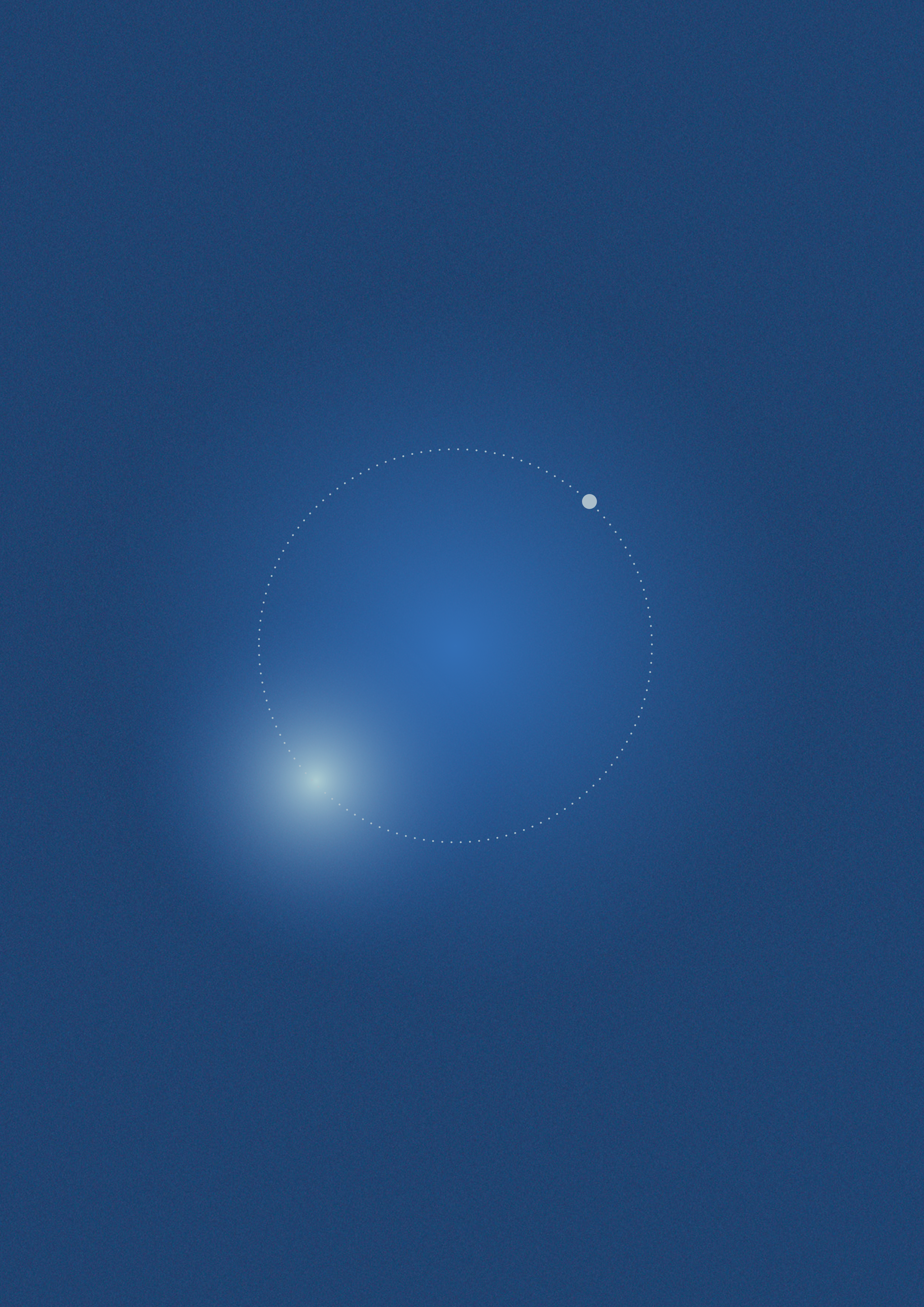
JIVE

Joint Institute
for VLBI ERIC

ANNUAL REPORT

2021



ANNUAL REPORT 2021

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

In 2021, JIVE had seven members:

- The French Republic: National Centre for Scientific Research (CNRS)
- The Kingdom of the Netherlands: Nederlandse Organisatie voor Wetenschappelijk Onderzoek (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: Instituto Geográfico Nacional (IGN)
- The Kingdom of the United Kingdom of Britain and North Ireland: Science and Technology Facilities Council (STFC)
- The Republic of Italy: National Institute for Astrophysics (INAF)

JIVE was also supported by the following Participating Research Institutes in 2021:

- China – National Astronomical Observatories of China (NAOC)
- South Africa – National Research Foundation (NRF)
- Germany – Max Planck Institute for Radio Astronomy (MPIfR)

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FOREWORD

Despite the continued effects of the COVID-19 pandemic during 2021, JIVE achieved its usual high level of service and innovation. Due to the pandemic, most Institutions adopted new flexible working modes and JIVE was no exception. JIVE was able in this way to ensure that all EVN operations could be performed despite the difficulties, minimising the impact of the international health emergency on EVN users and EVN science. I would like to thank all JIVE staff for their dedication and sense of responsibility during these difficult times.

An important event in 2021 was the entry into full membership of the JIVE ERIC by Italy. This was the successful culmination of a long process and strengthens the Italian commitment to support the EVN and its science. Italy was of course one of the founding members of the EVN and currently contributes to the array operations three antennas, located respectively at Medicina, Noto and in Sardinia.

In July 2021 the EC H2020 JUMPING JIVE project concluded. Its many achievements have been reported on earlier during the period of the project, but several results deserve special mention here. JUMPING JIVE has helped VLBI become an integral part of the SKA design via establishing technical and scientific requirements and developing an operational model. It also coordinated the production of the EVN scientific roadmap, which is the reference document for the implementation of future technological and operational requirements for the EVN. The project also made important contributions to training and other actions promoting the developments of VLBI in Africa. Finally JUMPING JIVE has developed JIVE's role coordinating EVN communication and outreach activities. Looking at the future, JIVE has a central role in the preparation of new EU proposals involving EVN partners and the broad Radionet European radio astronomy community.

The success of JIVE is of course ultimately measured by its contribution to scientific discovery. A selection of new and forefront scientific results enabled by JIVE are included in this report both using the EVN and other VLBI arrays. Amongst these science highlights, the study of FRBs using EVN telescopes and the EVN correlator continues to provide new and exciting clues on the nature of this phenomenon. Studies of the very inner regions of Centaurus A, imaged with EHT, with contributions from JIVE staff to the development of essential calibration tools, reveal crucial morphological details for our understanding of the jet launching, and show the validity of jet scaling laws.

This report additionally presents the many technical VLBI related developments with which JIVE staff are involved. These show the close collaboration between JIVE and the staff of the EVN stations, all with the common aim of facilitating the users' access to the EVN and the whole process from observations to the data delivery.

On behalf of the JIVE Council and its representatives, I warmly thank each member of JIVE for the invaluable work which is carried out with competence and dedication in the interests of the whole VLBI users' community.

Tiziana Venturi
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 hundreds to thousands of kilometres apart observe simultaneously the same radio source in the sky. The observations from the telescopes are presented as digital signals, which are then combined at a central, dedicated data processor (the correlator). Astronomers can use the resulting data to produce an extremely high resolution image of the radio sky. Alongside making images, the technique can be used to measure positions of bright radio sources with very high accuracy.

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

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

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

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

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

1.2 JIVE IN 2021

A great accomplishment during this year has been to achieve full membership of Italy in the JIVE ERIC. Italy was one of the founding members of the EVN in the early eighties, and its radio telescopes in Medicina, Noto, and, more recently, Sardinia, have regularly participated in EVN operations ever since. Through the Institute of Radio Astronomy (IRA-INAF), Italy has supported and been involved with JIVE for several decades. As of 12 March 2021, by joining the JIVE ERIC entity[1], Italy supports the sustainability of our institute for VLBI science, serving as the operational hub of the European VLBI Network and guarding the interests of the global radio-astronomical user community.

1 https://www.jive.eu/italy-joins-jive-eric

Figure 1.1: JIVE members.

The COVID-19 pandemic still had consequences in 2021. We had expected that the situation would become much better, however the JIVE staff has still been working mainly from home. Travel has been mostly absent, and many events and activities with JIVE participation have happened virtually: the SKA Science workshop, the special session on high-resolution astronomy at the European Astronomical Society (EAS) annual meeting, even the EVN symposium which had to be adapted to the circumstances. A special session to highlight the VLBI applications to astronomy, geodesy, geophysics and planetary science, was organised at the URSI GASS as a hybrid event, with participants in Rome (Italy) and also online, stresing the importance of the Global VLBI Alliance as a forum to align the different VLBI networks, also in view of cooperation with other instruments.

In 2021, the EC H2020 funded JUMPING JIVE project came successfully to an end. Many of the activities are however continuing, since these have become core activities in JIVE, like exploring new partnerships to JIVE and the EVN, support to training activities in Africa, and SKA-VLBI. JIVE also continues communicating the results of VLBI, maintaining the EVN and new JIVE websites, the EVN newsletter, and presence in social networks, and supporting the EVN e-seminars with great success. Other projects such as H2020 ESCAPE continued, and the ERIC Forum, of which the JIVE director became chair of the executive board and spokesperson towards the European Commission and other stakeholders. The kick-off of the H2020 OPTICON-RadioNet Pilot (ORP) project in March 2021 established also a firm stable financial basis for JIVE's work programme in the coming years.

JIVE also facilitated excellent science results using VLBI. These include the highest time resolution study of a repeating fast radio burst source to date by Nimmo et al. (2021), providing invaluable information on the magnetosphere enveloping the neutron star, a multi-wavelength campaign on the famous supermassive black hole M87, in which the EVN participated, by the EHT MWL Science Working Group et al. (2021), and a detailed study of radio-weak active galactic nuclei in the GOODS-N field by Radcliffe et al. (2021), among others.

The year 2021 also brought further development in Space and Planetary science at JIVE with the advancements on the PRIDE experiment, which will be the VLBI component of ESA's JUICE mission with an expected launch in April 2023. And the advancement of VLBI toward microarcsecond angular resolution got new momentum within the concept of THEZA initiated in 2019.

Furthermore, JIVE's software development and in-house expertise continued contributing to the worldwide VLBI community. For instance, JIVE staff finished installation, configuration and delivery of a Central Monitoring System for the

EVN in the framework of the H2020 JUMPING JIVE project.

Despite the challenges brought by COVID-19 restrictions, operations and support were able to continue to make the EVN an attractive instrument for a growing body of users to pursue innovative research. There were fourteen target-of-opportunity and one triggered observation, mostly via real-time e-EVN. Thirteen first-time PIs received support, and one of these had the first 4 Gbps observation conducted by someone from a non-EVN institute. The size of FITS files in the EVN archive expanded by 53% during 2021, surpassing 150 TB.

JIVE also continued working towards supporting new infrastructures that could become prospective EVN members such as ROT54/2.6 (Armenia) and the RT-32 Zolochiv antenna (Ukraine). In that framework, JIVE also organised test observations for telescopes that potentially could join in future EVN sessions, including the Arecibo 12m telescope (USA), the 500m FAST telescope (China) and the GMRT telescope (India).

1.3 PERSONNEL

JIVE is organised in four departments (Science Operations, User Support, Technical Operations and R&D, Space Science and Innovative Applications) plus a Coordination and Support Office that assists the JIVE director. In 2021 we were glad to welcome 4 new staff members, for a total of 25 in the JIVE family!

Dr. Shivani Bhandari joined JIVE as Astroflash project postdoc to work towards unravelling the sources of mysterious fast radio bursts using the EVN and LOFAR telescopes. Dr. Gabor Orosz is an expert of VLBI astrometry. He joined the EVN User Support group, and his scientific interests are VLBI maser astrometry, measuring distances to stars and studying how they behave on their deathbed. Dr. Suma Murthy is specialised in spectral line VLBI. She is part of the EVN Science Operations group. In her science time, she will focus on understanding the condition of cold gas in the nuclear region of radio galaxies.

Dr. Gina Maffey ended her contract as JIVE communications officer, this role taken by Dr. Jorge Rivero González.

Cristina García Miró ended her contract as SKA-VLBI scientist, and moved to the Yebes Observatory (IGN) in Spain.

Figure 1.2: Group picture from first in-person coffee meeting at JIVE in September 2021 after COVID-19 restrictions had been relaxed in the Netherlands. Credit: F. Colomer.

KEY FIGURES

7
Member Countries

3
Participating Research Institutes

25
JIVE staff

USER EXPERIMENTS CORRELATED

114
Experiments

1093
Network Hours

1224.5
Correlated Hours

2021

157.23 TB
Total size user-experiments files in Archive

60
JIVE Staff Publications

4
EC Projects

6
Online EVN Seminars organised

267
Media appearances in 38 countries

OVER 400,000
People reached with communication activities

Science Highlights

02

2.1 EXTREME COLLISION OF STELLAR WINDS AT APEP

Apep is a stellar system named after the Egyptian god of chaos due to its spectacular and elegant spiral dust structure. This pinwheel pattern originates from two Wolf-Rayet (WR) stars located at its heart. WR stars represent the very last stages in the life of the most massive stars, representing the phase of stellar life immediately before they collapse to produce a supernova explosion. In this case, Apep is strange as it is the — by over one order of magnitude — brightest of such kinds of systems, especially at radio wavelengths.

To understand the origin of its surprising brightness, and unveil what was happening at the core of the spiral of dust, astronomers conducted radio observations of Apep with the Australian Long Baseline Array (LBA).

These observations allowed us to unveil the origin of the radio emission: it arises from an extreme shock produced by the collision of the two stellar winds. This shock is observed as a bow-shaped structure.

Its orientation and shape was consistent with the expected separation and position angle of the two stars as derived by parallel observations in the infrared, and it allowed to recover an absolute position for both stars, and an estimation of the wind momentum rate ratio. Furthermore, the wind collision is now confirmed to be the basis for the spiral dust plume.

Apep is the first confirmed colliding wind binary comprising two WR stars. The more extreme winds of WR stars with respect to other systems hosting O or B-type stars, in combination of quite favourable orbital parameters, must be the responsible ones of providing a significantly higher energetic environment that bolsters the radio emission.

Given that the stars only spend a limited time on this Wolf-Rayet phase before their death in a supernova explosion, astronomers have confirmed that these systems must be very rare in our Galaxy.

If the environment around the system is already significantly more extreme than any other known system involving two massive stars, astronomers expect this system to end its life in an extreme explosion. Extreme enough to make Apep one the most potential systems to produce a gamma-ray burst at its end.

Marcote et al. 2021, MNRAS, 501, 2478

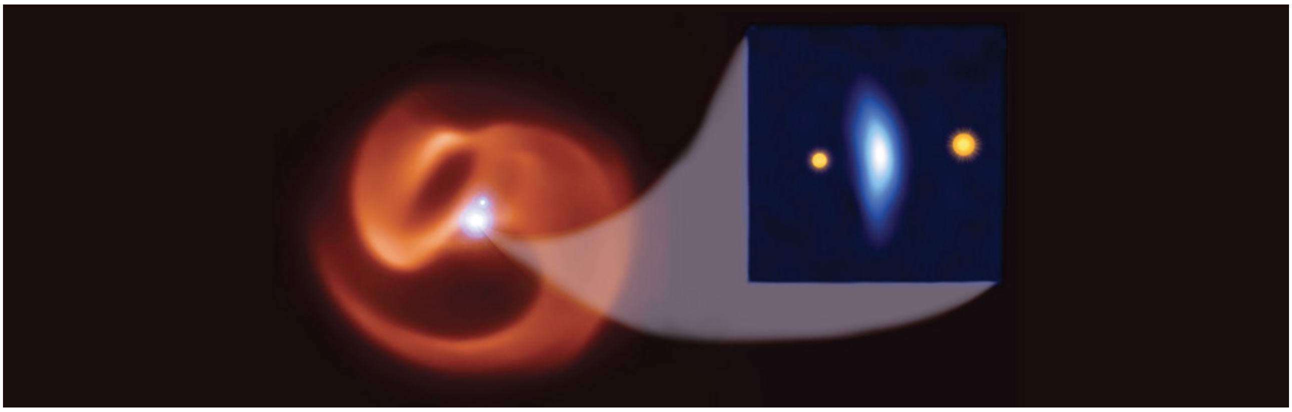


Figure 2.1: Real images of the dust spiral seen in Apep in infrared (orange) and, right at its centre, the region where the two stellar winds collide and emitting in radio (seen as the blue structure in the inset, where the two stars represent their real positions). Credit: B. Marcote & ESO/Callingham.

2.2 NEW CLUES TO UNDERSTANDING THE MOST POWERFUL ENGINES IN THE UNIVERSE — EVENT HORIZON TELESCOPE DEVELOPMENTS

A key science goal of the Event Horizon Telescope (EHT) is to understand the physics close to supermassive black holes, which are found in the centres of galaxies. In most galaxies these black holes lie relatively dormant, but in some cases they emit long and highly collimated jets of particles. The launching mechanism of these powerful jets is still poorly understood. The continued work of the Event Horizon Telescope Collaboration (EHTC) has unveiled new clues.

The first clue has come from the study of polarised light in the original ring image of M87. Radio telescopes are natural polarisers, yet the calibration of these data is very challenging. Driven by ongoing research and development in this field, the EHTC has managed to retrieve high quality linear polarisation results for M87. JIVE staff contributed to the development, testing and verification of these tools.

The paper also exploits a new visualisation technique by plotting the orientation of the magnetic field lines on top of the total intensity image. The length of the lines indicates the level of polarisation, the direction is equivalent to the electric vector position angle (EVPA). The result is a hair-like whirlpool. The orientation of the EVPA is directly related to the orientation of the magnetic field close to the black hole. Thus it provides direct clues to understanding the mechanism responsible for launching and collimating the large scale jet seen in M87. By combining this result with other known parameters, such as the jet power, models for jet jet creation can be constrained to the so-called Magnetically Arrested Disk (MAD) models.

An important result from the Centaurus A study is that the phenomena seen are extremely similar to what is seen in M87, which indicates that black hole physics is scale invariant over a large range of black hole masses. This implies that for future research we can study lower mass black holes as well as high mass black holes to increase the sample size, while still capturing the same physical processes and thus advance our understanding of these appealing objects.

