16th European VLBI Network Symposium and Users' Meeting

Monday 02 September 2024 - Friday 06 September 2024

CJD Bonn Castell

Book of Abstracts

The European VLBI Network Symposium is the main forum for discussion of the latest Very Long Baseline Interferometry scientific results and technical and technological developments within the EVN member countries. The 16th EVN Symposium and Users meeting, hosted by the Max-Planck-Institut für Radiostronomie, is held in Bonn in September 2-6, 2024. Here you find the book of abstracts. A volume with the conference proceedings will be prepared after the meeting by all contributors.

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Mitigating Source Structure in Geodetic VLBI on the Visibility Level

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Geodetic and astrometric VLBI has entered a new era with the implementation of the VLBI Global Observing System (VGOS, formerly known as VLBI2010). These broadband and dual linear polarization observations aim at an accuracy of station coordinates of 1 mm and a reference frame scale stability of 0.1 mm/year. Although the extended brightness distribution of many of the radio-loud AGN observed during VGOS sessions is resolved by the interferometer, the established processing chain still treats these objects as point sources. We investigate the impact of source structure on the visibility level and develop tools to remove the structure from the data as early as possible in the process. Here we present our approach and show results obtained from observational data.

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Dynamic VLBI Imaging with Resolve

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The high resolution of Very Long Baseline Interferometry (VLBI) allows us to access dynamic aspects of our Universe. However, the data are typically sparse, and certain sources, such as Sgr A*, can change significantly during observations, making traditional snapshot imaging techniques inadequate. In this talk, I will present how to use the resolve framework for dynamic imaging of VLBI data. This Bayesian method leverages adaptive Gaussian Processes and Variational Inference for data-driven self-regularization, enabling the reconstruction of spatiotemporal representations from sparsely sampled data. Rather than producing a single reconstruction, resolve generates a probability distribution, allowing for the quantification of uncertainty in the results. I will demonstrate the effectiveness of this approach with examples using Event Horizon Telescope (EHT)-like data. These examples will show how resolve captures the dynamic evolution of astronomical sources over time, providing a more comprehensive understanding of these processes.

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Black Hole Explorer - the next generation Space VLBI mission

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We present an overview of a proposal for the next generation Space VLBI mission Black Hole Explorer (BHEX). Its main scientific goal is to detect the photon ring and measure basic parameters of super-massive black holes in centers of M87 and SgrA*. Other science cases include black hole demographics as well as studying accretion, formation, and collimation of jets in active galaxies. In order to do it, a 3.5-m radio dish will be launched into space to an orbit longer than 3 Earth diameters and will observe together with the most sensitive ground millimeter telescopes. BHEX will be equipped with two cooled receivers covering a frequency range from 80-106 and 240-320 GHz, which can observe simultaneously. A laser-com link will deliver a real-time data stream of 100 Gbps to the ground. BHEX is planned to launch in 2031.

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Multi-messaging prelude: precursors of gravitational wave emitters at the milliarcsecond scale

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Formation of super-massive black holes binaries (SMBHB) is one of the most challenging problems of theoretical astrophysics, as well as observational astronomy in electromagnetic and gravitational wave domains. A process of inevitable dissipation of kinetic energy in SMBHB controls the evolution of these objects (also referred to as inspiralling or recoiling) and leads toward coalescing into a single black hole. This process is accompanied by increasingly intensive emission of gravitational waves (GW) and ends with the final GW burst. While the first direct detection of GW made by the LIGO and Virgo collaboration in 2015 dealt with coalescence of stellar-mass black holes [1], recent results based on multiple Pulsar Timing Arrays (PTA) [2, and references therein] triggered increased interest to the SMBHB population as a likely source of the GW background. However, SMBHB sources remain rather elusive: at present, there are only several dozens of candidates of which just a handful can be treated as certain cases. Besides several directly detected dual active galactic nuclei (AGN) with separations between black holes measured in hundreds kiloparsec, thus belonging to early stages of the SMBHB evolution, closer binary systems in more advanced stages of inspiralling are mostly suspected on the basis of temporal variability or morphological patterns of milliarcsecond-scale structures [3, section 6, and references therein]. Direct detections of the components of SMBHB at the sub-parsec scales, which correspond to the late stages of inspiralling, remain beyond reach for today's observing techniques at all domains of the electromagnetic spectrum.

Recently we noted several AGNs distinguished by oscillating astrometric positions at the milliarcsecond angular scale and periods of several years. One of plausible explanations of such the behavior is orbital motion of the components of SMBHB [6,4]. We emphasise that VLBI images in our study do not allow us to see" directly the components of possible SMBHBs. But we see asmoking gun" of orbital motion in these potential SMBHBs. We will demonstrate several examples of such the oscillating behavior in VLBI astrometry data in quasars 0119+115, 2101+600 and 2234+282. Using the available observational data as starting points we reconstruct physical models of these potential SMBHBs. At the next step we analyse the evolution of these binary systems leading to coalescence and associated with this GW outburst ("a chirp" as it is commonly called in the GW detection context).

The work offers an example of VLBI study of a potential GW event precursor. It can be seen as a multi-messenger prediction. It also offers a new vantage point for quantitative explanation of the recent PTA results.

Finally, we demonstrate how the estimates presented in this work offer inputs into design studies of future mm/sub-mm VLBI systems with spaceborne radio telescopes. Such the systems [5, and references therein] will allow us to resolve images of binary SMBHBs at the microarcsecond angular scales, principally unachievable with the Earth-based observational facilities.

References [1] Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2016, Phys. Rev. Lett., 116, 061102 [2] Agazie, G., Anumarlapudi, A., Archibald, A. M., et al. 2023, Astropys. J., 956, L3 [3] Ayzenberg, D., Blackburn, L., Brito, R., et al. 2023, arXiv:2312.02130 [4] Gurvits, L. I., Frey, S., Krezinger, M., et al. 2023, in The Multimessenger Chakra of Blazar Jets, ed. I. Liodakis, et al., Vol. 375, 86-90 [5] Gurvits, L.I., Paragi Z., Amils, R., et al., 2022, Acta Astronautica, 196, 314-333 [6] Titov, O., Frey, S., Melnikov, A., et al. 2023, Astronomical J., 165, id 69

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VLBA Observations of Four Radio-Selected Dual AGN in Stripe 82 Region

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We observed four confirmed dual AGNs in Stripe 82 region using VLBA at 5 GHz in multiple-phase-center mode, aiming to study their milliarcsec-scale radio emission properties. In the eight radio components of targets, we detected two pc-scale radio cores labelled J0051+0020B and J2300-0005A. The radio emission of the other six components was resolved out in the high-resolution images. The two VLBA-detected sources are not the radio-brightest in previous VLA C-band observations. Therefore, the VLBA detections should be due to beaming effect. We get their phase-referenced coordinates and flux densities of two VLBA-detected sources by Gaussian fitting, and estimate their brightness temperature and radio emission power. Their pc-scale radio emission properties are similar to typical jet-dominated AGN. For the other six undetected sources, we provide their upper-limit values of these parameters. Based on their pc-scale radio emission properties, we analyze their 5-GHz radio emission origins in detail for each target. The 5-GHz radio emission of J2206+0003B mostly originates from star formation, while for the other targets, their 5-GHz radio emission is dominated by jet activity. The multiband study of targets revealed a possible systematic X-ray deficit in our dual-AGN sample, which could be attributed to the tidally induced effect and possibly a viewing angle effect. In addition, we compared their VLBA phase-referenced positions of two detected sources with their Gaia positions, and discovered a significant (˜10 mas) radio-optical position offset. The two sources both have significant astrometry excess noise (AEN) in Gaia DR3, similar to Varstrometry selected dual AGN. We think their Gaia positions could be weighted centers of AGN and their host galaxies, and their VLBA positions correspond to the actual location of the black hole. The significant AENs could be caused by dark Gaia magnitudes of targets and possible merger effects. To confirm and study interesting dual-AGN candidates which have significant radio-optical offsets, we have presented an EVN observational proposal to reveal the fine radio structures of two Varstrometry selected dual-quasar candidates with z>0.5. The outstanding sensitivity and high resolution of EVN are helpful in achieving the above scientific goals.

Poster Session / 26

A new window into cool dwarf's magnetospheres: radiation belts and beyond

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Spatially-resolved radio observations of the ultracool dwarf (UCD) LSR J1835+3259 have shown extended radio emission consistent with the presence of a steady radiation belt powered by synchrotron emission, and aurora, powered by the coherent electron cyclotron maser mechanism. Those results show that, similar to the Jupiter case, radio emitting UCDs possess dipole-ordered magnetic fields with radiation belt-like morphologies and aurorae. In this talk, we will present the latest results on very-long baseline interferometry (VLBI) efforts on this magnetic structure akin to the Van Allen belts. We will also take a sneak peek into novel VLBI detections showcasing distinctive radio-emitting behaviors in various UCDs, and will discuss the potential implications of those behaviors on existing models of radio emission from UCDs.

Poster Session / 20

PKS 1424-418: A best case of the blazar radio/gamma-ray connection

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Blazars, a subclass of radio-loud AGN are among the best laboratories for high-energy astrophysics in the Universe. The relativistic jets in blazars are prominent gamma-ray emitters with rapid

variablity down to minute scales. The underlying physical mechanisms and origin of the gamma-ray emission, however, are not yet fully understood. One of the key diagnoses for the relevant studies is to explore statistically significant correlations between gamma-ray and lower-energy band (e.g., radio-to-optical) light curves in the sources. In this work, we analyzed the correlation with millimeter (> 90GHz) radio light curves in the blazar PKS 1424-418 and found a long-term, tight radio/gamma-ray connection which is atypical compared to the cases of other blazars. The correlation spans ˜8.5 years with a small amount of time lag (i.e., less than three days). Given the well-known blazar jet model with the core-shift theory, the results indicate that the gamma-ray production site is spatially connected to the location of the millimeter radio core at e.g., (sub)parsec scales in the jet of PKS 1424-418. Additional analysis of the evolution of radio spectral index (95GHz vs. 345GHz) clearly shows us the coincidence between the spectral hardenings and gamma-ray flares. This further implies that a small displacement between the gamma-ray origin and the radio core may occurs when the source flares at gamma-rays, perhaps due to the passage of a strong moving shock/blob. We suggest that this particular blazar might be a persistent source of the radio/gamma-ray connection.

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Exploring the Disk-Jet Connection in Nearby Jetted AGN

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Relativistic jets from Active Galactic Nuclei (AGN) are suggested to originate from supermassive black holes at the center of galaxies, surrounded by their accretion disks. The properties of the disks are intrinsically linked to the characteristics of the launched jets, in what is known as disk-jet connection. When considering their magnetization, accretion disks fall into two main categories: the low-magnetized Standard and Normal Evolution (SANE) disks, and the highly-magnetized Magnetically Arrested Disks (MAD). These distinct disk classes result in different magnetic fields within the jets, impacting observational signatures such as their acceleration, collimation, and polarization. These phenomena can be probed by means of cm-/mm-Very Long Baseline Interferometry (VLBI) observations. Through the characterization of the mentioned observational jet properties, we can employ theoretical models to constrain the magnetization of the jets and, correspondingly, their accretion disks. This poster will present our recent results on the disk-jet connection with a focus on the nearby jetted radio galaxy NGC315. For the latter, we are able to suggest the presence of a MAD starting from the physical properties of its sub-parsec, parsec scales jet inferred from a multi-frequency VLBI dataset.

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Accretion mode and γ-ray emission: A comparison between 3C111 and 3C371

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Active Galactic Nuclei (AGN) form the most abundant class of γ-ray sources. Due to Doppler boosting, the vast majority of these consist of Blazars (viewing angle $\vartheta < 8^\circ - 10^\circ$), while misaligned (MAGN) sources ($\vartheta > 8^\circ - 10^\circ$) account for a few percent of γ-ray-detected AGN. Despite their low abundance in the γ-ray sky, MAGN are a fundamental tool to study relativistic jets, precisely because of their larger ϑ that allows us to better resolve the jet structure on compact scales. Based on the efficiency of the accretion onto the SMBH, AGN can be divided into two classes: High Excitation Galaxies (HEG), with a radiatively efficient accretion, and Low Excitation Galaxies (LEG) with an inefficient one. In this work, we investigate the differences between these two types of objects in the γ-ray domain, with the help of Very Long Base-line Interferometry (VLBI) and multi-wavelength observations. As case studies, we select two MAGN: one HEG (3C111) and one LEG (3C371) with similar BH masses, redshifts, jet powers, and viewing angles. We analyze overall around 200 VLBI maps, spanning over 4 years at 3 frequencies (15 GHz, 22 GHz, and 43 GHz), to investigate the relation between the structural changes observed in the radio jet and the emission at higher energies. We find substantial differences between the two sources both in the kinematics and in the γ-ray activity. 3C111 shows mostly superluminal knots, while 3C371 is dominated by stationary components, presenting a single moving feature possibly ejected after a major optical flare. Concerning the γ-ray emission, 3C111 is undetected for most of the period analyzed and shows strong flaring activity related to superluminal features emerging at the jet base, while 3C371 has a less variable light curve with few small flares. In this talk, we discuss a possible scenario that links together the accretion mode, the kinematics, and the γ-ray activity. This will be further explored with the use of 2D RMHD simulations.

