB of data. It would be irrecoverable because the data had already been removed from the station's local flexbuff to what is, in principle, safe storage at JIVE.

Several tests were performed to see if the problem was with the disks, the system memory, or the chassis. Over the course of the next months, the disks were moved to a chassis that was purchased for a different purpose, which, accidentally, was delivered with the same type of hard disks, the data were copied from the disks, and the systems with these disks were put in read-only mode. The most likely root cause hypothesis was „the disks themselves" because they were of a new type of Western Digital manufactured disks not previously used in a flexbuff system.

Because of five layers of communication (JIVE → ASTRON → Bossers & Cnossen → ServerDirect →

Replaced HDDs	Warranty		
Year	no	yes	total
2023	30	2	32

Table of 2023 Hard Drive Disks (HDD) replacement under warranty.

The collection of FlexBuff hard-disks that failed in 2023.

SuperMicro → Western Digital), it was difficult to substantiate this hypothesis.

After much back-and-forth communication and running tests on behalf of (any of) the vendors in the chain, collecting and sending feedback, suddenly, halfway through July, a new firmware version for the HDDs was received. Unfortunately, this firmware did not install on each of them. After careful inspection, the seventy-two disks „of the same type" turned out to consist of a collection of two *subtly* different types, differing only in the fifteenth significant digit of the part number. Once the correct firmware for those disks was received, all hard drives' firmware was upgraded.

After three months of (read-only) operation, the upgraded WSRT flexbuff unit was brought back into production and monitored closely for several months. In the end, the „failures" turned out to be benign, being of a logic nature instead of physical failure. The hard disk firmware merely timed out under certain unknown or undisclosed to us circumstances; the disks themselves and the data on them were probably never in danger of failing.

The most difficult part proved to be convincing (one of) the vendors in the chain to acknowledge that this was an issue with the hard disks, despite a report from a huge data centre in Sweden seeing identical issues with the same hard disk type. It proved impossible to get the manufacturer to link that case and ours together and respond.

The accidental spare chassis on hand mentioned above was purchased as the annual „big server upgrade" for the off-site online backup system JIVE has running at the WSRT site. The current machine is fourteen years old; during a maintenance visit last year, it was discovered the CPU fans had fallen off because the thermal conductivity paste-cum-glue had disintegrated. Installation and deployment of the new machine were postponed to 2024 because the chassis was used for a test- and rescue system until about December, when it became credible to assume the firmware upgrade had fixed the hard-disk „failures".

The backup- and recovery setup was improved by implementing a mechanism in the Ansible-based central server management system to allow remotely backing up, restoring, upgrading, and configuring of the BIOSes of all flexbuffs and compute cluster nodes.

The project of re-spooling the old LTO-[345] and DAT-tapes onto the LTO-8-based system continued, requiring some maintenance and investment to keep the old DAT-drive(s) operational: the drive started to produce more frequent errors. It is uncertain if the DAT-drive will last until all tapes have been copied over to the new system.

Technical Operations/R&D staff continued to support White Rabbit (WR) rollouts and configuration for the SKA and LOFAR2.0 telescopes and developed a simplified calibration strategy for WR-links over already deployed fiber.

3.1.2 SOFTWARE

The EVN Archive migration project, moving the EVN Archive away from its current twelve-year-old hardware and O/S to early 2023 versions thereof, progressed significantly but has not finished yet. Several factors have contributed to this: relevant knowledgeable staff (un)availability, cleaning up and re-factoring or sometimes rewriting of more than a decade of organic growth of scripts and mechanisms into a documented, maintainable system that also allows for parallel test environments without breaking the production EVN Archive. It was decided to move all scripts, code, and other resources under modern version control (using `git`), triggering the phasing out of the `cvs` version control system, which in turn resulted in more repositories needing to be migrated to `git`.

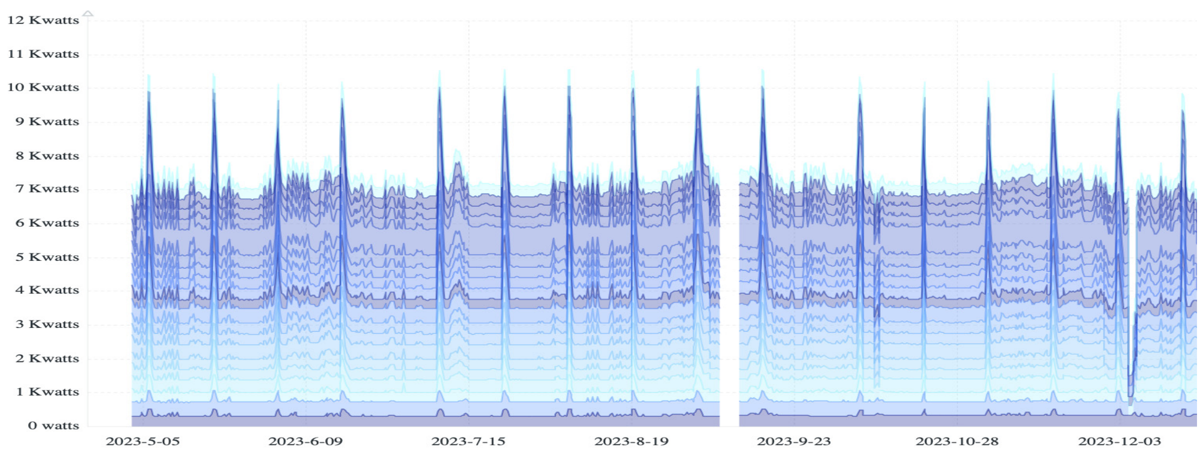
The new Mattermost-based feedback system was accepted by the EVN TOG in its meeting in January and put in production by Session III/2023. Several other services still remain to be moved off `old.evlbi.org` before that machine can be decommissioned.

The Zabbix-based internal monitoring system continues to be built out. Investigations started to evaluate two different network-traffic monitoring solutions, sFlow and NetFlow. These applications could provide insights about data flows (including source, destination, and protocol) instead of measured throughput only, as is currently being monitored. Initial tests showed that sFlow could add a lot of insight, however, rolling it out into production requires upgrading the 100 Gbps switches' firmware, which in turn requires the installation of extra fiber, both of which depend critically on key staff being available.

Another topic is power consumption monitoring. It was verified that BIOS readouts of these values, in fact, agreed with actual power consumption. This was done by comparing the reported power consumption values against those measured with an external, independent power consumption meter over a period. A more detailed investigation into power consumption has started and is expected to be completed in 2024. Early results show that the compute nodes are already quite energy efficient and that the storage cluster consumes a lot of power irrespective of the load (see the figure below): just over one kW per 1 PB of storage. The graph represents the power consumption of only the flexbuffs during the second half of 2023, after the Zabbix readouts were verified. The difference in power consumption between correlating or not is hardly visible. The regularly spaced high power consumption peaks are caused by the fortnightly „scrubbing" process. In such a process each disk is completely read and written by the file system to verify a disk's integrity. It is the main diagnostic tool to identify failing or failed disks.

The power-down of the twenty-three Mark5s since June led to a lower overall power consumption for the year 2023 by approximately 7%. This can be seen in the table on the next page, which is used to bill JIVE for electric power consumption.

JIVE purchased a built-to-order Microsoft Dynamics/Business Central-powered application for leave, sick leave, work-from-home, business trips, and hour logging administration. After employees submitted data, no reporting was



Power consumption in kW of the twenty FlexBuff storage systems (6+ PB) at JIVE as function of time.

available, such as to see who was where or expected to be available, except by the financial department of JIVE. To improve collaboration within JIVE, the Technical Operations/R&D group built a web tool to provide just that—an overview of who is where—while observing GDPR regulations by anonymising as much information as possible.

The first official EVN DOI was published: https://doi.org/10.48717/21qn-4a40. It refers to the oldest science data in the EVN Archive that has all the supporting information (standard plots, pipeline calibration, station feedback): Richard Schillizzi's ES023 experiment. Work towards minting DOIs is underway to be integrated with the new archive setup.

The group also supports JIV-ERIC member representatives by providing specific reports on JIVE/EVN usage statistics upon request. This is done by building targeted queries and graphs based on the available information in the hosted databases. GDPR regulations sometimes lead to conflicts of interest, which would be best discussed and handled at the JIVE Council level.

Supporting VEX2 at the operational level occasionally required attention to fixing issues or implementing improvements.

The ANTAB_editor program was updated to (automatically) read VLBA system temperature files.

2023	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
kWh	19.64	17.67	19.05	16.42	16.23	15.85	15.65	16.1	15.45	15.36	15.13	15.75	**198.35**

Table showing the total power consumption per month of the JIVE correlator-, storage-, and network equipment, as measured by ASTRON.

3.2 RESEARCH & DEVELOPMENT

Technical Operations/R&D staff participated in several EC-funded projects and contributed to several deliverables or milestones.

ORP

The EVN plugin for the TOM Toolkit system was improved by adding an OAuth2-based connection back to the EVN Northstar instance at JIVE. For EVN observations to be scheduled it is important to know if a particular user indeed has EVN observing time allocated. This information is kept in the EVN Northstar Proposal Submission Tool instance hosted at JIVE. The EVN plugin allows linking a BHTOM user's account with an account in the EVN Northstar. For this to work, an additional service providing an OAuth2 workflow was implemented. Behind the scenes, this authenticates against the EVN Northstar database at JIVE. After linking both accounts, the EVN plugin in a TOM Toolkit-based instance can (automatically) verify if the user can request (an) EVN observation(s).

During the ORP consortium meeting in Garching in November, the EVN plugin was integrated into the University of Warsaw's Blackhole TOM (BHTOM) installation, making it available to users of that system.

On the topic of automatically generated schedules, investigations within the LOFAR context have revealed that the LOFAR system is (a lot) larger than what the EVN uses or even requires, rendering it excessive. Specifically, the heuristics upon which automated LOFAR scheduling operates are therefore not applicable. However, the topic is not off the radar: the future ORP Multi-facility Call for Proposals might provide another opportunity to analyse what users actually request and explore automation in that area.

