European VLBI Network Newsletter

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Contents

Edited by Michael Lindqvist, EVN Secretary (Onsala Space Observatory, Sweden; Michael.Lindqvist@chalmers.se)

Message from the Chairman of the EVN Board of Directors

Dear Users of the EVN,

This Northern hemisphere Spring has been an exciting time for the world of VLBI with the announcement of the first image of a black hole shadow in M87, a result that that has created huge media interest. This impressive result, like all results in VLBI, came from a collective effort throughout the world, requiring both central leadership and many vital individual contributions. A strength of the VLBI world is the many technical developments for different applications (i.e. for geodetic VLBI, cm astronomy VLBI and for the Event Horizon Telescope) which can cross-fertilise and combine. A vital part of this cross-fertilisation are the annual international Technical Workshops in VLBI (see p. 19).

This newsletter reports a number of exciting science results produced by the EVN including observations of the gravitational wave source GW170817 (see p. 4) constraining emission models and of the compact sources in Arp220 (se p. 6). Two high sensitivity observations of radio quiet quasars are also reported (see p. 5 and p. 9) providing clues to the source of weak radio emission from these objects. This issue has exciting news about new investments in receivers for the Italian telescopes of the EVN including a set of simultaneous high frequency three band receivers. An important technical breakthrough reported in this issue is adding eMERLIN telescopes as a full part of the EVN cross-correlated with all other stations (see p. 15). This unique EVN capability is now fully tested and available for use for proposals submitted for the 1st June deadline. We look forward to see the inventiveness of the community via submitted proposals to fully exploit this new capability!

The combination of the great scientific prospects for VLBI and its ongoing technical development bodes well for the future of VLBI in general and the EVN in particular. While we plan for ever wider bandwidths and co-observing with the SKA (see p. 17) during the coming decade this should not blind us to the great potential we already have or which could be implemented relatively soon on the EVN. Technology for wide-bandwidth VLBI recording up to 4-8 GHz spanned bandwidth and wide-band receivers at cm wavelengths are already deployed in Geodetic VLBI and on the EHT and can be used by the EVN. In the coming decades its is clear that VLBI, in all its flavours, will form the third major leg of global cm/mm astronomy alongside the SKA and ALMA.

John Conway,

Chairman, EVN Consortium Board of Directors

Call for EVN proposals

The next deadline for submitting EVN proposals is **1 June 2019**. The details of the call can be found here. All EVN and Global proposals must be submitted using the NorthStar online proposal submission tool (http://proposal.jive.eu). Global proposals will be forwarded to NRAO and should not be submitted to NRAO separately.

The EVN facility is open to all astronomers with or without VLBI experience. Support on proposal preparation, scheduling, correlation, data reduction and analysis can be requested at the Joint institute for VLBI ERIC (JIVE).

Further information on EVN, EVN+MERLIN, Global VLBI and e-VLBI observations, and guidelines for proposal submission (including Target of Opportunity (ToO) and short-observation) are available at: http://www.jive.eu/jivewiki/doku.php?id=evn:guidelines.

Access to the EVN is supported, for eligible projects, by the Trans-national Access programme of the RadioNet project, which is funded by the EC Horizon 2020 Research and Innovation Programme under grant agreement No 730562. This trans-national access support includes also travel reimbursement for visits to JIVE in order to analyse and process EVN, EVN-MERLIN or global VLBI data.

Kazi Rygl, INAF-IRA, Bologna, Italy, EVN PC Chairperson

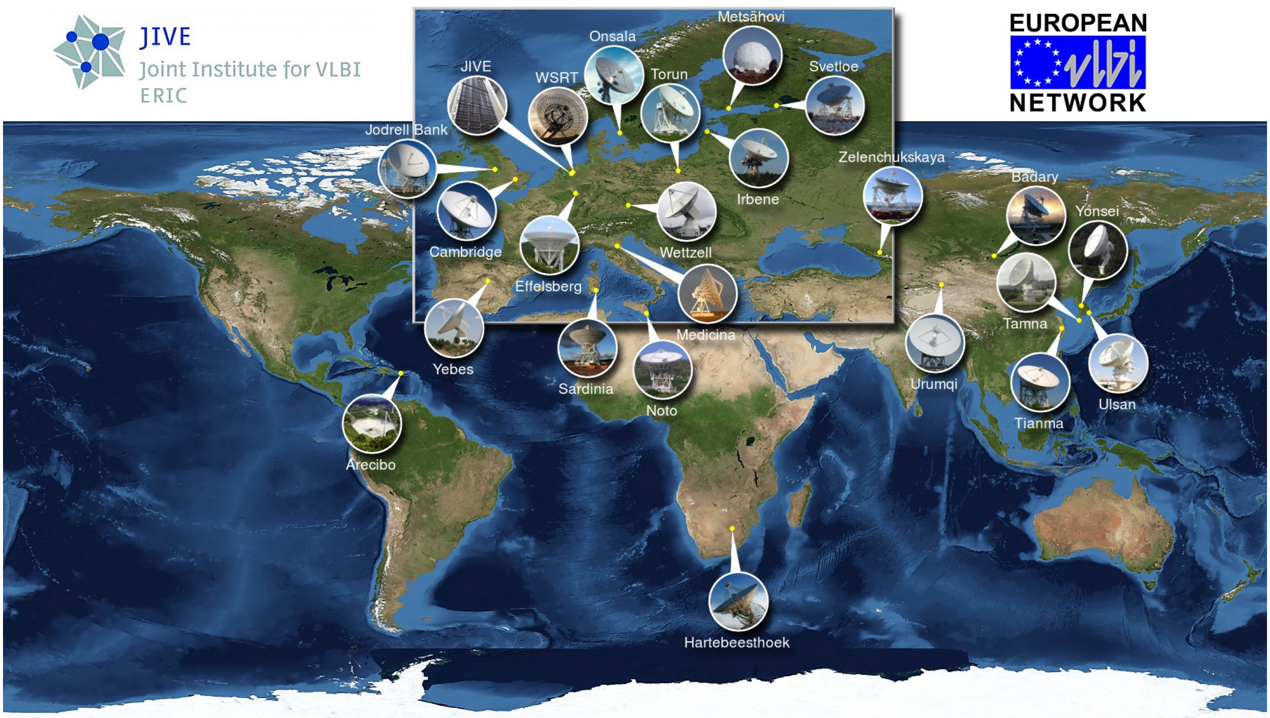

Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

EVN science highlights

VLBI exposes the aftermath of a violent merger of neutron stars

The binary neutron star merger event GW170817 was detected through both gravitational waves and electromagnetic radiation. The early optical observations located its host galaxy as NGC 4993 and found temporal and spectral properties consistent with a source powered by the radioactive decay of material ejected during and after the merger. Later afterglow emission detected at radio wavelengths is theorised to have been produced by either a narrow relativistic jet or an isotropic outflow interacting with surrounding material.