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VLBI study of a sample of low-power compact symmetric objects

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Compact symmetric objects (CSOs) are intrinsically compact extragalactic radio sources and are thought to represent the progenitors of classical radio galaxies. Several evolutionary models of the radio emission have been developed so far, but they mainly focus on the evolution of high-power jets. Low-power jets are more prone to instabilities than their high-power counterparts, and jet-medium interaction may decelerate or even disrupt the jet, preventing the formation of large scale structures. As a consequence, a large fraction of the energy of low-power jets is deposited in the host galaxy, and potentially impact the distribution and kinematics of the ISM of the host galaxy for longer time than high-power jets.
In this contribution, we present results on VLBI observations of sample of low-power CSO candidates selected from the FIRST. These observations allow us to confirm their CSO nature by the study of their pc-scale morphology and spectral index distribution. Increasing the number of confirmed low-power CSOs is crucial for improving our knowledge of the evolutionary path of the radio emission and the influence the ambient medium may have on low-power jets at the beginning of their evolution.

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VLBI astrometry of radio-emitting binary stars

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VLBI technique provides a means to investigate the nature of radio-emitting binary stars on mas or sub-mas scale. In astrometry, high-precision parallax, proper motion, and position measurements could be achieved through VLBI observations, assisting in the revision of our knowledge of the physical parameters of radio-emitting binary stars. Moreover, the binaries being both radio loud and optically bright can be used as link objects to tie the radio and optical celestial reference

frames together. Here we will discuss our VLBI astrometric studies of radio-emitting binary stars, especially close binary stars including magnetic cataclysmic variables and RS CVn binaries.

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A Distance Measurement for a Blazar TXS 0506+056 Using its Radio Variability and VLBI Images

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We present the result of the angular diameter distance measurements for a blazar TXS 0506+056 ($z = 0.3365$), a radio-bright active galactic nucleus (AGN) whose jet is aligned with the line of sight. We used the 15 GHz Owens Valley Radio Observatory (OVRO) 40 m single dish (SD) data from MJD 54474 to MJD 59023 (12 years) and the 15 GHz Very Long Baseline Array (VLBA) data from MJD 54838 to MJD 60126 (13 years). The OVRO SD flux density ranges from 0.29 ± 0.03 to 2.44 ± 0.03 Jy and the VLBA core flux density varies from 0.22 ± 0.03 to 1.90 ± 0.17 Jy. We used a variability timescale (τ) and a causality argument of a linear size $R = c\delta\tau/(1+z)$ (taking into account a Doppler factor δ and a cosmological redshift z) to constrain the angular diameter distance ($D_A = R/\theta_R$) to the source (with its angular size θ_R). Using the OVRO data, we estimated a variability timescale of $\tau = 296.2^{+0.4}_{-1.6}$ days for the giant flare in 2020 February. We found that the giant flare is dominated by the variability of the VLBA core by fitting circular Gaussian model components to the VLBA images. The rest frame brightness temperature of an emission region ($T_{\rm b}^{\rm em}$) and the observed brightness temperature by the receiver ($T_{\rm b}^{\rm rec}$) are related as $T_{\rm b}^{\rm em} = T_{\rm b}^{\rm rec}(1+z)/\delta$. To constrain the Doppler factor $\delta = T_{\rm b}^{\rm rec}(1+z)/T_{\rm b}^{\rm em}$, we assume that $T_{\rm b}^{\rm em}$ is saturated to the intrinsic brightness temperature $T_{\rm b,int}$ by the inverse Compton catastrophe when the flare of the emission region peaks. To calculate $T_{\rm b}^{\rm rec}$, a flux density variation and an angular size of the emission region are required. The angular size θ_R of the emission region (i.e., the VLBA core) is obtained from a Gaussian modelfit parameter $\theta_{\rm FWHM}$ ($\theta_R = 0.8\theta_{\rm FWHM}$), ranging in 0.047-0.228 milli-arcsecond (mas), and its uncertainty is determined to be 2.54-14.0 %. We considered the core's flux density variation is the difference between the maximum and the minimum flux density. With same timescale and core flux density variation, we calculate the angular diameter distance $D_{\rm A} = R/\theta_R$, along core sizes. At Λ-CDM model, the angular diameter distance of TXS 0506+056 is determined as $D_{\rm A} = 1038.9^{+7.7}_{-7.7}$ Mpc or $D_{\rm A} = 958.7^{+13.8}_{-13.5}$ Mpc at Hubble constant $H_0 = 67.4 \pm 0.50$ km/s/Mpc or $H_0 = 73.04 \pm 1.04$ km/s/Mpc, respectively, with a matter density parameter $\Omega_{\rm M} = 0.27$ and a vacuum density parameter $\Omega_\Lambda = 0.73$. From MJD 58468 to MJD 58968 near the total flux peak, we found the consistent results with Λ-CDM within the uncertainty 29.6-59.1 %.

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Developments in Long-Wavelength Southern-Hemisphere VLBI in the Context of the TANAMI Program

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The TANAMI program has been using the Southern-hemisphere LBA array and associated telescopes to monitor compact relativistic jets in active galactic nuclei (AGN) at X- and K-band frequencies since 2007 with a focus on bright sources (~1Jy) and synergies with the Fermi gamma-ray space telescope. In preparation for the upcoming era of the Cherenkov Telescope

Array (CTA) and to exploit the capabilities of new radio-astronomical facilities operating at low frequencies, S-band observations of fainter AGN jets have become an integral part of the TANAMI program since 2020. The SKA-MPG telescope is a prototype antenna of the South African Square Kilometre Array (SKA)-MID component, located in the Karoo desert, South Africa. This telescope will play a crucial role in future VLBI observations, including those by the EVN, as one of the longest baseline stations, thereby improving spatial resolution and providing scheduling flexibility. In this presentation, I will discuss recent developments of the VLBI mode for the SKA-MPG telescope, including first fringe detections and observations of TeV gamma-ray emitting AGN. Adding the SKA-MPG telescope into the array used for TANAMI VLBI observations is an important step in order to access the faint AGN jet population with SKA-VLBI.

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Probing the collimation and dynamics of radio galaxies

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Current VLBI observations allow us to study collimation in relativistic AGN jets. Among AGNs, radio galaxies provide the unique opportunity to test for jet asymmetry due to their large viewing angle. To better understand the complex interplay between the dynamics of the jet and its environment, we perform numerical simulations of a double sided jet, incorporating realistic ambient profiles as well as the effects of an obscuring torus. For direct comparison with VLBI observations, we create synthetic datasets at different radio frequencies, taking the properties of real observing arrays into account. We perform multifrequency image reconstructions of our datasets using MEM methods, followed by a study of the collimation profiles as well as sophisticated component extraction and tracking techniques. Our results show that the jet undergoes a change in collimation profile at a location corresponding to the first recollimation shock, exhibiting a cylindrical profile upstream followed by a parabolic one downstream. In addition, we provide observable signatures for the interactions between travelling and recollimation shocks.

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Faint compact radio quasars at redshifts z>5 observed with the European VLBI Network

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High-redshift quasars provide unique information about the formation and evolution of the first galaxies and supermassive black holes (SMBHs) in the early ˜1 billion years old Universe. Powerful relativistic jets, hosted by radio quasars, are thought to have an important role in building up SMBHs for such a short period of time. Thanks to dedicated high-resolution VLBI observations, our knowledge of the high-redshift ($z > 5$) radio quasars has greatly expanded. Despite the efforts, due to the limited amount of targets, the sample of VLBI-observed radio quasars is still too scarce to allow meaningful statistical conclusions. With our project, we aim to extend the list of VLBI-observed radio quasars while also investigate how the source structure and physical parameters are related to the radio loudness. We have selected a sample of 10 faint radio quasars at $5 < z < 6$ with radio-loudness indices ranging from 0.9 to 76 for observations with the EVN at 1.7 GHz. In addition to the EVN observations, we collected single-dish and low-resolution radio interferometric data to study the spectral properties and variability of our sources. A high, 90% detection rate was achieved. Both radio-quiet and radio-loud sources were detected with single compact radio components. By extending our sample with other VLBI-detected $z > 5$ sources from the literature, we investigated relations between physical parameters such as radio loudness, brightness temperature and monochromatic radio power.

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Scientific perspectives of VLBI operations in the frequency phase transfer mode

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The technique of frequency phase transfer (FPT), pioneered at the Korean VLBI Network, is now gaining strong momentum with a number of telescopes and VLBI arrays considering it as a backbone of future operations. These include, most notably, the Global Millimeter VLBI Array (GMVA) and the upgrade of the Event Horizon Telescope. Implementation of FPT at these instruments holds a promise of increasing sensitivity and dynamic range of imaging by factors of 10-70 and reaching an unprecedented ˜1 microarcsecond accuracy of relative astrometric measurements. Present state of developments of FPT VLBI and its scientific perspectives will be briefly discussed in this presentation

Poster Session / 82

Expansion of a subsample of methanol masers rings

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The 6.7 GHz methanol maser distribution showing a circular morphology in high-mass star-forming regions was discovered 2 decades ago using a sensitive European VLBI Network. Today, after multi-epoch observations, we derive the proper motions of single-masing cloudlets at the level of several kilometres per second. The motions are directed radially outward from the centres of fillet ellipses indicating that expansion motions dominate. After detailed analysis, we state that the maser spot distribution alone does not allow for a direct interpretation of the ongoing scenario. With the results, we can not distinguish, if the rings trace the outflows or are related to disc-winds. There is a need for complementary angular resolution images.

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DBBC4 - A 256 GHz bandwidth flexible VLBI environment

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The development of the newer version of the VLBI digital front- and back-end system belonging to the DBBC systems' family is under way as a work-package of the RadioBlocks Project. This instrument dedicated to increase the VLBI observation capabilities in terms of bandwidth and output data rate involves a number of relevant novelties ranging from the full 32 GHz digitized input band in a number of up to 8 RF/ IFs per system, to a fast recording system, and is including for the first time in a VLBI system the introduction of a hardware AI processor.
The DBBC4 can be implemented as a distributed system of elements to be positioned in different parts of the radio-telescope site, so as in a more traditional way in a single box. Distributed elements which can operate also as stand-alone are: DiFrEnd28 with full 28GHz bandwidth, DiFrEnd4T with 6 GHz bandwidth in the range 0-33 GHz, DiFrEndVGOS covering the entire VGOS range 2-14 GHz. This last one can also be used in conjunction with the DBBC3 to digitize the full VGOS band and replace any analogue frequency conversion. All the distributed elements can have backend functionality being able to produce channelized VDIF output packets to be recorded or sent through the correlator.
The progress of the DBBC4 development is reported together with a comprehensive description.

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Contribution of PRIDE VLBI to the ephemerides of Jupiter's moons

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In the 2030s, the ESA JUICE and NASA Europa Clipper missions will explore the Jupiter system and provide unprecedented insights into the dynamics of the Galilean satellites. A refined ephemerides estimation will enhance our understanding of their origin and thermal-orbital evolution. However, achieving a robust and consistent solution that matches the low uncertainty levels predicted by current simulations will be challenging. This is due to the need for models to reproduce the spacecraft and moons' dynamics accurately enough for the statistical uncertainty estimates to be physically meaningful.
To overcome these challenges, we propose a gradual approach, starting with local estimations of the flyby moon's state, which are then carefully analysed and validated before a global solution can be reconstructed. We investigate the role of JUICE's Planetary Radio Interferometry and Doppler Experiment (PRIDE) in this process. PRIDE will provide independent VLBI measurements of the spacecraft's angular position, complementing the line-of-sight constraints from classical radio science.
We simulated VLBI measurements for JUICE in various data acquisition and quality scenarios and identified eleven opportunities for simultaneous VLBI observations of the JUICE and Europa Clipper spacecraft. Our covariance analyses highlight how PRIDE VLBI observations can significantly improve the satellites' local state solutions, most notably in the out-of-plane direction.

The PRIDE data represent a powerful addition to the classical radio science solution and play a key role in progressing from local estimates towards a consistent, unprecedentedly accurate global solution for the moons' dynamics. This research paves the way for a deeper understanding of the Galilean satellites and their complex interplay with Jupiter.

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A search and multi-frequency investigation of the parsec-scale structure of curved jets in AGN

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Very long baseline interferometry (VLBI) observations reveal that active galactic nuclei (AGN) jets often exhibit bending at parsec scales. While individual cases have been studied, broader trends across a large sample remain unclear. We analyse 123,000 multi-frequency VLBI images of 17,000 AGNs. From the total number, we extract 7,927 objects with resolved jet structure, identifying 586 (7% of 7,927) with significantly curved jets and 744 (9% of 7,927) sources with bending signatures.
We use the Astrogeo VLBI FITS images collection (https://astrogeo.org/vlbi_images/), which includes multi-frequency VLBI observations. It covers 2 to 86 GHz and enables us to construct ridgelines of the jets. We utilise precession and Kelvin-Helmholz (KH) instability models to fit jets' geometry. By analysing these models, we estimate precession periods to be of the order of 100 – 300 yr. Our findings suggest that jet precession, driven by either accretion disk precession for high Eddington accretion rates (> 0.1) or supermassive black hole binaries, can potentially be the cause of the bending. The KH instability also consistently describes the observed structures. This study explores the physical mechanisms behind AGN jet bending, providing insights into the dynamics of their central supermassive black holes and accretion disks, offering constraints on models of jet precession and instability.