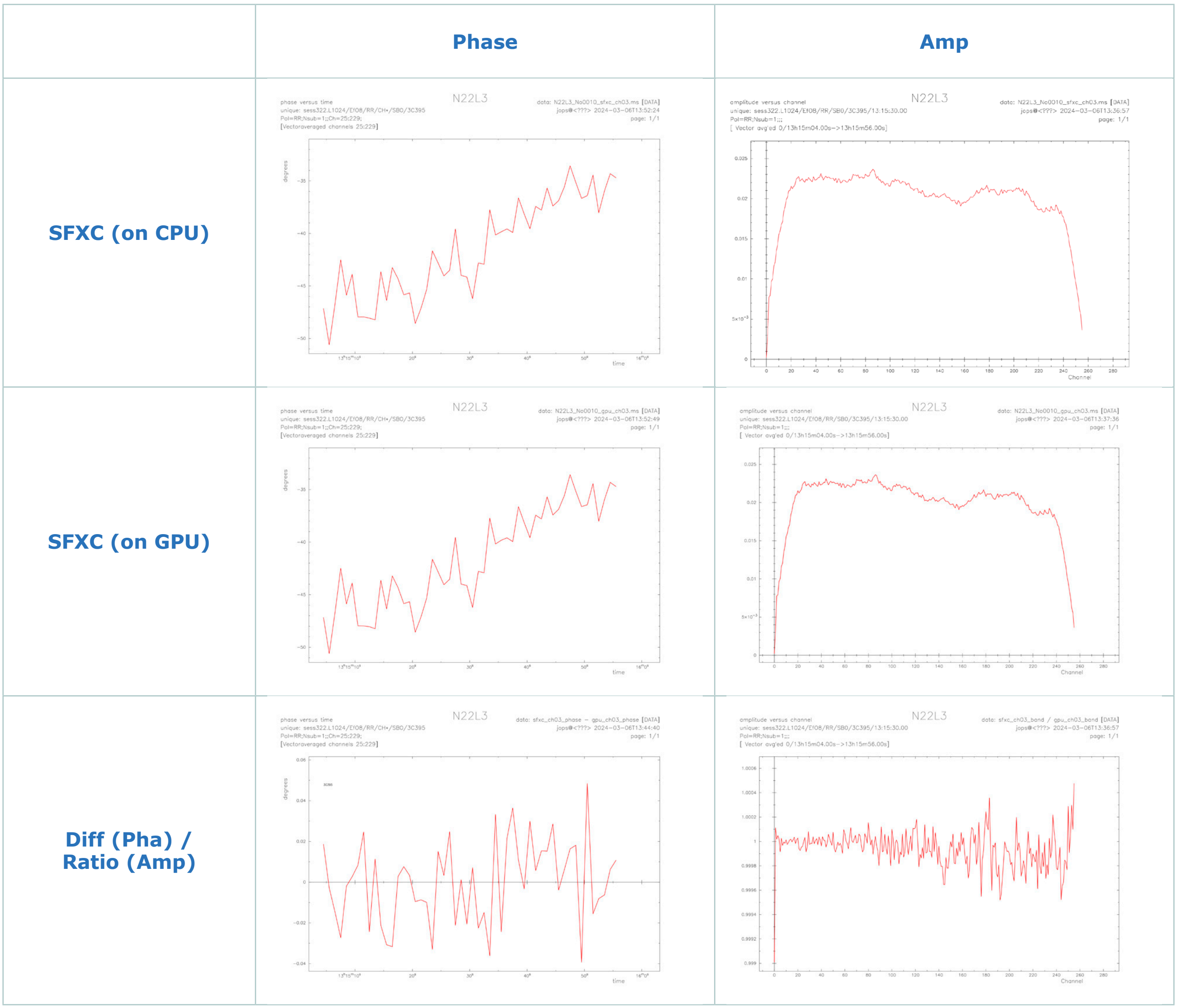
The Las Cumbres Observatory (LCO), the TOM Toolkit authors, collaborate within the same Joint Activity and have expressed interest in exploring Virtual Observatory (VO) protocols to link the TOM Toolkit with more archives. JIVE's VO expert was invited to present at one of the monthly meetings, generating enough interest to plan a follow-up meeting with LCO.

RADIOBLOCKS

The project started in March, with a kick-off meeting in Leiden, the Netherlands. It took a few months for the different work packages and tasks that Technical Operations/R&D staff is involved in, to get up to speed.

In WP4, work is being done on a GPU-version of the `sfxc` software correlator, specifically porting its delay compensation algorithm (Keimpema et al. *The SFXC software correlator for very long baseline interferometry: algorithms and implementation*, Experimental Astronomy, 2015ExA, 39, 259K) to this architecture. By December, a prototype version that implements all the necessary steps of the correlator (unpacking, `sfxc`-style delay compensation, and correlation) already produced very comparable results to the CPU version when correlating one second of data from the EVN's N22L3 Network Monitoring Experiment. The graphs in the figure below illustrate that the average absolute phase difference between the two implementations is below 0.02° and the average amplitude ratio is well within +/- 0.02% from the ideal ratio of 1. These differences are being investigated before expanding the features and capabilities of this initial version.

Another area of development is handling the integer delay compensation and improving the speed of dechannelising („cornerturning") and transferring a station's VDIF data to the compute nodes. The infrastructure developed for `sfxc` cannot cornerturn and send the data to (GPU-) nodes fast enough. A faster version, using newer low-level assembler instructions, was implemented and benchmarked to be capable of handling > 4 Gbps per VDIF stream. The previous limit prevented `sfxc` input nodes from handling more than 2 Gbps per stream. The plan is to backport this new cornerturning code into the CPU-version of `sfxc` to benefit from that development as well.



These graphs illustrate that the average absolute phase difference between the two implementations is below 0.02° and the average amplitude ratio is well within +/- 0.02% from the ideal ratio of 1.

Experiments with newer Message Passing Interface (MPI)-based mechanisms to transfer data from a flexbuff directly into GPU memory indicate that a more flexible and faster mechanism to transport data from one node to another is possible (tag-based asynchronous). Multiple underlying technologies are available—MPI is a high-level programming model based on top of one or more lower-level transport mechanisms such as TCP/IP, RDMA, ...— but none possesses all desired qualities to benefit maximally without losing generality. JIVE staff contributed to deliverables D4.1 (Assessment of the applicability of next generation technology, [10.5281/zenodo.10940605](https://doi.org/10.5281/zenodo.10940605)) and D4.2 (High-speed data handling techniques such as e.g. RDMA, [10.5281/zenodo.10941164](https://doi.org/10.5281/zenodo.10941164)).

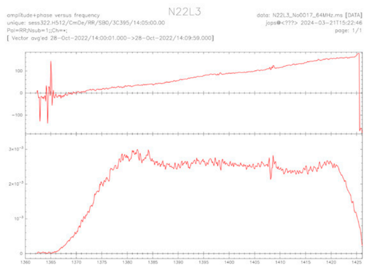
In WP5, staff worked on two different tasks. The first task revolves around porting the CASA `fringefit` algorithm to the Python DASK scalable high-performance computing framework. Because the next generation CASA („ngCASA") radio astronomical data calibration and analysis framework of the United States' National Radio Astronomy Observatory (NRAO) strives to be Python DASK-based as well, streamlining the RADIOBLOCKS effort with ngCASA developments is important. JIVE staff was invited to attend an ngCASA core developers' team meeting in Charlottesville, WV, to discuss the new Measurement Set data format in cloud-native formats and application interfaces on top of that.

The second task revolves around simulations with the goal of improving calibration and parameter extraction using Bayesian methods. The team has formed a dedicated simulations subgroup that had a fruitful on-site team meeting with all partners present in Dwingeloo. Over the year, the team acquired three extra members, from Yebes Observatory to University of Western Australia, working on SKA-VLBI and SKA-LOW calibration simulations. The team started by evaluating the available simulation packages for suitability and two were shortlisted as candidate tools for driving the actual simulations.

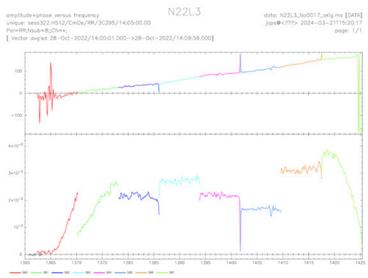
3.3 SOFTWARE CORRELATION

The software correlator SFXC underwent some minor bugfixes when new corners of (observing and correlation) parameter space were explored. Two diverging major branches of development (the main branch and the one supporting coherent dedispersion) have begun to be merged. The reason for splitting the developments was to avoid unnecessary performance degradation when not needed. Obviously, this is not optimal for maintenance, hence the desire to merge, but this may require some effort before being completed due to complexity.

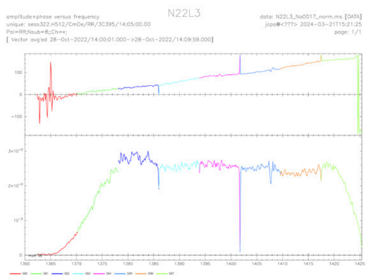
At the end of the year, the VDIF decoder was enhanced to support 8 bit per sample data streams. A target application is recording wide band data at L-band frequencies (1-2 GHz) with sufficient dynamic range that the (strong) RFI present in this band does not saturate (i.e. clips) the signal. The benefit is that RFI can be flagged, and the remainder of the data can be used. When the signal clips, there is no possibility to recover any of the information in the entire recorded band and all data in that band has to be discarded. Initial



Single 64-MHz wide band (Ca-De baseline).



Mixed bandwidth (old) 64 MHz vs 8 x 8 MHz bands.



Mixed bandwidth (new) 64 MHz vs 8 x 8 MHz.

test observations with this mode are expected in 2024.

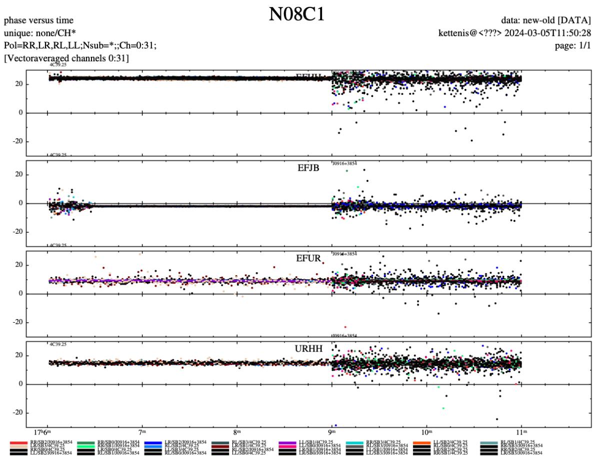
The EVN is an ad-hoc array of disparate technologies, resulting in data typically being recorded in mixed-bandwidth mode: one station may observe a single 64 MHz bands while another observes 2x32 MHz or 4x16 MHz due to hardware limitations. When such data is correlated against each other, the wider bands are split into several narrower bands. Previously, each of those narrow bands was normalised individually, which, especially around band edges or strong RFI, leads to discontinuities in the visibility amplitudes. A new normalisation scheme was created that uses the total power in the original wide band, rather than the power in each narrow band individually, thus eliminating the discontinuities. The graphs on the previous page illustrate the impact and the recovered correctness of the new method by comparing the correlation of a single 64 MHz-wide band (Cambridge to Defford on 3C395 in the EVN's N22L3 NME Scan No0017) versus the old and new normalisation schemes if one of the stations' band is (artificially) split into 8 x 8 MHz bands.