EHT Collaboration et al. 2021, ApJ, 910, L12
Janssen et al. 2021, NatAs, 5, 1017

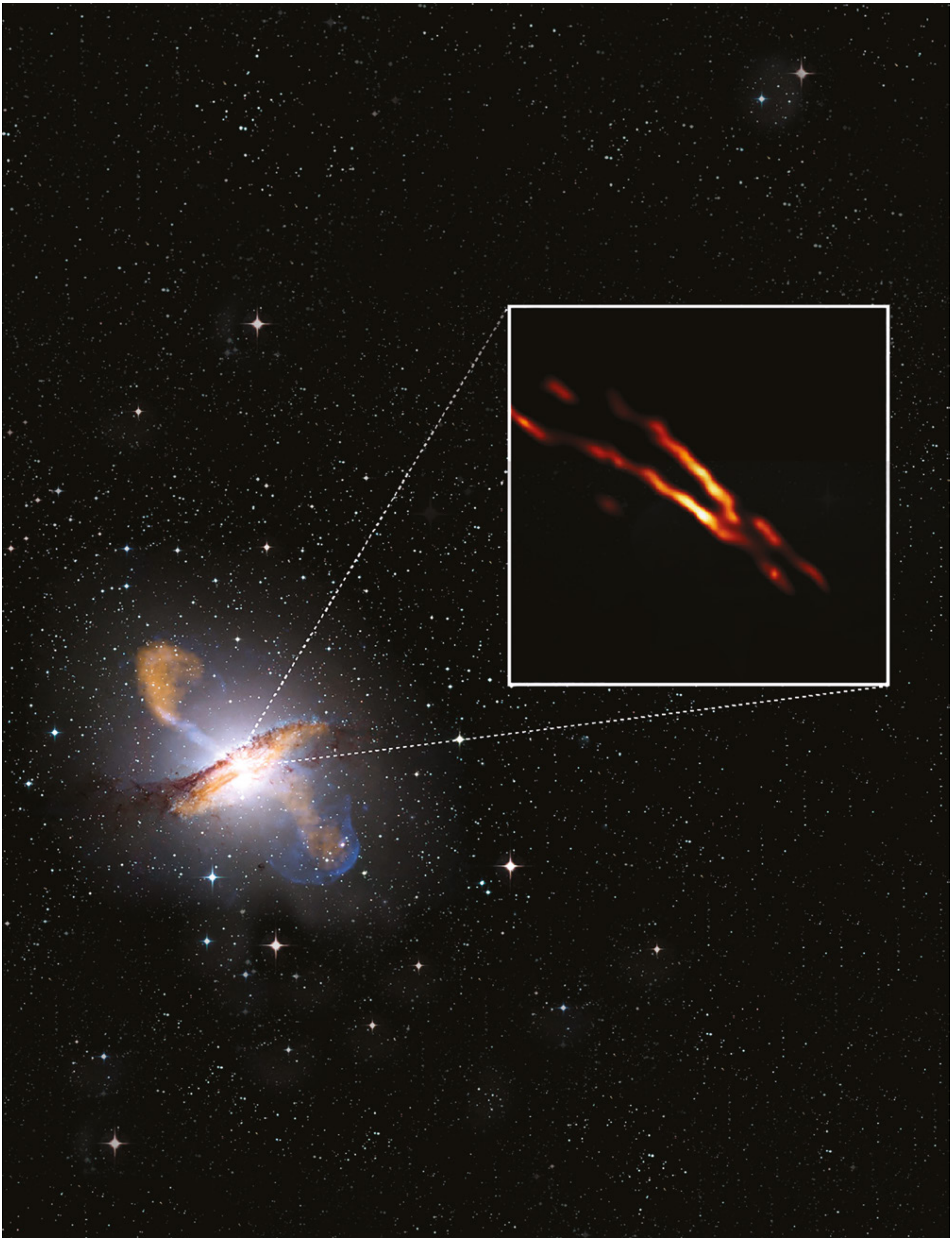


Figure 2.2: Highest resolution image of Centaurus A jet obtained with the Event Horizon Telescope on top of a colour composite image of the entire galaxy. Credit: Radboud University; ESO/WFI; MPIfR/ESO/APEX/A. Weiss et al.; NASA/CXC/CfA/R. Kraft et al.; EHT/M. Janssen et al.

2.3 FRB 121102: DRASTIC CHANGES IN THE BURST POLARISATION CONTRASTS WITH THE STABILITY OF THE PERSISTENT EMISSION

Fast radio bursts (FRBs) are bright millisecond-duration transients of an extragalactic origin. A great number of theories has been developed to explain this phenomenon in the past decade, many of those invoking neutron stars. Some FRBs are repeating, making it possible to organise detailed follow-up observations that include interferometers, so that to probe the emission regions with extreme resolution and sensitivity.

FRB 121102 is the first repeater discovered, and its properties make the source unique among FRBs. It lies within a star-forming region of a dwarf galaxy at a redshift of 0.19. The high rotation measure (RM) exceeding 105 rad/m^2 indicates dense highly magnetised plasma around the emitter. This plasma is likely related to the persistent radio source colocated with the bursts. The persistent source also has multiple alternative explanations, including an AGN or a young nebula. More focused studies of the source properties on milliarcsecond scales, and its relation to the bursts RM, would let us constrain all these models better. In Plavin et al. (2022), such studies are presented, including both EVN and single-dish observations, and discuss the results.

The brightest burst of FRB 121102 within the observation campaign was caught on 20 September 2016. Thanks to the VLBI backend at Effelsberg, astronomers managed to reanalyse the data at the highest spectral resolution of 4 kHz; this became crucial for the polarisation studies. They detected a significant linear polarisation of FRB 121102 bursts for the first time at a low frequency of 1.7 GHz. The rotation measure was the highest to date at 1.27 x 105 rad/m^2, qualitatively consistent with the falling trend on the years timescales. Linear polarisation fraction turned out to be much lower at 1.7 GHz: only 15%, compared to almost 100% observed at 5 GHz. This low fraction, combined with the requirement of a high spectral resolution, is the likely reason why no burst polarisation was detected at 1-2 GHz before. The team of astronomers explain this striking difference between frequencies with minor non-uniformities in the screen, leading to spatial depolarization: the emission Faraday width of just 150 rad/m^2, or 0.1% of the total RM, is enough.

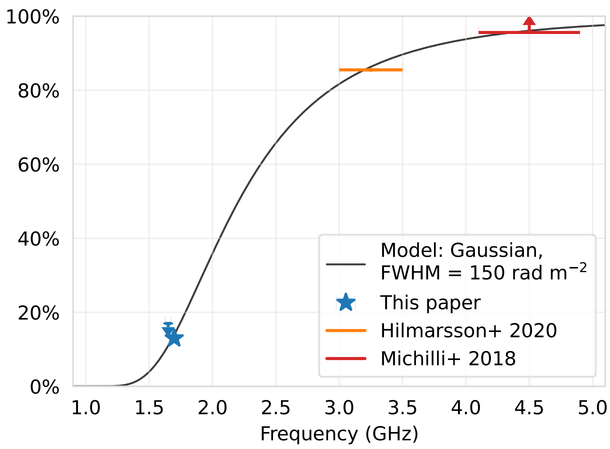


Figure 2.3: Measured fractional polarisation of bursts at different frequencies. The phenomenological model assumes 100% intrinsic polarisation with an effective width of 150 rad/m2 in the RM space. This model is consistent with our measurements at 1.7 GHz and with higher 3-5 GHz measurements.

Our dedicated EVN observations throughout 2017 caught no bursts, but this dataset provides invaluable information about the persistent radio counterpart. The observations included more telescopes than previous studies, leading to a better spatial frequency coverage and a higher sensitivity. The radio source flux density is only 0.2 mJy, so we used both a regular phase-referencing calibrator, and a secondary in-beam one for relative comparisons. As it turns out, the persistent emission is surprisingly stable: flux variations are less than 10% over a year; the apparent position stays the same up to 0.1 mas, and is consistent between 1.7 and 4.8 GHz. The upper limits on the source size of 1 pc further constrains the maximal potential expansion rate to ~104 km/s. The lack of variations in observed parameters of the persistent emission, combined with changes in the bursts rate and their RM, put strong constraints on models explaining the environment of FRB 121102. For example, an expanding supernova would show a decaying luminosity trend; an AGN could have frequency-dependent apparent positions, or a general flux variability; a nebula inflated by a magnetar outflow would lead to a correlation between the burst rate and the persistent emission.

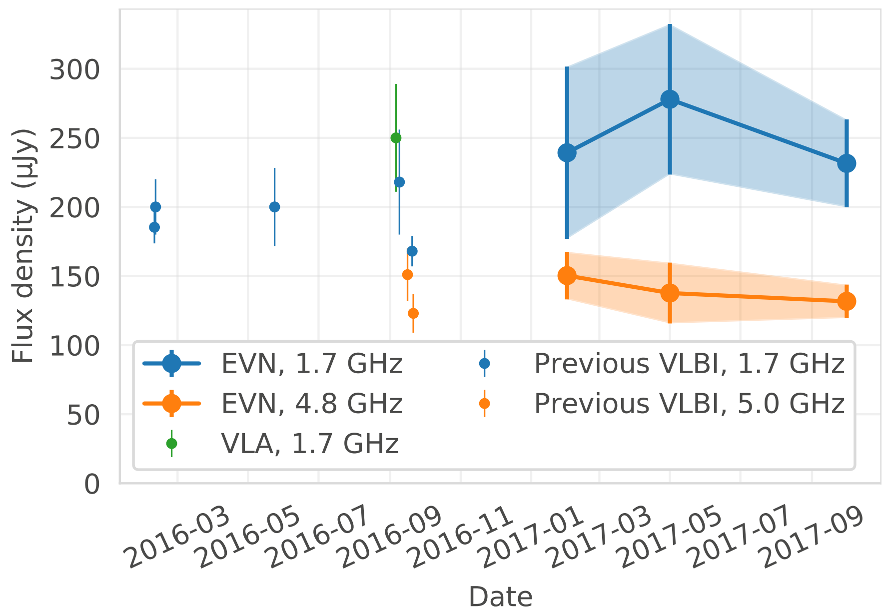


Figure 2.4: Flux density measurements of the persistent radio counterpart. The EVN measurements in 2017 are shown in comparison with earlier VLA, VLBA, and EVN observations. Variability within each frequency band is insignificant and lies below 10%.

Unique and dedicated observations of FRB 121102 performed by the EVN and the Effelsberg telescope lead to these results presented in Plavin et al. (2022). More observations, including polarisation, simultaneously at a wide frequency range and consistently over multiple years, would further help understanding the FRB environment evolution and the mechanisms underlying the bursting and persistent emission.

Plavin et al. 2022, MNRAS, 511, 6033

Research and Development

03

3.1 TECHNICAL OPERATIONS

2021 marked the second year of living and operating under COVID-19 pandemic restrictions. Over the year, there were periods when the Dutch Government loose restrictions and other periods when there was a full lockdown. The solutions experimented with and developed during the previous year successfully continued to operate JIVE and provide services for the EVN and its users. No observations or data products were lost because of restricted access to the premises and JIVE/EVN equipment.

3.1.1 HARDWARE

Following the EVN Consortium Board of Directors (CBD) decision to *"upgrade the storage at the stations and the correlator"*, JIVE received two new FlexBuffs during 2021 (Effelsberg (Ef) ~400 TB net, Yebes (Ys) ~260 TB net) that were added to the storage pool for a total of 19 FlexBuffs, amounting to a total capacity of 4.5 PB.

In an attempt to evaluate the performance of a more compact FlexBuff solution, a 4U, 90-bay hard-disk chassis were ordered. Normally the same 4U rack space holds "only" 36 hard-disks. With this new solution the overhead of rack space, power supplies, motherboard, network card(s), operating system disk, CPUs and memory per harddisk should go down significantly. This new machine was sharedly funded by the EVN stations Medicina (Mc), Noto (Nt), Onsala (On) and Sardinia (Sr) and will host approximately 1 PB of online storage. The chassis and a subset of the hard-disks were ordered in December 2021 but due to shortage of chip supplies and hiccups in the supply chain, delivery of the chassis is not expected until April-May 2022. The Italian stations transferred their part of the purchase amount; Onsala contributed by donating 30 hard-disks for the system.

There were no changes to the number of operational Mark5's and Mark6's.

Time consuming investigations following increasing reports from operators having erratic issues starting the distributed correlator system (involving 85 independent physical machines) resulted in identifying the root cause: faulty fibre optic modules causing packet loss on the local network. For the redundant internal network some 30 to 40 QSFP+ fibre optic modules are necessary. Because of the huge price differential – 32€ per item for the brandless FiberStore modules compared to 200€ per item for Mellanox/NVIDIA branded ones – and the amount of modules required the FiberStore products were purchased. Until the end of December 2021 some thirteen faulty modules were identified. For this process it was necessary to build a dedicated test setup including test execution and analysis scripts. All this was required by the vendor to prove that the modules were at fault, not the JIVE network setup. In order to help diagnose the root cause an *"internal network connection all to all"* test setup was developed by the Technical Operations/R&D staff. This test framework measures packet loss on all possible host-to-host links and generates a PNG visualisation of the test results using colour coded packet error rates (see Figure 3.1). This makes it extremely clear to identify single hosts or groups of hosts sharing network issues.

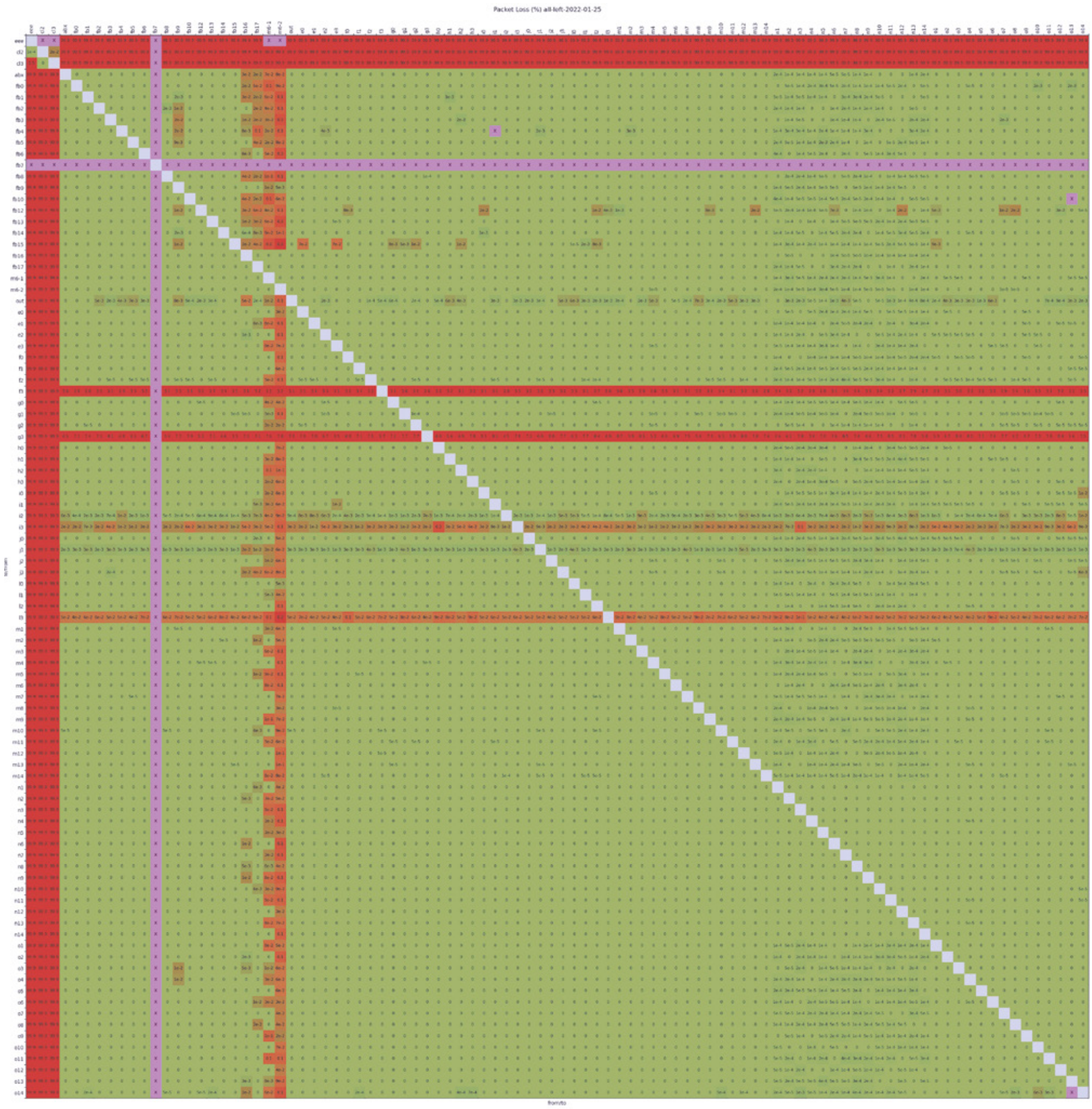


Figure 3.1: The all-to-all network test program produces a full matrix of colour-coded packet loss statistics because the links A→B and B→A are independent optical fibre links and measured separately. Some equipment is connected using a 40 Gbps → 4 x 10 Gbps break-out cable and the latest SFXC expansion consists of three crates where all fourteen nodes in the crate are connected through a built-in switch in that crate. Issues with individual, groups-of-four or groups-of-fourteen hosts immediately show up in this insightful, albeit not so pretty, plot.

In order to safeguard backups of correlated data and the archive, currently stored on a collection of LTO-3,-4,-5 and – 8 tapes, a fire-proof safe of the highest digital media protection category (S120IS[2]) was purchased and installed (see Figure used as Section 3 opening). The system can hold approximately 900 LTO tapes which should see it through the next decade, taking into account the

2 Digital media safeguarded against exposure for two hours at ~1100°C and a subsequent drop from 9m height.

archive growth of the last few years. The next step in safeguarding the data archive will be the process to spool the LTO-*n* (where $n < 8$) tapes onto the larger and more future proof LTO-8 format. A single point of failure to note here is the one LTO-5 tape drive available that is capable of reading LTO-3 tapes while it lasts.

In preparation for being able to accept a doubling of the FlexBuff storage space at JIVE the correlator room raised floor needed to be reinforced: a single FlexBuff loaded with 36 HDDs weighs in at least 60 kg. Starting 19 November 2021, all FlexBuffs, SFXC nodes, the virtual machine cluster and network switches were powered down and removed from the correlator room. A central rack with the switches and general purpose servers was set up, connected, and powered up within half an hour such that services such as Mattermost, planobs and others remained online during the upgrade. The correlator room was completely stripped and the opportunity was seized to remove old or irrelevant cabling, clean up under the floor, and rearrange the remaining cabling. The new floor was installed within half a day and is now rated up to 20 kN / m^2, sufficient to safely support racks filled with FlexBuff servers. The equipment was moved back in (see Figure 3.2) and the racks were rotated by 90°. This new orientation serves two benefits: one extra rack can be placed in the room if needed and secondly, the cooling air flow is more optimal. By the afternoon of 23 November 2021 most of the equipment was reconnected and operational again and production correlation could be resumed by 25 November 2021.

JIVE staff supported our host institute ASTRON rearranging and reconfiguring the local network with the goal of migrating all independent 10 Gbps connections onto the new 100 Gbps SURFnet8 connection. This migration succeeded in December 2021.

The production e-VLBI link to Irbene (Ir) started to exhibit significant packet loss (25% – 70%) in the last few e-VLBI sessions. It is unknown why this link suddenly started to underperform. Investigations are planned but are hampered because it is difficult to find the right technical contact for each section of the network the data passes through.

Figure 3.2: Reinstallation of the production equipment after the reinforcement of the raised floor, rotating the racks by 90° to allow for more rack space and improving the cooling air flow. Credit: P. Boven.

3.1.2 HIGH DATA RATE OBSERVATIONS

Two 16 Gbps DBBC3 based high data rate experiments were planned in January and September 2021. Both tests had to be cancelled just before their scheduled observing due to insufficient equipment being available in the end. Multiple DBBC3s were still out for repair back in Bonn (Germany); at another site a cryogenic problem developed that could not be addressed before the beginning of the test due to COVID-19 access restrictions; at another station insufficient workforce was available to repatch 2 x DBBC2 to participate as extra station; yet another station developed a servo issue just before the test; and at another station a problem in a DBBC3 GCOMO board was discovered meaning it was unusable.

In all planned tests the initial number of available stations was either five or even six in one test, but in the end never more than two stations turned out to be in working condition using the equipment necessary for these tests. In any VLBI test observation an absolute minimum of three stations is necessary, resulting in cancellation of both planned tests.