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Hunting of stellar flares by two-element interferometer

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Flares on the Sun and other stars result from rapid explosive releases of free magnetic energy stored in the solar/stellar coronae. Solar flares and connected with them coronal mass ejections (CME) have a crucial impact on physical conditions in the near-Earth space, known as "space weather", and on the functioning of various infrastructure facilities such as communication and navigation systems, energy supply lines, high-latitude flights, etc., with the financial risks up to billions of euros worldwide. Other stars (including solar-type ones) have been observed to host flares far

more energetic than the largest known solar flares. The occurrence of such ferocious "superflares" on the Sun would lead to devastating and long-lasting consequences for our civilisation. Therefore, the study of stellar superflares, processes operating in them, and assessment of the Sun's capability to produce similar events and their expected occurrence rate are among the prioritised research directions of modern heliophysics and astrophysics. Observations in the radio band are one of the most promising tools for studying solar/stellar flares. The advantages of the radio band are justified by the facts that radio emission is generated directly in the solar or stellar corona, i.e. where the energy release processes take place; radio emission is highly sensitive to parameters of the magnetic field and accelerated particles and, therefore, allows for determining these parameters. Usually, an accurate determination of radio emission source parameters requires simultaneous observations at several frequencies. Therefore, the VIRAC with its rich complex of radio-band instruments, such as solar radiopolarimeters at the radiotelescope RT-32 and the LOFAR LV614 antenna array, is one of the most suitable facilities for flare studies. In addition, the high temporal resolution traditionally available in the radio band makes it possible to track rapid changes in the characteristics of the magnetic field and accelerated particles in flares. Moreover, single-baseline radio interferometers, e.g., the VIRAC RT-16 and RT-32 complex, offer interesting opportunities in this emerging research field. Compared to single-dish radio telescopes they have a much deeper sensitivity to radio continuum emission thanks to the signal correlation process and spatial filtering of the background sky emission. The use of large, multi-telescope arrays, like EVN is shared among the international research community, and hence usually prohibits monitoring observations and regular observations needed to observe stellar flares at the timescales of their variability. We exploring opportunity to use two radio telescopes, RT-16 and RT-32, situated in Irbene, Latvia for employing a single-baseline interferometer capable of leading global research in the field of solar and stellar flares in radio band. The two radio telescopes, of 32 m and 16 m diameters, are capable of interferometric observations under the operation of the VIRAC. The telescopes are separated by 800 m, which provides rapid increase in sensitivity compared to the single-dish observations, reduces RFI influence and enhances credibility of observations. Such a configuration of accessible radio telescopes is now uncommon due to the recent move of focus to large arrays, therefore presenting a unique opportunity to make progress and innovation in the research field. An in-house interferometer also has the benefit of flexible time allocation to provide the monitoring observations necessary to detect rapid activity on stellar flares. The early testing of interferometric observations using two-element Irbene complex has demonstrated that the interferometer can reach close to its theoretical sensitivity limit of 6 mJy in a 2-minute integration. After calibration using a preliminary data processing pipeline developed in the IVARS project (see report by J.Šteinbergs), the stability of the interferometer was confirmed to be suitably stable for the detection of potential stellar flares events. As on solar-type stars the flare occurrence rate is rather low, on average 0.1–0.2 per day, we focus on stellar flares on rapidly rotating red dwarfs, in which the observed flare rate is much higher than on the Sun. The selected objects are M-type main-sequence stars situated at a distance of up to 25 pc. On red dwarfs, flares are observed at a rate of 1–2 per day in the X-ray, UV, and optical bands. The radio brightness temperature of flares on these objects reaches 10ˆ13 K. Typical values of the spectral density of the radiation flux varies as 50-200 mJy (cf. 6 mJy the expected sensitivity of Irbene interferometer). Thus, the choice of perspective targets is dictated by high flare activity, high radio brightness, and a fairly high position of the star in the Northern Hemisphere (declination): e.g. CR Dra (Dec=+55, M5.6V), DO Cep (Dec=+57, M4.0V), EV Lac (Dec=+44, M4.0V), AD Leo (Dec=+19, M3.5eV). The observed occurrence rate, 1-2 flares per day, allows us to expect that a series of observations in the tracking mode with the highest possible time resolution of one of these targets within one week will give us the opportunity to register several flares. The high time resolution will allow us to detect short-period Quasi-Periodic Pulsations (QPP) with periods about a minute, which are the most common QPP periods in solar flares and non-stationary processes in QPPs (period drift, amplitude modulation, multiple periodicities). Observations are carried out in both polarisations in the 6.7 GHz band corresponding to the typical gyrosynchrotron emission, with Irbene radiotelescopes RT-32 and RT-16 in the interferometer mode. This observational programme does not require high spatial resolution, since the selected flare stars are sufficiently isolated in the radio band. This work has been supported by project "Multi-Wavelength Study of Quasi-Periodic Pulsations in Solar and Stellar Flares. (lzp-2022/1-0017).

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TANAMI VLBI Observations of Southern-Hemisphere AGN Associated with High-Energy Emission

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TANAMI is the only large and long-term VLBI monitoring program focused on the Southern sky aiming at VLBI monitoring of active galactic nuclei (AGN) at X and K band since 2007, and at S band since 2020. The program concentrates on AGN with very high-energy gamma-ray emission and in recent years the source sample has been extended to accommodate the emerging field of neutrino astronomy as well. Recent observational results suggest that high-energy neutrinos may be associated with individual AGN jets which strongly calls for high-quality, high angular-resolution radio observations of neutrino-candidate blazars to study their parsec-scale jet structures. Here, we present first results of S-band observations of TeV blazars and neutrino-candidate blazars in the Southern sky. The complete sample of Southern-hemisphere TeV blazars is dominated by high-peaked BL Lac objects (HBLs). In agreement with other studies of HBLs, we find that these sources have comparatively low core brightness temperatures well below equipartition, in stark contrast to the high Doppler factors typically derived from high-energy studies (Doppler crisis). In the sample of neutrino-candidate blazars, we find both blazars with core brightness temperatures below and above equipartition.

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Status of the MOJAVE project

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MOJAVE (Monitoring Of Jets in Active galactic nuclei with VLBA Experiments) is a long-term program to monitor radio brightness and polarization variations in jets associated with active galaxies in the northern sky. It started in 1994 as the 2 cm VLBA survey, introduced polarization measurements in 2002, and is currently approved to continue until 2027. We monitor more than 60 jets to learn how relativistic flows accelerate, collimate, and evolve within a hundred of parsecs of the central engine. Regular imaging of a complete flux density-limited sample of about 150 active galactic nuclei will allow us to address highly energetic phenomena in the electromagnetic and neutrino domains. By continuing our policy of timely release of fully calibrated data and images, MOJAVE will serve as an invaluable resource for the community during the multi-messenger astronomy era. More details are presented in dedicated contributions at this meeting or can be found at https://www.cv.nrao.edu/MOJAVE

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New look at old friends: EVN imaging of prominent radio-loud active galactic nuclei with extremely large radio-optical positional offsets

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When comparing modern fundamental reference frames in the radio (ICRF) and optical (*Gaia*), a couple of bright radio reference sources appear to have very large radio-optical offsets, from tens up to hundreds of milliarcseconds. The amount of these positional misalignments exceeds the uncertainty of each individual technique by at least an order of magnitude. In most cases, complex and extended radio structure and its time variability, and thus the difficulty in pinpointing the true location of the central engine, is responsible for the large apparent offsets. Sometimes distant parts of the radio structure are not properly detected due to a lack of shorter interferometer baselines. For our 5-GHz EVN and e-MERLIN experiment, we selected 10 bright radio-loud active galactic nuclei with extremely large radio-optical offsets. Sensitive imaging involving a wide range of projected baseline lengths, as well as phase-referencing to nearby sources shed light on the possible causes of positional inconsistencies. Here we present the first results of this project.

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Polarization flare of 3C 454.3 in millimeter wavelengths seen from decadal polarimetric monitoring data sets

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A blazar 3C 454.3 ($z = 0.859$) has been extensively investigated in multi-wavelength high-resolution polarization studies, showing polarization variations in milli-arcsecond (mas) scale. We aim to investigate polarimetric characteristics on the blazar 3C 454.3 at 22-129 GHz using decadal (2011-2022) data sets. In addition, we also aim to delve into the origin of the polarization flare in 2019. The corresponding data sets were obtained from the monitoring programs of the Korean VLBI Network (KVN) single-dish and of the 43-GHz Very Long Baseline Array (VLBA). Using those data, we compared the consistency of the measurements between scales at mas and arcsecond. We also estimated the Faraday rotation measure (RM) by fitting a linear function and computing it at each of the adjacent frequency pairs. Relations between polarimetric measurements indicate a preferred polarization angle when the source is highly polarized. By comparing scales between mas and arcsecond at 43 GHz, we find consistency in polarized emission (flux density and polarization angle), indicating negligible convolution effect on polarization angle by the extended jet of 3C 454.3. While the linear fit yields an order of RM $\sim 10^3$ rad m^{-2}, |RM| from each frequency pair tends to be larger at higher frequency pair, indicating varying RM as a function of frequency. We found an interesting, notable flaring event in polarized emission in 2019 at the frequency range of 22-129 GHz from the KVN single-dish data. During the flare, the observed polarization angles rotate from $\sim 150^\circ$ to $\sim 100^\circ$ at all frequencies with chromatic m_p. We suggest the polarization flare in 2019 is attributed to the shock-shock interaction in Region C based on the observed m_p and χ_obs, and also the Faraday rotation measure. Change in the viewing angle of the jet lacks in explaining the increased brightness temperature, indicating an additional particle acceleration in Region C.

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SMILE: a pilot study in search for milli-lenses to distinguish dark matter models

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Currently viable dark matter (DM) models, such as the standard cold dark matter (CDM) model and alternative models developed to address its shortcomings - including warm DM, fuzzy DM, and self-interacting DM - differ in their predictions for DM halos at critical sub-galactic scales. If sufficiently dense, these sub-galactic DM halos could form a population of supermassive

compact objects (SMCOs). SMCOs could potentially also consist of a population of free-floating (primordial) supermassive black holes (SMBHs), that are DM candidates.
The DM halos are nearly devoid of stars, and so any SMCO may possibly be detected only through the gravitational effect they exert on ordinary matter. The SMILE (Search for MIlli LEnses) project aims at probing the number density of low mass ($\sim 10^6 - 10^9\,M_\odot$) DM halos searching for gravitational lens systems at milliarcsecond scales (milli-lenses), where the lens is expected to have a mass in the range of interest.
This is achieved by studying radio images of active galactic nuclei made with Very-Long-Baseline Interferometry (VLBI). In a recent pilot project, we have searched for milli-lens candidates in a sample consisting of 13,828 compact radio sources from the Astrogeo VLBI FITS image database. Forty candidates with compact double structures have been found using a citizen-science approach, for which I will present the final analysis of follow-up observations with the European VLBI Network at 5 and 22 GHz in phase-referencing mode. These observations with increased sensitivity and frequency coverage allow us to better constrain the nature of the lens candidates. We can confidently reject most systems as milli-lenses, given constrains such as surface brightness ratio, stability of flux density ratio of components over time, and their spectrum. Rejected candidates are still interesting as potential compact symmetric object (CSO) or even supermassive black hole binary (SMBHB) candidates. I will put the pilot study in the context of the SMILE project, which ultimately aims at using a sample of ˜5,000 sources with redshift information to test predictions from theoretical DM models about the number of expected milli-lenses.

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Position determination and imaging of bright radio stars by EVN observations using phase-referencing

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Abstract: The VLBI and GAIA observations are on the way to improve the accuracy of celestial reference frame (CRF). Accurate astrometric models of radio stars provide important means to evaluate the consistency between the optical and radio CRFs. This research aims to determine and evaluate the astrometric parameters for the radio stars that have not yet had these parameters determined at radio wavelengths. We proposed 5-epoch EVN phase-referencing observations (across one year) for 16 such radio stars at 8 GHz, and they have been carried out successfully. In data calibration, we employ the standard procedure of phase-referencing technique to ensure the highest accuracy in position determination using AIPS, which is validated with the model fitting using Difmap. We will report about the imaging results and the positions of the radio stars from the first epoch of our EVN observations as well as the comparison with the historical data. A data calibration/processing pipeline will be developed based on this first epoch of observations and used for the remaining four epochs, from which the astrometric models can be estimated.