3.4 USER SOFTWARE

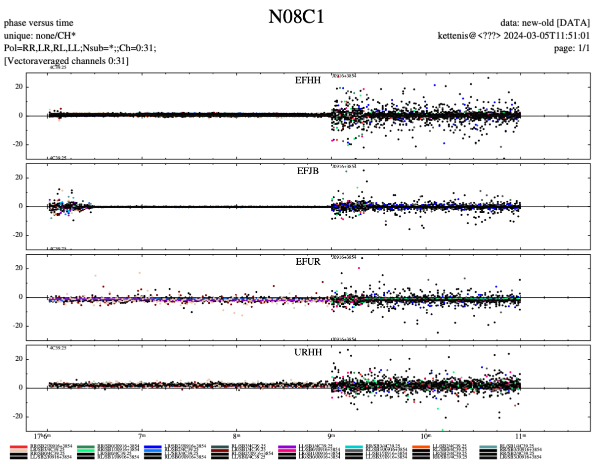
CASA

The Jupyter-CASA kernel was updated to use CASA6.6. A SATOSA proxy (A configurable proxy for translating between different authentication protocols such as SAML2, OpenID Connect and OAuth2,https://github.com/IdentityPython/SATOSA) was installed and configured on JIVE's Jupyterhub server. This proxy is a necessary first step towards enabling support for eduGAIN federation as an identity provider for, e.g., the Jupyterhub login. The proxy will allow our service to (automatically) discover and register the various identity providers supporting authenticating through eduGAIN. Without the proxy, this information must be manually collected and updated case-by-case, which is unwieldy and highly undesirable.

To enable Earth Orientation Parameters (EOPs) handling in CASA, a meta data table format defining a standardised format for storing these in the MeasurementSet was submitted (and accepted) as a pull request for `casacore`. This was a necessary precondition for implementing the EOP-correction task in CASA. This task enables correcting the visibilities for not-too-large EOP differences, for example, when data is correlated with predicted EOPs (such as in real-time observations). The final EOPs are typically only published approximately a month after correlation. The task was completed and already used on EVN data that was (inadvertently) correlated with erroneous EOP parameters and should become available in an upcoming version of CASA. The figure illustrates the phase difference between the data correlated with the right and with (deliberately) different EOPs, before and after running the EOP-correction program. After the EOP correction is applied, the differences vanish, indicating the visibilities are now rotated



Phase differences
new (wrong) - old (correct)



Phase differences
new (corrected) - old (correct)

as if correlated with the correct EOP values.

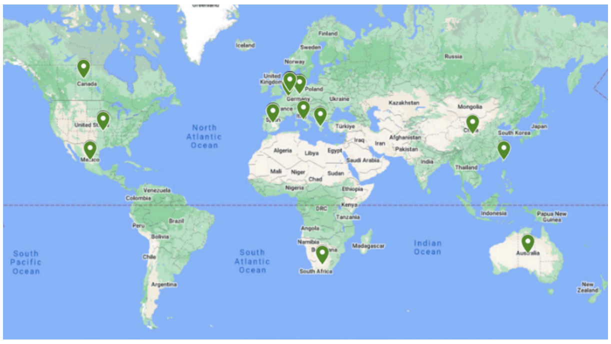
Another pull request to `casacore` implemented support for archival VLBA data in `importfitsidi`, which required special handling based on the values of certain header keywords in the FITS files.

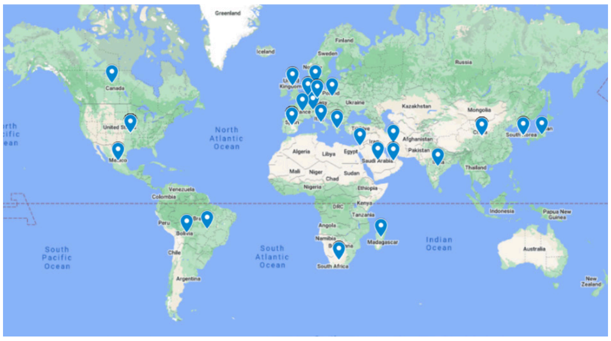
Effort was spent comparing CASA pipelines (*rPicard,* DOI: [10.1051/0004-6361/201935181](https://doi.org/10.1051/0004-6361/201935181) *VLBI_pipeline,* DOI: [10.5281/zenodo.4288760](https://doi.org/10.5281/zenodo.4288760)) for suitability for use by JIVE user support; a pipeline for quickly verifying data quality. Both systems require a lot of manual input, dispersed over different files. Both toolkits would require significant changes to fulfil this requirement, suggesting significant in-house development would be necessary. The lack of such available resources (there are resources, but they are committed otherwise) means this line of development is halted for the moment.

Together with Dr. Iván Martí-Vidal, an effort was started to produce a (C++) version of the (Python) PolConvert code that operates directly on CASA MeasurementSet format. By the end of the year, the C++ version produced calibration coefficients without crashing. Following this, the next steps include the verification and validation of those coefficients. It should be noted that this is not expected to be a user-facing task. The intent is to produce a native CASA tool that correlation centres can run once after correlation to fix mixed H/V and R/L correlated data sets into R/L only data sets.

JIVE hosted a very successful, approximately 100-participant, ORP-sponsored, hybrid CASA VLBI workshop in June 2023. The programme consisted of lectures and hands-on work, with a roughly 50/50 division. The lecture topics included basic VLBI calibration, imaging and self-calibration, as well as more advanced topics like polarisation calibration, mm-VLBI pipelines and wide-field observations.

The workshop had 114 registered participants, with 33 attending in-person, and on the first afternoon, there were almost 55 online participants attending. Due to the large spread in time zones of the online participants, many of them chose to work asynchronously for the remainder of the week. There was active involvement from the online participants during the questions after each talk. The hybrid format worked well, although the hands-on tutorials benefited (by design) the in-person attendants. Despite this limitation, a post-workshop survey on the schools' quality, held amongst all participants (tutors as well as students), indicated that this did not negatively impact the quality of the lectures or recommendations to others to attend a future version.





Global distirbution of participants: in-person (left image, green markers), online (right image, blue markers).

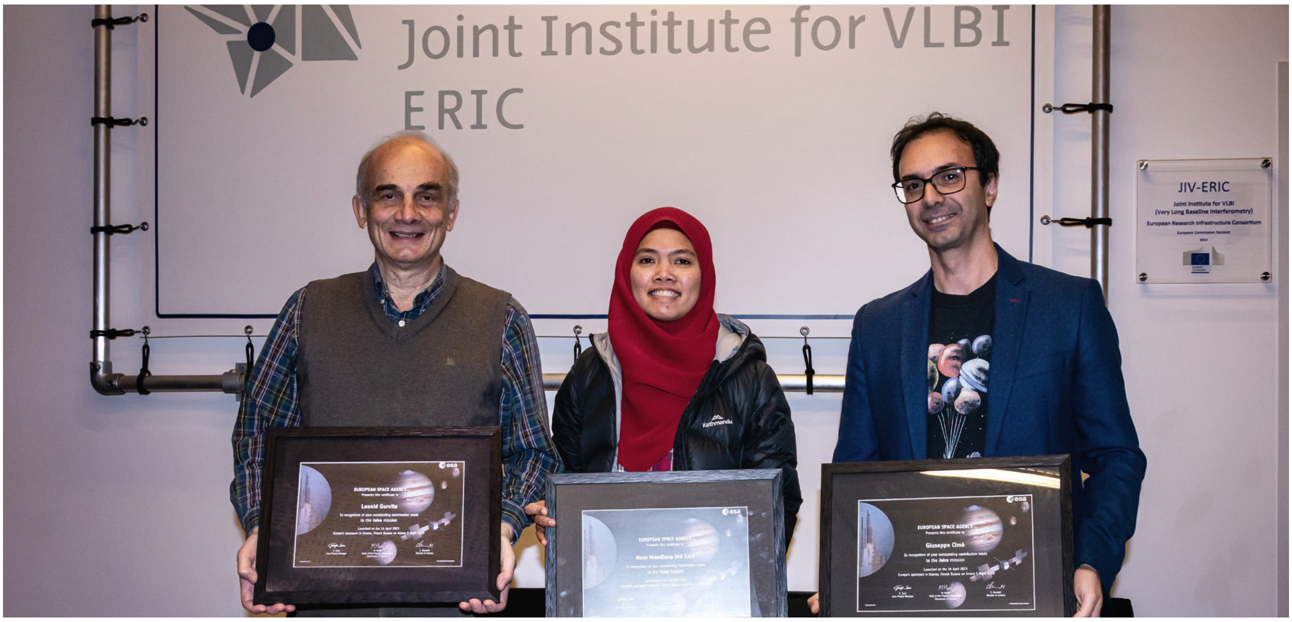
Space and Planetary Science

04

4.1 JIVE'S CONTRIBUTION TO ESA'S JUICE: THE PRIDE EXPERIMENT

The space and planetary science activities at JIVE seek to establish new collaborations to bridge the European and global VLBI community with new potential users. The year 2023 has been marked by significant progress and achievements in JIVE's preparation for the cruise and science phase of the European Space Agency's (ESA) flagship mission JUICE (Jupiter Icy Moons Explorer). In November, three JIVE scientists received an ESA certificate of excellence in recognition of their outstanding contribution to the JUICE mission.

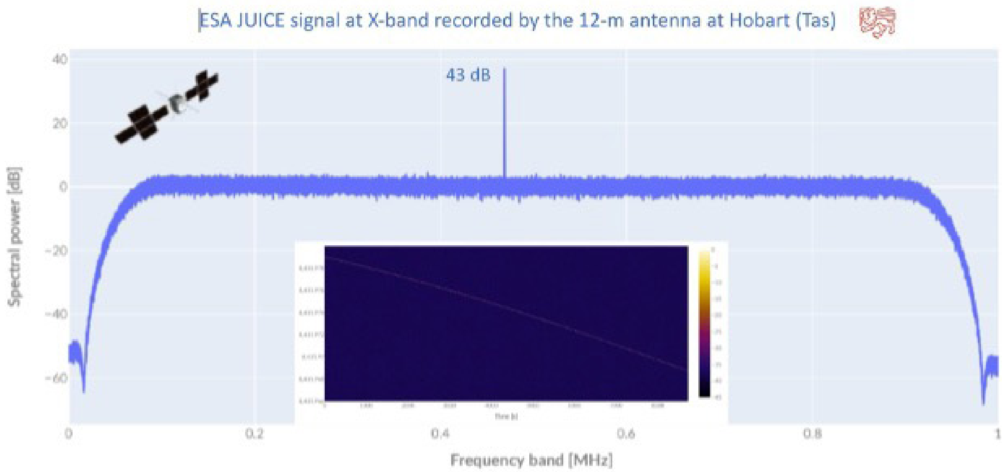
After years of preparations, JUICE successfully launched from Europe's Spaceport in Kourou, French Guiana, on Friday 14 April 2023. JUICE is now on its way to explore the largest giant gas planet in our solar system and its three large ocean-bearing icy moons: Ganymede, Europa and Callisto. The mission will characterise the icy moons as planetary objects and possible habitats, explore Jupiter's complex environment in-depth, and study the wider Jupiter system as an archetype for gas giants across the Universe.