A group of international astronomers, led by G. Ghirlanda (Italy), has recently presented the imaging results of VLBI observations with 32 radio telescopes, Fig. 1. The apparent source size, 207 days after the merger, is constrained to be smaller than 2.5 milliarcseconds at the 90 % confidence level. The compact structure indicates that GW170817 produced a structured relativistic jet instead of an isotropic outflow scenario, which would have produced a larger apparent size.

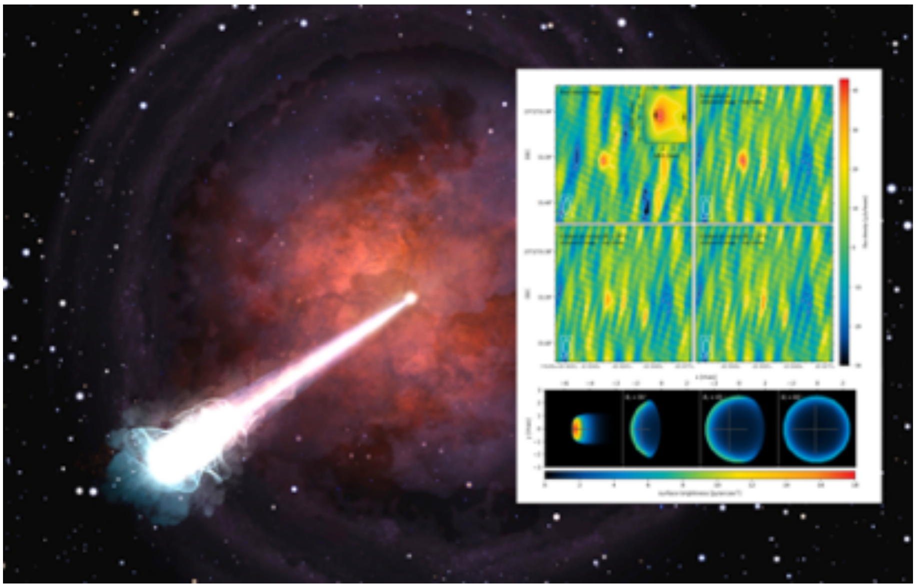

Figure 1. *The global VLBI imaging and simulation results of GW170817. The inset shows real and simulated pseudo-colour images (top), obtained in observations as well as based on model image distributions (bottom) for various scenarios (collimated jet, jet-cocoon with different opening angles). The background artist's impression (Beabudai Design) represents the jet braking through the dense gas ejecta, which was produced during the merger of neutron stars that caused the gravitational waves recorded as GW170817.*

Published in: Ghirlanda G. et al.: **Compact radio emission indicates a structured jet was produced by a binary neutron star merger**, https://doi.org/10.1126/science.aau8815.

J. Yang, Onsala Space Observatory, Sweden, on behalf of the GW170817 team

Uncovering a diffuse radio structure in the radio-quiet quasar PDS 456

Highly accreting active galactic nuclei (AGN) might host radiatively driven mildly relativistic outflows. Some of these X-ray absorbing but powerful outflows can produce strong shocks, resulting in a significant non-thermal emission.

The radio-quiet quasar PDS 456 has a bolometric luminosity reaching the Eddington limit on accretion and a relativistic X-ray outflow with a kinetic power high enough to quench the star formation in its host galaxy. To search for the outflow-driven radio emission in PDS 456, Yang et al (2019) used the EVN at 5 GHz. The result is presented in Fig. 2. There are two faint radio components with a projected separation of about 20 pc in the nuclear region. The VLBI structure at the deca-pc scale can be explained as either a poorly collimated young jet or a bidirectional radio-emitting outflow, launched in the vicinity of a strongly accreting supermassive black hole.

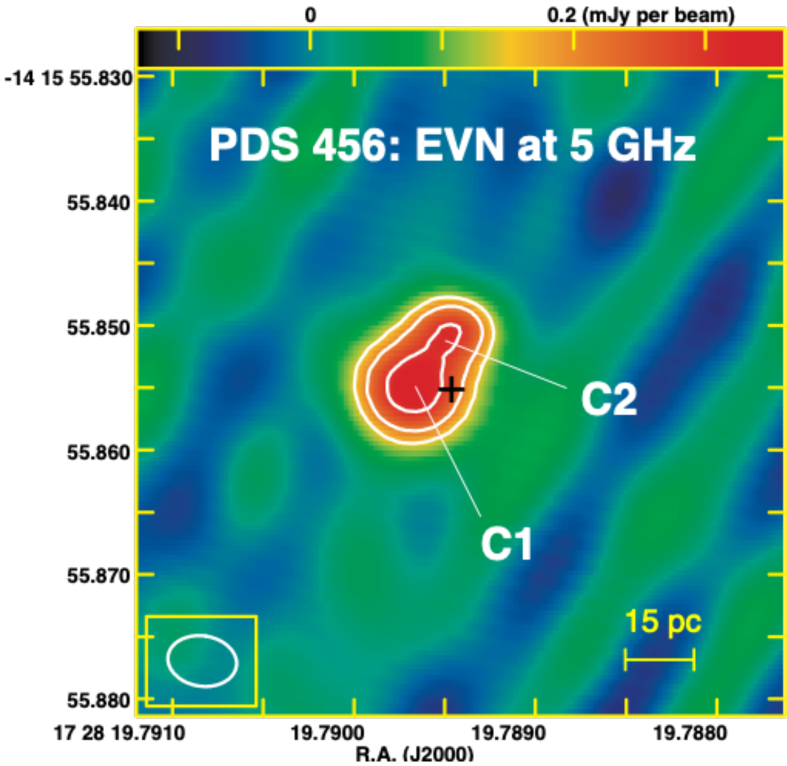

Figure 2. *The EVN 5 GHz image of the optically bright and radio-quiet quasar PDS 456 (Yang et al. 2019). There are two faint radio features, C1 and C2, found in the inner nuclear region. The black cross marks the optical centroid of the GAIA observations*

Published in: Yang et al.: **A radio structure resolved at the deca-parsec scale in the radio-quiet quasar PDS 456 with an extremely powerful X-ray outflow**, https://doi.org/10.1093/mnras/sty2798.