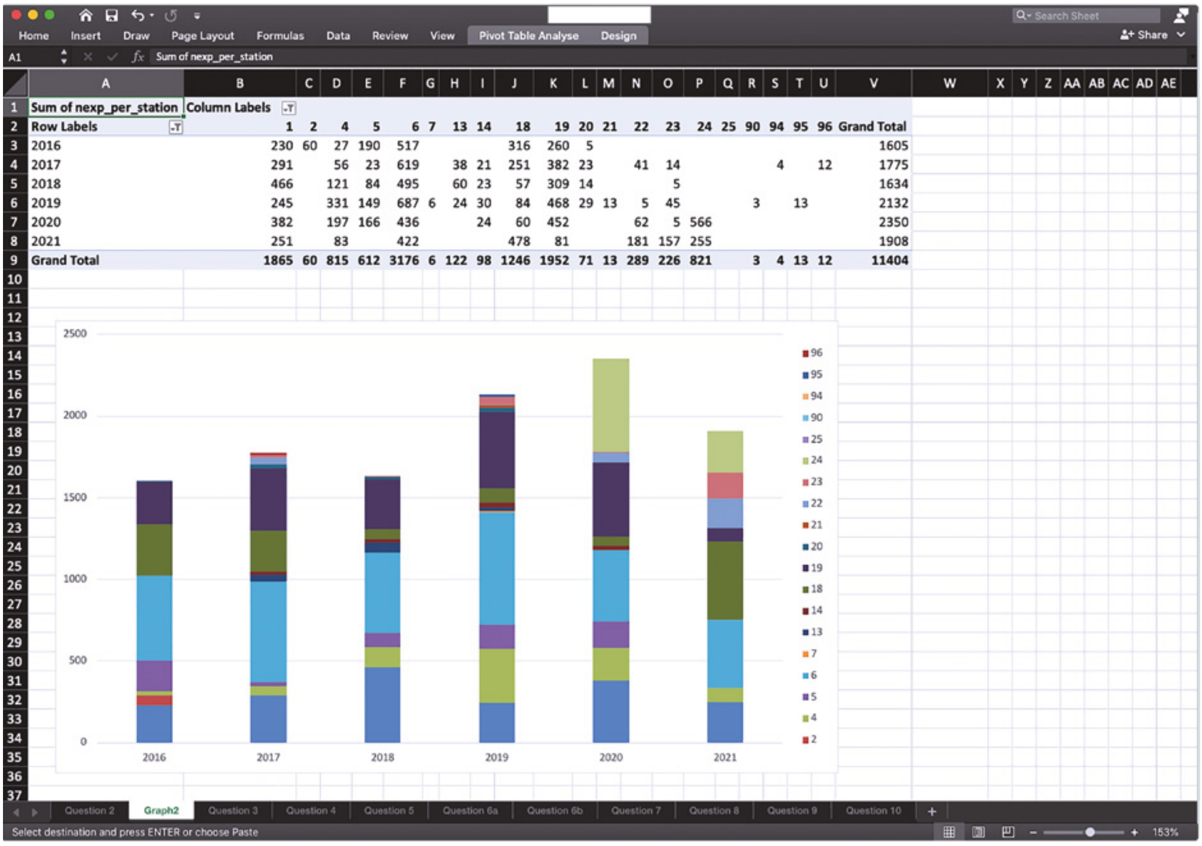
3.1.3 SOFTWARE

Individual databases at JIVE containing information about proposals, experiments, correlation, and resulting user data sets have been linked into a single database instance. This allows insightful statistics about the EVN and JIVE to be extracted using database query, filter and aggregation techniques. A short list of queries that were judged to be (1) doable given the current database contents and (2) if validated might provide useful statistics was created and database queries to answer those were realised. The result of those queries is currently returned as a Microsoft Excel Workbook with a tab per query result. This allows graphical reports to be generated using the advanced visualisations available in the Microsoft Excel desktop application (see Figure 3.4). Before publishing those numbers officially, validation is necessary. For a subset of the queries the automatic results were compared with those manually reported in earlier EC reports. Differences are present but it is believed that those are understood. For one particular query the observed deviations seem to be caused by the fact that the manual accumulation has to follow a different set of business logic rules for eligibility doing the accounting compared to summing the raw totals present in the JIVE database systems, as the automated system would do.

In order to produce meaningful results from linking the NorthStar proposal database a time-consuming database sanitisation was required. Because of the free-form text input fields in the NorthStar proposal tool several inconsistent spellings of the same entity appeared; see Figure 3.3 for illustrations of what users enter into the database. The approach to normalisation was implemented in such a way that future proposal database entries can also be easily sanitised by only having to add those misspelling(s) that do not occur in the list of synonyms yet.

Figure 3.3: Actual database content from free-form text input by users for entities such as country or institute. These must be normalised before meaningful statistics can be generated.

Following last year's progress towards technically supporting VEX2, i.e. the tools being capable of reading VEX2 schedules, verification of operation was still lacking. In 2021, a tool chain verification regression test suite was developed. This regression test suite allows any change in the JIVE post-correlator tool chain (**`j2ms2`**, **`tConvert`**) to be verified to the extent that the test suite – amongst others – asserts numerical equivalence between the visibilities produced by the tool chain under test running on a fixed set of correlator outputs and known-good reference Measurement Sets and FITS-IDI file generated from those.



Sum of nexp_per_station	Column Labels																				
Row Labels	1	2	4	5	6	7	13	14	18	19	20	21	22	23	24	25	90	94	95	96	Grand Total
2016	230	60	27	190	517				316	260	5										1605
2017	291		56	23	619		38	21	251	382	23		41	14				4		12	1775
2018	466		121	84	495		60	23	57	309	14			5							1634
2019	245		331	149	687	6	24	30	84	468	29	13	5	45			3		13		2132
2020	382		197	166	436			24	60	452			62	5	566						2350
2021	251		83		422				478	81			181	157	255						1908
Grand Total	1865	60	815	612	3176	6	122	98	1246	1952	71	13	289	226	821		3	4	13	12	11404

Figure 3.4: An example visualisation of usage statistics extracted from the combined databases at JIVE making use of Microsoft Excel's Pivot – table and chart functionality. This plot visualises the number of experiments per observing wavelength broken down by year, simultaneously illustrating its contribution to, as well as the total number of experiments of, that year.

New hardware for running the EVN archive was ordered because the current machine is well past its economic life-time. The hardware is getting so old that the risk of failing components is increasing and it is running an ancient operating system, which is a security risk. The migration of the archive to a completely new operating system and much newer versions of required tools such as web server, website implementation frameworks, and scripting languages used will be a time consuming task, requiring validation of operation at every step in order to guarantee a seamless transition and is expected to happen in 2022. However, in preparation for the upcoming transition, the archive interface scripts that are currently written in the PHP language, are being rewritten in modern-day Python, making use of one of the state-of-the-art website implementation frameworks. This process is executed in close collaboration with the support group because the new interface scripts also address proposed usability changes to the archive interface based upon a report the support group has written. A preview of the new archive interface can be seen in Figure 3.5. It should be noted that at this point the focus is on ensuring proper operation and functionality; aesthetic changes can be applied more easily later due to the use of modern-day website development technology.

Connected to collecting statistics was a rewrite of the web-based tool to link publications to EVN observations in **Flask**; a modern web-application development framework. The web-based tool is now integrated with the JIVE internal LDAP-based authentication system, allowing staff to log in to the tool remotely and continue classifying and linking papers. An important step to automating this currently labour-intensive task of manually linking papers to EVN data sets in the archive would be the possibility for authors to cite EVN data sets using a persistent identifier such as a Digital Object Identifier (DOI)[3]. To that intent JIV-ERIC became a member of the TUDelft DataCite Consortium and gained access to a DOI sandbox environment. DataCite-flavoured DOIs are persistent identifiers specifically geared towards citing data sets. Tooling was developed to mint and publish a DataCite DOI for a public EVN dataset in the sandbox environment. The metadata for EVN data sets does not only include links to the EVN archive for that data set but also to other persistent identifiers such as JIVE's entry in the Global Research Identifier Database[4] and the EVN Archive's re3data persistent identifier 10.17616/R3Z197[5], all increasing findability of EVN data. Before DOIs can be officially published for EVN datasets more work is necessary. This has already started but as the DOI infrastructure will be tightly integrated with the new archive website, progress on this is linked to and dependent on progress of the migration.

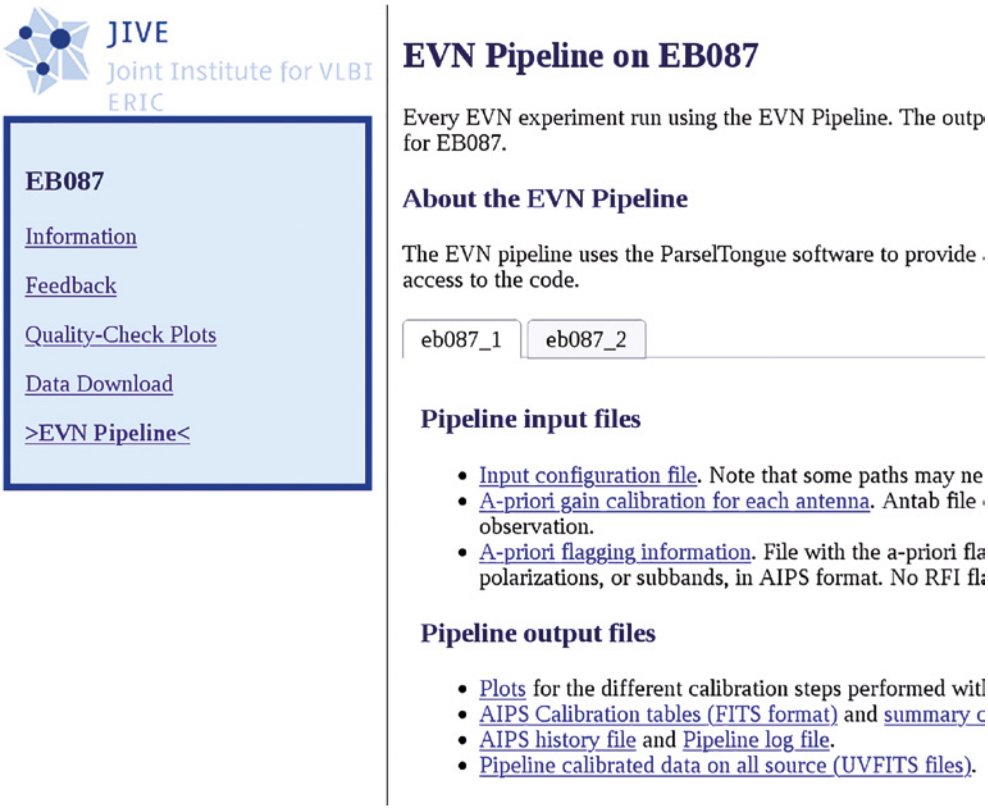


Figure 3.5: Screenshot of the initial re-implementation of the EVN Archive interface, featuring "tabs" for different passes of the experiment, using modern web technology behind the scenes.

3 https://doi.org
4 https://grid.ac/institutes/grid.425539.c
5 https://www.re3data.org/repository/r3d100012641

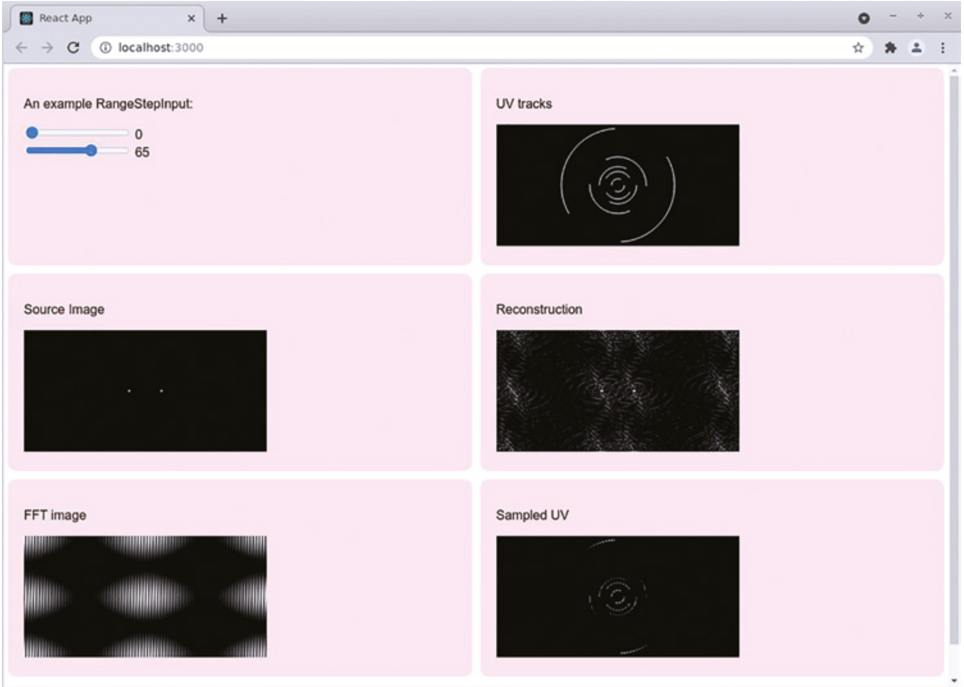


Figure 3.6: Screenshot of the fully javascript-based Virtual Radio Interferometer, demonstrating sufficient in-browser mathematic performance (2D-FFT, convolution) at an acceptable refresh rate if the user changes a parameter using the slide control(s) (top-left).

A fully javascript-based rudimentary Virtual Radio Interferometer website was developed in order to evaluate whether performance of current-day computers and web browsers was sufficient to run it at an acceptable speed, i.e. fast enough to provide near real-time visual feedback if the user changes a parameter. The conclusion was that current day hard – and software is indeed capable enough to execute two-dimensional Fast Fourier Transforms in javascript and render the results at an acceptable "frame rate". The VRI was originally written in the JAVA programming language as a demonstration tool but running JAVA code from the web stopped being easy already a decade ago. This fully web-browser based version (see Figure 3.7) has the focus on correct – and fast-enough operation, not aesthetics. At the expense of investing in adding features and proper user-interface design it could be made into a useful demonstration/outreach tool.

The automated FlexBuff transfer system was modified to change the strategy of when to start transferring data for an experiment. Instead of waiting for an experiment's transfer to finish completely, the system now already starts transferring data from the next finished experiment. This change was necessary to prevent a single station delaying transfers from all stations. This condition was triggered and held up production e-shipping briefly, until the issue was addressed. Production e-shipping returned to running efficiently soon after.

Some bugs in the **`antab_editor.py`** programme were identified and fixed. Following user requests it was updated to support multiple observing modes per experiment. The user interface was modified to have a tab per observing mode detected.

Maintenance and extension of the NorthStar proposal tool continued over the year. One of the enhancements dealt with the requirement that in proposals requesting e-Merlin stations the principal investigator is required to specifically justify the request for these resources. To this effect a mandatory-if-eMerlin-requested input field was added to the user interface.

In order to proactively address security on the > 100 managed servers in the JIVE data centre an experiment to automatically install available security patches was started. This process needs to be monitored closely initially in order to evaluate the impact on production: with each security update one or more of the tools in the operational environment can break unexpectedly. This test is ongoing and the results and possible subsequent action(s) are expected in 2022.

3.2 RESEARCH & DEVELOPMENT

JIVE staff was active in supporting the prospective EVN members ROT54/2.6 (Armenia) and the RT-32 Zolochiv antenna (Ukraine). The ROT54/2.6 advisory group met three times and provided technical guidance on possible ways to proceed validating the current antenna. The Zolochiv RT-32 co-observed with the EVN Network Monitoring Experiment N21C2, using a digital backend of its own design capturing two 16 MHz bands. JIVE staff visited Zolochiv in October 2021 to attend the "RT-32 Zolochiv: Current state, EU Collaboration, Radio Astronomy Frontiers" conference and meet with, amongst others, the developers. The RT-32 backend produces data in a non-standard native data format and requires conversion to VDIF before correlation with other EVN stations can be attempted. JIVE experts are guiding and helping RT-32 staff to get a conversion program written. A first version was delivered in December 2021 and tested but was not observed to produce valid VDIF data.

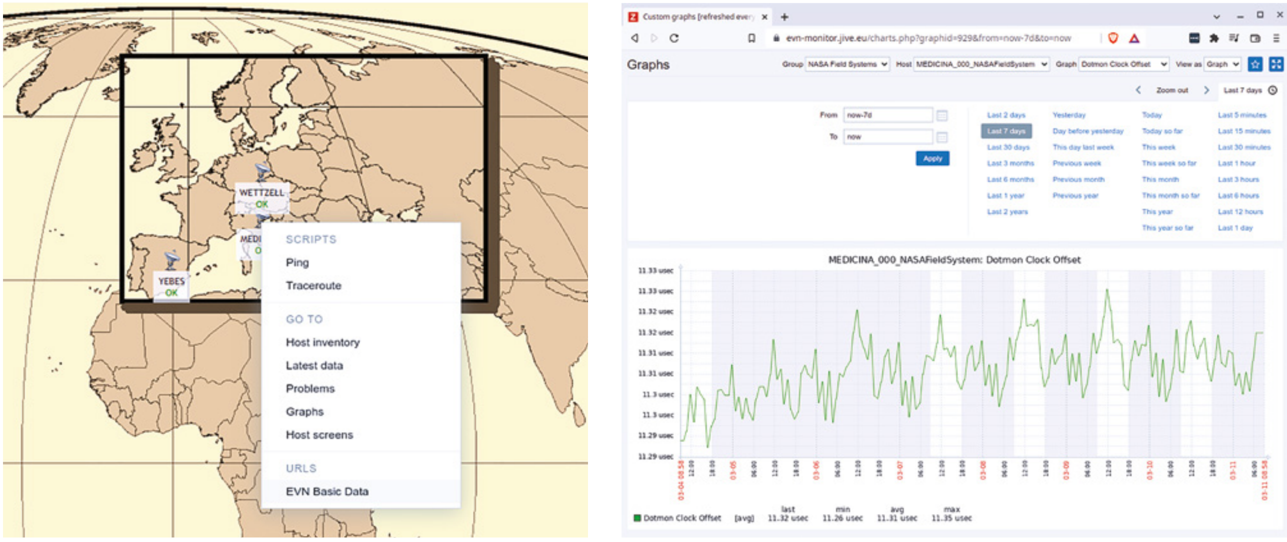


Figure 3.7: Two screenshots from the **evn-monitor.jive.eu** *web interface. Left: welcome screen: showing stations who upload monitoring data into the system with right-click context menu. Right: an example of a time series kept in the central monitoring system: the Medicina DOT clock offset measurement over the previous week.*

Work continued for several deliverables and work packages of EC funded projects.

JUMPING JIVE

Together with the Technische Universität München (TUM) JIVE staff finished installation, configuration and delivery of a Central Monitoring System[6] for the EVN. EVN stations can upload monitoring data from the equipment to the central database hosted at JIVE. After logging in[7] (Figure

6 https://evn-monitor.jive.eu
7 Username and password are "EVN Guest", including a space

3.7 (left)) the monitoring data can be displayed graphically after selecting details for a station. For example, see Figure 3.7 (left) showing a time series of Medicina's uploaded DOT CLOCK monitoring values. EVN stations can get involved at three levels of sharing monitoring information: varying from the most basic uploading individual values using a script executing on the station's FieldSystem computer to a full-fledged integration with the FieldSystem monitoring everything. Subsequently higher levels of involvement require more setup and configuration from the station. The lowest level of involvement requires nothing more than contacting JIVE and requesting an account, after which an ssh public key is enough to push values into the system. The monitoring system supports extraction of monitoring values programmatically for subsequent use in analysis or calibration scripts.

ESCAPE

For the Open Source Software Registry (OSSR, WP3) JIVE was active in discussing appropriate metadata to best describe the entries in the OSSR and updating its own entry (the Jupytercasa kernel) in the OSSR. The latter now is based on the latest CASA6.3 release, contains bug fixes, and its **plotcalng** module was improved. The metadata discussions happen in close collaboration with the ESCAPE Science Analysis Platform (ESAP, WP5) with the intent that ESAP can use the metadata of entries to guide the user in down selecting appropriate software for the science use case or automatically deploy software on the appropriate platform capable of running it.

The EVN continuum calibration Jupyter Notebook for WP5 was finished and a prototype spectral line data reduction notebook is maturing. Its development is somewhat hampered by changes in the support group, to the extent that access to spectral line data reduction expert(s) is currently limited.