Leonid Gurvits, Mas Said, and Giuseppe Cimò with their ESA awards for their contributions to the PRIDE experiment, a pivotal component of the ESA's JUICE mission. Credit: Silvio Zangarini

One of JUICE's experiments is PRIDE (Planetary Radio Interferometry and Doppler Experiment), led by JIVE. The essence of the experiment is a refinement of the VLBI radio astronomy technique for objects in our solar system. It provides the most accurate measurements of the celestial position of the spacecraft's radio transmitter with a precision measured in tens of meters. In addition, the experiment will supply measurements of the radial velocity of the JUICE spacecraft with the precision of the order of ten micrometres per second.

The development of the PRIDE technique has strengthened JIVE's position as an expertise centre in VLBI: classical VLBI methods have found novel applications for a new set of users for the EVN. JUICE has been observed using the EVN to study the solar wind environment at different solar elongations. JIVE leads this work in collaboration with the University of Tasmania and the Hungarian Research Centre for Astronomy and Earth Sciences.



JUICE signal observed by a 12-metre antenna of the University of Tasmania on the day after the spacecraft launch.

JUICE spacecraft was launched on Friday 14 April 2023 and will enter orbit around Jupiter in 2031. Credit: ESA

4.2 SPACE APPLICATIONS TO FOSTER COLLABORATION

The contribution of VLBI to space science has also been recognised by the planetary science community. In the Netherlands, JIVE is a key partner of the Space and Planetary Science network. A proposal for an expertise network of NWO and NSO (the Dutch Research Council and the Netherlands Space Office) on planetary research has been approved. The institutes in the network will share postdoc positions funded by NWO to investigate how space missions could be used to observe possible traces of life in the solar system. They mainly look at the interior and surface of objects: from Mars to the icy moons of Jupiter.

A fruitful collaboration with Delft University of Technology in the Netherlands has allowed JIVE to co-supervise master and PhD students of the Aerospace Engineering faculty. An outcome of such collaboration is a study on how simultaneous VLBI observations of the upcoming ESA's JUICE and NASA's Europa Clipper missions will improve the estimation solution for the Galilean satellites' ephemerides and related dynamical properties. Another joint experiment between Delft University of Technology and JIVE involves a series of global VLBI observations of NASA's JUNO spacecraft to complement stellar occultation observations for moons' ephemerides. Together with NASA's JUNO science team, represented by its Project Scientist, astronomers of the Observatoire de Paris will use these VLBI measurements to improve significantly the current determination of the ephemerides of Jupiter's moons.

In 2023, a team led by astronomers at the University of York published (10.1088/1361-6382/ace609) the results of the analysis of the observations of the space VLBI radio telescope, the Russian-led mission RadioAstron, to test Einstein's equivalence principle by measurements of the gravitational redshift of spacecraft. According to the equivalence principle, the inertial and gravitational masses are equivalent. One of the approaches for the verification of this equivalence is based on measurements of the effect of gravitational redshift. The Space VLBI mission Radioastron offered a unique opportunity to conduct such an experiment owing to the presence of an active Hydrogen-maser oscillator on board the mission's spacecraft. The experiment involved JIVE astronomers for the technical implementation and the data acquisition, but also for their contribution to the scientific interpretation of the results. A Master's thesis project at the Department of Astrodynamics and Space Missions of the Delft University of Technology, co-supervised at JIVE, addressed statistical properties of the Radioastron gravitational redshift experiment and provided an important input into the overall experimental data evaluation.

The gravitational redshift experiment and the numerous space science applications demonstrate the synergies between VLBI and communities outside the typical radio astronomy user base and they are further testimony to the innovative space applications of VLBI.

Communication and Training

05

5.1 COMMUNICATION AND OUTREACH

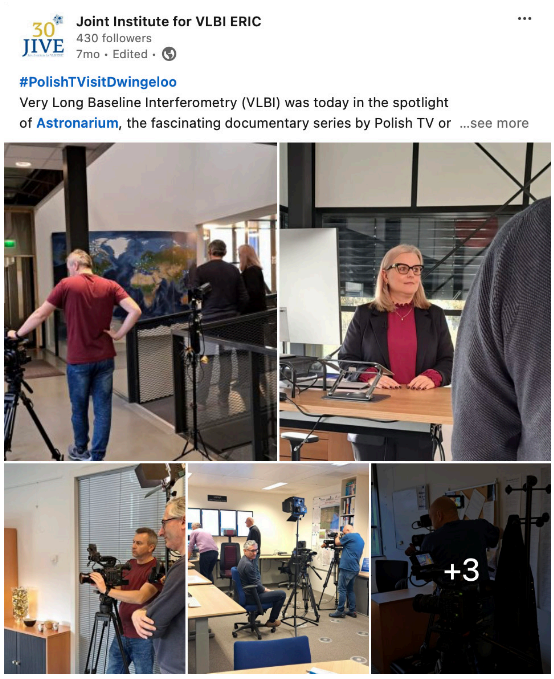
In the final quarter of 2023, JIVE welcomed a new communications officer, Ioanna Kazakou.

To gain a comprehensive understanding of JIVE's multifaceted operations, our communications officer is in constant contact with staff members. These discussions are crucial for generating ideas to inform about our activities and those of our partners within the EVN and the EU projects JIVE contributes to.

Among JIVE's communication priorities is ensuring that the work of our staff members is visible, both within the scientific community and to the wider public. Contributing to the dissemination of the press releases regarding the publications of JIVE's scientists is an essential way to achieve this. A more exceptional initiative was the small ceremony we organised on November 15, 2023, to honour and inform about the role of JIVE's space scientists in the PRIDE experiment of ESA's flagship mission JUICE. With PRIDE, JIVE became the first institute in the Netherlands to have researchers assume the role of Principal Investigator in a planetary science mission, formerly Leonid Gurvits and currently Giuseppe Cimò.

Another key outreach objective is to establish consistent, two-way communication with JIVE's various audiences to foster engagement and feedback.

To this end, JIVE's communications officer makes consistent use of JIVE's platforms such as its website and social media accounts, sharing diverse and high-quality content regarding the activities of JIVE's staff and partners. Additionally, we



build on the success of our EVN newsletter, which continues to be published three times a year.

The content published online is systematically evaluated to assess its impact and refine JIVE's future communication strategies. Additionally, collaborating with staff members, our communications officer reviews the type and content of JIVE's printed outreach material and oversees the creation of new.

Upon assuming her role, JIVE's communications officer handles various outreach tasks related to the projects in which JIVE is a partner. In November, she attended the ORP Consortium Meeting in Garching and reported on it together with the other two members of the project's outreach team. She focuses on curating content and establishing effective communication channels for the Radioblocks project, which JIVE coordinates. Additionally, she plays an active role in the Sharing a Baseline project, a collaboration involving school classes, scientists, and radio astronomy infrastructures across five countries. This project aims to explore how young people can engage with science and connect with peers globally.

An overarching goal for JIVE's outreach efforts is to strengthen what we call the „communication infrastructure" for JIVE, EVN, and the projects we contribute to. This includes building robust contact networks, fostering vibrant communication channels, and adopting processes to enable the creation of high-quality content and information flow.

This will increase visibility and enhance the cohesive role that JIVE holds within its EU projects and the EVN, bringing together telescopes and people for scientific advancement.

This was the idea—and the promise—that we expressed and celebrated on December 21, 2023, when JIVE turned 30. With a DIY seasons card, we invited our partners to create something small but symbolic of the larger achievements we accomplish together every day.

5.2 TRAINING

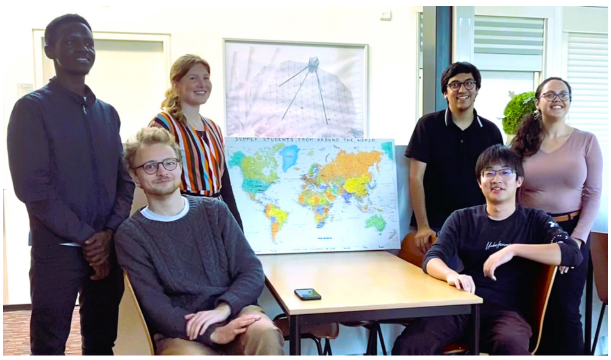
The ASTRON/JIVE summer student programme continued in 2023. JIVE offered two research positions in the fields of fast radio bursts and maser astrometry of water fountain outflows, respectively. A third position, shared with ASTRON, was also offered in the field of jet-driven feedback in low-luminosity radio galaxies.

In June 2023, JIVE organised the CASA-VLBI workshop, aiming to train participants on data processing and imaging of VLBI observations with the CASA package. Fifty participants joined in person (limited by the site), along with a similar number of online participants.

JIVE participated in the ORP 2023 Online Proposal Writing School (under the OPTICON-RadioNet Pilot project, which aims to entangle the optical and radio communities), training astronomers in both domains on how to submit observing proposals for both optical and radio facilities, including the EVN.

Finally, during 2023, JIVE started organising the following events scheduled for 2024: first, the second online training for using the EVN, similar to the one that took place in 2022. This training guides participants through the different steps to allow them to prepare and submit an observing proposal as well as the scheduling of observations. Second, the restart of the online EVN Seminars, where speakers make a wide range of topics related to VLBI accessible to the broad astronomical community, shedding light on the role that VLBI can play in all these fields.

Snapshots from the third CASA VLBI workshop, organised by JIVE.



The ASTRON/JIVE summer students.

Operations

06

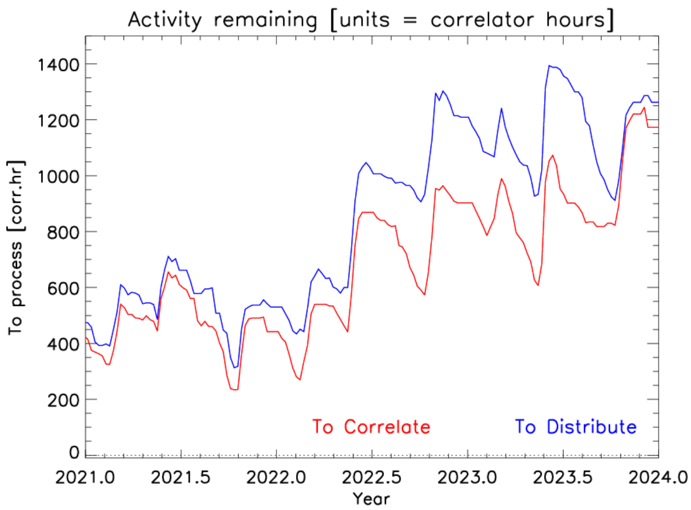
6.1 CORRELATION

The core of JIVE's service is the correlation of astronomers' observations conducted with the EVN and global VLBI arrays. The table below summarises experiments that were correlated or distributed in 2023. For a detailed list of the user experiments, see Section 9.5, "Correlator Activity".