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The KVN-Mopra VLBI Network: System Performance, Early Results, and Recent Updates

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Global VLBI observations with baseline lengths of ˜10,000km allow detailed imaging at sub-milliarcsecond resolution at the expense of reduced observation cadence. Given the typical variability of blazars, investigation of flaring AGNs benefits from high cadence and long-term

monitoring of targets of interest. Observations with a VLBI array consisting of a smaller number of antennas allow the high-cadence observations necessary to probe the high angular resolution and high cadence variability characteristics of AGN radio cores (i.e., compact and bright emission regions in radio VLBI images). With such a goal, we have started joint VLBI observations between the KVN and a radio telescope, Mopra, located in Australia. Through commissioning and early science observations, we have successfully observed at all three common frequency bands of 22, 43, and 86 GHz, including the application of linear-to-circular polarization conversion at 43 and 86 GHz. The VLBI beam minor axis is found to be 0.2/0.1/0.05 mas at 22/43/86 GHz respectively due to the KVN-Mopra baselines, while the major axis is comparable to the KVN-only beam (6/3/1.5 mas). Coherence times were found to be approximately 10 seconds at 86 GHz. However, the (up to) 16 Gbps observations provided by the OCTAD backend and Mark6 recorder allowed the detection of fringes on the KVN-Mopra baselines for a number of sources at 86 GHz with flux densities down to 0.2˜0.3 Jy. With careful calibration and imaging, we are able to produce high-resolution CLEAN images, with residual calibration errors of ˜4% in amplitude and ˜3 degrees in phase at 22 GHz. We also find that direct model fitting to the measured visibilities and closure quantities of the data (e.g., constraining the flux density, size, and position of 2-D Gaussian model-fitted jet components) allows us to reconstruct the sub-mas source structure in the vicinity of the radio cores. Based on our initial success, we have expand our observations to relative astrometry observations with the East Asian VLBI Network + Mopra, and regular joint observations between the KVN, Mopra, and the Hartebeesthoek 26m radio telescope in South Africa.

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Interferometric Monitoring of a Potential Neutrino-Emitting Blazar PKS 0735+178: a Connection between Neutrino Events and Radio Flares?

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A blazar PKS 0735+178 is a potential candidate for emitting high-energy neutrinos through a relativistic jet. Neutrino observatories (e.g., IceCube, Baikal-GVD, etc.) detected neutrino events with energies ranging from GeV to TeV, from the direction of the source in 2021 December. However, the nature of the neutrinos still needs to be clearly understood. Interestingly, multi-wavelength flares have been reported in PKS 0735+178 at the time of neutrino events. Very long baseline interferometry (VLBI) observations enable us to track temporal radio variability from the innermost region of the blazar jet, which offers a critical opportunity for connecting the changes to the broad-band emission properties of the source and further localizing the emission region associated with neutrinos. We conducted observations of the source with the Korean VLBI Network (KVN) at 22, 43, 86, and 129 GHz simultaneously over a period in a time range from 2021 December to 2023 November. We used imaging and model-fitting techniques to analyze the KVN data and thus parameterized the milliarcsecond-scale source structure and its variation. We found a continuous increase in the flux density (e.g., from 0.8 to 1.3 Jy at 22 GHz) across all the KVN frequencies, confirming the consistent results from single-dish monitoring of the source. Utilizing simultaneous 22-129 GHz flux density measurements, we present the preliminary results of the spectral properties of the source such as spectral indices, synchrotron self-absorption features, etc.

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Intercontinental decametric VLBI

WUCKNITZ, Olaf[None]

Between December 2023 and April 2024 we conducted a VLBI experiment with LOFAR, NenuFAR, KAIRA and several stations of the LWA to try transatlantic interferometry below 100MHz. Targets were Jupiter (at times of expected decametric bursts) and three bright pulsars. First goal is

detecting fringes at all, which was not possible in a smaller experiment more than ten years ago. In the case of success, we can study the decametric emission from Jupiter at the finest scales. I will report on the progress, show preliminary results, and explain what can be done in the case of Jupiter, based on earlier European interferometry.

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Resolving extreme star formation and black hole activity in a high redshift quasar

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Understanding the feedback processes occurring in quasars and the nature of their faint radio emission is needed to reconcile known theories of galaxy formation and AGN evolution. In particular, it is not clear whether the faint radio emission from optically bright quasars is associated with weak jets, ongoing star-formation or another emission process occurring close to the black hole. To shed light on this area, for which there have been several recent statistical studies, I will present new detailed observations of an extremely luminous high redshift quasar that aims to resolve the underlying emission mechanism at radio wavelengths. The extreme radio luminosity of the gravitationally lensed quasar APM08279+5255, at redshift 3.911, results in a star-formation rate density that exceeds the Eddington-limited star-formation rate by a significant fraction. By using very long baseline interferometry (VLBI), we dissect the relationship between star formation and accretion processes driving the quasar activity. First, we present high angular resolution observations (50 to 100 mas) of this AGN with the VLA at 22 GHz and with e-MERLIN at 1.5 and 5 GHz. With these data, we find evidence for a flat-spectrum radio component associated with the optically bright quasar, but also evidence for offset steep spectrum emission. Next, using observations with the European VLBI Network (EVN) at 1.7 GHz, we detect a compact radio core that is co-located with the quasar, whose brightness temperature is consistent with AGN activity. However, a significant amount of radio emission is resolved-out on VLBI-scales, which suggests there is an extended component that is likely associated with star-formation. Finally, to understand the fuelling of such an AGN-starburst composite, we present the deepest (VLA; 80 h) and highest angular resolution imaging (100 mas) of CO (1-0) for such an object, which detects the cold molecular gas around the AGN. Our results demonstrate that high angular resolution imaging of both the continuum and spectral emission from individual objects are needed to interpret the weak radio emission being found for the large fraction for quasars (>65%) observed in recent statistical studies.

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The EATING VLBI monitoring of the M87 jet

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We introduce high-cadence monitoring of the M87 jet using EATING VLBI, a joint facility between the East Asia VLBI Network (EAVN) and three Italian telescopes. Currently, EATING VLBI is the only array focusing on regular monitoring of the sub-mas-scale structure of the M87 jet. Here, we present the first images from this program, successfully detecting jet emissions up to $\sim$10 mas from the core with typical angular resolutions of $\sim$0.3 mas (naturally weighted) or $\sim$0.2 mas (uniformly weighted). In particular, images of joint observations with the Tidbinbilla-70m telescope effectively resolve the transverse jet structure by extending the N–S baseline. Using this intensive (3-week interval), high-resolution monitoring, we aim to investigate the connection between long-term position angle changes at horizon-scale and mas-scale, as well as the origin of the recently discovered small-scale fast transverse oscillations. Preliminary results of the ridgeline analysis are presented, along with plans for regular joint observations of EATING VLBI and Long Baseline Array (LBA).

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Herbig Ae/Be Signatures in the AUKR Spectra of V700 Mon and LP Ori

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Herbig Ae/Be stars are pre-main-sequence stars that exhibit distinctive visual emission features as well as infrared excess. Both provide valuable information about the physical conditions, kinematics, and composition of the circumstellar material surrounding the Herbig Ae/Be stars. The high-resolution (R $\sim$ 30 000) spectra of V700 Mon and LP Ori were obtained using the échelle spectrograph attached to the 0.8-m Prof. Dr. Berahitdin Albayrak telescope at the Ankara University Kreiken Observatory (AUKR), covering a wavelength interval from 4000 to 7600 Å. LP Ori was observed on February 25, 2023, and V700 Mon on January 23, 2024. We investigated the spectral emission signatures arising from the circumstellar material surrounding both of these young Herbig Ae/Be stars. In both spectra, emission in the core of the Balmer profiles as well as in the neutral helium line at λ5875 are visible. The other indication, which is emission in the He I line at 6678 Å, is only present for LP Ori. Furthermore, the spectral energy distribution of V700 Mon was constructed to derive its extinction factor and to confirm the infrared excess caused by its circumstellar disk. Finally, both Herbig Ae/Be stars are placed on the H-R diagram to estimate their mass and age.

Poster Session / 11

Influence of Galactic Magnetic Field on Black Hole Magnetospheres and Jet Phenomena

Dr. TURSUNOV, Arman[1]

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Magnetic fields surrounding black holes are responsible for a variety of astrophysical phenomena related to accretion processes and relativistic jets. Depending on the source, the strength and configuration of the field lines may differ significantly, which can, in turn, affect the trajectories of charged particles and the corresponding observables. Usually, the magnetic fields around black holes are modeled within a single source or current generating the field. However, magnetic field can have more than a single origin, being a combination of different fields, such as, e.g., that of an accretion disk and external large-scale or galactic ones. Here I will present a new solution to black hole magnetospheres taking into account an ambient magnetic field. I will show that, depending on the relative orientation of internal (accretion-induced) and external (galactic) fields, the model can potentially help distinguish between radio-loud and radio-quiet AGNs.

Poster Session / 15

Automated VLBI data reduction with rPICARD

Prof. JANSSEN, Michael[1]

[1] *Radboud University*

With my poster, I will show how to use the CASA/rPICARD pipeline (https://bitbucket.org/M_Janssen/picard) for the calibration of VLBI data. The purpose is to introduce new and interested VLBI users to the automated reduction of VLBI data. I will also present advantages over traditional calibration methods and current rPICARD use cases. Specifically, I will show how to work with publicly available raw EHT data.

Poster Session / 17

High-resolution radio observations of TeV candidate sources

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Radio-loud AGNs with their jets pointed close to our line of sight constitute the majority of extragalactic gamma-ray sources and significantly contribute to the radiation observed in the even higher energy regime. The upcoming Cherenkov Telescope Array (CTA) is expected to detect fainter TeV objects, leading to an anticipated increase in the proportion of non-blazar extragalactic high-energy sources. Balmaverde et al. (2020) compiled a list of radio and X-ray-detected objects that are good TeV-emitting candidates (Te-REXes). Here we present the results of our dual-frequency (1.6 and 4.8 GHz) EVN observations of two faint radio sources (J1519+2053 and J1832+5202) from this list. They do not show signs of nuclear activity in their optical spectra, but they were hypothesized to contain faint AGN that is outshone by the host galaxy. We used the mas-scale resolution radio data to pinpoint the location of the compact radio emitting feature, determine its radio power and brightness temperature, and thus identify the origin of the radio emission. We found that both optically passive-looking galaxies host faint radio-emitting AGNs.

Poster Session / 19

A new Python tool for inspection of GMVA metadata

Dr. KIM, Daewon[1]

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GMVA observations are accompanied by a lot of metadata (e.g., so-called ANTAB files) which include system temperature (Tsys), antenna gain, and weather information (WX) for each of all those participated GMVA stations. They are required for amplitude calibration of GMVA data which is an essential part in the data calibration. Unfortunately, Tsys measurements almost always have some erroneous values or technical problems: for instance, the typical 999.0 values in VLBA ANTABs. This can lead to incorrect results in the amplitude calibration and thus need to be corrected with proper inspection/treatment. However, most of the GMVA stations have their own data format in ANTAB files and this makes the situation tricky and time consuming. Plus, in some parts (i.e., gain Info. and indexing Tsys columns), user input may required depending on the ANTAB format and strategy of the calibration. To remedy all these issues, we have developed a new Python program. With this program, one can perform extraction/inspection/visualization/correction of Tsys data and finally generate one single ANTAB

file that contains the data of all the stations. Using the program, WX data can also be merged into a single WX file. This program is expected to be very useful for future GMVA users. In this talk, we intend to introduce and advertise this new tool to the VLBI community.

Poster Session / 18

VLBI monitoring of the structure of the ICRF sources – The Bordeaux VLBI Image Database

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The extragalactic radio sources that make up the International Celestial Reference Frame (ICRF) can exhibit extended and time-variable brightness distributions (or structures) on VLBI scales, setting limits on the accuracy of the astrometric source positions determined from the VLBI measurements. For this reason, the International VLBI Service for Geodesy and Astrometry (IVS) has organized regular VLBI observations, the so-called "Research & Development with the VLBA" (RDV) sessions, for more than two decades to monitor these structures. The RDV sessions are conducted six times a year using a network of 14 to 20 radio telescopes (including the VLBA plus several IVS antennas) for a duration of 24 hours at S/X band (2/8 GHz). We carry out systematic imaging of the sources observed in these sessions with the goal of tracking the structural evolution of the ICRF sources on the long-term. The VLBI images produced along with metrics that characterize the source structure (compactness, structure index, flux density) are made available to the scientific community via the *Bordeaux VLBI Image Database* (BVID). Occasionally, other sessions, either at higher radio frequencies, i.e. K band (24 GHz) and Q band (43 GHz), or from other observing programs, are also used for imaging, the results of which are made available to the community similarly through the BVID. At present, the database includes more than 8000 VLBI images for more than 1500 sources, with up to 50+ epochs per source. The available data may be used for astrometric and astrophysical research, like selecting the defining sources for the ICRF, modeling source structure in astrometric and geodetic VLBI, and studying the nature and evolution of the sources. The BVID is accessible at the following url: https://bvid.astrophy.u-bordeaux.fr.