J. Yang, Onsala Space Observatory, Sweden

20 years of VLBI monitoring of the starburst galaxy Arp 220

The nearby ultra-luminous infrared galaxy (ULIRG) Arp 220 at 77 Mpc is an excellent laboratory for studies of extreme astrophysical environments. It is a merger, with two radio-emitting disk nuclei about 1 arcsecond apart (Norris 1988). For decades, global cm-VLBI has been used to monitor a population of compact sources in the disks, thought to be supernovae (SNe), supernova remnants (SNRs), and possibly active galactic nuclei (AGNs) (Smith et al. 1998; Rovilos et al. 2005; Lonsdale et al. 2006; Parra et al. 2007; Batejat et al. 2011, 2012). SNe and SNRs are thought to be the sites of relativistic particle acceleration which power star formation induced radio emission in galaxies, and are hence important for studies of for example the origin of the FIR–radio correlation.

In this work we analyse new and archival VLBI data, spanning 20 years, and present 23 high-resolution radio images of Arp 220 at wavelengths from 18 cm to 2 cm. Stacking the images, we obtain the deepest (4 μJy/beam) images to date of the Arp 220 nuclei, see Fig. 3.

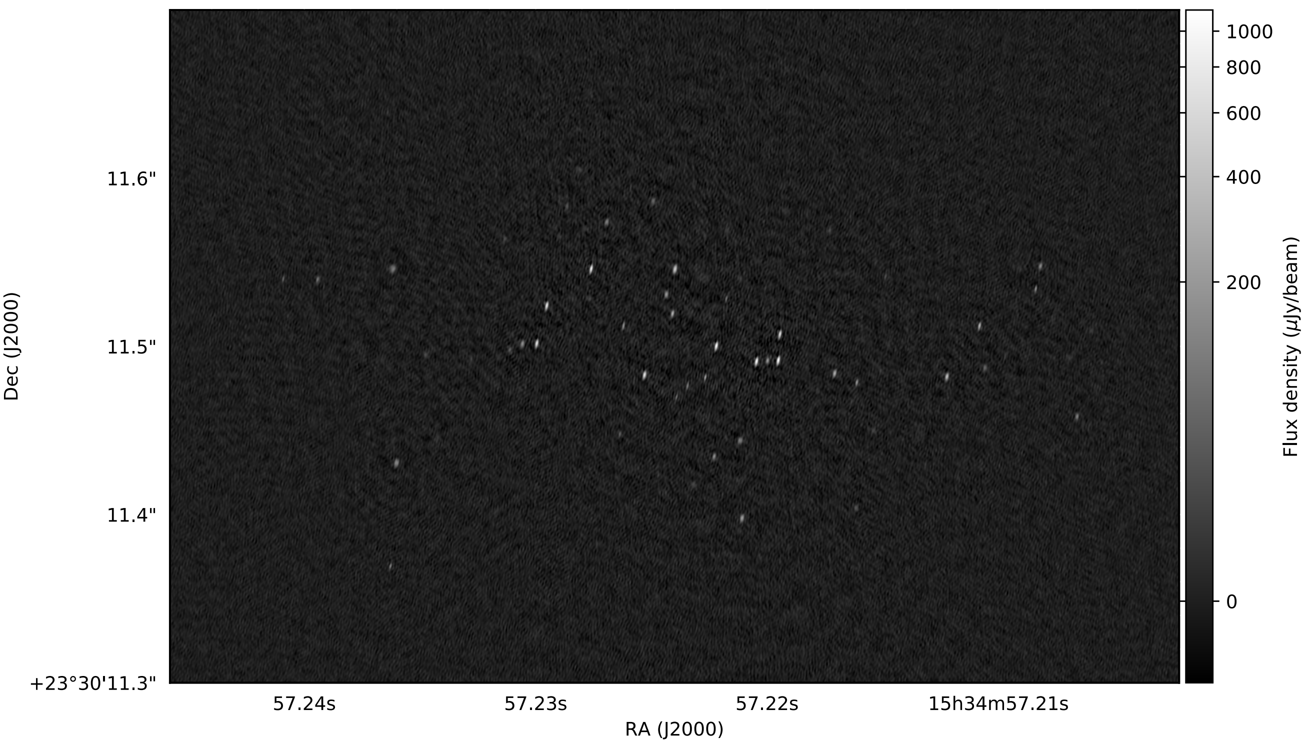

Figure 3. *Stacked 6 cm VLBI image of the western nucleus of Arp 220, with off-source rms noise σ=4 μJy/beam.*

In this work we detect radio continuum emission from 97 compact sources and present flux densities and sizes for the analysed observation epochs. We find evidence for a luminosity-diameter (LD) relation within Arp 220 (see Fig. 4), with larger sources being less luminous, where the Arp 220 population appears to be a brighter and more compact version of the sources found in the nearby starburst galaxy M82.