	USER EXPERIMENTS			TEST & NETWORK MONITORING		
	Number Experiments	**Network Hours**	**Correlator Hours**	**Number Experiments**	**Network Hours**	**Correlator Hours**
Correlated	117	950	1157	17	49	49
Distributed	145	1116	1373	14	45	45
e-EVN experiments	24	165.5	165.5			
e-EVN ToO/ triggers	7	43.5	43.5			

Summary of experiments for which correlation or distribution to PIs finished in 2023. Here, „network hours" sum the total duration of experiments, while „correlator hours" are the network hours multiplied by any multiple correlation passes required—the actual time to correlate can be several times larger than this for the more complex correlations.

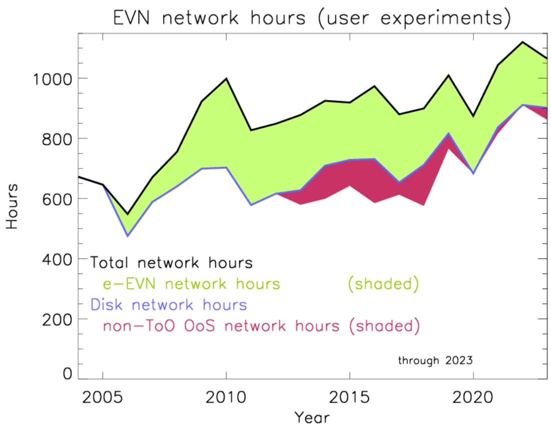
The number of correlator hours completed in 2023 was 1206, the third highest since shifting to the SFXC correlator in 2011. The amount of correlation to distribute built up towards mid-year, but was largely worked through by the end of the year.

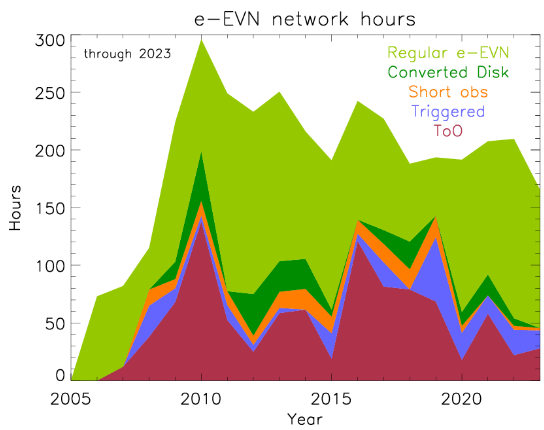


The size of the correlator queue at different stages in the processing cycle. The red line shows the number of correlator hours that remain to be correlated. The blue line shows the number of correlator hours in experiments whose data remain to be distributed to the observing teams.

The left-hand panel of the figure below traces the evolution of the annual EVN network hours. 2023 saw the second highest amount ever (1065.5) and the past three years have each been higher than any prior to 2021. Note that 434.5 uncorrelated network hours from the new EVN-lite pilot are not included in this plot (see the 2023 highlights).

The right-hand panel focuses on e-EVN experiments, showing their division among the proposal categories. Total e-EVN network hours fell off in 2023, but the amount of target-of-opportunity and triggered e-VLBI observing maintained their level seen in 2022.





Left: Annual EVN network hours, with separate colour-coded areas for different categories of user observations, from top to bottom: real-time e-EVN (light green), non-ToO out-of-session disk-based (dark red), and „traditional" disk-based (white). Right: e-EVN network hours, with separate colour-coded areas for different proposal categories, from bottom to top: target-of-opportunity, triggered, short observations, converted from disk, and regular.

A sampling of highlights from 2023:

— The first ever EVN „service" observation took place during the June e-EVN day, observing SN2023IXF during a two-hour gap in the schedule. This was a core-collapse supernova discovered on 19 May, but which was not covered by any existing triggered proposal or a new ToO one.

— Session 2 set a record for generating the most correlator hours in a single session at 502 (there were six spectral line observations, three of which requiring three passes – and one of those comprising 48 network hours).

— There were seven 4 Gbps user observations in the third session of 2023. The first global 4 Gbps observation occurred in the second session, followed by two more in the third (all at 6cm); a new frequency tuning configuration was designed to accommodate the more limited LO-setting possibilities in the RDBE2 back-end used by NRAO stations.

— There were ten EVN target of opportunity observations (five via e-EVN) and two e-EVN trigger observations, together arising from nine proposals. These projects covered scientific topics ranging from super-massive binary black hole candidates (three different projects), a new core-collapse supernova, the evolution of a relatively close-by „long" GRB, jet ejections from an AGN undergoing a state transition, an accretion event in a high-mass proto-stellar object (via methanol masers), and whether jets in blazars could be associated with neutrinos detected by IceCube (two different targets).

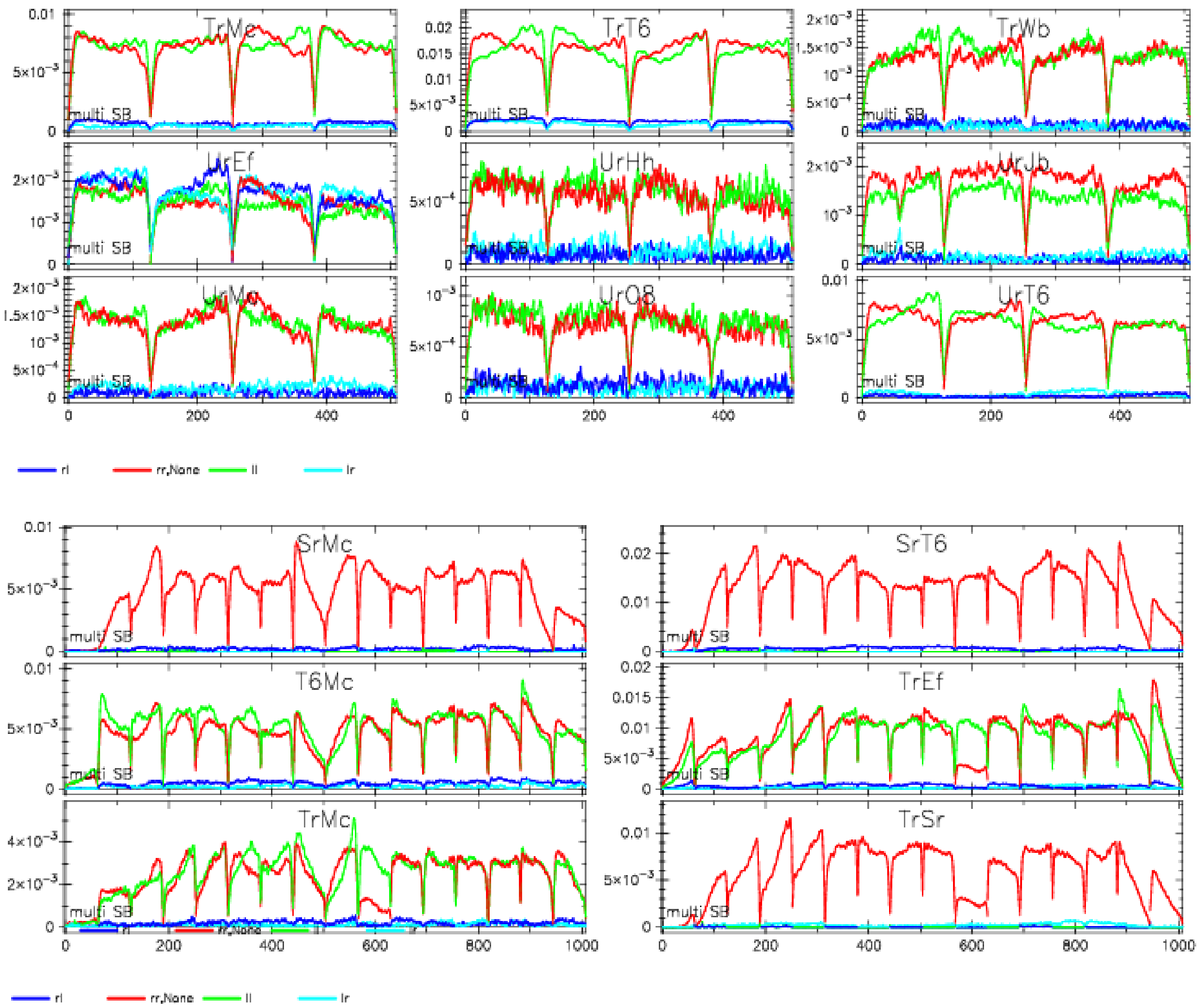
— There were four FRB triggers from the ongoing projects based primarily on shadowing CHIME (EK053A-D), covering two different FRB targets. These observations for the first time were conducted under the pilot EVN-lite concept. Correlation is triggered if a burst is detected by the tracking facilities. The underlying EVN-lite programme comprised 48 observations and 447.5 network hours, resulting in the four triggered correlations comprising 14 correlator hours.

6.2 EVN SUPPORT

JIVE coordinated various tests of new receivers/ back-ends at EVN stations. Support scientists investigated a quasi-periodic phase jitter at Torún over the past few sessions and, together with station technical staff, conducted tests during test periods with e-EVN days to see how the behaviour reacts to various equipment change-outs at the telescope. In the end, the „new" clock distribution module was the culprit; the behaviour was not tied to either the local nor the remote maser.

In the third session, Urumqi participated for the first time at 5cm and Sardinia for the first time 6cm. The figure below shows some baselines from the NME at each band. Note that at 5cm Effelseberg (Ef) uses a linearly polarized receiver, and at 6cm the testing uncovered an issue with one of the CorBoards being used in Sardinia's DBBC (leading to fringes only in one polarisation).

JIVE coordinated inclusion of Usuda (64m) and Misasa (54m) telescopes in Japan into the 3.6 cm NME during the third session. This was the first time ever Misasa had observed in an EVN context and the first time for Usuda at this frequency. The data from these stations had to be translated into a format that SFXC can use prior to shipping. This process had not yet run its course by the end of the year, but fringes have been seen in the new year.