Poster Session / 48

Probe the parsec-scale radio emission in 5 nearby radio-quiet Seyferts with EVN

Dr. CHANG, Ning[1]

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The origin of radio emission in radio-quiet (RQ) active galactic nuclei (AGN) has always been controversial. VLBI observation is crucial for studying the inner radio properties of RQ AGNs. We use the EVN to observe five nearby RQ Seyfert galaxies at 1.7 GHz and 5 GHz. These targets were selected from the Swift/BAT AGNs, with selection criteria of compact single-component structures and peak flux densities exceeding 10 mJy/beam in VLASS images. Observations are currently underway, and data have not yet been obtained. We will introduce the research methods and expected results. Through the observations, we will obtain the morphology, spectral indices, and other quantitative parameters to determine whether the radio emission is dominated by jets. Combined with the arcsecond-scale flux and other available physical parameters of these Seyferts, we also plan to re-examine the possible empirical correlation between parsec-scale radio emission and black hole activity, aiming for a clearer understanding of the radio properties of these target sources.

Poster Session / 40

Probing the polarized innermost structure of the relativistic jet of 4C +01.28

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The formation of relativistic jets from active galactic nuclei remains a subject of intense debate. Despite significant advances in understanding the underlying mechanisms, numerous questions remain. To address them, high-angular-resolution observations performed with the very long baseline interferometry (VLBI) technique are needed. In this context, we present preliminary results on 4C +01.28 (B1055+018), a blazar that shows a relevant correlation between emission at radio and gamma-ray wavelengths, and whose previous VLBI observations highlight the presence of a remarkable jet stratification. The latter consists of an inner spine with a transverse magnetic field and a distinct boundary layer - the sheath - with a longitudinal magnetic field. Exploring the properties of this unique jet stratification, alongside the jet magnetization on sub-parsec and parsec scales, is key to unlocking the secrets of the jet launching mechanisms in such a source. Thanks to the synergy between VLBI maps at various frequencies, including new 86 GHz GMVA and 230 GHz EHT observations, and relativistic MHD numerical simulations, 4C +01.28 offers an excellent opportunity for testing state-of-the-art models of jet formation.

Poster Session / 41

The M2FINDERS project: Mapping Magnetic Fields with INterferometry Down to Event hoRizon Scales

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Active galactic nuclei (AGN) are the most extreme sources of power in the Universe, outshining their entire host galaxies. The Event Horizon Telescope collaboration has successfully imaged supermassive black holes in M87 and SgrA* at event horizon scales, confirming theoretical predictions from general relativity. However, to determine the physical properties of these black holes, precise information about the magnetic field near the event horizon is crucial. The M2FINDERS project aims to address this challenge by mapping magnetic fields at distances smaller than a thousand gravitational radii. We will approach the problem using multi-frequency polarimetric VLBI imaging, opacity measurements, and novel image analysis and relativistic flow modelling techniques. Our plan is to place strong constraints on the magnetic field near the event horizon, providing evidence for the existence of black holes and their event horizons. Here we present progress on data analysis and interpretation.

Poster Session / 140

Scintillation of PSR B1133+16 Revealed by EVN

Ms. STOCK, Ashley[1]

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Pulsars are routinely observed to vary in brightness on timescales of a few minutes due to variations in electron density in the interstellar medium (ISM) on angular scales of several

microarcseconds–a process known as scintillation. The only way to unambiguously measure the geometric properties of the ISM structures causing scintillation is with VLBI. However, few VLBI scintillation studies have been conducted to date. I will present work on the scintillation of PSR B1133+16 as seen by the EVN. This pulsar probes a particularly interesting line of sight of the ISM as at least five distinct structures significantly contribute to the scintillation of this pulsar, with three of the structures previously shown to overlap in distance. Measuring these structures in detail may give insight into the ISM environments that are highly favourable to scintillation. Additionally, scintillation has impacts on pulsar astrometry and timing array science from the scatter broadening of pulses. These impacts can be mitigated through careful characterizing of the ISM structure.

Poster Session / 76

Benefits of VLBI observations to Next-Generation GNSS satellites

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This study explores the benefits of placing a Very Long Baseline Interferometry (VLBI) transmitter onboard a next-generation Global Navigation Satellite Systems (GNSS) satellite. Classical VLBI to extra-galactic radio sources is the only space geodetic technique that can determine all five Earth Orientation parameters (EOPs) in an absolute sense, including UT1-UTC and Celestial Intermediate Poles (CIPs), which are needed by other satellite techniques and interplanetary spacecraft as a priori information. However, classical VLBI is not sensitive to the Earth's origin, namely the geocenter; therefore, No Net Translation (NNT) conditions must be imposed in addition to No Net Rotation (NNR) conditions. Adding satellite observations could help resolve this issue by providing access to the geocenter. In the current study, we simulate a VLBI network with 20 legacy and future stations to observe a VLBI transmitter on a single Galileo-like satellite along with extra-galactic radio sources simultaneously, spanning a time period of one year. Dynamic Precise Orbit Determination (POD) to the satellite is performed, and orbital parameters are estimated along with geodetic parameters such as station positions, the complete set of EOPs, and geocenter coordinates, and we discuss the performance of all estimated parameters. Furthermore, an optimal ratio of satellite and source observations should provide adequate geocenter information without exacerbating the geodetic parameters primarily estimated by classical VLBI. We found an optimal ratio of satellite observations of approximately 30% of the total observations.

Poster Session / 74

VLBI detections of nearby (<100 pc) young stars

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I will present a new project aiming to increase the number of sources with Very Long Baseline Interferometry (VLBI) astrometry available for comparison with the Gaia results. Using the Very Long Baseline Array, we have observed 31 stars with recently reported radio emission, located <100 pc from the Sun, and all are in the Gaia DR3 catalog. Our first observations yielded 10 detections (a 30% detection rate). Using the astrometric Gaia results, we have extrapolated the target positions to the epochs of our radio observations and compared them with the position of the radio sources. I will discuss the results of this analysis and the importance of further Gaia - VLBI stellar astrometry comparisons.

Poster Session / 73

The nature of the radio host galaxy of the QPE source RXJ1301.9+2747

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Quasi-periodic eruptions are repeating burst of X-ray emission, that occur roughly periodically on time intervals of a few hours. Only 6 QPE source were so far detected. While the underlying mechanism for the observed X-ray emission is not fully understood, it is generally believed to be caused be the interaction between a star or stellar remnant with the accretion disk of a super massive black hole, potentially related to partial Tidal Disruption Events (pTDEs).
The some of the host galaxies of QPEs are detected in radio, and share that they are faint (few tenths of micro-Jansky). Here, we report on new HSA observations of the RXJ1301.9+2747 at 5GHz, which sheds light on the nature of the radio emission of the host galaxy.

Poster Session / 70

LAMBDA - the Low-frequency Australian Megametre Baseline Demonstrator Array.

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SKA-Low is being constructed in Western Australia and due to become operational in 2027. With a maximum baseline length of 65 Km SKA-Low will be unable to provide high resolution observations on its own, but will have a multi-beam tied array capability allowing it to participate as an element in conventional VLBI arrays. By this means the community will be able to pursue some of the high-sensitivity high-resolution science cases that have been described. Currently there is a dearth of low frequency telescopes in the Southern Hemisphere which can be leveraged to provide a VLBI array for co-observing with SKA-Low. To address this issue we have proposed LAMBDA - the Low-frequency Australian Megametre Baseline Demonstrator Array.
LAMBDA is planned to be a 5-6 station array disributed across Australia leveraging the existing site infrastructure of the cm-wavelength Long Baseline Array. Individual stations will comprise: - 256 dual-polarization dipoles providing comparable sensitivity to a single SKA station. - a bespoke CSIRO-designed backend design which aims to leverage a low-cost, largely COTS, system with great flexibility for multi-beam single station processing (e.g. RFI mitigation, transient searching, pulsar timing, SETI searches, all-sky monitoring) - power and timing leveraged from existing LBA infrastructure - data transport and correlation leveraging existing LBA infrastructure
In this talk I will describe the LAMBDA system, outline the planned roll-out and briefly describe some of the science cases driving this development.

Poster Session / 79

ACor: Automated Observation Scheduling and Data Management

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The Automatic Correlation System (ACor) is a web-based platform designed to enhance observation planning, data storage, and processing. It automates scheduling for both single-dish and interferometric modes using the VIRAC radiotelescope complex in Irbene, Latvia, which includes the RT-32, RT-16, and LOFAR radiotelescopes. Key requirements for ACor include open access, web-based functionality, and organizing observation schedules involving researchers, radiotelescope operators, and data processing specialists. This system integrates observational data into a structured database, streamlining data management and analysis workflows. If observation results are unsuccessful, the system automatically plans for rescheduling to optimize data collection efforts. By automating various tasks, ACor significantly boosts efficiency for researchers, radiotelescope operators, and data processing specialists in their daily work.
The ACor system has been developed by the "A single-baseline radio interferometer in a new age of transient astrophysics" (No.lzp-2022/1-0083), with a particular emphasis on advancing automated data processing technologies. The comprehensive functionality of the ACor system, including its capabilities in observation planning, data storage, and analysis, will be thoroughly described in the upcoming presentation. This presentation will cover how the system integrates with the Irbene radiotelescope complex, automates observation scheduling, and enhances data management, ensuring an optimized and efficient approach to observational data collection and processing.

Poster Session / 78

VIRAC automated Single baseline interferometre data processing

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Single baseline interferometre at VIRAC uses SFXC correlator. This work automated using The Automatic Correlation System (ACor) system. This system is web-based platform which one of the tasks is to automate the correlation and data processing.
The ACor system allows two types of observations to be processed: 1) Data processing with single scan correlation - to experiment with correlation parameters. 2) Data processing with multi scan correlation - to run line or continuum or both pass correlation. This correlation run selected pass for all scans. Multi scan correlation use these correlation parameters: 1) 2 s integration time is used, 2) In the continuum pass, all channels is correlated with 128 FFT points, 3) In the line-only channel containing the maser signal is correlated with 4096 FFT points. These parameters are sufficient for 8 MHz bandwidths. For multi scan correlation automatic clock search is executed. This is done, by parsing the key file and finding fringe source. After that it is checked if scan which is fringe finder scan, has raw data file. If none of the fringe finder scans have raw data files, clock search is not done. Clock search is done with 1024 FFT points, 2 s integration time and for all channels. This process is done in 5 iterations after the first iteration fringe mean offset value is found. If standard deviation of fringe offset for all channels is larger than 2, clock search is stopped. In the next four iterations, the fringe mean offset is subtracted and added to RT-32 GPS offset and RT-16 GPS offset values. After all iteration from all four gps offset changes, the version where the mean of fringe offset is lower is chosen. If multi scan correlation with both passes are done automatic data processing is done with ParselToung Pipeline. After the correlation MS and FITS files are created, diagnostic plots also is created. To users of system diagnostic plots and ParselToung Pipeline outputs is displayed.
Single baseline interferometre at VIRAC uses standardised processing of astronomical data, with the use of an automated data reduction pipeline written in ParselTongue which is a Python interface to the Astronomical Image Processing Software - AIPS.
The ParselTongue pipeline works as follows. The line and continuum data sets are first loaded. Beginning with the continuum data, corrections for the losses during digital sampling are applied. Then a-priori gain calibration tables (system temperature and gain curve) derived from noise diode temperature measurements conducted during observations are used to calibrate the flux

density of visibilities. Bandpass corrections for all targets are made based on the observed bandpass shapes of all continuum calibrators. Then, three stages of fringe fitting and integrations are performed. Starting with a 'manual phase-cal' stage, the phase difference between the RCP and LCP data are corrected, and any phase delay difference between the baseband channels is corrected allowing the channels and both polarisations to be integrated to improve signal to noise. The group delay is then determined on continuum sources by fringe fitting on the partially integrated data at a solution interval of about 20 minutes in order to trace the slowly drifting delay differences and slowly changing phase residuals imparted by the ionosphere. Solutions are applied to all targets in the experiment. Finally the continuum sources are then fringe fitted again and in so dealing with the individual baseband channels individually to obtain channels specific solutions. It should be noted that all fringe fitting stages up to this point are instructed to discard phase rate solutions. At this point, the solutions for the continuum data baseband channel which matches in frequency to the line data set is copied to the line data, thus providing gain, delay and slowly changing phase solutions which can be interpolated to the timeranges of the maser target data. The peak channel of maser emission for each source is then determined and used as the input of a fringe fitting stage which determines the phase and rate fluctuations of the atmosphere with 20 second solution intervals. Phase and rate solutions are concatenated into a single solution table and copied back to the continuum data set, thus enabling long integrations capable of detecting the continuum emission associated with maser targets. A final fringe fitting stage is conducted on the continuum data of all targets as an inspection step as the success or failure at this stage indicates the overall detectability of continuum emission in all sources, both quasars and high-mass protostars. Finally the spectra and visibility plots of all sources are output and the integrated radio continuum flux densities of all sources determined.
This work has been done in "A single-baseline radio interferometer in a new age of transient astrophysics" (No.lzp-2022/1-0083), which focuses on advancing automated data processing technologies.