JIVE is an active partner in the International Virtual Observatory Alliance (IVOA) Radio Interest Group (RadioIG) driven by CEVO (ESCAPE WP4), where global partners discuss standards to be able to support radio data (single dish, pulsar, visibilities) into the Virtual Observatory (VO). Based on discussions within the RadioIG a test VO server was installed and configured at JIVE. This experimental service is used to evaluate the performance of the proposed IVOA extensions for radio data, such as an attempt to quantify u,v-coverage and imageability of a visibility data set in single floating point numbers, and to debug the service. For test purposes the catalogue service was filled with metadata harvested by processing a small set of public data from the EVN archive.

Integrations were started for several initially discrete developments within the ESCAPE project. In order to deploy Jupyter notebooks an experimental BinderHub service was set up running on the jupyterhub.jive.eu server. The BinderHub technology is a promising way to allow users to transform a version controlled github project into an executable data analysis environment. This service is set up to provide the WP5 ESAP a backend to test against. A Jupyter notebook for educating/demonstrating users how to use VO-powered searches and crossmatch results against observations in the EVN archive using the experimental VO search interface was developed.

Within the JIVE Jupyterhub environment two plugins are under active development, the EVN archive query and the PublishNotebook plugin. The latter facilitates publishing a currently private notebook version in the public archive.

The EVN archive query plugin exploits the experimental VO search interface to the EVN archive developed in WP4. It supports search by experiment, source, waveband or a cone search around a specific position, see Figure 3.8. From the search results a new data reduction notebook based on the current best known EVN continuum notebook can be started by double-clicking the search result. The plugin downloads the data through the VO DataLink protocol, following links pointing into the EVN archive included in the VO search results.

In the JIVE Jupyterhub system notebooks are version controlled in a private-to-the-user **git** repository. For citation purposes of the methods used to extract a science result, a specific version of such a notebook can be published in the public archive. The second plugin will take care of transferring only the meta data necessary to identify the user as the original author, together with the actual notebook into the (also version controlled) public archive. After this step the notebook can be cited in a paper. Whether it is desired, useful, or necessary to issue a DOI for such a notebook is under active discussion.

Access to the JIVE Jupyterhub is controlled by a login process. Currently the server has been configured to allow ESCAPE partners to log in using the ESCAPE Identity and Access Management service[8] operated by INAF. It is realised that most of the EVN users are *not* ESCAPE partners and thus cannot have such an account. Therefore a process towards (ultimately) federating with eduGAIN[9], such that any user whose institute is a member of the eduGAIN federation can have access to the JIVE Jupyterhub service, was initiated.

JIVE entered into a contract with SURFconext[10] – the federated service and identity management system of the Dutch NREN SURF – to act as a Service Provider. Access to the SURFconext sandbox service provider environment for testing was made available. JIVE is in the process of addressing GDPR issues as these need to be signed off by SURFconext before being allowed to publish the JIVE Jupyterhub in the production environment. Federating with eduGAIN is predicated on the JIVE Jupyterhub being available in the production SURFconext environment.

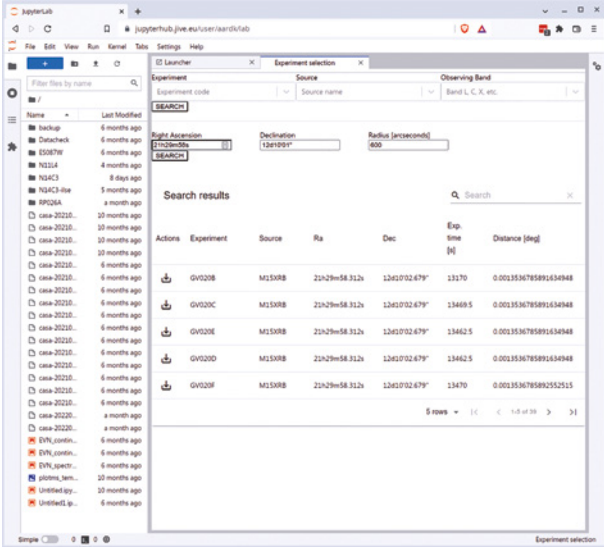


Figure 3.8: ESCAPE integration: the JIVE Jupyterhub EVN Archive search plugin (WP5) enables querying and downloading data from the EVN Archive by experiment code, source name or cone search around a sky position using the Virtual Observatory ObsTAP service (WP4) behind the scenes, for subsequent processing with the EVN continuum notebook (WP5) using the Jupytercasa kernel (WP3).

3.3 SOFTWARE CORRELATION

Some bugs discovered in the SFXC software correlator were fixed. One of them addressed correct handling of an invalid frame inserted into an e-VLBI data stream on packet loss at an unfortunate time, specifically the start of a correlation run. This bug was found being triggered during e-VLBI with the Irbene link exhibiting an extraordinary amount of packet loss.

Sometimes a delay between polarisations of the same station exists, e.g. if multiple digital backends are used that happen to be slightly unsynchronized. SFXC was modified to allow generic per-channel offsets to be programmed. In this approach a “per polarisation” offset between channels is easily fixable as will other, future, multiple backend driven observations will likely require.

In order to help the operations group find fringes in problematic experiments two useful features were implemented:

8 https://iam-escape.cloud.cnaf.infn.it/login
9 https://edugain.org/
10 https://www.surf.nl/en/surfconext-global-access-with-1-set-of-credentials

— SFXC can now sweep through a range of LO offsets, making it easier to test for such a misconfiguration, if there exists the suspicion that the actual LO is not according to description in the VEX file or has been mistuned. Before this feature each LO-offset to be tested needed to be configured manually, the correlator re-run, checked for fringes, repeat until success or giving up;

— for stations where the channel layout may be unknown or not according to description in the VEX file, it is now possible for SFXC to "broadcast" one channel to all others. This will run the correlation several times; each run broadcasts a different channel of the station to all others. That way the station channel layout can "easily" be inferred, provided no other problems exist.

3.4 USER SOFTWARE

The **fringefit** task now supports an option to combine polarisations before the fringe search. This feature can help increase the number of detections in low signal to noise data, such as mm-VLBI observations and is expected to appear in the next CASA release. A prototype for overlapping solution intervals was implemented and is currently under review by NRAO staff. The per-scan interpolation method was implemented.

Following user reports in 2020 on excessive memory usage by the **fringefit** task, the issue was investigated. The proposed solution was tested, found optimal, and will appear in the upcoming CASA6.4 release. Fringe fitting LOFAR HBA long baselines was demonstrated to work, including fitting for dispersive delays. Fringe fitting on a single spectral channel (needed for spectral line VLBI) was likewise implemented, tested, found optimal and should also appear in the same CASA release. An issue with mismatching reference frequency (1 Hz off on an observing frequency of 230 GHz – a floating point issue) prohibiting fringe fit to run was fixed. For the CASA documentation a fringe fit task memo, describing the principles behind the task and how its parameters influence what the calibration step does, was written and is currently pending approval to be admitted into NRAO's CASA memo series. Work on an efficient wideband fringe fitting algorithm continued. Finally, several improvements related to (VLBI) metadata were made.

A user request to support > 255 antennas in UVFITS files was received. A documented recommendation on how AIPS supports this exists. Subsequently the procedure was implemented in casacore and from there this automatically propagated into **importfitsidi**.

Linearly polarised receivers are increasingly used for VLBI. The PolConvert software[11] that can be used to change those signals into circular polarisation runs on FITS-IDI files. A program was developed that can take the solutions derived by PolConvert and apply those to a full Measurement Set. PolConvert is normally run on a few short calibrator scans to derive the telescope calibration parameters before being run on the full dataset. Being able to apply the solutions at MeasurementSet level saves a lot of disk space and runtime.

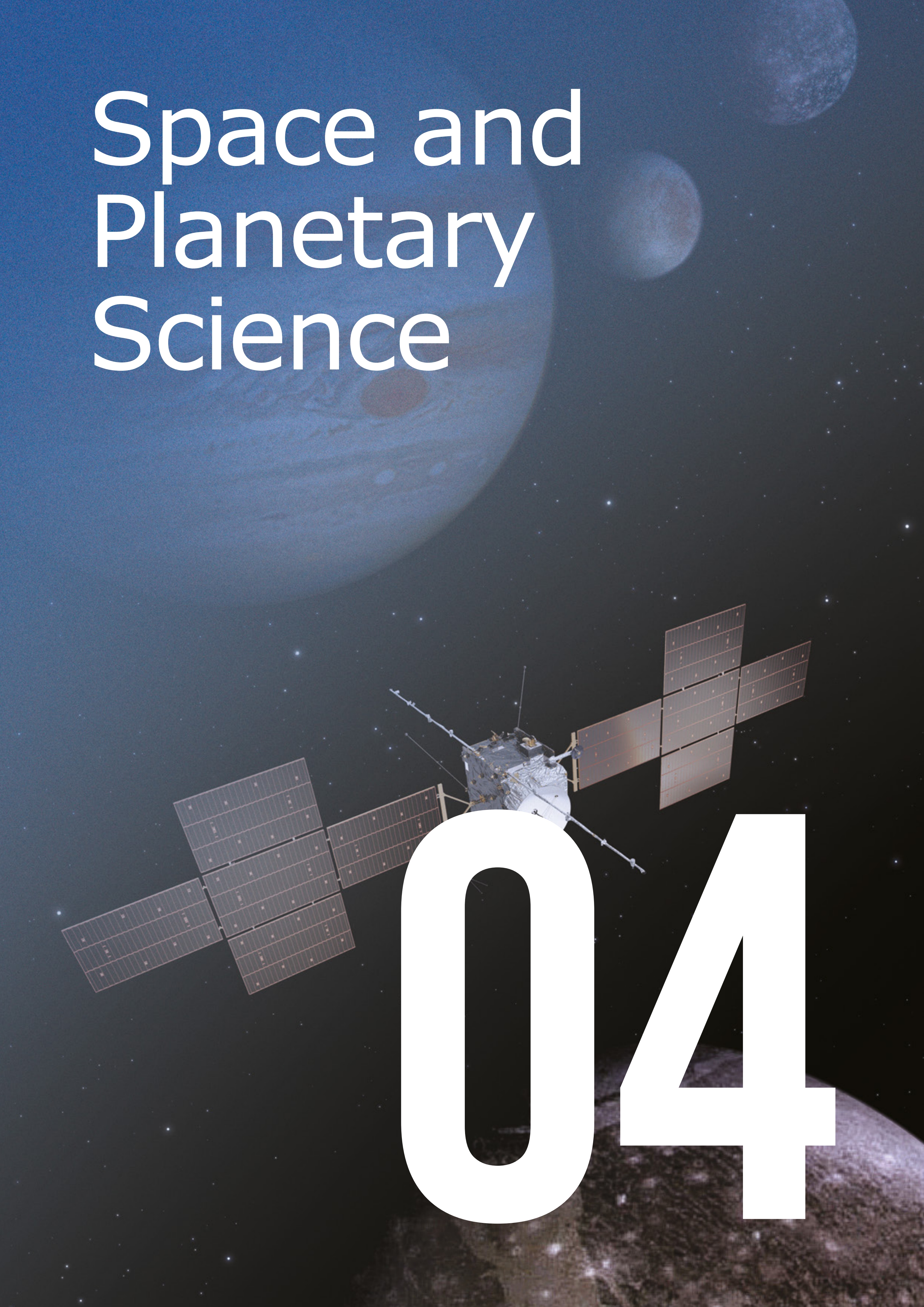
NRAO's CASA Next Generation Infrastructure (CNGI) project is progressing – it is an attempt to change MeasurementSet access into a more scalable infrastructure, geared towards enabling parallel processing: the MeasurementSet infrastructure is a show-stopping roadblock for distributed/scalable algorithms. Some time was spent on investigating this as the impact on existing CASA tools is tremendous.

During the year several user submitted bugs and feature requests for the pySCHED software were received and addressed, as well as issuing catalogue updates for EVN sessions.

11 https://github.com/marti-vidal-i/PolConvert

Space and Planetary Science

04



Two major directions of development of space and planetary science have been on the agenda of JIVE in 2021. The near-field VLBI technique was getting ready for participation in the ESA's Jovian system mission JUICE. And the advancement of VLBI toward microarcsecond angular resolution got new momentum within the concept of THEZA initiated in 2019. The concept is based on the advances of millimetre VLBI on the ground by the EHT and centimetre wavelength space VLBI missions.

4.1 GETTING READY FOR JUPITER SYSTEM TOUR

During the year of 2021 several major milestones have been achieved toward the launch of the ESA's large-class mission Jupiter Icy moons Explorer (JUICE), see Figure 4.1. The nominal launch window of the mission is to take place in April 2023. The VLBI component of the JUICE mission will be implemented as Planetary Radio Interferometry and Doppler Experiment (PRIDE) led by JIVE. The main aim of PRIDE is to support improvement of the Jovian system ephemerides which, in turn, are crucial for maximising scientific return of many in situ measurements and observations of the mission instruments.

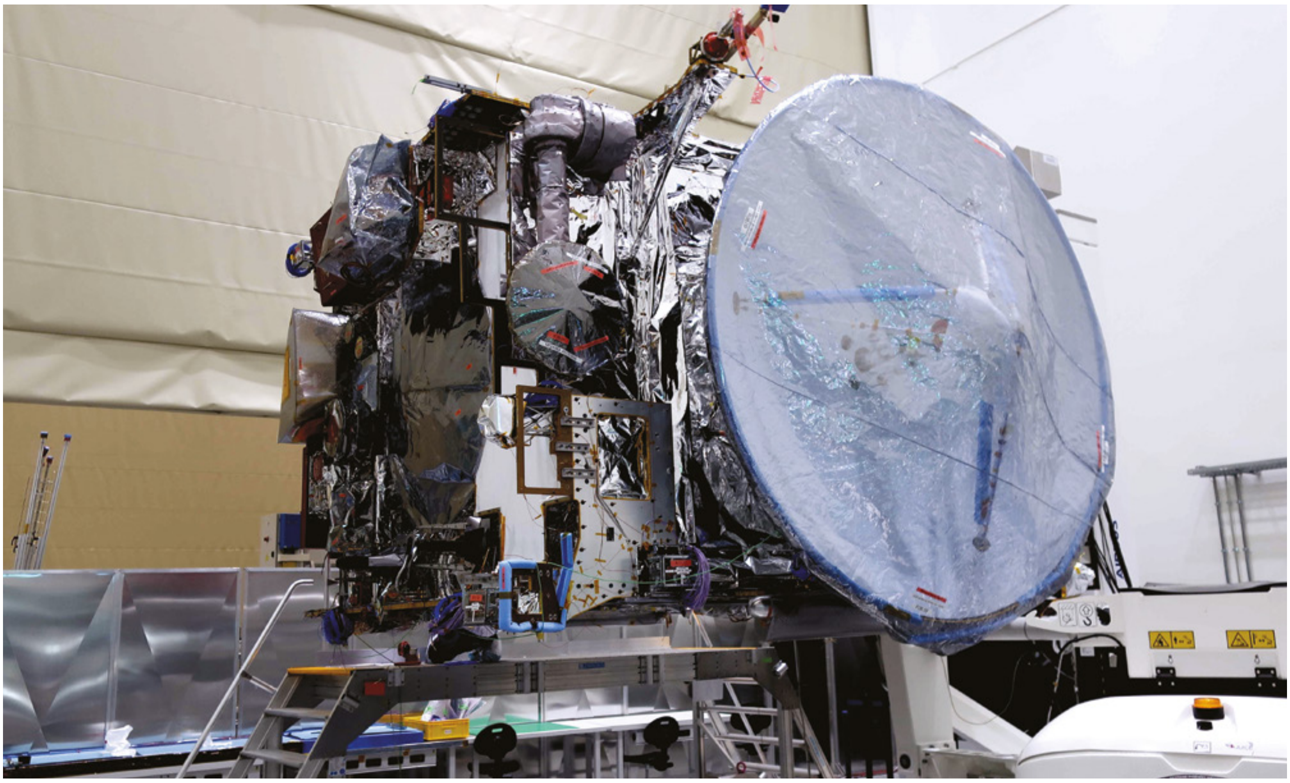


Figure 4.1: The flight model of the JUICE spacecraft at the assembly and test facility of the Airbus Defence and Space, Toulouse, France. On the face side of the spacecraft, the large white circular component is the high-gain antenna, and a smaller black one is the medium-gain antenna. PRIDE will work signals emitted by both antennas. Credit: ESA and Airbus Defence and Space.

In 2021, the international PRIDE team published a detailed description of the data processing algorithms of Doppler tracking component of the experiment (Molera Calves et al. 2021, *High spectral resolution multi-tone Spacecraft Doppler tracking software: Algorithms and implementations*, PASA 38, e065). This paper presents a software package for single-dish data processing of spacecraft signals observed with VLBI-equipped radio telescopes (Figure 4.2).

The Spacecraft Doppler tracking (SDtracker) software allows one to obtain topocentric frequency detections with a sub-Hz precision as well as reconstructed and residual phases of the carrier signal of any spacecraft or landing vehicle at any location in the Solar System. This part of the PRIDE data processing will be used for tracking of the JUICE spacecraft during the cruise and science phases of the mission.

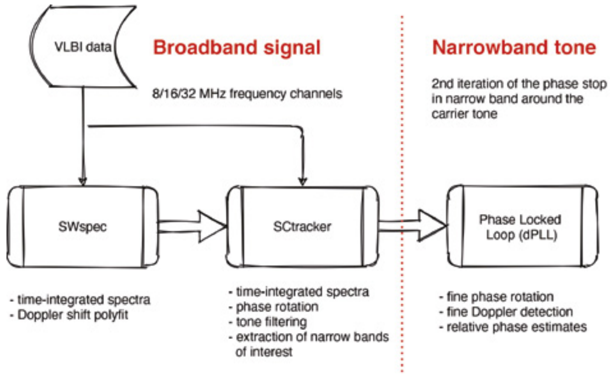


Figure 4.2: A spacecraft signal is received by a VLBI–equipped radio telescope and processed by three software packages SDtracker which consists of three sub-packages: SWspec, SCtracker and dPLL. The main products of SDtracker are the topocentric frequency detections and the residual phase of the spacecraft carrier signal.

In order to verify the SDtracker software, the PRIDE group conducted regular observations of several operational planetary missions. Figure 4.3 presents the result of a phase extraction in one of the observations of the ESA's Mars Express spacecraft. As shown in the paper by Molera Calves et al. (2021) mentioned above, the data products of PRIDE tracking can be used in various multi-disciplinary applications, ranging from determination of spacecraft state vectors to diagnostics of the interplanetary plasma.

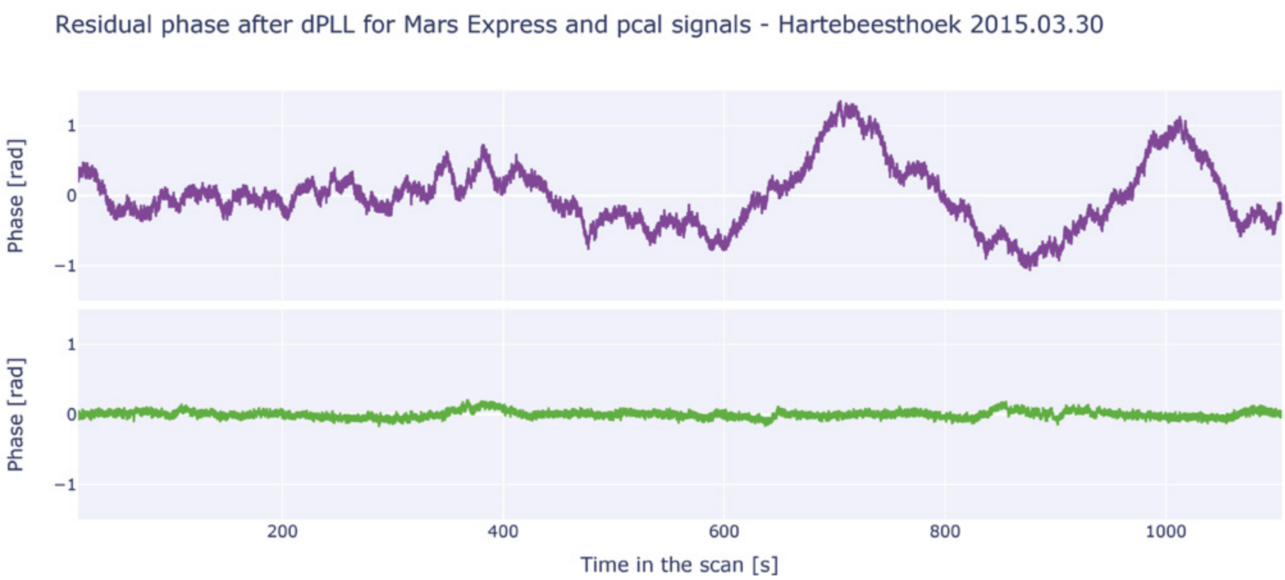


Figure 4.3: Phase extraction from the Mars Express signal (top) and telescope phase calibration tone (lower panel). The data were collected on 30 March 2015 with the Hartebeesthoek 26-m telescope in South Africa for interplanetary scintillation studies.