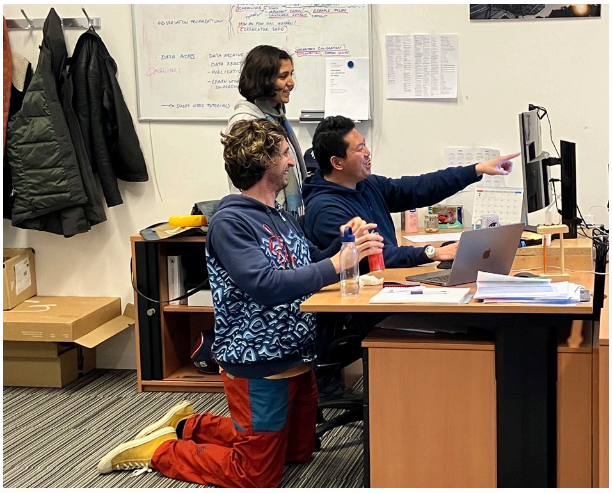
Top: Amplitude versus time for some baselines to Urumqi from their first observation at 5cm. Some other baselines are also included for comparison. Bottom: Similarly for some baselines to Sardinia from their first observation at 6cm.

6.3 USER SUPPORT

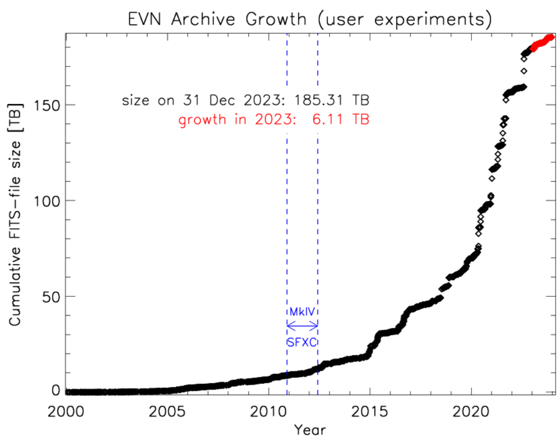
JIVE provides support in all stages of a user's EVN observation, from proposal definition to data analysis, including providing experiment-specific set-up templates when needed to track the evolving configurations of equipment at EVN stations, and making corresponding updates to the pySCHED catalogs. There were seven first-time PIs in 2023 observations; five of them were female and three of those were students. Countries represented include Finland, Germany (2), Italy, the Netherlands, Poland, and China. The first-time users from Finland, Italy, and the Netherlands were from universities rather than the country's EVN-institute, as was one of the two first-time PIs from Germany. The observations from their „first-time PI" projects accounted for 202.5 network hours in 2023 (19% of the total for the year).

JIVE is fully open now to host data reduction visits and to help working on proposals in person at the institute. A number of PIs visited JIVE in 2023: Patrik Veres and Björn Adebahr (U. Bochum, Germany), Stefano Giarratana (IRA-INAF, Italy), Krisztina Gabányi (ELTE, Budapest, Hungary), Sina Chen (Technion, Israel), Ranieri Diego Baldi (IRA-INAF, Italy) and including the JIVE founding director Richard Schilizzi. The AstroFlash Group VLBI trainees from UvA (Amsterdam) spent a week in JIVE as well. Dr. Iván Martí-Vidal spent some time with us to work jointly with support staff and R&D to improve PolConvert, a tool to fix polarisation products (and correct for polarisation leakage) for some of the telescopes in EVN data.

The EVN Archive remains the entry point for users to retrieve their correlated EVN data, and provides open access to others following the one-year proprietary period (six months for ToO projects). The total size of user-experiment FITS files in the Archive reached over 185 TB by the end of 2023, increasing by 3.4% during the year.



JIVE support scientists Dr. Gábor Orosz (left), Dr. Suma Murthy (middle) and Dr. Junghwan Oh (right) at work.



Growth of user experiments in the EVN Archive. Experiments archived in 2023 are plotted in red. Vertical dashed lines show the transition period between the MkIV and SFXC correlators.

07 Finances

7.1 JIVE FINANCIAL REPORT

BALANCE (AFTER ALLOCATION OF RESULTS)

	31 DECEMBER 2023	31 DECEMBER 2022
ASSETS	in €	in €
TANGIBLE FIXED ASSETS		
Tangible fixed assets	92,559	53,712
Total of tangible fixed assets	*92,559*	*53,712*
CURRENT ASSETS		
Work in process	0	0
Receivables	314,346	465,036
Cash at bank	2,800,464	3,124,496
Total of current assets	*3,114,810*	*3,589,532*
TOTAL ASSETS	**3,207,369**	**3,643,244**

	31 DECEMBER 2023	31 DECEMBER 2022
LIABILITIES	in €	in €
CAPITAL		
General reserve	1,511,454	1,537,405
Designated funds	300,000	300,000
Total capital	*1,811,454*	*1,837,405*
OTHER LIABILITIES		
Short term debts	1,395,915	1,805,839
Total of current liabilities	*1,395,915*	*1,805,839*
TOTAL LIABILITIES	**3,207,369**	**3,643,244**

STATEMENT OF PROFIT AND LOSS

	2023			2022
	BUDGET	**ACTUAL**	**DIFFERENCE**	**ACTUAL**
REVENUES	in €	in €	in €	in €
INCOME				
Contributions/subsidies third parties	2,479,087	2,494,311	15,224	2,104,160
Interest	0	117,648	117,648	9,885
Other	245,857	271,733	25,876	266,190
Total income	*2,724,944*	*2,883,692*	*158,748*	*2,380,235*
TOTAL REVENUES	**2,724,944**	**2,883,692**	**158,748**	**2,380,235**

	2023			2022
	BUDGET	**ACTUAL**	**DIFFERENCE**	**ACTUAL**
EXPENDITURES	in €	in €	in €	in €
OPERATIONS				
Grants/expenditures	2,936,322	2,909,642	-26,680	2,737,924
Total operations	*2,936,322*	*2,909,642*	*-26,680*	*2,737,924*
TOTAL EXPENDITURES	**2,936,322**	**2,909,642**	**-26,680**	**2,737,924**

RESULT	**-211,378**	**-25,950**	**185,428**	**-357,689**

EC Projects

08

H2020 OPTICON-RADIONET PILOT

Launched in 2021 and funded by the EU H2020 programme, the Opticon RadioNet Pilot (ORP) aims to enable astrophysical discoveries with a comprehensive set of Research Infrastructures across the domains of optical and radio astronomy.

From November 21 to 23, the Opticon RadioNet Pilot project hosted its Consortium Meeting at the European Southern Observatory Headquarters in Garching, Munich. A rich schedule of sessions, coupled with meaningful discussions on the fringes of the official program, contributed to a dynamic assessment of experiences from the last 15 months and a promising plan for the next 18 months to come.

As a partner in the ORP, JIVE actively participated in the meeting with a delegation of four people, showcasing its multidimensional involvement with the project. Notably, the director of JIVE, Aga Słowikowska, holds a key role as the Vice Chairperson of the ORP Board.

One of the highlights of the meeting was the progress on the ORP multi-facility proposal submission tool that allows observations using more than one astronomical facility for the same scientific project.

HORIZON EUROPE ERIC FORUM

The ERIC Forum project aims to strengthen the coordination within the European Research Infrastructure Consortium (ERIC) community and enhance collaboration between partners. The strategic approach of the ERIC Forum contributes to addressing critical challenges, developing best practices and framing the necessary knowledge to support ERICs in various aspects. Moreover, this will contribute to building the brand identity of ERICs as an important body and stakeholder in consultation of related policy action.

Participating in the ERIC Forum has allowed JIVE to explore a network of infrastructures that share common challenges, such as long-term sustainability, reporting, VAT exemption practices, and training of governance representatives. JIVE had a prominent role in the project, with Paco Colomer (JIVE director at the time) serving as Chair of the Forum.

HORIZON EUROPE RADIOBLOCKS

The Radioblocks project is a collaborative initiative aimed at advancing Europe's position in radio astronomy research. It brings together leading institutes, industry partners, and academia to develop innovative solutions for shared challenges in radio astronomy. The project involves 32 partners from 12 countries.

Key objectives include the development of new components for sensitive, wideband receivers and digital receivers to improve system temperature, bandwidth, and field-of-view. The project also focuses on data transport and correlation, aiming to provide efficient signal processing tools using commercially available technology. It aspires to offer a modular and open-source data processing toolkit for swift and scalable analysis of large-volume data products.

Radioblocks started in March 2023. The project is on track to exceed current standards in radio astronomy instrumentation and technology.

RADIO BLOCKS

After the project's kick-off meeting on March 29, Radioblocks partners began working on key components for the analog signal chain, which are already in the manufacturing phase. Efforts included widening the spectral coverage and enhancing wide-field imaging.

A technological review on the advantages of using GPUs for the next generation correlators was carried out and we already see progress in building the toolbox for astronomers to use across various instruments, enabling groundbreaking scientific discoveries.

Participants of the Radioblocks kick-off meeting on March 29, 2023.

Tables and Metrics

09

9.1 JIVE COUNCIL

MEMBER REPRESENTATIVES

Dr. Patrick Charlot	*Laboratoire d'Astrophysique de Bordeaux,* Pessac, France
Dr. Chiara Ferrari	*Observatoire de la Côte d'Azur*, France
Dr. Tiziana Venturi	*Istituto di Radioastronomia (IRA-INAF)*, Italy
Dr. Grazia Pavoncello	*Ministero dell'Istruzione, dell'Università e della Ricerca,* Roma, Italy
Dr. Vladislavs Bezrukovs	*Ventspils University of Applied Sciences,* Ventspils, Latvia
Mr. Jānis Paiders	*Ministry of Education and Science,* Latvia
Dr. Jessica Dempsey	*ASTRON,* Dwingeloo, the Netherlands (Vice Chair)
Mrs. Saskia Matheussen	*NWO,* Den Haag, the Netherlands
Dr. José Antonio López Fernández	*Instituto Geográfico Nacional, MITMA*, Madrid, Spain
Dr. Pablo de Vicente	*Instituto Geográfico Nacional, MITMA,* Madrid, Spain (Chair)
Dr. Alexander Burgman	*Swedish Research Council,* Stockholm, Sweden
Prof John Conway	*Onsala Space Observatory,* Onsala, Sweden
Prof. Simon Garrington	*Jodrell Bank Centre for Astrophysics,* Manchester, UK
Dr. Jenny Hiscock	*Science and Technology Facilities Council,* Swindon, UK

ASSOCIATED RESEARCH INSTITUTES REPRESENTATIVES

Prof. Zhinqiang Shen	*Shanghai Astronomical Observatory, NAOC,* Shanghai, China
Dr. Fernando Camilo	*National Research Foundation, South African Radio Astronomy Observatory,* Cape Town, South Africa
Prof. Anton Zensus	*Max-Planck-Institut für Radioastronomie,* Bonn, Germany