Session I: Cosmology and Dark matter – Chair: John McKean / 117

Latest constraints on dark matter from strong gravitational lensing VLBI observations

Dr. VEGETTI, Simona[1]

[1] *MPA*

The Cold Dark Matter (CDM) model for structure formation is currently the most successful at reproducing many observations, but it remains largely untested in the non-linear sub-galactic regime. A clear prediction of this model is that a significant number of low-mass haloes should populate any galaxy and its line of sight. As most of these objects are expected to be completely dark, strong gravitational lensing provides a unique channel to detect them and determine the properties of dark matter by constraining the halo-mass function at the low-mass end.
The sensitivity of strong lensing observations to the presence of low-mass haloes strongly depends on the angular resolution of the data. At present, only VLBI observations at cm-wavelength provide us with the milli-arcseconds resolution needed to probe the halo mass function in the regime of 106 Msun, where predictions from different dark models differ the most. In this talk, I will discuss the latest constraints on FDM and CDM from existing VLBI observations. In particular, I will present the first detection of a 106 Msun low-mass halo and discuss its implications for CDM and WDM models. I will then provide some insights into what we could expect from future observing facilities such as the SKA and the ngVLA.

Session I: Cosmology and Dark matter – Chair: John McKean / 16

Sub-haloes or scattering: Flux ratios anomalies of quadruply lensed radio AGN

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Anomalous flux ratios between lensed images can provide a key test of the dark matter sub-halo population, and hence the properties of dark matter particles. However, the observed anomalous flux ratios at radio frequencies can also be the result of systematics associated with our lack of knowledge about the source structure, source variability, and propagation effects within the lensing galaxy. Removing or ruling-out these systematic effects is crucial for confirming and improving existing constraints on dark matter. Here, I present some early results of high-resolution imaging with the High Sensitivity Array and monitoring with the Very Large Array at 15 GHz of a sample of 6 radio-loud lensed quasars. In some cases, the high resolution imaging shows evidence of extended source structure, which provides a more accurate determination of the image magnification's compared to when assuming a point source. From high cadence monitoring, we rule out any intrinsic source variability for the systems analyzed thus far. For one system with frequency-dependent flux ratios caused by scattering in the ionized medium within the lensing galaxy, we showcase our new method for jointly modeling lensing and scattering, which will be applied to our new multi-frequency global VLBI observations with the European VLBI Network and the Very Long Baseline Array.

Session I: Cosmology and Dark matter – Chair: John McKean / 43

VLBI study of a flaring blazar in the early Universe

BENKE, Petra[None]

Very-long-baseline interferometry (VLBI) observations enable us to study the parsec-scale structure of active galactic nuclei (AGN), and connect changes in the jet brightness distribution, morphology, and opacity to the multiwavelength variability exhibited by these sources. In this talk, I will discuss the connection between the radio and gamma-ray variability in the high-redshift blazar, TXS 1508+572 (z=4.31). The source exhibited a bright gamma-ray flare in February 2022, after which we initiated a multiwavelength follow-up campaign, including three epochs of multi-frequency VLBI observations. This is the first case of such a multiwavelength campaign, including VLBI, on a gamma-flaring AGN at z>4. Our data provided a comprehensive insight into the nature of the flare, and the VLBI observations revealed possible sites for the gamma-ray production. We found that the jet component was not ejected during the 2022 flare, and we conclude that an interaction between a standing and a traveling shock can be the reason for the gamma-ray flare. The spectral energy distribution constructed from the multiwavelength data can be described with a single-zone leptonic model, and the fit parameters are in good agreement with the ones derived from the radio data.

Session I: Cosmology and Dark matter – Chair: John McKean / 1

Angular-Size and Angular-Velocity Redshift Relations for Quasars and AGN

Dr. KELLERMANN, Keneth[1]

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The angular size − redshift relation for radio galaxies was first discussed by Fred Hoyle at the 1957 Paris Symposium on Radio Astronomy. Unlike for optical measurements of angular size, which are systematically influenced by the effects of redshift and sky brightness, radio measurements of component separations are true metric rods. However attempts to observationally test the predicted dependence of the angular size of extended radio galaxies has been limited by evolutionary effects including the systematic dependence of radio galaxy dimensions on redshift. The compact radio sources associated with quasars and AGN are, by contrast, young compared with the age of the Universe so are not systemically affected by cosmic evolution Moreover as quasars are located in the nuclei of galaxies, unlike the extended radio galaxies, they are unaffected by the intergalactic medium and its dependence on red shift.. I have examined the observed angular size and apparent angular velocity dependence on redshift for the complete MOJAVE 1.5 Jy quarter-century (QC) flux-density-limited sample. The data are consistent with models having H0 = 70 km/sec/Mpc, ΩM = 0.3, and ΩDE = 0.7, but the existing data are inadequate to place significant limits on cosmological models. With the enhanced sensitivity and resolution of the ngVLA it will be possible to extend these studies to higher redshift quasars where there is a greater distinction among different cosmologies.

Session II: Black hole and galaxy evolution – Chair: Paola Castangia / 23

Jet properties of FR0 radio galaxies

Dr. BALDI, Ranieri D.[1]

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Radio galaxies (RGs) are active galactic nuclei (AGN) able to launch relativistic jets, the most energetic phenomena in the Universe, which can have a large impact on galaxy evolution. Current high-sensitivity and high-resolution surveys have shed new light on properties of RGs, particularly in the local Universe (z<0.3) and at low luminosities (<10^24 W/Hz a 1.4 GHz), where the bulk of the AGN population was not much explored in opposition to the well-studied powerful RGs. A large population of compact RGs, named FR0s, which differ from classical FRI/IIs, by lacking large-scale (>10 kpc) jet emission, is emerging from recent studies and is revolutionising our idea of an ordinary RG. These sources show host and nuclear characteristics similar to those of FRI radio galaxies. However, in the radio band, while FR0 and FRI share the same nuclear properties, the kpc-scale diffuse component dominant in FRI is missing in FR0s. High-resolution and high-frequency radio observations of FR0s can probe the parsec-scale region to study their actual capability of launching jets with respect to FRIs. I will present new EVN+eMERLIN (5 GHz) and AMI (15 GHz) observations of a sample of FR0s, which delineate the jet physics of this large population of compact (but not young) RGs.

Session II: Black hole and galaxy evolution – Chair: Paola Castangia / 122

High-angular Resolution Galaxy Evolution Science in the SKA Era

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The physics that drives galaxy evolution operates on a large dynamic range of spatial scales and across a wide range of gas phases. The unique perspective enabled by high-resolution radio continuum, polarimetric, and spectral line observations offers important insights not possible in other parts of the electromagnetic spectrum. I will present several examples of this, where SKA precursors/pathfinders are delivering results that require a VLBI perspective to understand fully, ranging from AGN-driven HI outflows in nearby disk galaxies to the highest redshift hydroxyl megamasers known, deep extragalactic legacy fields and dual/binary supermassive black hole candidates. I will give an update on several VLBI programmes that provide a more complete picture of galaxy evolution physics, demonstrating the importance of the high resolution radio perspective in achieving the SKA galaxy evolution key science goals.

Session II: Black hole and galaxy evolution – Chair: Paola Castangia / 59

The GRACE project: High-energy giant radio galaxies and their duty cycle

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The advent of new generation radio telescopes is opening new possibilities on the classification and study of extragalactic high-energy sources, specially the underrepresented ones like radio galaxies. Among these, Giant Radio Galaxies (GRG, larger than 0.7 Mpc) are among the most extreme mani- festations of the accretion/ ejection processes on supermassive black holes. Our recent studies have shown that GRG can be up to four times more abundant in hard X-ray selected (i.e. from INTEGRAL/IBIS and Swift/BAT at >20 keV) samples and, most interestingly, the majority of them present signs of restarted radio activity. This makes them the ideal testbed to study the so far unknown duty cycle of jets in active galactic nuclei. Open questions in the field include: How and when jets are restarted? How jets evolve and what's their dynamic? What is the jet's duty cycle and what triggers them? Our group has recently collected a wealth of radio data on these high-energy selected GRGs, allowing us to study their jet formation and evolution from the pc to kpc scales, across different activity epochs. In particular, thanks to our EVN large programme, we were able to probe the new radio phase in the core of these giants. Furthermore, we are devoting an effort to the exploitation of new radio surveys data for the discovery of new classes of counterparts of Fermi/LAT and ANTARES catalogues. In particular, we are unveiling the hidden population of radio galaxies associated with gamma-ray sources, and possibly with neutrino events.

Session II: Black hole and galaxy evolution – Chair: Paola Castangia / 42

The Synoptic Wide-field EVN–eMERLIN commensal Pilot Survey (SWEEPS) - Overview and Results

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The high angular resolution and sensitivity of VLBI offers a unique tool to identify and study AGN and star-formation activity over cosmic time. VLBI observations are crucial for identifying young radio sources and unveiling older restarted radio sources. Also, radio imaging over a large range of angular scales is needed to determine the role of black hole feedback and jet-induced star formation in galaxies. To answer these questions and to find rare radio sources, such as gravitational lenses and binary/dual AGN, all-sky VLBI surveys are needed. Despite recent technical advances, such as multiple phase centre correlation and multi-source self-calibration, only a limited part of the sky has been observed within a few well-studied fields. To enter the realm of large statistical studies, a significantly larger area of sky must be observed, which would limit the VLBI available time for other single-target science projects.
SWEEPS (Synoptic Wide-field EVN–eMERLIN commensal Pilot Survey) is a pilot for a potential future commensal survey mode for the EVN+e-MERLIN, where single-target PI-led observations are re-correlated at the position of all known radio sources within 12 arcmin. Initially, the phase centres are selected using the LoTSS survey program of LOFAR, in the future however, additional phase centres will be provided by a wide-field image using the short baselines of e-MERLIN that will be generated on-the-fly the initial correlation. Full implementation of this program has the potential to observe up to ˜9000 radio sources per year, yielding an expected 1900 VLBI detections without any additional observing time. Here, we present results and methods from the pilot program, where we selected and processed 257 additional phase centres using a PI-led single target observation. In this study, we combined our high resolution data with LOFAR, FIRST and VLASS to characterise our detections. Along the way, we investigated imaging methods for the multiple angular-scales of e-MERLIN + EVN and have tested robust pipelines to accurately detect sources.

Session II: Black hole and galaxy evolution – Chair: Paola Castangia / 9

Searching for remnants among young radio sources

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The evolutionary stage of a powerful radio source originated by an AGN is thought to be related to its linear size. However, the fraction of young radio sources in flux density-limited samples is much larger than what is expected from the number counts of large radio sources, suggesting the existence of short-lived objects and/or intermittency of jet activity. Determining the incidence of young but fading radio sources is thus pivotal for improving our knowledge of the life-cycle of radio emission in radio-loud AGN. Despite its importance for constraining evolutionary models, there are no systematic studies of remnants in complete samples of young radio sources.
In this contribution we will present results on high-resolution multifrequency radio observations of candidate remnants selected from the B3-VLA CSS complete sample. These new observations allow us to constrain the integrated radio spectrum and unveil the presence, or not, of active regions. Then we will discuss the observational limitations in inferring the incidence of remnants among young radio sources and how forthcoming radio facilities will circumvent these issues.

Session III: Compact relativistic objects – Chair: Pikky Atri / 116

Multi-wavelength-messenger study of Gamma Ray Bursts

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Gamma Ray Bursts power highly collimated relativistic jets which shine throughout the electromagnetic spectrum from the radio to the TeV energy range. Short GRBs, produced by the merger of compact binaries hosting at least a neutron star, are key targets to exploit the multimessenger power of combining gravitational waves and electromagnetic observations. I will present the current knowledge of GRB jets with particular focus on what radio flux density monitoring and high resolution imaging can bring to the field and how the multi-messenger field may evolve towards the third generation of gravitational wave interferometers.

Session III: Compact relativistic objects – Chair: Pikky Atri / 2

Constraining the structure and the dynamics of Gamma-Ray Bursts with VLBI

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The very long baseline interferometry (VLBI) technique offers unique insights into the structure and dynamics of Gamma-Ray Bursts (GRBs). Specifically, VLBI serves as a fundamental tool for measuring the apparent superluminal expansion (if the GRB is seen on-axis) and proper motion (if the GRB is observed slightly off-axis) of the GRB outflow, enabling constraints on its geometry and characterisation of the circum-burst medium. This complementary information already proved to be crucial in alleviating, or even breaking, the degeneracy in the modelling. In this talk, I will focus on the results from two recent bursts, GRB201015A and GRB221009A. For the former, interferometric observations played a critical role in characterising the density profile of the circum-burst medium, while VLBI observations of GRB221009A, the brightest GRB ever recorded to date, enabled us to measure the size and the expansion of the outflow. Lastly, I will discuss future prospects of radio interferometry in GRB research.