4.2 TOWARD MICROARCSECOND ANGULAR RESOLUTION

The next major leap in VLBI aims to reach microarcsecond angular resolution. This is the main driver behind the proposal submitted in 2019 by a large group of researchers in response to the ESA Call for ideas Voyage 2050. The proposal, entitled THEZA (TeraHertz Exploration and Zooming-in for Astrophysics), presents a concept of a multi-element spaceborne millimetre/submillimetre interferometric system. Such a system is a natural development of the ground-based millimetre VLBI systems, like EHT, and space VLBI missions of the first generation, VSOP (1997–2003) and RadioAstron (2011–2019). A White Paper describing this concept has been published in 2021 (Gurvits et al. 2021, Experimental Astronomy 51, 559–594). The work on this concept continued in 2021 with the emphasis on the formation of the science case that can define major mission specifications. The results of this collective effort have been presented at the 72nd International Astronautical Congress in Dubai in October 2021, see Figure 4.4.

The THEZA rationale is focused on the physics of spacetime in the vicinity of super-massive black holes as the leading science drive. However, it will also open up a sizable new range of hitherto unreachable parameters of observational radio astrophysics and create a multi-disciplinary scientific facility and offer a high degree of synergy with prospective "single dish'' space-borne sub-mm astronomy and infrared interferometry. As an amalgam of several major trends of modern observational astrophysics, THEZA aims at facilitating a breakthrough in high-resolution high image quality astronomical studies.

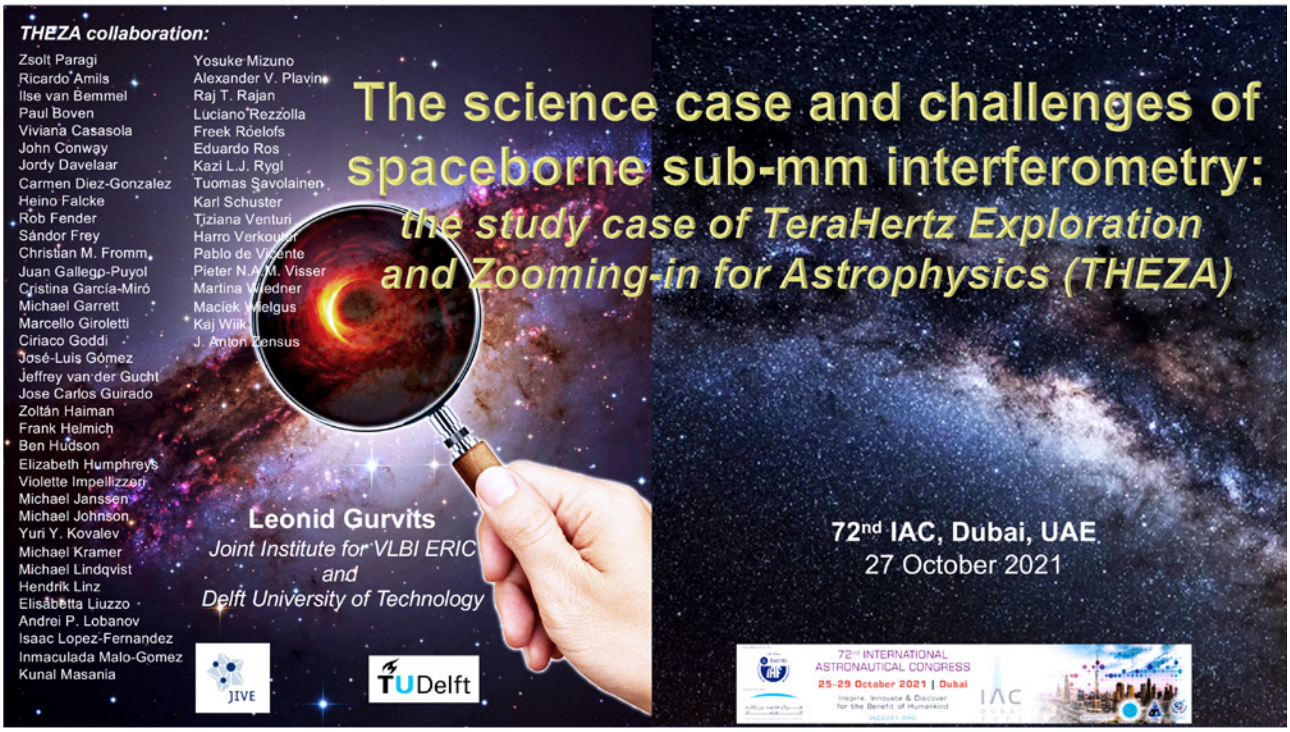


Figure 4.4: The title slide of the THEZA concept presentation at the 72nd International Astronautical Congress, Dubai, United Arab Emirates, 27 October 2021.

Communication and Training

05

5.1 COMMUNICATION AND OUTREACH

JIVE coordinates and organises different communication and outreach initiatives to expand the visibility of JIVE and the EVN activities among the international community of astronomers, policy-makers and the general public.

Due to the COVID-19 pandemic restrictions still in place in most countries around the world in 2021, the JIVE communication and outreach activities were mostly developed in online settings, using centralised platforms such as the JIVE and EVN websites, JIVE social media channels, periodic publications such as the JIVE/EVN Newsletter and the organisation of special events.

One of the highlights of JIVE communications activities comprised the publication of 28 news items over the year, including highlights such as Italy becoming a member of the JIVE European Research Infrastructure Consortium, the launch of Europe's largest astronomy network with the kick-off of the H2020 ORP project or different exciting scientific results using the EVN. These lead to a total of 267 appearances (6% increase from previous year) from JIVE and the EVN in media outlets in 38 countries, with a combined potential reach of around 1.5 billion people[12].

Regarding online presence, JIVE administers the JIVE and EVN websites that received a total of 5,246 and 31,475 views, respectively, for a total of 36,721 views. In addition, JIVE presence in social media was quite active:

— The most successful channel was Twitter with our publications reaching 341,902 impressions and the channel gaining 126 new followers leading to a total of 712 followers at the end of the year;

— JIVE Facebook channel reached 25,020 people (146,6% increase with respect to 2020) leading to 92 new likes (87.8% increase with respect to 2020) for a total of 692 likes at the end of 2021;

— The JIVE/EVN YouTube channel experienced a high activity due to the success of the EVN online seminar series (see below) that made the channel reach 32,600 impressions, including 3798 views and 475 total hours viewed, and 115 new subscribers for a total of 222 subscribers.

During 2021, JIVE also produced three JIVE/EVN Newsletters, which were distributed quarterly in January, May and September, for a total of 569 downloads

Overall, the central communication activities of JIVE had a total reach of over 400,000 people in 132 countries, with an extended potential reach of 1.5 billion people considering media coverage.

Regarding JIVE outreach activities, we can highlight the continuation of the successful EVN e-seminar series that started in 2020 and continued through 2021 with 5 more seminars leading to the organisation of the EVN mini-Symposium in June 2021. The EVN e-seminars proved to be an important legacy for the worldwide VLBI community since the recordings can be accessed in the JIVE/EVN YouTube channel, being watched already thousands of times. The success of the first edition encouraged the organisation of the second edition that started in November 2021 and will comprise several seminars throughout 2022 leading up to the 2022 EVN Symposium to be held in Cork (Ireland) in July 2022.

12 Media coverage data provided by Meltwater Media Monitoring Service.

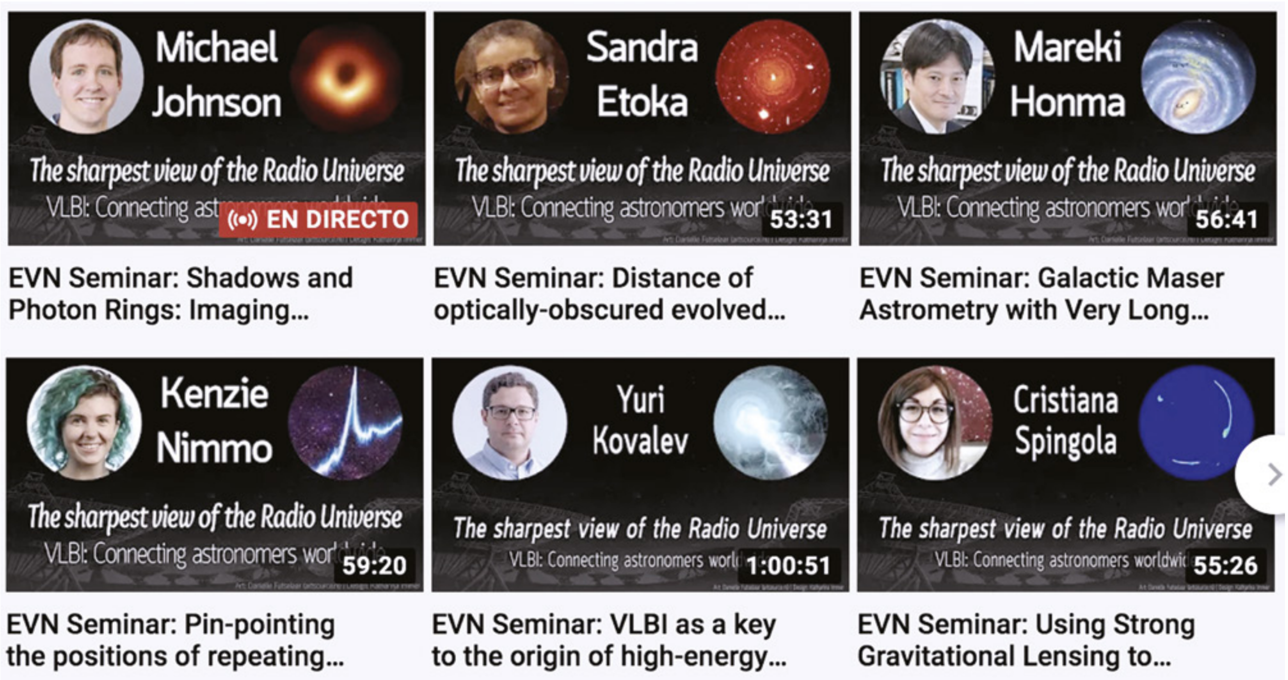


Figure 5.1: Overview of some of the EVN Online Seminars.

Following the successful experience in 2020, with the support of the H2020 JUMPING JIVE project, another Special Session around VLBI was organised as part of the EAS Conference 2021 (EAS 2021). Like 2020, the EAS Conference was a fully virtual event organised by Leiden Observatory. In the organisation for the special session S11: Extreme astrophysics at extremely high resolution, close attention was paid to diversity, both for invited speakers and SOC members. For contributed talks, an additional weighting was done regarding career level and origin, favouring early career researchers and those from under-represented countries. The session was attended by around 60 participants.

The year 2021 also served to review the current communications initiatives and prepare a new communication strategy for JIVE and the EVN for the period 2022-2023. The strategy – approved by the EVN Consortium Board of Directors in December 2021 – was developed considering the feedback of the outreach officers of all EVN members to ensure that the strategy was as inclusive as possible. In that sense, a strong effort has been focused to provide momentum to the EVN Outreach Officers Network (EOON) organising periodic communications between the JIVE Science Communications Officer and the EVN Partners Outreach Officers to streamline the communications within the network to maximise the dissemination reach of the EVN partners individually and as a whole.

One of the first activities of the new communication strategy was the publication of the new version of the JIVE website already developed at the end of 2021. The new version follows the design already present for the EVN website. Also at the end of 2021, a new online version of the JIVE/EVN newsletter hosted at the EVN website – was prepared for its implementation from 2022 on. This change will serve to modernise the way the newsletter is disseminated as well as to more efficiently evaluate it.

Finally, JIVE was also responsible to coordinate the communication actions of the H2020 ORP project, including the establishment of a communication strategy, development of visual identity, production and management of the project's website and Twitter channel, production of an internal newsletter among other activities.

5.2 TRAINING

JIVE staff provided different online training during 2021. Highlights include:

- Participation in the DARA Programme activities in the framework of the H2020 JUMPING JIVE project. The DARA programme aims at training early-career African astronomers in Botswana, Kenya, Madagascar, Ghana, Mozambique and Namibia in the use of VLBI. JIVE staff participation included VLBI lectures and hands-on training on the basics of VLBI data reduction using the CASA tool.

- The IVS Technical Operations Workshop (TOW) is a biennial meeting of technical staff from VLBI stations, both geodetic and astronomical, providing hands-on training and problem resolution techniques, as well as the opportunity to confer with people from other stations and correlators. The 11th TOW was held virtually from 3-5 May 2021. For the 2021 TOW, JIVE contributed to the "Recorder, Media Handling, and e-Transfers" live-streamed session on 5 May, particularly for the areas of FlexBuff recorders and managing data transfers via the jive5ab package, or the e-transfer software developed in the ASTERICS project, and also the pre-recorded seminar on "Pointing and Amplitude Calibration".

- As part of the EVN Users' Meeting in 2021, a summary of the EVN support and operations, as well as the resources available for the EVN users, including the contribution that JIVE has made in the last years to make the use of the EVN easier for the users.

- On 22-26 November 2021, five visiting users from the University of Amsterdam (the Netherlands) participated in an on-site training at JIVE on EVN data reduction.

Figure 5.2: Group from Amsterdam University attending on-site training at JIVE in November 2021. Credit: B. Marcote.

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 2021. 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	114	1093	1224.5	16	45	51
Distributed	109	1058	1183	15	41	44
e-EVN experiments	25	207.5	207.5			
e-EVN ToO/ triggers	8	74	74			

Summary of projects correlated or distributed in 2021. Here, "Network Nours" sum the total duration of experiments, and "Correlator Hours" are the network hours multiplied by any multiple correlation passes required – the actual time to correlate can be several times larger for the more complex correlations.

COVID-19 restrictions continued to cast a shadow over all aspects of correlator operations in 2021. Correlation proceeded primarily remotely, as has been the case since March 2020. An operator presence in JIVE headquarters in Dwingeloo two to three days per week has been maintained, in part to permit logistics and equipment maintenance to stay on track. Restrictions were loosened over the summer 2021, resulting on average in an additional day per week of operator presence in Dwingeloo. Throughout this COVID-era, at least one operator has controlled the correlator directly from Dwingeloo during the first shift of e-EVN days (which is when unanticipated problems would be more likely to come to light). Support scientists have continued to work predominantly remotely. There was a vacancy in the support-scientist ranks from September 2020 until the beginning of October 2021.

Resiliency and responsiveness have naturally suffered somewhat in this environment. However, the number of correlator hours completed in 2021 exceeded 1,200 for only the second time since shifting to the SFXC correlator in 2011. The number of correlator hours in the queue to correlate stood 4% lower at the end of 2021 than it was at the end of 2020.

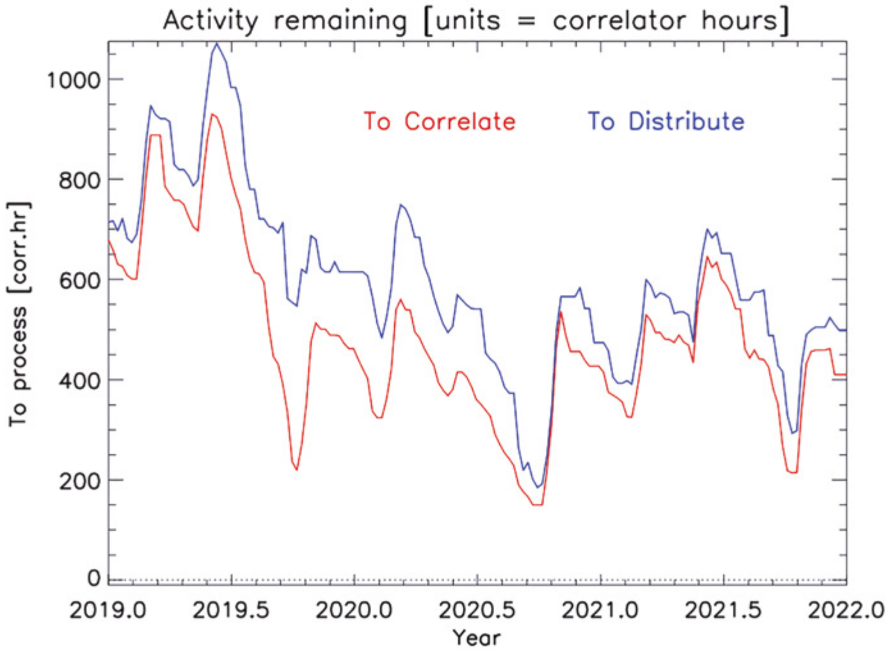
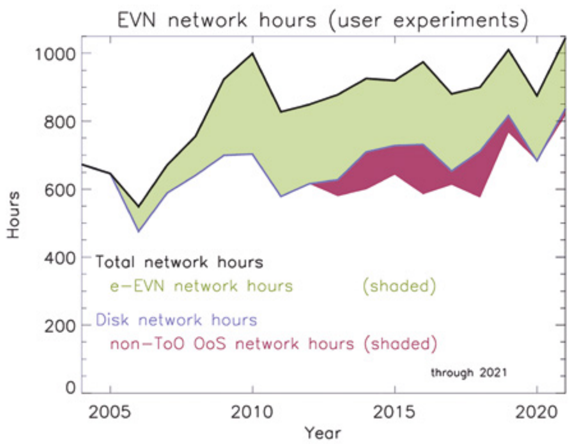


Figure 6.1: The size of the correlator queue at different stages in the processing cycle. The red line shows the number of correlator hours that remain to be correlated. The blue line shows the number of correlator hours in experiments whose data remain to be distributed to the PI.

In Figure 6.2, the image on the left traces the evolution of the annual EVN network hours. Despite the impact of COVID-19 on network-wide operations, 2021 saw a new record established for most EVN network hours (1044.5; was 1010 from 2019). e-EVN network hours exceeded 200 for the first time since 2017. The image on the right focuses on e-EVN experiments, showing the break-down into individual proposal categories, with a recovery in the amount of target-of-opportunity observations being evident.