9.2 JIVE PERSONNEL

Mr. Paul Boven	*Network Systems Engineer*
Mr. Wybren Buijs	*Linux/Netwerk Specialist*
Dr. Bob Campbell*	*Head of Science Operations*
Dr. Giuseppe Cimò*	*Head of Space Science and Innovative Applications Group*
Drs. Bob Eldering	*Software Engineer*
Mr. Bert Harms	*Chief Operator*
Ioanna Kazakou	*Communications Officer (from 1 september 2023)*
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. Waleed Madkour	*CRAF Frequency Manager*
Dr. Benito Marcote Martin	*Support Scientist*
Dr. Mas Md Said	*Postdoctoral Near-field VLBI Support Scientist*
Dr. Suma Murthy	*Support Scientist*
Dr. Junghwan Oh	*Support Scientist*
Dr. Gábor Orosz	*Support Scientist*
Dr. Zsolt Paragi*	*Head of User Support*
Dr. Agnieszka Słowikowska*	*Director*
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. Marjolein Verkouter*	*Head Technical Operations and R&D*

** JIVE Management Team member*

9.3 EDUCATIONAL RESPONSIBILITIES

SECONDARY AFFILIATIONS

Agnieszka Słowikowska	affiliated with *Nicolaus Copernicus University*, Toruń, Poland
Leonid Gurvits	affiliated with the *Department of Astrodynamics and Space Missions, Faculty of Aerospace Engineering, Delft University of Technology*, the Netherlands
Huib Jan van Langevelde	affiliated with *Sterrewacht Leiden, Leiden University*, the Netherlands and adjunct staff at *University of New Mexico*

PHD SUPERVISION

Paul Boven	H.J. van Langevelde (expected completion in 2025)
Vidhya Pallichadath	L.I. Gurvits and L.L.A. Vermeersen (expected completion in 2025)

9.4 VISITORS TO JIVE

NAME	INSTITUTE	PERIOD	HOST
Y. Hagiwara	*Tokyo, University, Japan*	26 April 2022- 30 March 2023	Paragi
F. Colomer	*Ministerio de Ciencia, Innovación y Universidades, Spain*	9-11 January	Słowikowska
B. Adebahr	*Ruhr-Universitaet Bochum, Astronomisches Institut*	17-18 January	Paragi
P. Veres	*Ruhr-Universitaet Bochum, Astronomisches Institut*	17-18 January	Paragi
I. Martí-Vidal	*University of Valencia, Spain*	13-17 February	Marcote
K. Gabányi	*ELTE, Budapest, Hungary*	25-27 January	Paragi
D. Haggard	*McGill University/McGill Space Institute, Canada*	8-9 March	van Langevelde
S. Giarratana	*INAF-IRA, Italy*	13-24 March	Marcote
S. Chen	*Technion, Haifa, Israel*	11-27 September	Paragi
S. Breen	*SKA Observatory, UK*	6-8 November	Slowikowska
R. Baldi	*INAF-IRA, Italy*	6-10 November	Oh
S. Frey	*Konkoly Observatory, Budapest, Hungary*	6-10 November	Cimò
J. Fogassy	*Konkoly Observatory, Budapest, Hungary*	6-10 November	Cimò
K. Perger	*Konkoly Observatory, Budapest, Hungary*	6-10 November	Cimò
J. Radcliffe	*University of Pretoria, South Africa*	6-14 November	van Bemmel
C. García Miró	*Observatory de Yebes, Spain*	9-16 November	van Bemmel
E. Bempong-Manful	*Manchester University, UK*	14-17 November	van Bemmel
W. Baan	*Xinjiang Astronomical Observatory, Urumqi, China*	19 December 2023- 26 January 2024	Paragi

9.5 CORRELATOR ACTIVITY

User experiments with correlation or distribution completed in 2023. In column „Observation Month/Session”, in-session observations are specified by the EVN session in which they are observed (s.N/YY, for the Nth session of year YY); e-VLBI and out-of-session observations are specified by the month and year in which they are observed.

PROJECT CODE	OBSERVATION MONTH/ SESSION	PI	TITLE
EA065K	Feb.23	Atri	*Identifying the true nature of compact steep spectrum sources*
EA067	s.2/23	Aberfelds	*Studies of three variable methanol masers in HMSFRs*
EA069A-B	s.2/23	An	*Is SRGE J170245.3+130104 a blazar?*
EA071A	Nov.23	An	*Jet proper motion in two radio quiet quasars*
EB086B	s.1/22	Brooks	*Revealing a sub-kpc-scale binary AGN*
EB092A-F	s.3/22	Baczko	*The collimation region in nearby Radio Galaxies*
EB096B-H	s.2/22	Bhandari	*A sharper view of the local environment of localized fast radio bursts*
EB096I	Oct.22	Bhandari	*A sharper view of the local environment of localized fast radio bursts*
EB096J-L	s.3/22	Bhandari	*A sharper view of the local environment of localized fast radio bursts*
EB096M	Nov.22	Bhandari	*A sharper view of the local environment of localized fast radio bursts*
EB100A	s.2/23	Bhandari	*Long-term monitoring of FRB20121102A and its associated persistent radio source*
EC073A-B	s.2/22	Cao	*Towards solving the X-ray puzzle of misaligned high-redshift radio quasars*
EC088A-D	s.3/22	Chen	*Resolving powerful nuclear outflows in radio-quiet quasars with EVN*
EC088E-H	s.1/23	Chen	*Resolving powerful nuclear outflows in radio-quiet quasars with EVN*
EC089A-B	s.3/22	Chen	*A gamma-ray and infrared flare towards an RQ NLS1 1H 1934-063?*
EC092	s.2/23	Charlot	*Geodesy astrometry and high-resolution imaging with the EVN at K-band*

EC095	Oct.23	Cao	*Proper motion of a Galactic BHXB candidate AT2019wey with the EVN*
ED050B	s.1/23	De Becker	*Gradual revival of synchrotron radiation from the massive binary WR125*
EG110A-B	s.1/22	Gabanyi	*Do Te-REXes have jets?*
EG119B	s.3/22	Giroletti	*Finding hidden relativistic jets at z>5*
EG123B	Feb.23	Gawronski	*Ross 15 - a possible planetary system around a nearby red dwarf*
EG123C	Apr.23	Gawronski	*Ross 15 - a possible planetary system around a nearby red dwarf*
EG123D	Jun.23	Gawronski	*Ross 15 - a possible planetary system around a nearby red dwarf*
EH040B	s.1/22	Hartley	*Jet speeds in a radio quiet quasar*
EH042A-B.	s.2/23	Hovatta	*Spatially resolved near-infrared and EVN observations of two blazars*
EJ027A-D	s.1/23	Jackson	*Lensed radio-quiet quasars and the origin of their radio emission*
EK051C	Aug.22	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs III*
EK051E-F	Sep.22	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs III*
EK051G-H	Oct.22	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs III*
EK052A-D	s.2/23	Kobak	*g-factor of 6.7 GHz methanol maser via polarization observations*
EK053A-B	Feb.23	Kirsten	*Localising repeating FRBs with EVN-lite*
EK053C-D	Sep.23	Kirsten	*Localising repeating FRBs with EVN-lite*
EL062A	May.23	Liu	*Radio emission from the radio-weak quasars at the reionization era*
EL064A-B	s.3/22	An	*Exploring the jet in a z > 6 blazar DES J0322-18*
EL065A-B	s.1/23	Lunz	*Enhancing the VLBI/Gaia alignment with new observations of radio stars*
EL065C	s.2/23	Lunz	*Enhancing the VLBI/Gaia alignment with new observations of radio stars*
EL068	s.2/23	Lemon	*A puzzling new quad quasar: flux ratio anomalies and extreme microlensing*

EM155A-B	s.1/22	Mueller	*Multiresolution imaging of the innermost wisp region of the Crab Nebula*
EM156C	s.3/22	Miller-Jones	*The outflow speed of a long-lived thermal tidal disruption event*
EM165A	s.3/23	Marcote	*Tightening the origin of the gamma-ray binary HESS J1832-093*
EM166A-C	s.3/22	Motta	*Looking for a nova-like shell around the black hole X-ray binary V404 Cyg*
EM168A-B	s.1/23	Marti	*A lensing Algol-type binary?*
EM169	s.1/23	Murthy	*Radio galaxies in the baby Universe*
EM170A	s.1/23	Miller-Jones	*Direct measurement of the jet Lorentz factor in a tidal disruption event*
EN011D	Apr.23	Nanci	*Are blazar jets associated with IceCube neutrinos?*
EN011E	Oct.23	Nanci	*Are blazar jets associated with IceCube neutrinos?*
EO019B	s.1/23	OFionnagain	*The stellar wind of lambda And a RS CVn binary system*
EP124A-B	s.3/22	Perez-Torres	*From the detection of nuclear transients to testing TDE jet physics*
EP125A	May.23	Perez-Torres	*The puzzling companion of HD 220242: A brown dwarf in the desert or a star?*
EP125B	s.2/23.	Perez-Torres	*The puzzling companion of HD 220242: A brown dwarf in the desert or a star?*
ES103A-F	s.3/22	Y.Shu	*Confirmation of close dual quasars at z=0.6-2.5*
ES103G-J	s.1/23	Y.Shu	*Confirmation of close dual quasars at z=0.6-2.5*
ES104	s.3/22	X.Shu	*Resolving possibly evolved radio jet ejections associated with AGN outburst*
ES106A-B	s.1/23	X.Shu	*Mas-scale imaging of transient radio emission from a candidate "turn-on" AGN*
ES107	s.2/23	X.Shu	*Fast jet ejections towards the end of an AGN state-transition*
ET048A-C	s.1/22	Titov	*Imaging extragalactic radio sources with extremely large radio-optical offsets*
EV024A	s.1/22	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*
EV024C	s.2/22	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*

EV024D	Oct.22	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*
EV024F	Jan.23	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*
EV024G	s.1/23	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*
EV024H	s.2/23	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*
EV024J	Dec.23	Vaddi	*Orbital period evolution of candidate supermassive BH binary 3C66B*
EV027	s.2/23	Veres	*Radio structure of a TDE coincident with a high-energy neutrino*
EW022A	s.1/22	Wu	*EVN observations of OH megamaser galaxy IRAS 17526+3253*
EW029A-D	s.2/22	Williams	*Monitoring the old discovering the new; mas-scale radio emission in M82*
EW031A	Feb.23	H.Wang	*Deep-Dive into Gaia Varstrometry Selected Dual Quasar Candidates with EVN*
EW031B	Mar.23	H.Wang	*Deep-Dive into Gaia Varstrometry Selected Dual Quasar Candidates with EVN*
EW031C	Jun.23	H.Wang	*Deep-Dive into Gaia Varstrometry Selected Dual Quasar Candidates with EVN*
EW034	Mar.23	A.Wang	*Pc-scale jet of the radio-quiet quasar Mrk~110*
GG087A	s.2/23	Giarratana	*Structure and the dynamics of the outstanding GRB 221009A*
GM079	s.1/22	MacDonald	*Nature of the jet's magnetic field within PKS1510-089*
GM081C	s.2/22	Murthy	*Radio-AGN feedback: an extension to low-power sources*
GM081D-E	s.3/22	Murthy	*Radio-AGN feedback: an extension to low-power sources*
GP060	s.3/22	Park	*Are all AGN jets intrinsically limb-brightened on parsec scales?*
GV028A-C.	s.1/23	Varenius	*Starburst galaxy Arp 220*
RA006	Feb.23	An	*Physical origin of the nascent outflow in J1430+2303*
RB008	Jun.23	Bruni	*1ES 1927+654: constraining the origin of extreme radio variability*