Session III: Compact relativistic objects – Chair: Pikky Atri / 90

Unveiling the nature of thermonuclear runaway supernovae with radio observations

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Type Ia supernovae (SNe Ia) are thermonuclear explosions of degenerate white dwarf stars destabilized by mass accretion from a companion star. Despite SNe Ia having been used to unveil the accelerated expansion of the universe, the nature of their progenitors remains poorly understood. To distinguish between a degenerate and non-degenerate progenitor companion, one can use radio observations. A non-degenerate companion star is expected to lose material through winds or binary interaction before the explosion, and the supernova ejecta colliding with this circumstellar material should produce radio synchrotron emission. However, despite extensive efforts, including some of the deepest upper limits ever obtained by our team using e-MERLIN and the EVN, no type Ia supernova has been detected at radio wavelengths. This suggests a clean environment and a companion star that is itself a degenerate white dwarf.
Here we present the results of our study of SN 2020eyj, showing the first-ever radio detection of a SN Ia. SN 2020eyj exhibits helium-rich circumstellar material, as demonstrated by its spectral features, infrared emission, and a radio counterpart detected with e-MERLIN. Based on our modeling, we conclude that the circumstellar material probably originates from a single-degenerate binary system in which a white dwarf accretes material from a helium donor star. We will briefly discuss this detection in the context of the previous radio upper limits and their implications, and describe in detail how we achieved this remarkable result. We will also discuss how a comprehensive radio follow-up of SN 2020eyj-like SNe Ia can improve the constraints on their progenitor systems.

Session III: Compact relativistic objects – Chair: Pikky Atri / 5

A Close-Up Look Into Explosive Transients

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High-resolution imaging of explosive transient systems, such as supernovae and gamma-ray bursts, enabled by VLBI offers a valuable and complementary perspective for studying these systems. By resolving the system down to milli-arcsec level, VLBI studies of these transients shed important insights into both intrinsic and extrinsic properties of the system. Measurements of source size expansion, proper motion, and resolved morphology can reveal important details about the geometry of the emitting region, which in turn can help constrain the physical properties of the system such as the energetics, magnetic field, and ejecta/shock velocities. In milli-lensed transient systems, they can even provide a unique opportunity to resolve the lensed images of the system, an important element for performing time-delay cosmography. In this poster, I will show a few examples of gamma-ray bursts and supernovae which our team have conducted EVN and VLBA observations for and demonstrate the important insights we have gained from them. I will also demonstrate the important need for improved real-time correlation capabilities, showing an example VLBI campaign where outcomes could be greatly improved with better real-time correlation capabilities.

Session IV: IMBH and ULX – Chair: (tbd) / 45

VLBI views on ultra-luminous X-ray sources and accreting intermediate-mass black holes

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Ultra-luminous X-ray sources (ULXs) are likely powered by stellar-mass objects in the super Eddington accretion phase. In some extreme cases, ULXs might originate from accreting massive or intermediate-mass black holes (ULXs)). IMBHs are usually located in the nuclear regions of low-mass and low-luminosity dwarf galaxies. Because of accretion activity, ULXs and IMBHs have been well revealed by optical and X-ray surveys in nearby galaxies. They might also have detectable radio counterparts due to ejection activity. In the talk, I will show some recent results of VLBI research on these relatively faint radio sources. With high-resolution radio observations, we do see strong hints for scaled-down episodic outflow and jet activity (e.g. in ULXs)). Moreover, ULXs) show that ULX jets might propagate through narrow X-ray funnels.

Session IX: Neutrino astrophysics – Chair: Matthias Kadler (tbc) / 102

Probes of Jet Physics in Neutrino-Candidate Blazars with cm- and mm-VLBI

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In recent years, evidence has accumulated that some high-energy cosmic neutrinos may be associated with blazars. The strongest evidence for an individual association was found in the case of the blazar TXS 0506+056 which exhibited a major multi-wavelength flare coinciding with an IceCube neutrino event in 2017. A major open question is the production site of neutrinos in blazar jets, especially the possible seed photon fields needed for the hadronic processes are not well constrained. VLBI observations can constrain the jet geometry, magnetic field and

Doppler factor in AGN jets to gain insight into the possible neutrino production regions. We have performed a multi-frequency VLBI study from 15 GHz up to 86 GHz on TXS 0506+056 and two additional neutrino-candidate blazars (PKS 0215+015, PKS1502+106) to study the radio structure of neutrino-candidate blazars. We have obtained target of opportunity observations with the VLBA for all three sources within ˜1 month from the associated neutrino event and are performing multi-epoch studies on the jet kinematics at 15 GHz as part of the MOJAVE program. Here, we present first results on the contemporary parsec-scale jet morphology of all three sources in total intensity and polarization to constrain possible physical processes leading to neutrino emission in blazars.

Session IX: Neutrino astrophysics – Chair: Matthias Kadler (tbc) / 101

Constraining sub-structures in TeV-emitting gamma-ray blazars with the GMVA

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Blazars are found to cover a broad range in luminosity and the lowest-luminosity objects turn out to be the ones whose spectral energy distribution extends to the highest energies. In the most extreme blazars their spectral energy distribution can peak at very high gamma-ray energies above 10 TeV. These extremely high peaked BL Lac objects typically are faint radio sources and thus make up a poorly studied source sample, especially at high radio frequencies. Due to their relatively low redshifts, VLBI observations of such sources can achieve very high linear resolution, which makes it possible to constrain limb brightened and/or spine-sheath structures on the smallest accessible scales with the Global Millimetre VLBI Array (GMVA) at 3mm. The GMVA imaging capabilities are of particular importance as such jet sub-structures might explain the origin of the seed photons for high-energy processes. Here, we present first results of the (sub-)parsec-scale jet morphology in a sample of GMVA observed extreme blazars.

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Blazars as the Multi-messenger Lighthouses of the Universe

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The discovery of extreme brightness in blazars, made with space VLBI observations, has set new limits on the very high rates of energy release in plasma and a very efficient particle acceleration. The mounting observational indications for extragalactic neutrino production in blazar-type AGN now begin to deliver key understanding about the physics of proton acceleration in blazars, either nearby central supermassive black holes or in plasma shocks embedded in the relativistic jets. In this talk we show that complete samples of VLBI-compact extragalactic objects effectively

select neutrino-emitting blazars. Using results of the MOJAVE program, we find jets of neutrino candidates to have preferentially higher Doppler boosting and lower viewing angles. Continuing blazar monitoring within the MOJAVE program supplemented by neutrino-triggered observing campaigns and the expected advent of a true era of multi-messenger astronomy provide solid grounds for a breakthrough in our understanding of active galaxies as extreme cosmic accelerators and efficient neutrino factories.

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Neutrino Astrophysics

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Neutrinos are a unique and complementary messenger to probe the high-energy universe. I will introduce the currently operating neutrino telescopes, and review what we have learned about the spectrum, flavor composition and sources of astrophysical neutrinos since their discovery in 2013. I will also give a glimpse into the future of the field and the scientific potential of new instrumentation envisoned for construction in the next decade.

Session V: GW astrophysics and Gas kinematics – Chair: Sandor Frey / 120

Binary black holes across cosmic time

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The number of gravitational-wave detections approaches the 100 mark and starts revealing the big picture of binary black hole populations. Several detected black holes have mass in the lower (2-5 Msun) or upper (˜60-120 Msun) mass gap, challenging models of stellar and binary evolution. Furthermore, evidence for unequal-mass systems and non-negligible spin misalignment advocate for unconventional scenarios of binary black hole formation. We recently proposed that the mass function of the LIGO-Virgo black holes evolves with redshift. This result, if confirmed, favors scenarios in which the properties of black hole progenitors and their birth environment change across cosmic time. One key aspect is the metallicity of the progenitor star: a metal-poor environment enhances the formation of massive black holes (>20 Msun) and boosts their merger rate via stable mass transfer. Moreover, formation in a globular cluster environment leads to a great variety of unconventional features in binary black holes: hierarchical mergers favor the formation of oversize black holes and close gravitational encounters randomize their spin orientations. Next-generation gravitational-wave detectors will mark a turning point to interpret the formation of binary black holes, by observing their mergers at cosmic dawn.

Session V: GW astrophysics and Gas kinematics – Chair: Sandor Frey / 84

New insights on supernova remnants and HII regions in M82

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The nearby supernova factory M82 has been intensely studied by e-MERLIN and other radio interferometers over the last 4 decades. The high optical absorption in M82 has prevented study of the supernovae, HII regions and exotic transient objects in this galaxy in optical bands. However, the increased sensitivity from e-MERLIN and the EVN has provided new data and enabled the study of more sources.
In this oral contribution, we give an update on the current efforts to monitor this source, including re-analysis of 2014 e-MERLIN data to provide resolved spectral index maps using new widefield imaging techniques, the renewed search for transient sources further afield at the edges of the optical extent of the galaxy, and, provide the results of the latest tranche of e-MERLIN and EVN monitoring efforts in recent years.

Session V: GW astrophysics and Gas kinematics – Chair: Sandor Frey / 77

Cold gas in the nuclear region of radio AGN

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The interplay between the nuclear activity and the interstellar medium (ISM) of galaxies plays an important role in their evolution: the gas accreting onto the dormant supermassive black hole turns it into an active galactic nucleus (AGN) and the ensuing activity is believed to starve the host galaxy of the fuel needed to form stars. The contribution of radio-loud AGN to this feedback effect is yet to be well understood. In order to understand the impact of radio AGN, we need to study the jet-ISM interaction in detail at high spatial resolution and also cover a wide range of parameters such as age/morphology, radio power. I will present the recent results from sub-kpc scale studies of cold gas in the very central regions of radio galaxies. I will also detail how such studies, in combination with theoretical modelling, provide new insights into the morphology, kinematics and physical condition of gas directly impacted by the radio jets. This is a step forward in quantifying the impact of radio jets on the ambient ISM and thereby the evolution of their host galaxies.

Session VI: Radio quiet AGN – Chair: Anne-Katrin Baczko / 135

A multiscale and multi-frequency radio study of local U/LIRGs

Session VI: Radio quiet AGN – Chair: Anne-Katrin Baczko / 27

High Resolution VLBI Imaging of Nearby Low Luminosity AGN jets

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Low-luminosity Active Galactic Nuclei (LLAGN) represent a unique class of AGN in the local universe. Extensive studies on them are essential for a comprehensive understanding of jet physics, as past research has been biased towards powerful radio sources. In this talk, we will present our recent VLBI studies of two prominent nearby LLAGN, NGC 4261 and M104 (the Sombrero galaxy). The presentation will address the kinematics, collimation, and fundamental

physical parameters of the jets, as well as the potential origin of the radio emission at millimeter wavelengths.

Session VI: Radio quiet AGN – Chair: Anne-Katrin Baczko / 58

A multiscale and multi-frequency radio study of local U/LIRGs.

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The study of star formation activity (SF), active-galactic-nuclei (AGN) and their relation with feedback and accretion mechanisms plays a fundamental role to understand how galaxies evolves. Local Luminous and Ultra-Luminous Infrared Galaxies (U/LIRGs) serves as a key point to facilitate such studies. Radio observations can be made with high-angular resolution, are unaffected by dust, allowing to resolve their nuclear regions with great detail. This is essential for the inference of physical properties of distant U/LIRGs in later studies, where angular resolution is limited. As part of the e-MERLIN Legacy Project & Collaboration (LIRGI), this work has as objectives to stablish resolved calibrated star formation (SF) rates for local ($z < 0.1$) U/LIRGs. We focus on the relevance of disentangling the SF emission from AGN emission in a multi-frequency and multiscale approach, sampling regions from a few parsecs to several kilo-parsecs.
With recent published results, our strategy is to use multiscale imaging and image processing techniques to decompose the radio emission into multi-components, at various spatial scales. With e-MERLIN observations at 6 GHz and VLA-A configuration observations above 22 GHz, we reach angular resolutions from 0.05" to 0.1", respectively. We can resolve the nuclear regions at ˜ 20 - 100 pc scales in order to probe compact radio components and disentangle them from the nuclear diffuse emission at scales ˜ 100 - 200 pc. With the VLA-A configuration below 10 GHz and VLA-B/C configuration above 15 GHz, we characterise the large scale diffuse emission (˜ 1 kpc), mostly associated with SF activity, at > 0.3" angular scales. With this, we can build up a multiscale spectral energy distribution to separate thermal and non-thermal emission mechanisms. The next step is to use VLBI observations at angular resolutions below 10 mas to completely disentangle core-compact components (unresolved by e-MERLIN) from any nuclear diffuse emission. Combining multiple visibilities allows us to characterise the structure of these sources at all scales. Hence, we can apply our decomposition method simultaneously to the three instruments as a proxy to remove the contribution of core-compact components (AGNs) and map the diffuse emission. We will be able to provide constrained and calibrated estimates to our multiscale tracer for star formation. In an attempt to tackle the problem of underestimation of the radio emission coming from SF activity, we discuss the relevance of a simultaneous multiscale characterisation of radio sources to constrain their total star formation rates and associated physical properties.

Session VI: Radio quiet AGN – Chair: Anne-Katrin Baczko / 37

The Impact of Jets on Host Galaxies in Radio-quiet AGN

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AGN are expected to influence galaxy evolution through their fast and powerful outflows which are prominent at radio frequencies, and through ionizing radiation from their accretion disks through processes termed broadly as "AGN feedback". The vast majority of AGN are however radio-quiet and have radio outflows that rarely extend beyond their host galaxies. In this talk, I will present multi-frequency, multi-scale radio data on small samples of radio-quiet AGN and show

that despite their smallness radio-quiet AGN jets can influence their surrounding environments. I will present data showing that jet propagation in radio-quiet AGN is complex and warrants VLBI monitoring to fully understand them.