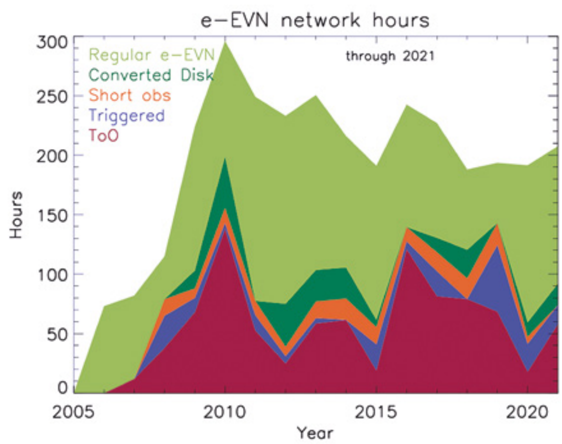


Figure 6.2: Left: Annual EVN network hours, with separate colour-coded areas for different categories of user observations, from top to bottom: real-time e-EVN (light green), non-ToO out-of-session disk-based (dark red), and "traditional" disk-based (white). Right: e-EVN network hours, with separate 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 other highlights from 2021:

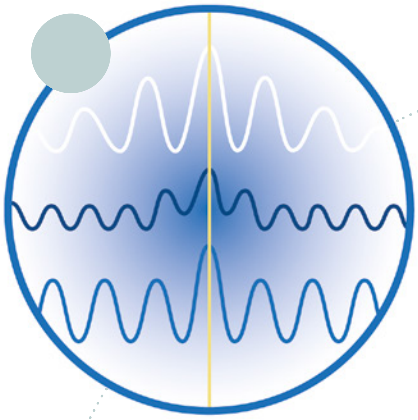
- GM077 was a large (24 hour, 25 station) global Galactic water maser phase-referencing observation, resulting in the largest set of output FITS files for a single phase-centre observation at 4.1 TB. Spectral zooming was used for the high-resolution line correlator pass – otherwise the size would have been almost double.

- The second 4 Gbps user experiment, which was the first one with a PI from a non-EVN institute, was observed in the October/November session (EW025A).

- Correlation and distribution of the final epochs of ER047, a 72-hour project investigating the contributions of AGN and star formation in a faint (~few uJy) population of radio sources, were completed. This project holds the current record for the highest number of outputphase centres at 761, and in the end the total time to correlate its six 12-hour epochs occupied 660.5 hours, and the total size of its output FITS files amounted to 66 TB.

- There were fourteen EVN target of opportunity observations (seven via e-EVN) and one e-EVN trigger observation, arising from six proposals (one project had ten observations – five epochs each at two different frequency bands spread over 51 days from August to October – some epochs using e-EVN and others using disk-pack recording). These projects covered scientific topics ranging from the persistent radio source associated with a fast radio burst (FRB), the afterglow of an extreme short gamma-ray burst, the progenitor of a new type Ia supernova, the shocks generated during outbursts of two different novae (i.e., two separate projects, each observing "its" nova), and the changing outflow in an AGN apparently transitioning from a Seyfert 2 to a Seyfert 1.

- There were nine FRB-burst triggers from the on-going correlation-only projects based on observations shadowing CHIME (EK048A-G, EK050A-B). The triggers cover four different FRBs. Correlation of the shadowing VLBI observations is triggered if a burst is detected in the CHIME observations. Depending on the accuracy of the a priori position of the FRB, one or two correlation passes over the whole range of the phase-referencing data (typically 3 to 11 hours) would ensue with the ultimate goal of deep-imaging to detect any associated persistent radio source. There would also be a special off-line high time-resolution correlation of the burst itself (i.e., no more than a few ms of data).



6.2 EVN SUPPORT

There were no further stations transitioning from Mark5 disk-pack to FlexBuff in 2021. With only four remaining Mark5-based regular EVN stations, it has proven straightforward to mount all disk packs from a session simultaneously in the available playback units at JIVE, which has greatly improved the flexibility in shifting correlation from one observation to another, especially in this COVID-19 era in which an operator may not be in Dwingeloo every day.

JIVE coordinated tests of new receivers at EVN stations, including X-band at Torun (Tr) in the May/June session, Q-band at Urumqi (Ur) in the October/November session, and the Ys C-X wide-band receiver in December. All tests resulted in successful fringes, with the receivers ready for operational use in EVN observations. The new frequency capabilities for Tr and Ur were added to the EVN Proposal Tool.

JIVE also coordinated test observations for telescopes that potentially could join in future EVN observations. The 32m telescope at Zolochiv, Ukraine, participated in the May/June 6 cm NME, observing with two 16 MHz subbands in their native data format. Coordination between JIVE and colleagues at Zolochiv continued throughout the subsequent months to effect a translation into VDIF format. The Arecibo 12m telescope participated for the first time in an EVN context during the October/November 3.6 cm NME. Good fringes were seen in RCP channels (which come from one of their two RDBE back-ends; the LCP channels come from the other RDBE, auto-correlations there suggested a problem configuring it). The 500m FAST telescope in China also participated successfully in its first EVN observation during the October/November L-band NME, the last portion of which was conducted at 21 cm to accommodate their upper-limit in frequency.

Discussions about organising EVN test observations with the Indian GMRT and with the new digital back-end at Robledo got underway this year, with the prospect for first observations to come in early 2022 in both cases.

6.3 USER SUPPORT

JIVE provides support in all stages of a user's EVN observation, from proposal definition to data analysis. There were thirteen first-time PIs in 2021 observations; five of these were students and five were female (there was one female student). Countries represented include China, India, Mexico, Hungary, Italy (2), Germany (2), the Netherlands (3) and the United States of America (2; one from Arecibo).

Due to circumstances produced by COVID-19 restrictions, travel to JIVE was limited to a few visits only. Support scientists were in touch with each other on Zoom and with chat apps (mainly Mattermost). In October new support scientists arrived. Their training started in person at JIVE, but due to another COVID outbreak we moved back to home-office work.

During 2021 the EVN pipeline has been updated to include the primary beam corrections as well. Together with the continuous improvements to the antab-editor, this will secure a more precise and robust calibration for the EVN. Another important milestone was the integration of PolConvert with CASA by the R&D group. This will allow us to handle the various issues identified by the support scientists in house. Converting linear to circular polarisations is becoming part of our regular operations. Although there are still some difficulties with this approach, in the long run this will lead to a better polarisation calibration for the EVN.

During the EVN mini-Symposium and Users' Meeting support scientists presented the results of the EVN Users questionnaire. Most users (by far!) see the main advantage of the EVN being its sensitivity, and its main disadvantage is the limited time for observing (3 main sessions + 10 e-VLBI days). About half of the users who filled in the questionnaire have used the real-time correlation e-EVN before, and most of them use other VLBI arrays as well (mainly VLBA and e-MERLIN). The users are very happy about the information available about proposal deadlines and with the support they receive from JIVE, but there may be some room for improvement in the proposal toolkit and updates on the EVN/technical information. The individual suggestions included having more observing sessions and kick-start EVN-lite, as well as organising tutorials/guides/open access problem-solving channels of communication – which we indeed plan to do in the coming year.

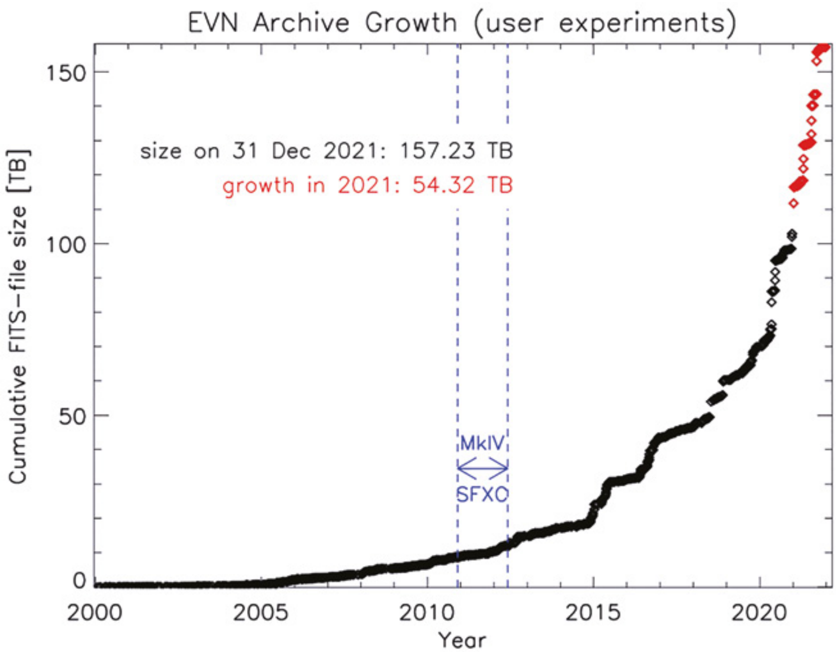


Figure 6.3: Growth of user experiments in the EVN Archive. Experiments archived in 2021 are plotted in red. Vertical dashed lines show the transition period between the MkIV and SFXC correlators.

As for the problems users and/or support scientists found in the data included jumping phase at scan boundaries in Irbene (problem solved by station after reporting), Yebes amplitude dropouts at 5 GHz, gradually disappearing fringes at Noto in one project, and e-MERLIN outstation issues with sometimes very poor sampstats, and being much later on source than Sched expects them. Most of the reported errors have been solved or are being worked on. Users proposed to include optional multi-phase centre correlation in real-time e-VLBI sessions for a few phase-centres, to help phase calibration. Initial tests have identified issues which were fixed, but more tests are needed before this could be made operational.

JIVE continued to provide PIs with experiment-specific scheduling templates to track the evolving configurations of equipment at EVN stations. The GM077 global water-maser observation mentioned in Section 6.1 also used sub-netting during the period when EVN and NRAO telescopes were observing at the same time, in order to use different phase-referencing tactics for each of these two parts of the overall array. This approach did require recasting the observing schedule to be able to drive the correlation, in order to bundle all stations that observed the same source at the same time into a single scan, so that all possible baselines would be formed.

The EVN Archive remains the entry point for users to retrieve their correlated EVN data, and provides open access to others following the one-year proprietary period (six months for ToO projects). The total size of user-experiment FITS files in the Archive passed the 150 TB mark by the end of 2021, increasing by 53% during the year.

Finances

07

7.1 JIVE FINANCIAL REPORT

BALANCE (AFTER ALLOCATION OF RESULTS)

ASSETS	31 DECEMBER 2021 in €	31 DECEMBER 2020 in €
TANGIBLE FIXED ASSETS		
Tangible fixed Assets	52,468	53,912
Total of Tangible fixed Assets	*52,468*	*53,912*
CURRENT ASSETS		
Work in Process	0	0
Receivables	277,476	1,073,694
Cash at bank	3,269,199	2,014,973
Total of Current Assets	*3,546,675*	*3,088,667*
TOTAL ASSETS	**3,599,143**	**3,142,579**

LIABILITIES	31 DECEMBER 2021 in €	31 DECEMBER 2020 in €
CAPITAL		
General reserve	1,895,094	1,952,533
Designated funds	300,000	82,932
Total capital	*2,195,094*	*2,035,465*
OTHER LIABILITIES		
Short term debts	1,404,049	1,107,114
Total of Current Liabilities	*1,404,049*	*1,107,114*
TOTAL LIABILITIES	**3,599,143**	**3,142,579**

STATEMENT OF PROFIT AND LOSS

	2021			2020
	BUDGET	**ACTUAL**	**DIFFERENCE**	**ACTUAL**
REVENUES	in €	in €	in €	in €
INCOME				
Contributions/subsidies third parties	2,448,727	2,530,785	82,058	2,364,580
Interest	0	0	0	0
Other	305,109	255,586	-49,523	256,893
Total Income	*2,753,836*	*2,786,371*	*32,535*	*2,621,473*
TOTAL REVENUES	**2,753,836**	**2,786,371**	**32,535**	**2,621,473**

	2021			2020
	BUDGET	**ACTUAL**	**DIFFERENCE**	**ACTUAL**
EXPENDITURES	in €	in €	in €	in €
OPERATIONS				
Grants/expenditures	2,737,210	2,626,742	-110,468	2,524,995
Total Operations	*2,737,210*	*2,626,742*	*-110,468*	*2,524,995*
TOTAL EXPENDITURES	**2,737,210**	**2,626,742**	**-110,468**	**2,524,995**

RESULT	**16,626**	**159,629**	**143,003**	**96,478**

Figure 7.1: Dwingeloo Telescope. Credit: Uberprutser / Wikimedia Commons.

EC Projects

08

H2020 OPTICON-RADIONET PILOT

The OPTICON-RadioNet Pilot (ORP) project brings together the well established ground-based astronomy community to offer, support and develop access to radio and optical facilities in an efficient, coordinated and future-looking programme.

JIVE is involved in the project through the EVN participation as well as coordinating the communications of the project.

H2020 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 address critical challenges, develop best practices and frame the necessary knowledge to support ERICs with various aspects. Moreover, this will contribute in building the brand identity of ERICs as an important body and stakeholder in consultation of related policy action.

H2020 ESCAPE

JIVE is a partner in the ESCAPE project which aims to find solutions for common problems identified between astronomical, astrophysical and particle physics research domains with the intent to define requirements of the European Open Science Cloud. Common problems have been identified in the areas of handling (extremely) large datasets, finding the scientifically verified / curated software for extracting science from those datasets and knowledge of requirements to run it, enabling discovery of datasets and a science analysis platform that allows joint analysis of datasets from different (ESCAPE) partner instruments or observations.

Those four areas are addressed by work in four WPs (DIOS, OSSR, CEVO and ESAP) of which JIVE participates in three: OSSR (Open Source Software Registry), CEVO (Connecting ESFRI projects to EOSC through VO framework) and ESAP (European Science Analysis Platform). JIVE is actively involved both in defining standards such as metadata for the software (OSSR), radio visibility data in the VO (CEVO) as well as improving the Jupytercasa entry in the OSSR, making the EVN Archive findable and searchable in the VO and providing an analysis platform for (EVN) visibility data using CASA in version-controlled Jypyternotebooks.

THE JUMPING JIVE PROJECT SUCCESSFULLY CONCLUDED ITS ACTIVITIES

The Horizon2020 JUMPING JIVE project, which successfully passed its final review by the European Commission in October 2021, has been instrumental during the past four and a half years in the development and reinforcement of JIVE and the EVN activities in key aspects for their sustainability that will impact the VLBI community in the next decades.

The Joining up Users for Maximising the Profile, the Innovation and Necessary Globalisation of JIVE (JUMPING JIVE) project aimed to strengthen JIVE, enhance the EVN, advocate its services and enlarge its partnerships, and prepare JIVE and the EVN for future scientific and technological challenges in preparation for global VLBI in the era of multi-messenger astrophysics. JIVE coordinated the project, which ran from December 2016 to July 2021 and comprised the participation of 12 institutes from 8 European countries.

The effort that resulted in the success of JUMPING JIVE started already at the time of the formation of the collaboration that became an H2020 project. All partner institutions demonstrated the importance of working in synergy to reach common goals. The activities of the project, such as supporting the development of radio astronomical communities in Africa or the work in the definition of the SKA-VLBI science cases, have highlighted to potential new partners the role of JIVE and the EVN as centres of technological and scientific excellence.

Towards a Sustainable JIVE

Over the course of the project, JIVE has been established as an open and welcoming community with a strong emphasis on its ability to provide high-quality support for anyone interested in doing science with the EVN. In this sense, JUMPING JIVE fostered an active presence at international astronomy meetings, reaching thousands of astronomers by bringing the scientific potential of VLBI to a broad community.

JUMPING JIVE worked towards strengthening the sustainability of JIVE with actions to establish new partnerships including, most notably, efforts to support new countries to become JIV-ERIC members, which resulted in the formal adoption of Latvia (2017) and Italy (2021) as JIV-ERIC members; the assistance to VLBI groups and facilities in several countries around the world to start collaborations that eventually could initiate the process to become JIV-ERIC members – e.g. the signature of Memorandum of Agreement between JIVE and NARIT (Thailand); or actions to support national radio astronomical communities, e.g. efforts linking the Portuguese interests (and membership) in SKA and those of the EVN expansion in Azores and Africa.

The project provided a forum to explore potential synergies between JIVE and the International LOFAR Telescope (ILT), which finally resulted in the support of JUMPING JIVE to ILT in their first steps in 2021 to become an ERIC. Both entities are open to the possibility of collaborating in the future in the astronomy research infrastructure landscape.

Figure 8.1: Attendees of the ITAC-TNRT meeting in Thailand in November 2019. Credit: TNRT.

New Science Capabilities

A key achievement of the JUMPING JIVE project was the improvement of VLBI user capabilities. On one hand, this was done through the integration of new telescopes that enhanced the EVN roster. On the other hand, the project worked on new technical implementations for the EVN such as incorporating geodetic capabilities, which ensure relevance for new audiences and therefore will eventually increase the number of EVN users.

JUMPING JIVE also focused on modernising tools used by the VLBI community, including setting up a centralised monitoring system for the EVN at JIVE and building pySCHED, a modernised version in Python of the legacy programme SCHED that is used for the scheduling of VLBI networks around the world. Both new tools have seen a good uptake within the VLBI community in general and the EVN users specifically.

VLBI in the next decade

One of the most important achievements of the project was the development of the "VLBI20-30: a scientific roadmap for the next decade – The future of the European VLBI Network" White Paper, describing the science case for VLBI and providing suggestions toward upgrade paths for the EVN. The White paper – involving 80 astronomers and engineers from different countries around the world in its preparation – has become a scientific roadmap for the VLBI community as well as becoming one of the reference scientific white papers of the present decade.

Figure 8.2: VLBI training in Africa – JUMPING JIVE Lecture, Sarrvesh Sridhar (ASTRON) teaching Interferometric data. Credit: DARA-JUMPING JIVE.

Another key focus of JUMPING JIVE was building capacity for VLBI in Africa. For this, the project enhanced the awareness of the opportunities in physics and astronomy to broaden the knowledge of astronomy and related projects within African institutes and local communities, including the training of over 250 early-career researchers in seven African countries in collaboration with the UK and South African DARA programme, and support for short-term placements in EU institutions for several African students.

The participating early-career researchers benefited in a variety of ways with the majority transferring the training, skills and knowledge obtained to local colleagues and institutes in Africa, including success stories such as Dr. Asabere (Ghana) who after attending JUMPING JIVE training lead the development, commissioning and operations of the converted 32-m in Ghana that, with the assistance of JUMPING JIVE, became the first African radio telescope, outside of South Africa, to link with and gain fringes with the EVN. Finally, JUMPING JIVE pursued the globalisation of VLBI in the era of the Square Kilometre Array (SKA). The project was instrumental in developing a possible operational model for SKA-VLBI and based on that, initial steps have been taken to form a Global VLBI Alliance as well as a SKA VLBI Consortium. JUMPING JIVE also supported the VLBI science working group for the elaboration of the portfolio of SKA-VLBI science cases.