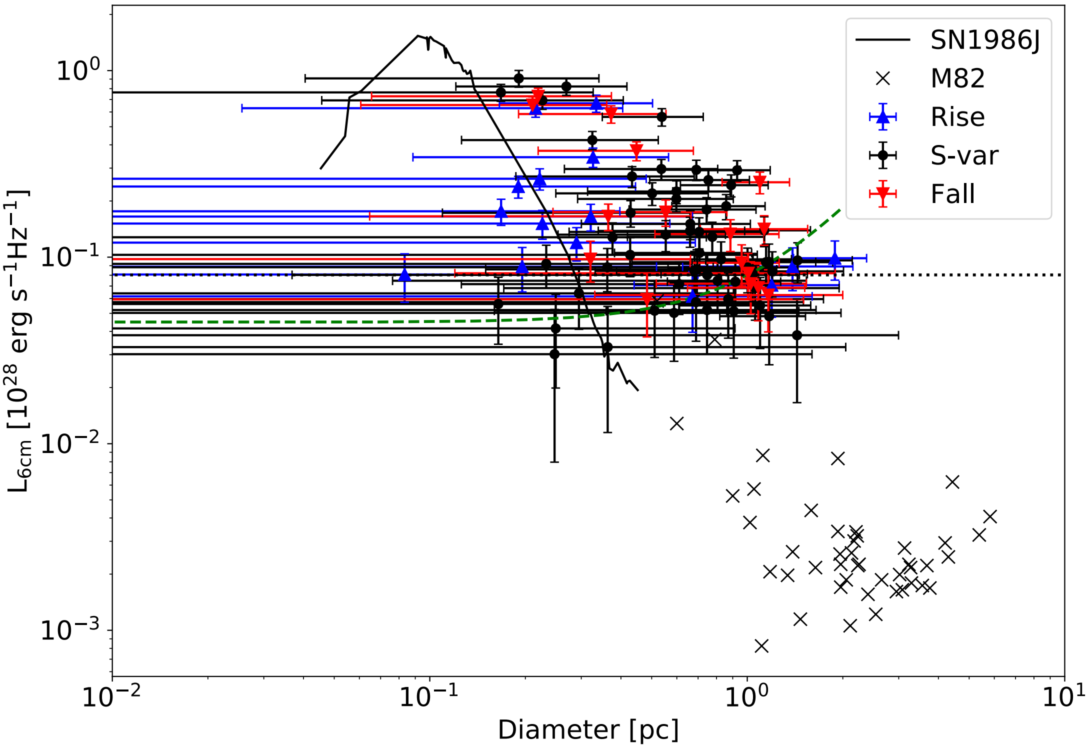

Figure 4. *Fitted spectral luminosity vs diameter of the compact sources in Arp 220, labelled according to their light-curve behaviour as rising, falling or slowly-varying (S-var). The black crosses show 45 SNRs in M82 (Huang et al. 1994, their Table 2, scaled to 6 cm assuming α = −0.5). The evolution of SN1986J during its first 30 years is plotted as a solid curve.*

The most luminous objects in Arp 220 are likely very bright radio SNe or SNRs, observed near their peak luminosity, which in the following years will expand and fade similar to other bright radio SNe such as SN1986J. The brightest (at 6 cm) object 0.2195+0.492 is modelled as a radio SN with an unusually long 6 cm rise time of 17 years, see Fig. 5.

We find a compact source luminosity function (LF) with slope −2.19 ± 0.15, similar to SNRs in normal galaxies (Chomiuk & Wilcots 2009), and we argue that there are many more relatively large and weak sources below our detection threshold. Extrapolating the LF below our detection threshold we find that the population make up at most 20 % of the total radio emission from Arp 220 at GHz frequencies. However, secondary cosmic rays (CRs) produced when protons accelerated in the SNRs interact with the dense ISM, and/or re-acceleration of cooled CRs by overlapping SNR shocks, may increase radio emission compared to the extrapolated value.

Future high-sensitivity observations, ideally using global VLBI including eMERLIN baselines, could possibly constrain the origin of the missing smooth radio component by sampling the full range (arcsecond to milliarcsecond) of spatial scales. Such observations may also allow further studies of the evolution of source lightcurves and sizes for the existing sample, as well as detections of new rising sources as well as old sources currently below the detection threshold.

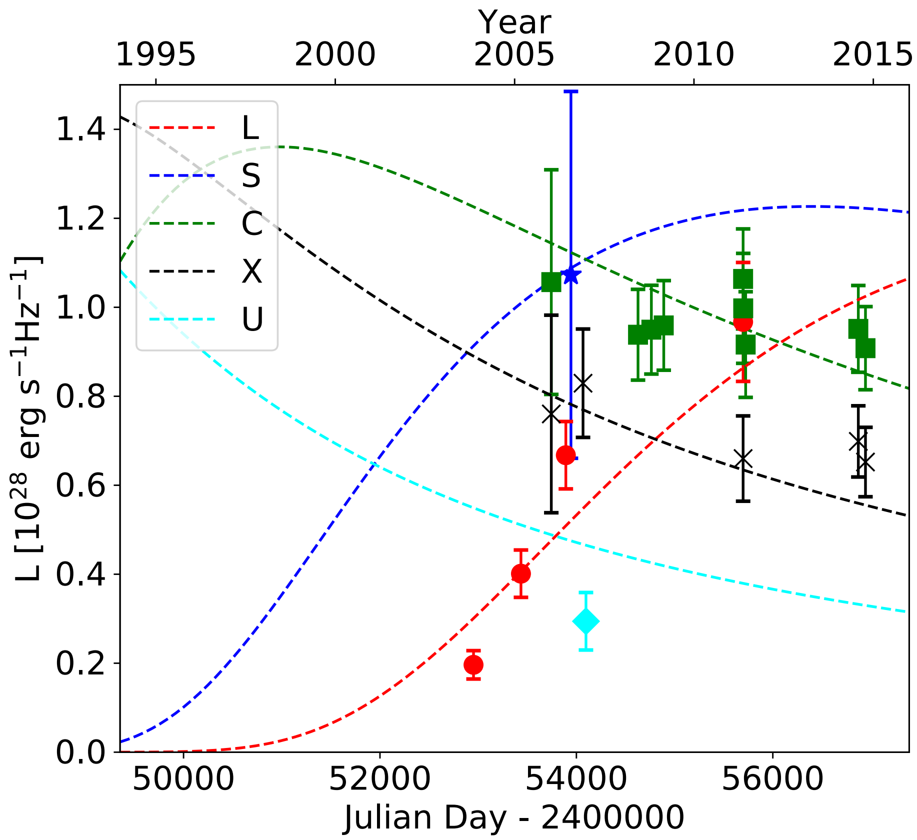

Figure 5. *Best-fit light curve (spectral luminosity vs time) model over-plotted on the observed detections of the brightest object 0.2195+0.492.*

Published in: E. Varenius et al.: **The population of SNe/SNRs in the starburst galaxy Arp 220 - A self-consistent analysis of 20 years of VLBI monitoring.**

https://doi.org/10.1051/0004-6361/201730631

E. Varenius, JBO, UK

Strong lensing reveals jets in a sub-microJy radio-quiet quasar

Despite their discovery in the radio, most quasars produce relatively little radio emission. Consequently, the emission mechanism within so-called radio quiet quasars (RQQs) has been difficult to observe directly, and continues to be hotly debated. This means that the phenomenological description of the one of the largest radio source populations remains incomplete. For galaxy evolution models, feedback processes during the most common state of existence of an AGN are not understood. The radio behaviour of RQQs has largely been investigated using statistical studies, which variously cite either starburst, coronal or AGN jet activity as the dominant emission mechanism. By using strong gravitational lenses as cosmic telescopes in combination with the very high resolution and sensitivity of the EVN, we can instead constrain the emission mechanism by directly imaging it. To this end, a team led by Neal Jackson (Jodrell Bank Centre for Astrophysics, Manchester) undertook 1.65 GHz VLBI observations of HS 0810+2554, a RQQ located at z=1.51 which is magnified and quadruply-imaged by a lensing galaxy located at approximately z=0.8.