RG013A	Oct.22	Giarratana	*GRB221009A*
RG013B-C	Nov.22	Giarratana	*GRB221009A*
RG013D-E	Feb.23	Giarratana	*GRB221009A*
RG013F	Jun.23	Giarratana	*GRB221009A*
RM019	Oct.23	Miller-Jones	*Jet launching in the black hole candidate X-ray binary Swift J1727.8-1613*
RSY09	s.3/22	Yang	*Candidate calibrator near Cyg X-3*
RSY10	Oct.23	Yang	*Nearby calibrator for NGC 1068*
SE001A	Jun.23	EVN	*SN2023IXF*

9.6 JIVE STAFF PUBLICATIONS

JOURNAL ARTICLES

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— Hudson, B., **Gurvits, L. I.**, Wielgus, M., et al. (including **Paragi, Z.**): *Orbital configurations of spaceborne interferometers for studying photon rings of supermassive black holes*, 2023, Acta Astronautica, 213, 693-681

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— Roelofs, F., Johnson, M. D., Chael, A., et al. (including **Kettenis, M., Oh, J., Small, D., van Bemmel, I., van Langevelde, H. J.**): *Polarimetric Geometric Modeling for mm-VLBI Observations of Black Holes*, 2023, The Astrophysical Journal, 957,-L21

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— Doeleman, S. S., Barrett, J., Blackburn, L., Bouman, K. L., et al. (including **Kettenis, M.**): *Reference Array and Design Consideration for the Next-Generation Event Horizon Telescope*, 2023, Galaxies, 11,-107

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— Gómez, J. F., Torrelles, J. M., Girart, J. M., et al. (including van **Langevelde, H. J.**): *An SiO Toroid and Wide-angle Outflow Associated with the Massive Protostar W75N(B)-VLA2*, 2023, The Astrophysical Journal, 956,-L45

— Fletcher, L. N., Cavalié, T., Grassi, D., et al. (including **Gurvits, L. I.**): *Jupiter Science Enabled by ESA's Jupiter Icy Moons Explorer*, 2023, Space Science Reviews, 219,-53

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— Nakagawa, A., Morita, A., Sakai, N., et al. (including **Orosz, G.**): *Astrometric VLBI observations of H₂O masers in an extreme OH/IR star candidate NSV 17351*, 2023, Publications of the Astronomical Society of Japan, 75, 545-529

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Acronyms and Abbreviations

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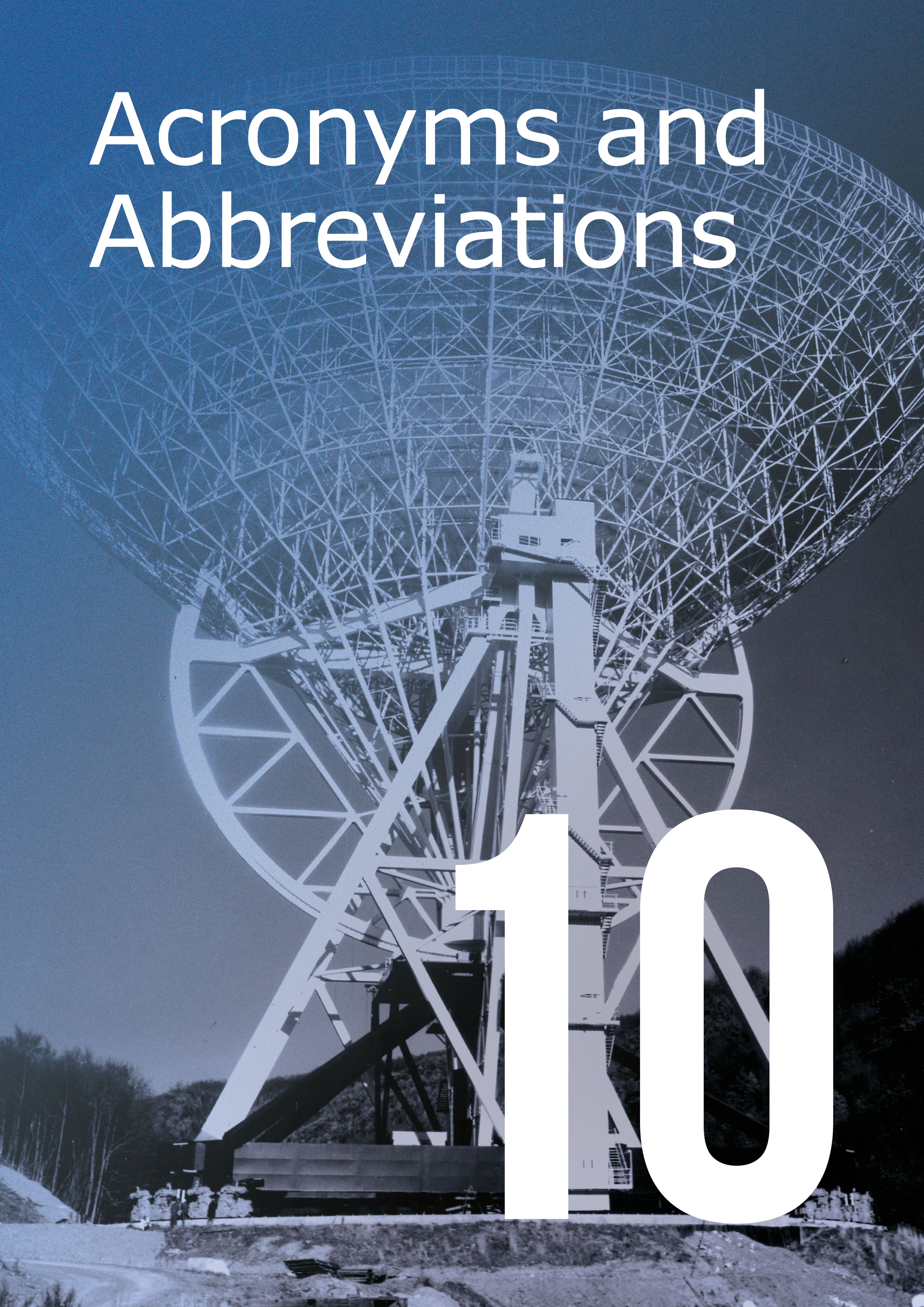

AGN	*Active Galactic Nucleus/Nuclei*
ALMA	*Atacama Large Millimetre/submillimetre Array*
ASTRON	*Netherlands Institute for Radio Astronomy*
BH	*Black Hole*
BHTOM	*Black Hole Target Observation Manager*
CHIME	*Canadian Hydrogen Intensity Mapping Experiment*
CASA	*Common Astronomy Software Applications*
CNRS	*Centre National de la Recherche Scientifique,* *National Centre for Scientific Research (France)*
CPU	*Central Processing Unit*
CRAF	*Committee on Radio Astronomy Frequencies*
DBBC	*Digital Base Band Converter*
DOI	*Digital Object Identifier*
e-EVN	*electronic (realtime) European VLBI Network*
EHT	*Event Horizon Telescope*
EOP	*Earth Orientation Parameter*
ERIC	*European Research Infrastructure Consortium*
ESA	*European Space Agency*
ESO	*European Southern Observatory*
e-VLBI	*electronic Very Long Baseline Interferometry* *(implies real-time correlation: e-EVN)*
EVN	*European VLBI Network*
FAST	*Five-hundred-meter Aperture Spherical Telescope (China)*
FITS	*Flexible Image Transport System*
FRB	*Fast Radio Burst*
Gbps	*Gigabit per second*
GDPR	*General Data Protection Regulation*
GHz	*Gigahertz*
GPU	*Graphics Processing Unit*

GRB	*Gamma Ray Burst*
IAA-CSIC	*Instituto de Astrofísica de Andalucía, (Spain)*
ITU	*International Telecommunication Union*
H2020	*Horizon 2020 EC Funding Programme*
HDD	*Hard Disk Drive*
IGN	*Instituto Geográfico Nacional, National Geographic Institute (Spain)*
IGO	*Intergovernmental Organization*
INAF	*Istituto Nazionale di Astrofisica, Italian National Institute of Astrophysics*
INAF-IRA	*Istituto di Radio Astronomia, Institute of Radio Astronomy (Italy)*
JUICE	*JUpiter ICy moons Explorer*
LOFAR	*Low Frequency Array*
LCO	*Las Cumbres Observatory*
LTO	*Linear Tape-Open*
M87	*Messier 87*
Mbps	*Megabit per second*
MHz	*Megahertz*
MITMA	*Ministerio de Transportes y Movilidad Sostenible (Spain)*
MPI	*Message Passing Interface*
MPIfR	*Max-Planck-Institut für Radioastronomie*
NAOC	*National Astronomical Observatories of the Chinese Academy of Sciences*
NASA	*National Aeronautics and Space Administration*
NFFA	*Nanoscience Foundries and Fine Analysis*
NRAO	*National Radio Astronomy Observatory*
NRF	*National Research Foundation (South Africa)*
NME	*Network Monitoring Experiment*
NSO	*Netherlands Space Office*
NWO	*Nederlandse Organisatie voor Wetenschappelijk Onderzoek, Netherlands Organisation for Scientific Research*

OPTICON	*Optical Infrared Coordination Network for Astronomy*
ORP-Pilot	*OPTICON RadioNet Pilot*
PB	*PetaByte*
PI	*Principal Investigator*
PRIDE	*Planetary Radio Interferometry and Doppler Experiment*
RAS	*Radio Astronomy Service*
R&D	*Research and Development*
SCHED	*VLBI Scheduling software*
SFXC	*Software Correlator at JIVE*
STFC	*Science and Technology Facilities Research Council (United Kingdom)*
SKAO	*Square Kilometre Array Observatory*
TB	*Terabyte*
TOM	*Target Observation Manager*
UvA	*University of Amsterdam*
VDIF	*VLBI Data Interchange Format*
VEX	*VLBI Experiment Description*
VIRAC	*Ventspils International Radio Astronomy Centre*
VLBA	*Very Long Baseline Array, United States of America*
VLBI	*Very Long Baseline Interferometry*
VO	*Virtual Observatory*
VR	*Vetenskapsrådet, Swedish Research Council*
VUAS	*Ventspils University of Applied Science*
WSRT	*Westerbork Synthesis Radio Telescope*
WRC-23	*World Radiocommunication Conference 2023*

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