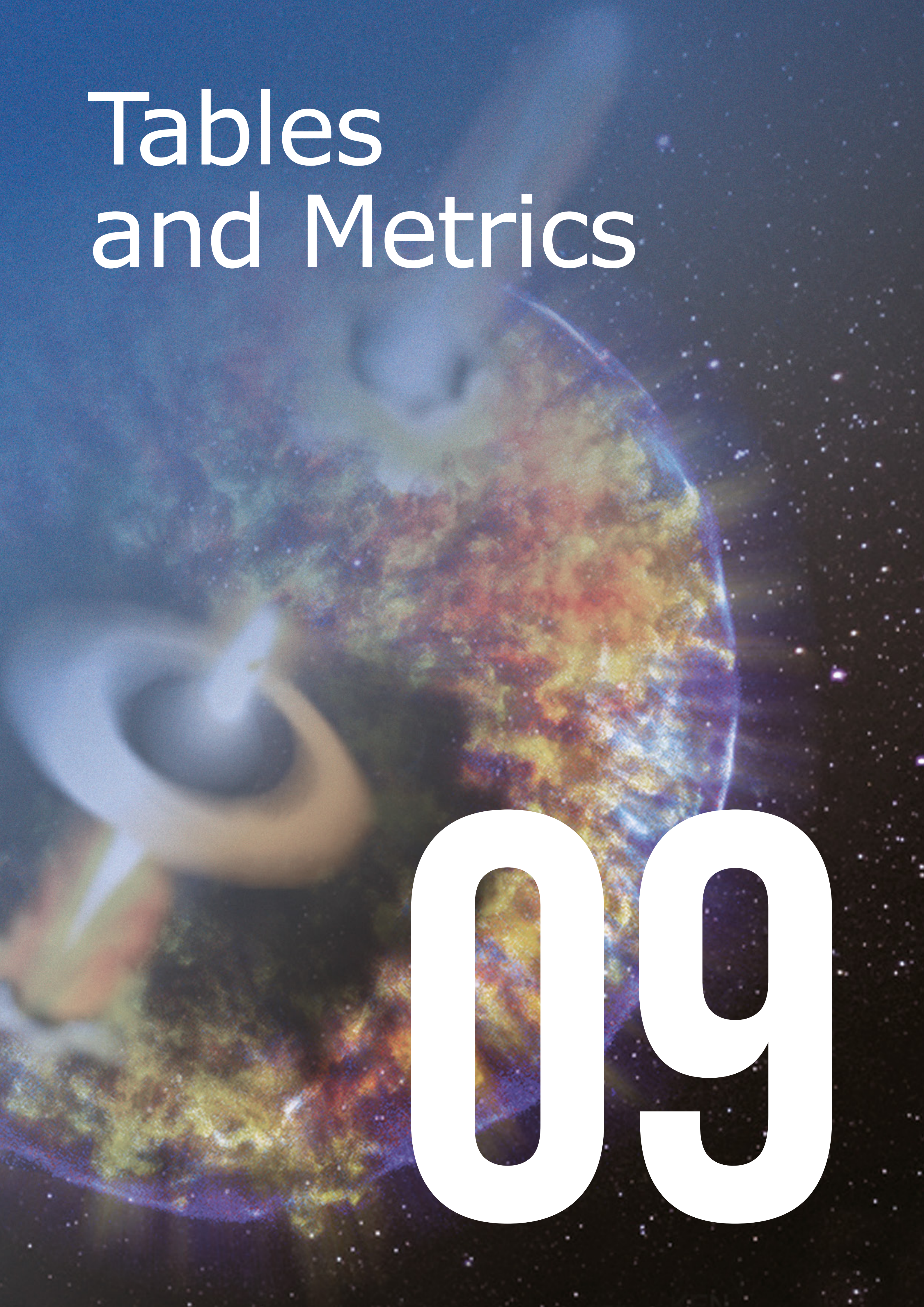
JUMPING JIVE Legacy

JUMPING JIVE has been instrumental in the development of JIVE and the strengthening of the EVN, ensuring its future relevance and sustainability and reasserting the role of JIVE as a key global player in the field of VLBI, with the EVN at the core of its activities. Many actions of the project are considered core activities of JIVE and the EVN nowadays, ensuring its continuation beyond the lifetime of the project.

The activities in the JUMPING JIVE project have provided the main scientific and technological ingredients for a bright future, and have had a huge impact on the visibility of VLBI among astronomers, other facilities, and society in general.

Figure 8.3: SKA-VLBI Workshop Participants. Credit: JUMPING JIVE.

Tables and Metrics



09

9.1 JIVE COUNCIL

MEMBER REPRESENTATIVES

Dr. Patrick Charlot	*Laboratoire d'Astrophysique de Bordeaux,* Pessac, France
Dr. Guy Perrin	*National Centre for Scientific Research,* Paris, France
Dr. Tiziana Venturi	*representing the EVN Board of Directors, IRA-INAF,* Bologna, Italy (Chair)
Dr. Grazia Pavoncello	*MIUR – Ministero dell'Istruzione, dell'Università e della Ricerca,* Roma, Italy
Dr. Aleksejs Klokovs	*Ventspils University of Applied Sciences,* Ventspils, Latvia
Mr. Dimitrijs Stepanovs	*Ministry of Education and Science,* Latvia
Dr. Marco de Vos	*ASTRON, Dwingeloo,* the Netherlands
Mrs. Saskia Matheussen	*NWO, Den Haag,* the Netherlands
Dr. José Antonio López Fernández	*Instituto Geográfico Nacional,* Madrid, Spain (Vice chair)
Mrs. Monica Groba López	*Instituto Geográfico Nacional,* Madrid, Spain
Prof. John Conway	*Onsala Space Observatory,* Onsala, Sweden
Mr. Mathias Hamberg	*Vetenskapsrådet / Swedish Research Council,* Stockholm, Sweden
Prof. Simon Garrington	*Jodrell Bank Centre for Astrophysics,* Manchester, UK
Dr. Colin Vincent	*Science and Technology Facilities Council,* Swindon, UK

ASSOCIATED RESEARCH INSTITUTES REPRESENTATIVES

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

9.2 JIVE PERSONNEL

Dr. Olga Bayandina	*Support Scientist*
Dr. Shivani Bhandari	*Postdoctoral Researcher* (from 4 October 2021)
Mr. Paul Boven	*Network Systems Engineer*
Dr. Bob Campbell*	*Head of Science Operations*
Dr. Giuseppe Cimò	*Space VLBI Scientist*
Dr. Francisco Colomer Sanmartin*	*Director*
Drs. Bob Eldering	*Software Engineer*
Dr. Dhanya G. Nair	*Support Scientist*
Dr. Cristina Garcia-Miro	*SKA-VLBI scientist* (until 18 April 2021)
Prof. Leonid Gurvits*	*Head of Space Science and Innovative Applications Group*
Mr. Bert Harms	*Chief Operator*
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. Gina Maffey	*Science Communications Officer* (until 1 February 2021)
Dr. Benito Marcote Martin	*Support Scientist*
Dr. Suma Murthy	*Support Scientist* (from 1 October 2021)
Dr. Gabor Orosz	*Support Scientist* (from 1 October 2021)
Dr. Zsolt Paragi*	*Head of User Support*
Dr. Jorge Rivero González	*Science Communications Officer* (from 1 May 2021)
Dr. Des Small	*Scientific Software Engineer*
Dr. Ilse van Bemmel	*Project Scientist*
Drs. Aukelien van den Poll	*Finance and Project Officer*

** – JIVE MT member*

Prof. Huib Jan van Langevelde	*Chief Scientist*
Drs. Marjolein Verkouter*	*Head Technical Operations and R&D*

** – JIVE MT member*

9.3 EDUCATIONAL RESPONSIBILITIES

MSC PROJECT SUPERVISION

Théo Furst	by B. Marcote (co-supervisor), *University Of Liége,* Belgium. From fall 2021 to Spring 2022

PHD PROJECT SUPERVISION

Paul Boven	by H.J. van Langevelde, *Leiden University* (completion in 2023)
Kenzie Nimmo	by Z. Paragi and B. Marcote, *UvA* (main supervisor J.Hessels) (completion in September 2022)
Vidhya Pallichadath	by L.I. Gurvits and L.L.A. Vermeersen, *Delft University of Technology* (completion in 2025)

SECONDARY AFFILIATIONS

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

9.4 VISITORS TO JIVE

NAME	INSTITUTE	PERIOD	HOST
T. Hollema	*Culture Teams Virtual Leadership Organisation,* the Netherlands	1 November	van Langevelde
D. Hewitt	*University of Amsterdam/API,* the Netherlands	22-26 November	Marcote
O. Ould-Boukattine	*University of Amsterdam/API,* the Netherlands	22-26 November	Marcote
P. Chawla	*University of Amsterdam/API,* the Netherlands	22-26 November	Marcote
M. Snelders	*University of Amsterdam/API,* the Netherlands	22-26 November	Marcote

9.5 CORRELATOR ACTIVITY

User experiments with correlation or distribution completed in 2021. 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
EA065A	Sep.21	Atri	*Identifying the true nature of compact, steep spectrum sources*
EA065B	Nov.21	Atri	*Identifying the true nature of compact, steep spectrum sources*
EA065C	Dec.21	Atri	*Identifying the true nature of compact, steep spectrum sources*
EB064I-J	s.1/21	Bach	*Does Cygnus A harbor a binary black hole?*
EB074C-F	s.3/20	Bruni	*Zooming into the cores of restarted giant radio galaxies*

EB081B	s.3/20	Boven	*Astrometry Ross 867*
EB081C	s.1/21	Boven	*Astrometry Ross 867*
EB082	s.3/20	Boven	*VLBI observations of low-frequency detected stellar systems*
EB084	s.1/21	Bayandina	*Episodic ejection from a low-mass young stellar object traced by H2O masers*
EB085	s.1/21	Bietenholz	*SN 2014C: Renewed Deceleration and the Nature of the Opposing Hot Spots*
EC071F-H	s.3/20	Casadio	*Search for 10^6 to 10^{10} solar-mass gravitational lenses*
EC071I-J	s.1/21	Casadio	*Search for 10^6 to 10^{10} solar-mass gravitational lenses*
EC071L-N	s.2/21	Casadio	*Search for 10^6 to 10^{10} solar-mass gravitational lenses*
EC076	s.3/20	Charlot	*Improved positions of non-geodetic EVN telescopes from 22GHz VLBI*
EC077A-D	s.2/21	Climent	*Probing the nature of radio emission in Ultracool Dwarfs*
EF029A	s.2/21	Frey	*J2102+6015: a powerful high-redshift quasar to reveal its secrets*
EG112	Mar.21	Gabanyi	*Origin of the double-peaked broad emission lines in a merging galaxy*
EG116A	May.21	Gabanyi	*Appearance of a jet feature due to the accretion rate increase in KUG 1141+371?*
EG116B	s.2/21	Gabanyi	*Appearance of a jet feature due to the accretion rate increase in KUG 1141+371?*
EG118A-B	s.3/21	Giarratana	*Exceptional star formation or an hidden AGN in the host of a short GRB?*
EH038A-B	s.1/21	Hada	*Dissecting Formation and Collimation Scales of Jets in Nearby LLAGNs*
EJ024	Dec.21	Jiang	*Probing the compact radio emission of two special magnetic White dwarf binaries*
EK048A-B	Feb.21	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs*
EK048C	Mar.21	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs*
EK048D-F	Apr.21	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs*

EK048G	Jun.21	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs*
EK050B	Nov.21	Kirsten	*Correlation of an ad-hoc VLBI array monitoring CHIME repeating FRBs II*
EM142	s.3/20	Marcote	*Towards a possible connection between fast radio bursts and star-forming regions*
EM144A	s.3/20	Motta	*Probing radio jets in GRS1905+05 in a new puzzling accretion state*
EM144B	s.1/21	Motta	*Probing radio jets in GRS1905+05 in a new puzzling accretion state*
EM144C	s.2/21	Motta	*Probing radio jets in GRS1905+05 in a new puzzling accretion state*
EM145	s.3/20	Muxlow	*Characterising the intermediate radio structure of luminous blazar J1955+5131*
EM146	s.2/21	Marecki	*Compact steep-spectrum source at the centre of a giant radio galaxy*
EM148	s.1/21	Muxlow	*Does M82 remnant 41.95+57.5 harbour an emerging pulsar wind nebula?*
EM149	s.2/21	McKean	*Resolving the faintest radio quasars detected by LOFAR*
EM150	s.2/21	McKean	*Resolving the AGN/starburst connection in a high-z quasar on pc-scales*
EM152	s.2/21	Marecki	*Has the jet in J0028+0035 been restarted at multiple times?*
EM153A-B	s.2/21	McKean	*Resolving a gravitationally lensed dual back-hole system at z = 2.37*
EM154	s.2/21	McKean	*A VLBI follow-up of the first (of many) OH Megamasers detected with Apertif*
EM156A	Sep.21	Miller-Jones	*The outflow speed of a long-lived thermal tidal disruption event*
EN006E	s.1/21	Nimmo	*EVN observations of a possible extragalactic pulsar wind nebula*
EN007A	s.3/20	Nimmo	*A repeating FRB survey: precise localisation and radio counterparts*
EN007B	s.1/21	Nimmo	*A repeating FRB survey: precise localisation and radio counterparts*
EN007C	s.2/21	Nimmo	*A repeating FRB survey: precise localisation and radio counterparts*

EN008A-B	s.1/21	Nandi	*Confirmation of a Dual AGN using Radio Spectral Indices*
EN009A-B	s.3/21	Nair	*Resolving the radio cores of the Quasar Feedback Survey sample with EVN+e-MERLIN*
EN010A	Sep.21	Nimmo	*Characterising the local environments of repeating fast radio bursts*
EN010B	Feb.21	Nimmo	*Characterising the local environments of repeating fast radio bursts*
EN010C	Nov.21	Nimmo	*Characterising the local environments of repeating fast radio bursts*
EN010D	Dec.21	Nimmo	*Characterising the local environments of repeating fast radio bursts*
EO018A	Apr.21	Ould-Boukattine	*Compact radio sources in dwarf galaxies: massive black holes or FRB sites?*
EO018B	Jun.21	Ould-Boukattine	*Compact radio sources in dwarf galaxies: massive black holes or FRB sites?*
EP121A	Jan.21	Perez-Torres	*Unveiling the progenitor scenarios of Type Ia supernovae*
ER047C	s.3/19	Radcliffe	*EVN-COSMOS – Taming AGN star-formation across cosmic time*
ER047D	s.1/20	Radcliffe	*EVN-COSMOS – Taming AGN star-formation across cosmic time*
ER047E	s.3/20	Radcliffe	*EVN-COSMOS – Taming AGN star-formation across cosmic time*
ER047F	s.1/21	Radcliffe	*EVN-COSMOS – Taming AGN star-formation across cosmic time*
ES093A-B	s.3/20	Spingola	*The parsec-scale view of the most distant blazar at z=6.1*
ES094	s.3/20	Shu	*Observing the nascent and evolving radio jet from an intriguing "turn-on" AGN*
ES095A-B	s.2/21	Salome	*The subarcsec-scale radio emission in IRAS17020+4544: jet or shocked outflow*
ES096A-B	s.1/21	Spingola	*Confirming the final lens candidates in the mJIVE-20 survey*
ES098A-B	s.2/21	Shu	*Mas-scale imaging of transient radio emission from a heavily dust-enshrouded TDE*

ES099A-B	s.2/21	Shu	*Mas-scale morphology of long-lasting radio emission from a dust-enshrouded TDE*
ES100A	Apr.21	Shao	*High-Resolution Radio Observations of 7 Radio Galaxies at z > 4*
ES100B	Jun.21	Shao	*High-Resolution Radio Observations of 7 Radio Galaxies at z > 4*
ES100C	Oct.21	Shao	*High-Resolution Radio Observations of 7 Radio Galaxies at z > 4*
ET045A-C	s.1/21	Tarchi	*A definite answer to the nature of the water gigamaser in TXS2226-184*
EV023	Sep.21	Vaddi	*Investigating orbital period evolution of candidate supermassive BH binary 3C66B*
EY035A-B	s.3/20	Yang	*Observing the IMBH feeding and feedback in the dwarf galaxy RGG9*
EY036A-B	s.1/21	Yang	*Resolving the nuclear radio structure of NGC 1068*
GK053	Apr.21	Kim	*Continued Ultra-Deep Polarization Imaging of the Twin-Jet Structure in M87*
GM076	s.2/21	McKean	*Resolving extreme star formation and AGN activity in a high redshift quasar*
GM077	s.3/20	Moscadelli	*The velocity and magnetic field structure of the disk-winds*
GM080	s.1/21	Marcote	*Solving the puzzling persistent emission associated to FRB 121102*
RG012A-B	Aug.21	Giroletti	*Imaging the evolution of the shock in the 2021 outburst of RS Oph*
RG012C-H	Sep.21	Giroletti	*Imaging the evolution of the shock in the 2021 outburst of RS Oph*
RG012I-J	Oct.21	Giroletti	*Imaging the evolution of the shock in the 2021 outburst of RS Oph*
RM016C	Feb.21	Marcote	*GRB 201015A: an extreme short gamma-ray burst with a luminous radio afterglow?*
RP032A	May.21	Panessa	*Nature of the persistent radio source associated with FRB 20201124A*
RP033	Jun.21	Paragi	*Non-thermal radio emission in the fastest evolving classical nova to date*
RY009	s.3/21	Yang	*Newborn ejecta associated with the changing-look AGN 1ES 1927+654*

9.6 JIVE STAFF PUBLICATIONS

JOURNAL ARTICLES

- **O. S. Bayandina**, I. E. Val'tts, S. E. Kurtz, et al.: Search for Collisionally Pumped 1720 MHz OH Masers in Star-forming Regions: A VLA Survey of 18 cm OH Masers toward 80 Class I Methanol Masers, 2021, The Astrophysical Journal Supplement Series, Volume 256, Issue 1, id.7, 15 pp.
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- Event Horizon Telescope Collaboration; K. Akiyama, J.C. Algaba, et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H.J. van Langevelde**): First M87 Event Horizon Telescope Results. VIII. Magnetic Field Structure near The Event Horizon, 2021, ApJ 910, 13
- Event Horizon Telescope Collaboration; K. Akiyama, J.C. Algaba, et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H.J. van Langevelde**): "First M87 Event Horizon Telescope Results. VII. Polarization of the Ring", 2021, ApJ 910, 12
- EHT MWL Science Working Group; J.C Algaba, J. Anczarski, et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H.J. van Langevelde**): "Broadband Multi-wavelength Properties of M87 during the 2017 Event Horizon Telescope Campaign", 2021, ApJ 911, 11
- K.E. Gabányi, S. Frey, T. An, et al. (including **Z. Paragi** and **L.I. Gurvits**): A small radio galaxy at z = 4.026, 2021, Astronomische Nachrichten, 342, 1092, 1092-1096
- C. Goddi, I. Martí-Vidal, H. Messias, et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H.J. van Langevelde**): Polarimetric Properties of Event Horizon Telescope Targets from ALMA, 2021, ApJ 910, 14
- M. Guainazzi, A. De Rosa, S. Bianchi, et al. (including **Z. Paragi**): An XMM-Newton study of active-inactive galaxy pairs, 2021, MNRAS, 504, 1, 393-405
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- P. Kharb, S. Subramanian, M. Das, et al. (including **Z. Paragi**): The Nature of Jets in Double-peaked Emission-line AGN in the KISSR Sample, 2021, AJ, 919, 2, 108, 22
- P. Kocherlakota, L. Rezzolla, H. Falcke, et al. (including **M. Kettenis**, **D. Small**, **I. van Bemmel**, **H.J. van Langevelde**): Constraints on black-hole charges with the 2017 EHT observations of M87*, 2021, PhRD 103, 104047
- L.V.E. Koopmans, R. Barkana, M. Bentum, Mark, et al. (including **L.I. Gurvits**): Peering into the dark (ages) with low-frequency space interferometers, 2021, Experimental Astronomy, 51, 3, 1641-1676
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- M. Ma, G.M. Calvés, **G. Cimò**, et al.: VLBI Data Processing on Coronal Radio-sounding Experiments of Mars Express, 2021, AJ, 162, 4, 141, 13

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— Z. Pleunis, D. Michilli, C.G. Bassa, et al. (including **A. Keimpema**, **B. Marcote**, **Z. Paragi**): LOFAR Detection of 110-188 MHz Emission and Frequency-Dependent Activity from FRB 20180916B, 2021, ApJL, 911, 1, L3.

— F. M. Pötzl, A. P. Lobanov, E. Ros, et al. (including **L.I. Gurvits)**: Probing the innermost regions of AGN jets and their magnetic fields with RadioAstron. IV. The quasar 3C 345 at 18 cm: Magnetic field structure and brightness temperature, 2021, A&A, 648, id.A82, 10

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— S. P. Tendulkar, A. Gil de Paz, A.Y. Kirichenko, et al. (including **A. Keimpema**, **B. Marcote**, **Z. Paragi**): The 60-pc Environment of FRB 20180916B, 2021, ApJL, 908, 1, L12.