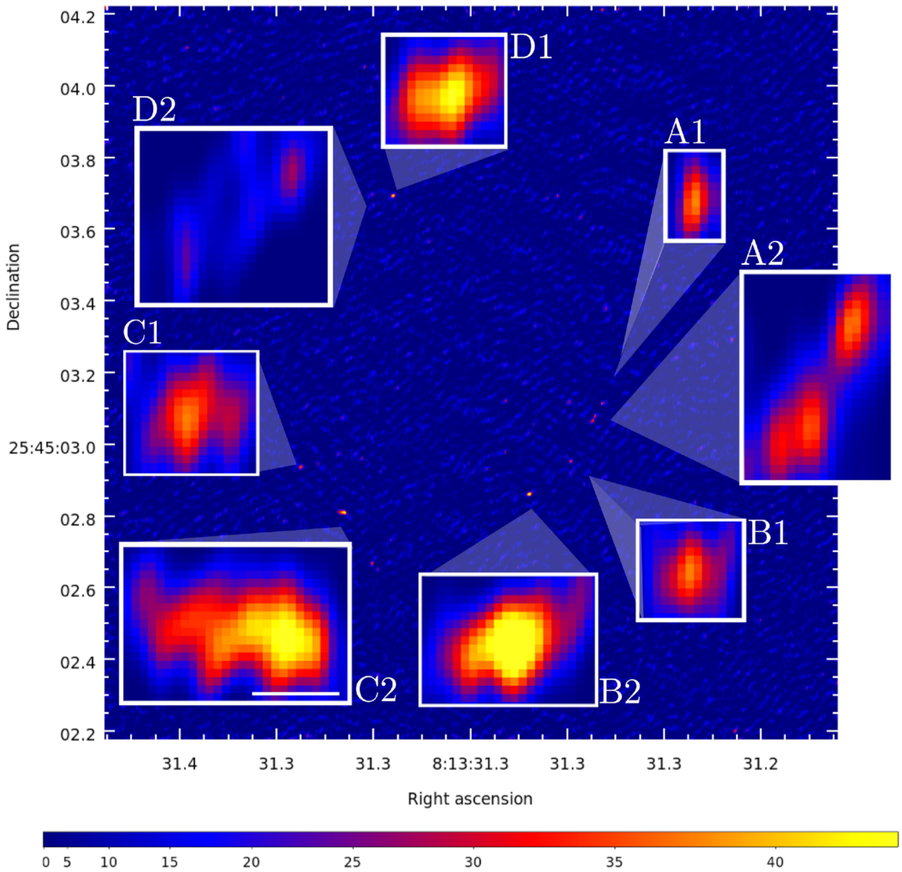

Figure 6. *EVN image of HS 0810+2554 at 1.65 GHz produced using a natural weighting scheme. The peak surface brightness is 52 microJy per beam, at component B2. The beam is at full width of half maximum (FWHM) at 12.0x8.5 mas at a position angle of -3. The nomenclature of Reimers et al. (2002) is assigned to respective pairs of components associated with background sources 1 and 2.*

The resulting maps (Hartley et al., 2019) find a clear detection of two highly compact source components (Fig. 6) with brightness temperatures exceeding the limit from starburst activity, pointing instead to the presence of small-scale AGN jets. Additional observations made using e-MERLIN find a relatively steep spectral index in both components, ruling out possible coronal emission from the AGN core. A final piece of evidence results from modelling of the lensed pattern in combination with HST data, revealing a linear alignment of twin radio components on opposing sides of the optical quasar core, with the typical morphology of a compact symmetric object (CSO) (Fig. 7). Magnification values obtained from the model determine an intrinsic source brightness of just 880 nJy per beam: the faintest radio source ever imaged. Thanks to lensing, the components are not only visible, but with the EVN are imaged to an intrinsic scale of just 0.27 pc: the highest ever resolution image of a RQQ. The model points to a non-smooth mass distribution in the lensing mass itself, hinting at the presence of dark matter substructure which has manifested as astrometric perturbations of the VLBI lensed images.

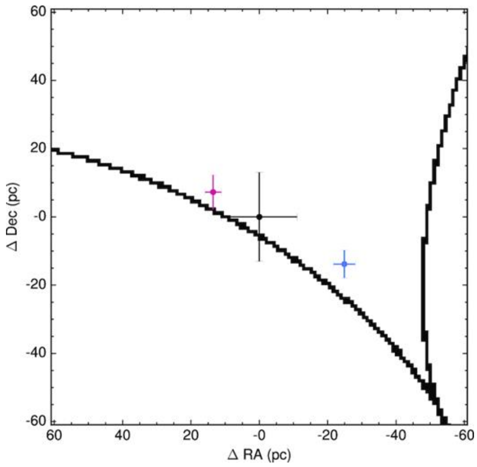

Figure 7. *Reconstruction of the lensed sources using both HST (black) positions and VLBI (blue and red) positions from the best-fit EVN+HST model. The black curve represents the lensing tangential caustic, which is traced back to the source plane from points in the lens plane where magnification reaches theoretical infinity. Positional uncertainties were obtained from the Multinest Bayesian sampling tool and are represented at 1 sigma by the error bars. The components are plotted in the source plane at z = 1.51, assuming a standard flat cosmology with* Ω_m *= 0.27 and* H_0 *= 68 km/s/Mpc.*

Given that this lensed RQQ has been found by Stacey et al. (2018) to fall on the radio–FIR correlation, the latest observations lead the team very tentatively to suggest that radio–FIR correlation cannot always be used to rule out AGN activity in favour of star-formation activity. The correlation – or at least its scatter – may conceal the coexistence of kinetic and radiative feedback modes within AGN. With new EVN data from two other RQQ soon to be analysed, the team will be able to test this hypothesis. Detection of more jetted sources in this region would demand an urgent review of the use of the correlation to classify star-forming and AGN activity within low-power radio sources.

Published in Hartley et al. (2019): **Strong lensing reveals jets in a sub-microJy radio-quiet quasar** , https://doi.org/10.1093/mnras/stz510.

P. Hartley, JBCA, Manchester UK

Update on the JUMPING JIVE project

In the first months of 2019, all partners of the Horizon2020 JUMPING JIVE project worked on a number of exciting activities. The on-going efforts of all work-packages produce always impressive results. The project is engaging with prospective new partners, exploring new science cases for the EVN and looking forward to expanding VLBI by looking at Africa and the SKA.

Another important aspect of JUMPING JIVE is the technical improvement that will be beneficial to the EVN. With the aim of exploring new global VLBI interfaces, WP8 has been developing the monitoring and the remote control of radio telescopes. After extensive research into the different systems currently in use around the world, ZABBIX was chosen as main monitoring system because it has the best user comfort and a wide community within the industrial systems. A central, web-based monitoring system, usable for both astronomical and geodetic VLBI was then created. Figure 8 shows a test of transfer of NASA Field System data over long-haul WAN connections with O'Higgins (Antarctica). This was very successful with continuous real-time data from Antarctica during several weeks.

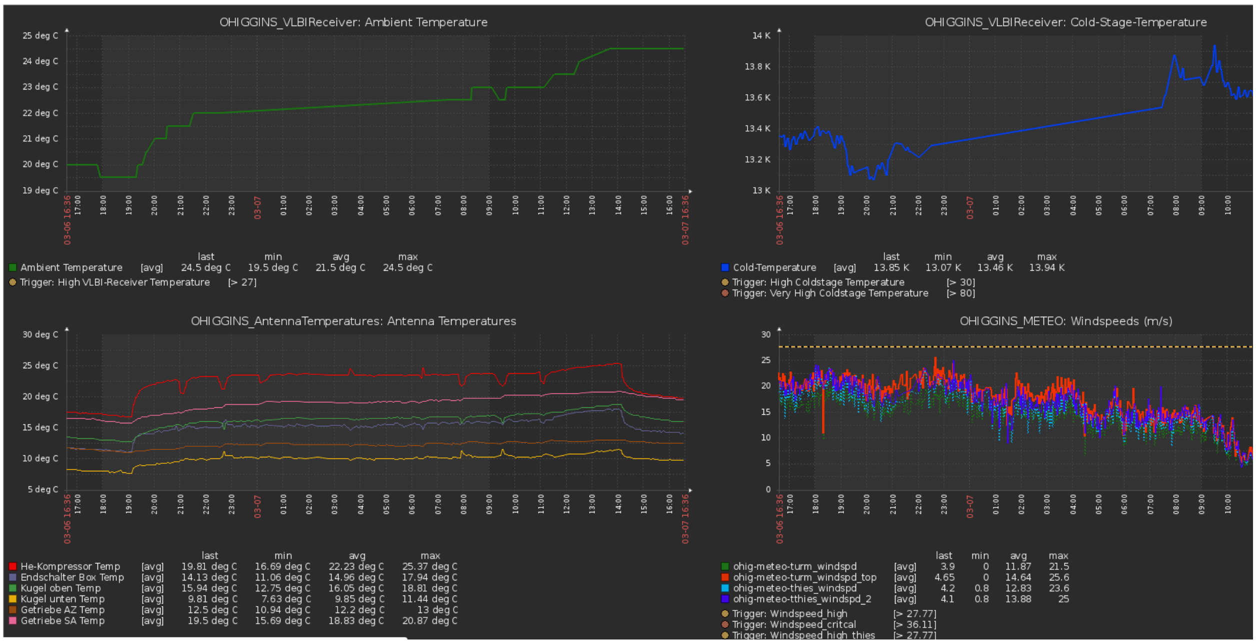

Figure 8. *Test of data transfer of NASA Field System data via tunnelled HTTP connections and parallel tunnelled ZABBIX-Proxy connections for additional parameters over long-haul WAN connections with O'Higgins (Antarctica).*

Another global interface effort is "pySCHED", a python re-factoring of the NRAO's SCHED. An operational version of pySCHED is being tested by the JIVE Support Scientists. Current features include a new VEX1 and VEX2 writer, the availability of matplotlib (Fig. 9), and support for the use of DBBC2 and 3. The next step will be to make pySCHED an Anaconda package, which will greatly simplify installation. If anyone is interested to try out pySCHED, please contact eldering@jive.eu or szomoru@jive.eu.