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- **F. Colomer**: Towards a Global VLBI Alliance, Scientific symposium and Users' meeting of the European VLBI Network, held 12-14 July 2021, online
- **F. Colomer**: Masers, what can VLBI do for you?, Special Session "Very Long Baseline Interferometry" at the URSI GASS, held in Rome (Italy) on 29 August – 5 September 2021
- **F. Colomer**: Contribution of JIVE and EVN to the UN SDGs, UN76 Science Summit, 29 September 2021, online
- **F. Colomer**: Present and Future of the European VLBI Network, International Workshop "RT-32 Zolochiv: Current state, EU collaboration, Radio Astronomy frontiers", 4-5 October 2021, Zolochiv, Ukraine
- **F. Colomer**: Towards a Global VLBI Alliance, Australia-Europe Symposium on Research Infrastructures, 5-7 October 2021, online
- M. Fayolle, D. Dirkx, V. Lainey, et al. (including **L.I. Gurvits**): Coupled and decoupled strategies for spacecraft's and natural bodies' state estimation – Application to the JUICE mission, 2021, 15th Europlanet Science Congress 2021, held virtually, 13-24 September 2021. Online at https://www.epsc2021.eu/, id. EPSC2021-364
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- **L.I. Gurvits**, **Z. Paragi**, R.I. Amils, et al. (including **I. van Bemmel**): The science case and challenges of space-borne sub-millimeter interferometry: the study case of THEZA, 72nd International Astronautical Congress, Dubai, United Arab Emirates, 25-29 October 2021, IAC{21{A7.2.5"}}
- H. Hase, J.A. López-Pérez, M. Bautista-Duran, et al. (including **W. Madkour**): Spectrum Management for the VGOS, 2021, Proceedings of the 25th European VLBI Group for Geodesy and Astrometry Working Meeting, 14-18 March 2021 Cyberspace, Gothenburg, Sweden, Ed. R. Haas, ISBN: 978-91-88041-41-8, 43-48
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BOOKS AND MSC/PHD THESES

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9.7 EVN PUBLICATIONS

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- Salafia, O. S. et al.: Multi-wavelength view of the close-by GRB~190829A sheds light on gamma-ray burst physics (2021) arXiv e-prints , arXiv:2106.07169 (RG010A, RG010B, RG010C)

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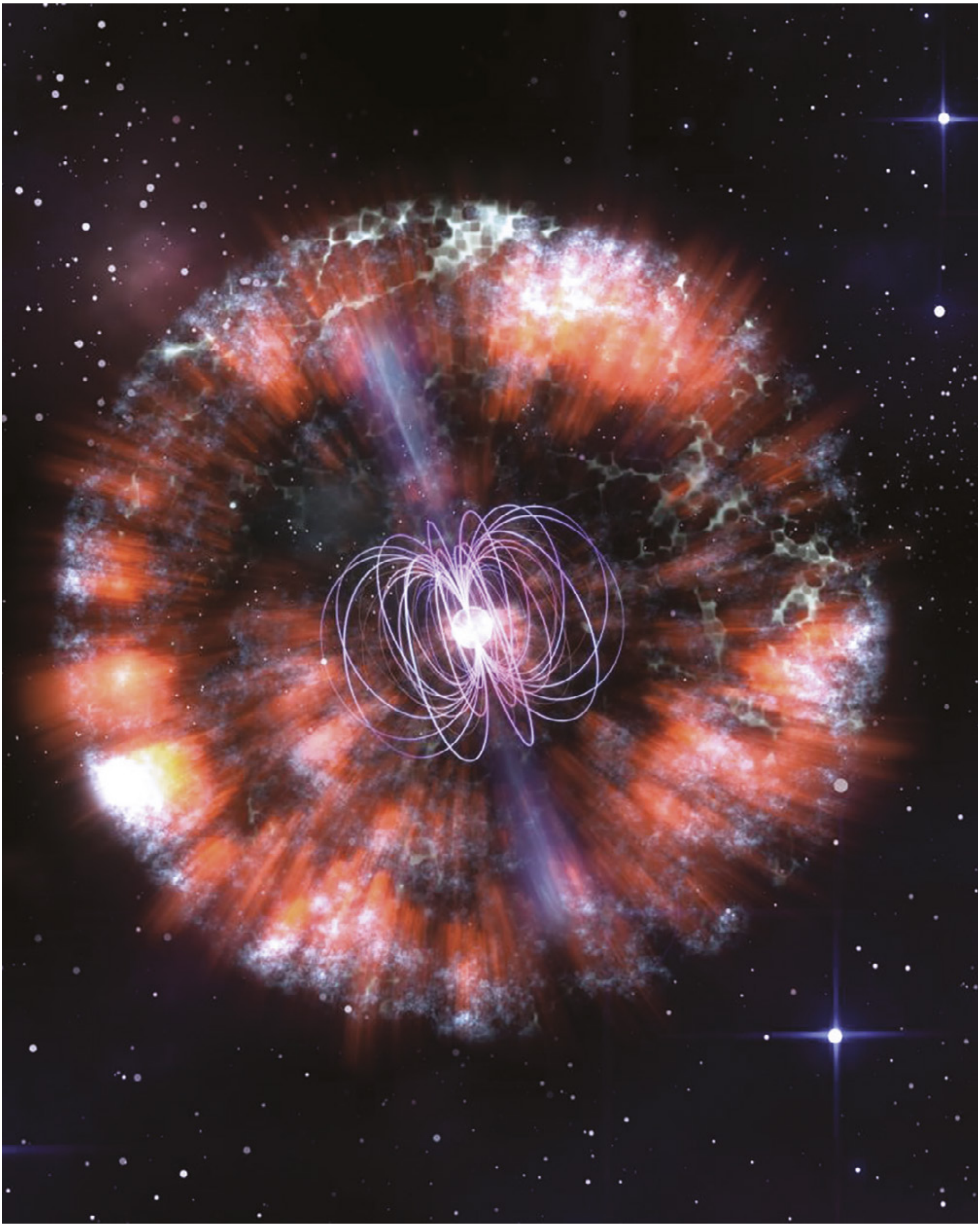

Figure 9.1: Artist's impression of the cosmic cow. Credit: Shanghai Astronomical Observatory, China.

Acronyms and Abbreviations

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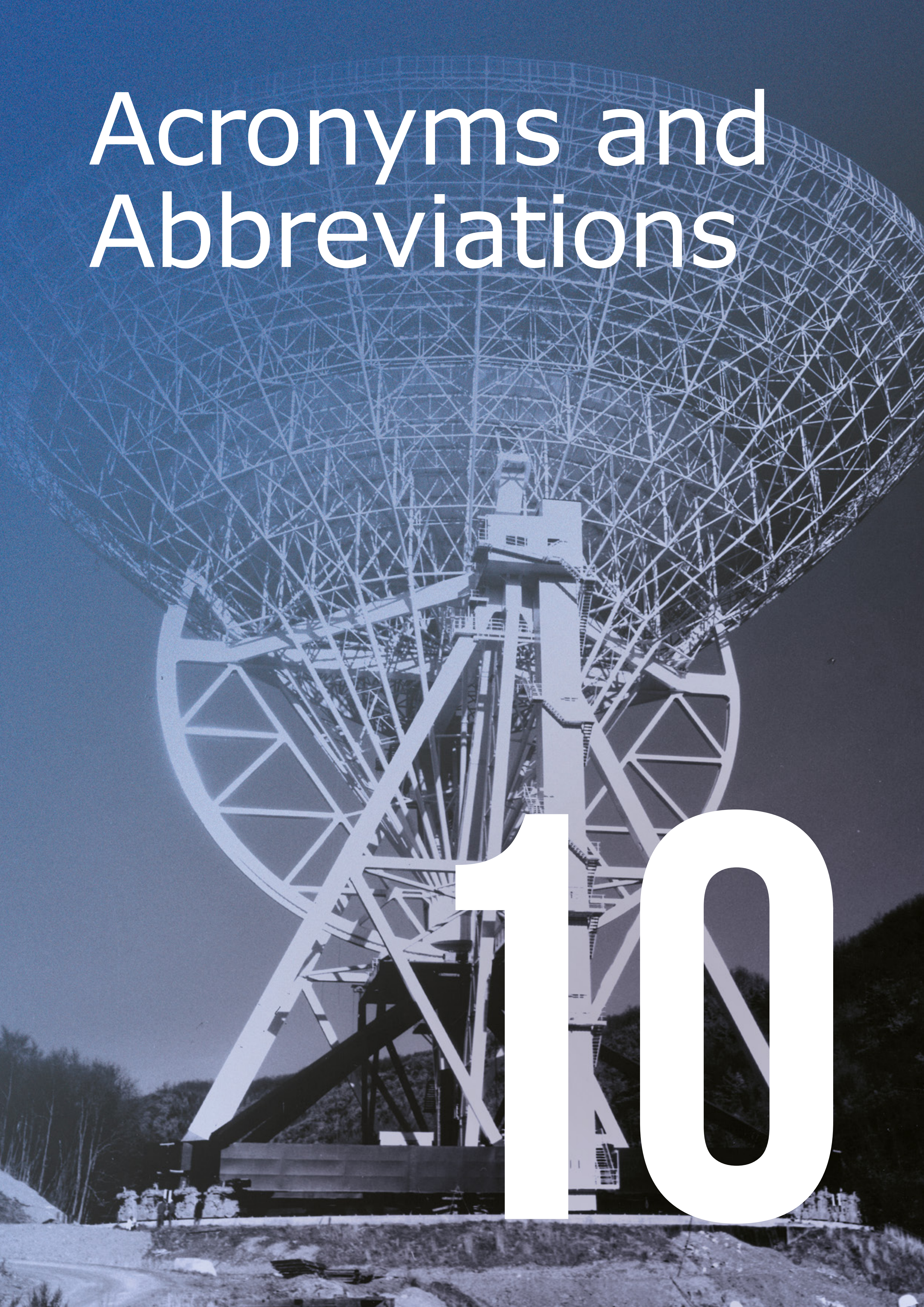

A&A	*Astronomy & Astrophysics*
AGN	*Active Galactic Nucleus/Nuclei*
AIPS	*Astronomical Image Processing System*
ALMA	*Atacama Large Millimetre/submillimetre Array*
ApJ	*The Astrophysical Journal*
ApJL	*Astrophysics Journal Letters*
ASTRON	*Netherlands Institute for Radio Astronomy*
CBD	*Consortium Board of Directors*
CASA	*Common Astronomy Software Applications*
CHIME	*Canadian Hydrogen Intensity Mapping Experiment*
CASA	*Common Astronomy Software Applications*
CNGI	*CASA Next Generation Infrastructure*
CNRS	*Centre National de la Recherche Scientifique National Centre for Scientific Research, France*
COVID-19	*COrona VIrus Disease 2019*
CPU	*Central Processing Unit*
CRAF	*Committee on Radio Astronomy Frequencies*
DARA	*Development in Africa with Radio Astronomy*
DBBC	*Digital Base Band Converter*
DOI	*Digital Object Identifier*
EAS	*European Astronomical Society*
EC	*European Commission*
Ef	*Effelsberg station, Germany*
e-EVN	*electronic (realtime) European VLBI Network*
EHT	*Event Horizon Telescope*
e-MERLIN	*enhanced Multi-Element Radio Linked Interferometer Network*
EOON	*EVN Outreach Officers Network*
EOSC	*European Open Science Cloud*
ERIC	*European Research Infrastructure Consortium*

ESA	*European Space Agency*
ESCAPE	*European Science Cluster of Astronomy and Particle physics ESFRI research infrastructures*
ESFRI	*European Strategy Forum on Research Infrastructures*
ESO	*European Southern Observatory*
EVPA	*Electric Vector Position Angle*
e-VLBI	*electronic Very Long Baseline Interferometry (imples real-time correlation) e-EVN*
EVN	*European VLBI Network*
FAST	*Five-hundred-metre Aperture Spherical Telescope*
FITS	*Flexible Image Transport System*
FITS-IDI	*Flexible Image Transport System – Interferometry Data Interchange format*
FRB	*Fast Radio Burst*
Gb	*Gigabit*
Gbps	*Gigabit per second*
GDPR	*General Data Protection Regulation*
GHz	*Gigahertz*
GVA	*Global VLBI Alliance*
GMRT	*Giant Metrewave Radio Telescope*
GOODS-N	*Great Observatories Origins Deep Survey North*
GRB	*Gamma Ray Burst*
H2020	*Horizon 2020 EC Funding Programme*
HDD	*Hard-Disk*
Hh	*Hartebeesthoek station, South Africa*
IGN	*Instituto Geográfico Nacional, National Geographic Institute, Spain*
ILT	*International LOFAR Telescope*
INAF	*Istituto Nazionale di Astrofisica, Italian National Institute of Astrophysics*
IRA-INAF	*Istituto di Radio Astronomia, Institute of Radio Astronomy, Italy*

IRAS	*Infrared Astronomical Satellite*
IVOA	*International Virtual Observatory Alliance*
IVS	*International VLBI Service for Geodesy and Astrometry*
JIVE	*Joint Institute for VLBI ERIC*
JUICE	*JUpiter ICy moons Explorer*
JUMPING JIVE	*Joining up Users for the Maximising the Profile, the Innovation and the Necessary Globalisation of JIVE*
Km	*Kilometre*
kN	*KiloNewton*
LBA	*Long Baseline Array, Australia*
LCP	*Left circular polarisation*
LOFAR	*Low Frequency Array*
LTP	*Linear Tape-Open*
m^2	*Square metre*
M87	*Messier 87*
MAD	*Magnetically Arrested Disk*
Maser	*Microwave amplification through stimulated emission of radiation*
Mbps	*Megabit per second*
MHz	*Megahertz*
MNRAS	*Monthly Notices of the Royal Astronomical Society*
MoU	*Memorandum of Understanding*
MPIfR	*Max Planck Institut für Radioastronomie*
MT	*Management Team*
mJy	*Mili-Jansky*
uJy	*Micro-Jansky*
MWL	*Multi-wavelength*
NAOC	*National Astronomical Observatories of China*
NRAO	*National Radio Astronomy Observatory*

NREN	*National Research and Education Network*
NRF	*National Research Foundation (South Africa)*
NWO	*Nederlandse Organisatie voor Wetenschappelijk Onderzoek* *Netherlands Organisation for Scientific Research*
OSSR	*Open Source Software Repository*
OPTICON	*Optical Infrared Coordination Network for Astronomy*
ORP	*OPTICON RadioNet Pilot*
PI	*Principal Investigator*
PNG	*Portable Network Graphics*
PRIDE	*Planetary Radio Interferometry and Doppler Experiment*
pySCHED	*python SCHEDuling software*
QSFP+	*Quad (4-channel) Small Form-factor Pluggable*
Rad	*Radians*
RadioIG	*Radio Interest Group*
R&D	*Research and Development*
RCP	*Right Circular Polarisation*
RDBE	*ROACH Digital Back End*
ROT-54/2.6	*Radio Optical Telescope ROT-54/2.6, Armenia*
RM	*Rotation measure*
rPICARD	*Radboud PIpeline for the Calibration of high Angular Resolution Data*
s	*Second*
SCHED	*VLBI Scheduling software*
SDtracker	*Spacecraft Doppler tracking*
SFXC EVN	*Software Correlator at JIVE*
SHAO	*Shanghai Astronomical Observatory*
SKA	*Square Kilometre Array*
SOC	*Scientific Organising Committee*
STFC	*Science and Technologies Facilities Research Council, United Kingdom*
TB	*Terabyte*

THEZA	*TeraHertz Exploration and Zooming in for Astrophysics*
ToO	*Target of Opportunity*
VDIF	*VLBI data interchange format*
VGOS	*VLBI Global Observing System*
VLA	*Very Large Array, United States of America*
VLBA	*Very Long Baseline Array, United States of America*
VLBI	*Very Long Baseline Interferometry*
VO	*Virtual Observatory*
VR	*Vetenskapsrådet Swedish Research Council*
VSOP	*VLBI Space Observatory Programme*
WP	*Work Package*
WR	*Wolf-Rayet*
Ys	*Yebes observatory, Spain*

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IMAGE CREDITS:

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- Section 1: Dwingeloo Radiotelescope with Milky Way in the background. Credit: Cities and Skies (https://cities-and-skies.com/).
- Section 2: Polarised view of the black hole in M87. The lines mark the orientation of polarisation, which is related to the magnetic field around the shadow of the black hole. Credit: EHT Collaboration.
- Section 3: New storage system to safeguard backups of correlated data and the archive. Credit: Bert Harms.
- Section 4: Artist impression of the Juice mission exploring the Jupiter system. Credit: Spacecraft: ESA/ATG medialab; Jupiter: NASA/ESA/J. Nichols (University of Leicester); Ganymede: NASA/JPL; Io: NASA/JPL/University of Arizona; Callisto and Europa: NASA/JPL/DLR.
- Section 5: Participants at the VLBI session at URSI GASS 2021 organised in Rome (Italy). Credit: Francisco Colomer.
- Section 6 : JIVE operators working at the Correlator. Credit: JIVE.
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- Section 8: Activities with high-school students in Kenya in the framework of the H2020 JUMPING JIVE project. Credit: JUMPING JIVE.
- Section 9 : Artist's impression of a jet piercing the material that is launched into space during the merging of two neutron stars. After the merger a black hole is formed, surrounded by a disk of hot matter, from which the jet is launched. This model is based on actual EVN observations of GW170817. Credit: O.S Salafia & G. Ghirlanda | X ray: NASA/CXC/RIKEN & GSFC/T. Sato et al. | Optical: SDSS.
- Section 10: The 100-m radio telescope Effelsberg – member of the EVN Network – celebrated its 50th anniversary in May 2021. The picture showcases the radio telescope shortly before its opening in May 1971. Credit: Max-Planck-Institut für Radioastronomie (MPIfR).

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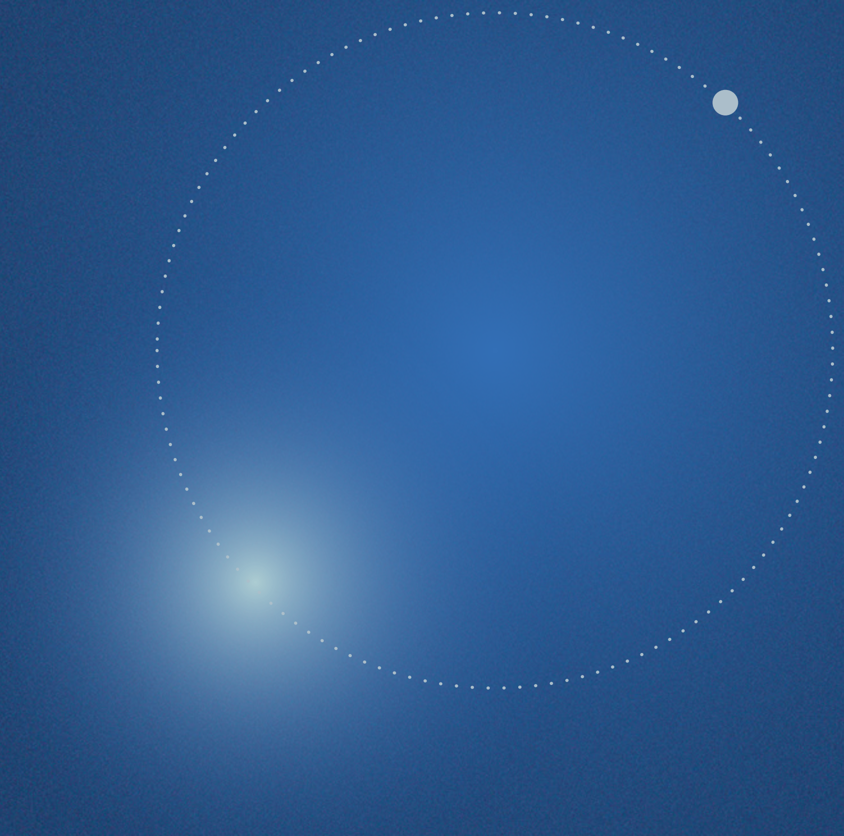

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