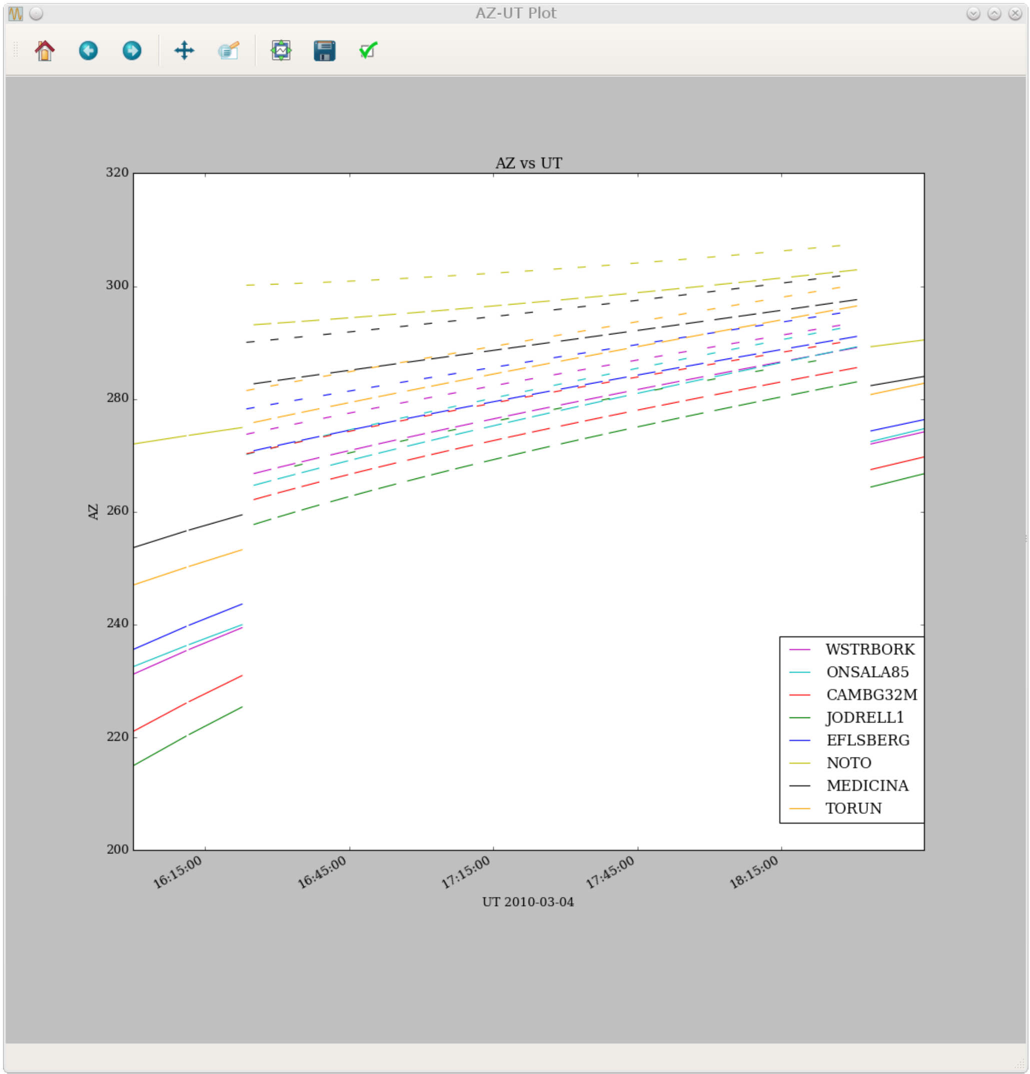

Figure 9. *AZ vs UT plot created within pySCHED using matplotlib.*

More exciting JUMPING JIVE news and results in the next EVN newsletter. In the meantime, the EWASS 2019 participants can come and visit the JIVE booth where some outreach material (goodies and info) will be freely distributed.

Giuseppe Cimò (JUMPING JIVE Project Manager), JIVE, The Netherlands

EVN/JIVE Technical Developments

Start of the ESCAPE project

The ESCAPE project (European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures) kicked off on 7 – 8 February 2019, at the CNRS - LAPP headquarters in Annecy, France, Fig. 10. ESCAPE is funded by the Horizon 2020 programme of the European Union, to an amount of almost 16 Meuro.

Figure 10. *Participants to the ESCAPE kick-off meeting in Annecy*

As the complexity of new facilities in science grows, the data volume produced by them is seeing a tremendous increase and the software to analyse the data is becoming more and more complex. On the other hand, these data should be freely accessible to the growing scientific communities, as they collaborate and interact. To enable this, the ESCAPE project brings together partners from astronomy and particle physics (CTA, ELT, EST, FAIR, HL-LHC, KM3NeT, SKA, CERN, ESO, JIV-ERIC, EGO-Virgo) to collaborate on building the EOSC, the European Open Science Cloud. The ESCAPE actions aim at delivering solutions to ensure integration of data, tools, services and scientific software, to foster common approaches to implement open-data stewardship and to establish interoperability within EOSC as an integrated multi-probe facility for fundamental science.

In this project the EVN is represented by JIVE, who will work on a variety of topics, like the inclusion of radio astronomy data into the Virtual Observatory (VO), which itself will become a part of the EOSC, new pipelines for VLBI data reduction, modernisation and VO-ification of the EVN archive, adding mechanisms to feed back scientific results and tracking the provenance of data products, and further development of VLBI data reduction functionality to CASA and to Jupyter notebooks.

The official project launch date was 1 February 2019. The project has a runtime of 42 months and it will be coordinated by CNRS-LAPP, Annecy.

Arpad Szomoru, JIVE, the Neterlands

Updates from EVN stations

INAF update

The three Italian antennas will be equipped with new simultaneous microwave compact triple-band receiving systems, i.e. K- (18-26 GHz), Q- (33-50 GHz), W-bands (80-116 GHz), and with the DBBC3 backend. This will be finalised in roughly three years from now. Beyond this, each antenna is undergoing the following developments.

Medicina

Funding for upgrading the antenna up to 3 mm band have been recently approved. Over the next three years the main upgrade will be the installation of an active surface system on the 32 m primary mirror to overcome gravity deformations, as well as non-systematic effects.

Noto

The SXL receiver has been assembled and tested in Medicina, and will be installed on the antenna in Noto at the beginning of May. Some components of the X-band chain need to be replaced, hence only L and S observations will be possible in Session 2, 2019. The X-band receiver will be available as soon as the replacements arrive. We expect this to happen before the end of the summer 2019.

Funding for maintenance has been allocated. This will allow to renew the air conditioning system in the vertex room and the helium lines to the secondary focus. Moreover, the broken actuators in the active surface will be replaced.

SRT

The Sardinia Radio Telescope has been awarded one of the grants recently announced by the Italian Ministry of Education, Universities and Research (MIUR) aimed to enhance research infrastructures, pursuant to Action II.1 of the National Operative Programme Research and Innovation 2014-2020. Thanks to this grant the SRT will be equipped with new high-frequency receivers and backends within the next 3 years. Beyond the three band receiver, the future receivers are: a multi-beam cryogenic receiver in W Band (75-116 GHz), a multi-beam cryogenic receiver for Q Band (33-50 GHz), and a millimetre camera (80-116 GHz).

Tiziana Venturi, INAF, Italy

eMERLIN+EVN is working!

eMERLIN, an array of up to 7 UK telescopes controlled from Jodrell Bank Observatory/University of Manchester, is now back in regular EVN operations! In addition to sensitivity, a combined array allows imaging of radio structures on a wide range of angular scales (~1 arcsecond to 1 milli-arcsecond) in the same observation. This opens up exciting scientific possibilities, such as multi-scale imaging of AGN jet structure and star formation processes in nearby galaxies, or improved image-fidelity for transient phenomena such as fast radio bursts.

Standard EVN and eEVN experiments usually involve one of the two main telescopes at Jodrell Bank: either the Lovell 76 m, or Mark2 25 m. Now, also the five so called out-stations (Cm, Pi, Da, Kn, De) can participate in VLBI observations. The out-stations deliver data via optical fibres to the eMERLIN WIDAR correlator, located at Jodrell Bank. The current capabilities allow for one 512 Mbps (i.e. 64 MHz dual-polarisation 2-bit sampled) VLBI data stream from each eMERLIN telescope, in addition to the standard (DBBC2) “home” station. The out-station data streams can either be recorded on flexbuff disk storage, or sent to Jive for real-time (eEVN) observing. An example of 5 UK stations participating in real-time eVLBI can be seen in Fig. 11.

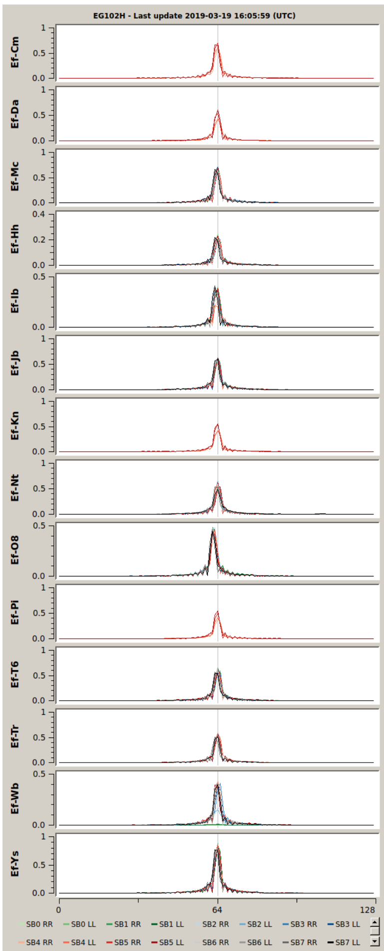

Figure 11. *Live eVLBI fringe plot of data 15 stations during experiment EG102H in March 2019 with 4 eMERLIN stations (Cm, Da, Kn, Pi) in addition to the Jodrell Bank (Jb) home station. The out-stations appear red because they send a reduced bitrate compared to other stations.*

The return of eMERLIN telescopes to EVN operations is the result of significant efforts by Jodrell and JIVE staff. During this work, some early commissioning data were taken which have already been included in publications (e.g. Marcote et al.; arXiv:1902.06731), and more recent observations are in the process of being analysed. Everyone is now encouraged to propose for joint eMERLIN+EVN observations for the upcoming 1 June proposal deadline.

E. Varenius, JBO, UK

Upcoming meetings

SKA-VLBI Key Science Projects and Operations Workshop

We are happy to announce that the registration is open for the SKA-VLBI Key Science Projects and Operations Workshop, which will be held between 14-17 October 2019, Jodrell Bank, United Kingdom. Note there is no registration fee but we will charge 30 GBP for the conference dinner. The space for the meeting is limited, and late registrants will be put onto a waiting list. To register, please visit the meeting web pages: https://indico.skatelescope.org/event/539/

The goal of the workshop is to bring together the community interested in very long baseline radio astronomy at the SKA HQ, to think about how VLBI science can be best done with the phase I Square Kilometre Array telescopes. What are the major science drivers, what are the technological challenges, and what is the best way to formulate Key Science Programmes for the SKA? The plan is to have talks as well as breakout sessions for which we will locally form KSP groups, who will then brainstorm about SKA-VLBI proposal ideas.

Young researchers are particularly encouraged to participate. There will be some limited travel support available in special cases – please contact Sarah Lamb if you are interested, with a cc to Zsolt Paragi.

The invited speakers for the science sessions are:

- Dana Simard (U. Toronto, CA, TBC): Pulsar scattering
- Jack Radcliffe (RU Groningen, NL): Wide-field VLBI
- Marcello Giroletti (INAF, IT): GW-EM counterparts VLBI follow-up
- Jan Forbrich (U. Hertfordshire, UK): Stellar continuum, young stellar objects
- Yoon Kyung Choi (MPIfR-Bonn, D): Maser astrometry, evolved stars
- Manisha Caleb (U. Manchester, UK): Fast radio bursts
- Pikky Atri (ICRAR, AU): Black hole X-ray binaries
- Leah Morabito (U. Oxford, UK): Low-frequency AGN surveys
- John McKean (ASTRON, RU Groningen, NL): Gravitational lensing, cosmology
- James Chibueze (North West U., SA): VLBI in Africa

The SKA and SKA-VLBI will be introduced by:

- Phil Diamond (SKAO, UK)
- Robert Braun (SKAO, UK)
- Antonio Chrysostomou (SKAO, UK)
- Cristina Garcia-Miro (SKAO, UK)
- Cormac Reynolds (CSIRO, AU)
- Richard Dodson (ICRAR, AU)
- Richard Schilizzi (TBC)

The SOC co-Chairs, Antonio Chrysostomou, SKAO, UK, Zsolt Paragi, JIVE, the Netherlands

This workshop is supported by JUMPING JIVE, the SKA, and RadioNet.

The Eighth International VLBI Technology Workshop

The Eighth International VLBI Technology Workshop will be hosted by CSIRO Australia Telescope National Facility (ATNF) and will take place from November 18 to 20, 2019, at ATNF headquarters in Marsfield, Sydney.

The International VLBI Technology Workshops have evolved from the highly successful 10 year series of International e-VLBI workshops. The scope of the technology workshops aims to encompass all areas of hardware and software development relevant to VLBI.

The eighth workshop in this series will feature (but not be limited to) traditional VLBI topics, such as receivers, backends, recording equipment, and e-transport. Up to one day will be dedicated to software digital signal processing and the use of accelerators in VLBI and non-VLBI fields (such as pulsar processing), to explore and facilitate collaboration with groups outside traditional VLBI. We will invite a number of experts from non-VLBI fields.

Important dates:

June 15: Call for Abstracts

September 30: Abstract submission deadline

November 1: Registration Deadline

More information will be available on

https://www.atnf.csiro.au/ivtw19

Chris Phillips, CSIRO, Australia