Session VI: Radio quiet AGN – Chair: Anne-Katrin Baczko / 12

Windy or not: Radio pc-scale evidence for a broad-line region wind in radio-quiet quasars

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Does a broad-line region (BLR) wind in radio-quiet (RQ) active galactic nuclei (AGN) extend to pc scales and produce radio emission associated with the BLR wind? We present the results of EVN (including e-MERLIN) observations at 1.7 and 4.9 GHz of ten (six detected) RQ Palomar-Green (PG) quasars, of which five were selected to have CIV blue excess wing and five without. Together with 13 RQ PG quasars detected in our earlier VLBA observations we find the following. All five objects with both radio and BLR winds are found at high Eddington ratios L/L_Edd (> 0.66), and eight of the nine objects without either radio or BLR winds reside at low L/L_Edd (< 0.28). This suggests that all BLR winds and most radio outflows in RQ AGN are related to a radiation pressure driven wind. The high L/L_Edd ($= 2.0$) in one of the nine no wind objects is probably overestimated due to a face-on view. Evidence for free-free absorption by the AGN photoionized gas, which flattens the spectral slope, is found in two objects. The radio outflow in three objects, which reside at very low L/L_Edd ($= 0.05$-0.12), is likely from a low-power jet, as suggested by additional evidence. Four intermediate L/L_Edd ($= 0.2$-0.4) objects may represent a mild equatorial BLR wind, which may be weakened in a face-on view or enhanced in an edge-on view. Future spectropolarimetry can test this inclination bias.

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The faint radio nucleus of the megamaser galaxy IC485: AGN or SF activity?

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Water masers associated with AGNs (the 'megamasers') constitute a unique way to directly map the molecular gas at (sub-)parsec distance from SMBHs and, hence, to study the physical properties, the structure, and the kinematics of the gas surrounding the central engine. In particular, high angular resolution radio continuum and maser observations have been used to

test the alignment of the radio jets and the rotation axis of accretion disks and to pinpoint regions of strong interaction of low power jets and/or nuclear outflows with the interstellar medium in radio quiet AGNs.
Located at a distance of 122 Mpc, IC485 is a spiral LINER/Seyfert 2 galaxy hosting a bright H2O megamaser. A recent study indicates that the maser emission might be produced (at least in part) in an edge-on accretion disk oriented north-south, with a radius of 0.24 pc (Ladu et al. 2024). Sensitive radio continuum EVN measurements at 1.7 and 5 GHz, did not show confident emission from the nuclear region, suggesting a diffuse morphology resolved out at the pc-scale.
By taking profit of a resolution intermediate between that of the VLA and VLBI, very recent observations with the e-MERLIN at 1.4 and 5 GHz revealed a flat-spectrum nuclear source, coincident in position with the maser location and with a tentative source visible in our EVN L-band map. The e-MERLIN source is slightly resolved with an orientation of the extended emission approximately perpendicular to that of the putative accretion disk. These characteristics suggest the presence of a weak jet or an outflow in the nucleus of IC485. Here, we present the results of our e-MERLIN observations and discuss them by combining the information obtained from the radio continuum and maser studies, thus providing relevant clues on the maser and radio continuum origin.

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Investigating launching of black hole jets with the combined power of the EVN and the EHT

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AGN-launched jets are a crucial element in the study of super-massive black holes (SMBH) and their closest surroundings. The formation of such jets, whether they are launched by magnetic field lines anchored to the accretion disc or directly connected to the black hole's (BH) ergosphere, is the subject of ongoing, extensive research.
3C 84, the compact radio source in the central galaxy NGC 1275 of the Perseus super-cluster, is a prime laboratory for testing such jet launching scenarios, as well as studying the innermost, sub-parsec AGN structure and jet origin. Very long baseline interferometry (VLBI) offers a unique view into the physical processes in action, in the immediate vicinity of BHs, unparalleled by other observational techniques. With VLBI at short wavelengths particular high angular resolutions are obtained.
Utilising such cm and mm-VLBI observations of 3C 84 with the European VLBI Network and the Event Horizon Telescope, we study the magnetic field strength and associated accretion flow around its central SMBH. This is possible, as VLBI measurements are capable of peering through the dusty torus surrounding the central engine of 3C 84, which is known to block the line of sight to the sub-parsec counter-jet via free-free absorption. Furthermore, we study the magnetic field's signature in the core region, as manifested in polarised light. As part of this analysis we compare

our observations to relativistic magneto-hydrodynamic simulations. Finally, we investigate the effect of instabilities on the shape of the jet's parsec-scale funnel and try to connect them to its historical evolution. In this talk I will present our most recent results and offer a comprehensive summary of BH jet launching in AGN.

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Event Horizon and Environs (ETHER) Sample: VLBA Imaging of 11 more Supermassive Black Holes

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In this talk, we will first present the Event Horizon and Environs (ETHER) sample compiled with an extensive sample of black hole masses and radio-to-sub-mm fluxes to select and enhance targets for Event Horizon Telescope (EHT) and next-generation Event Horizon Telescope (ngEHT). Currently, the ETHER database consists of ˜3.8 million supermassive black hole (SMBH) mass estimates, ˜19.3K VLBI radio fluxes, and ˜14K hard X-ray fluxes. We will also present the results from an extensive 1 mm survey of 236 large-ring supermassive black holes selected from the ETHER sample with black hole ring size $>$ 3.0 micro-arcsec using the Atacama Compact Array (ACA) and Submillimeter Array (SMA) conducted in 2022-23. The constrained 1 mm fluxes obtained from this survey are a timely requirement to drive the technical requirements of the ngEHT.
In this talk, we will also discuss the 43 GHz VLBA observations and imaging results of a sub-sample of 11 supermassive black holes' with ring size $>$ 3 micro-arcsec selected from the ETHER sample (which can be imaged with the EHT on a scale better than 100 gravitational radii). Constraining the 43 GHz nuclear fluxes and morphology of these 11 ETHER targets will enable future deep imaging of this optimal sub-sample with GMVA+ALMA, and EHT+ALMA, thus constraining General Relativity and the physics of jet launching and accretion inflows, over a large multi-parameter space. We will also present preliminary results of our GMVA+ALMA deep observations of the largest ring sources in the ETHER sample: Messier 84, and NGC5077; and the snapshot GMVA+ALMA observations of five SMBHs, which will all offer a unique opportunity to resolve and image accretion inflows and jets at less than 100 gravitational radii resolution in a sample of nearby low luminosity AGNs.

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AGN jets from formation to dissipation

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The process of jet formation and collimation in Active Galactic Nuclei (AGN) as well as their interaction with the host galaxy are still key open problems despite decades of astrophysical studies. While cm- and mm-VLBI studies have made progress in understanding jet collimation in strongly Doppler-boosted one-sided jets, the symmetry of these systems and the interplay with the properties of the host galaxy are still poorly understood. On the other hand, AGN feedback and black hole feeding can be probed with sub-arcsecond resolution by telescopes such as the International LOFAR Telescope, eMERLIN, and Jansky-VLA. To improve our understanding

of jetted AGN, we need to connect these two scales from mpc to Mpc. This is challenging with current instruments, but has good prospects with future advances represented by the SKA and the ngVLA. In this talk I will present first results of combining these different scales to follow the evolution of jets from formation to dissipation in a pilot study of misaligned jets combining HSA, EVN+eMERLIN, and LOFAR. Special emphasis will be placed on the LINER NGC 3894, which shows a change in its jet position angle of at least 40 degrees, visible only on VLBI scale. To overcome the problem of the low number statistics of VLBI studies of double-sided jets required for symmetry studies, I will present possible solutions using clustering algorithms on large radio astronomical datasets such as the LOFAR Two-metre Sky Survey.

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Accretion mode and properties of the jet base in AGN

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Nearby radio galaxies are the ideal targets for VLBI studies aimed at exploring the regions surrounding the supermassive black hole at the center of AGN. In this talk I will present results from millimeter and centimeter VLBI studies of several misaligned jets, focusing on the relation between the accretion mode, efficient vs. inefficient, and the observed properties of the jet base on scales of 10^2-10^5 Schwarzschild radii from the black hole. Jets of different power, previoulsy unexplored due to their faintness, are examined to investigate aspects such as the absorption induced by the circumnuclear material, the magnetization at the jet base, and the extent of the jet collimation region.

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MOJAVE XXII: The Spatial and Temporal Evolution of Faraday Rotation in AGN jets

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Active Galactic Nuclei (AGN) generate extreme luminosities, and their central engines have strong magnetic fields and high electron densities which play a major role in the formation of relativistic jets. The Faraday Rotation (FR) MOJAVE project presents resolved polarimetric images of 25 AGN derived from 15/24/43 GHz observations using the Very Long Baseline Array (VLBA). These span across 23 epochs between August 2019 to June 2021, giving us a unique view into both the spatial and temporal evolution of the magneto-ionic media of AGN. We derive FR, intrinsic electric vector position angle (EVPA), spectral index, and depolarisation maps. For "quasar" jets, we see longitudinal magnetic fields, whereas for "BL Lac objects" we see transverse jet magnetic fields indicative of shocks. We find that AGN cores have large FR values that are highly spatially and temporally variable. At variable times core regions also show evidence for non-lambda2 dependent FR, which is suggestive of FR internal to the emission of the source. By combining depolarisation and FR information we find further evidence of internal FR and find a collection of sources that show a transition between internal and external FR between the core and jet regions, which change over time, allowing us to unravel the nature of their magneto-ionic environments.

Session VIII: Nuclei of radio loud AGN II – Chair: Michael Janssen / 54

HST-1 knot: Results from quad-frequency observations of the M87 Jet

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HST-1 is a knot in the conical kiloparsec-scale M87 jet, observed for the first time by the Hubble Space Telescope. In the images, it is the first the resolved feature near the jet's "core" on the arcsecond scale. HST-1 showed superluminal speeds up to 6c and significant flaring activity in optical and across all bands from radio to X-rays and even gamma-rays. Through the perspective of VLBI, the M87 jet exhibits a parabolic geometry, hinting at the significant role of HST-1 in the jet's collimation and evolution. However, due to its distance from the jet base and consequently, the smearing effects limiting the field of view for VLBI, HST-1 remains a challenging feature to study in detail, resulting in a lack of high-resolution VLBI data and spectral information.
In this talk, I will present our attempt to mitigate the problems introduced above using quad-frequency observations of HST-1 at 2, 5, 8, and 15 GHz with the VLBA and the EVN arrays. By utilizing these four frequencies, we have constructed a spectral index map of the knot and notably, a turnover frequency map for the first time.
The spectral index maps reveal a uniform structure with a steep spectrum slope of approximately -0.7, suggesting that HST-1 is likely part of an optically thin jet rather than a standing shock. The turnover frequency maps have also allowed us to estimate a magnetic field strength of the order of milliGauss.

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The time evolution of the filaments in 3C279 with space-VLBI mission RadioAstron

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The quasar 3C279 is very well known for its high luminosity, polarization, and variability, has been widely studied and monitored. Recently, the space-VLBI mission RadioAstron revealed a filamentary structure in the jet of this source, offering unprecedented insights into its innermost region. Building on these findings, new data were analyzed four years later at 22 GHz (K-band) using the same mission RadioAstron along with 14 ground-based stations, including several from the European VLBI Network (EVN), and achieving a resolution of almost 15 microarcseconds. The new results shed some light on the temporal evolution of the jet's structure, with notable changes in its filamentary features and polarization properties, further broadening our understanding of this fascinating and complex source.

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MAD accretion and AGN jets - observational perspective

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One of the major open questions related to the production of jets by accreting black holes is: why sources with similar accretion powers produce so vastly different jet powers? What are the conditions that are required to produce a powerful jet? If jets are powered by the Blandford-Zjanek mechanism, there are two obvious parameters controlling the jet power besides the black hole mass - black hole spin and the magnetic flux threading it. Since there appears to exist highly

spinning black holes without jets, it seems possible that the jet production efficiency depends on whether the black hole has been able to accrete high enough magnetic flux. The highest-efficiency jets in this picture are launched from magnetically arrested disks (MADs). We will discuss a method to test this hypothesis using VLBI core-shift measurements to estimate the jet magnetic flux, and present what we have learned about the MAD systems from such studies over the past decade.

Session VIII: Nuclei of radio loud AGN II – Chair: Michael Janssen / 91

Space VLBI Studies of the Blazars 3C 454.3 and OJ287 at 22 GHz with RadioAstron

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In 2016, we conducted high-resolution VLBI observations of the blazars 3C 454.3 and OJ287 at 22 GHz, utilizing the space antenna RadioAstron simultaneously with nearly 30 ground-based antennas. These unique observations enabled us to achieve an angular resolution of ˜40 microarcseconds, resulting in unprecedented detailed images of the blazars' inner jet structures. The study of 3C 454.3 revealed intricate features in the innermost jet region, including extreme jet bending at ˜0.6 mas radial distance from the VLBI core and several distinct jet features upstream of this bending. This jet morphology is consistent with our quasi-simultaneous observations at 86 GHz with GMVA. Meanwhile, the observations of OJ287, a blazar well-known for its periodic optical outbursts believed to be triggered by a binary supermassive black hole system at its center, show a complex innermost jet structure, significantly different from the 2014 RadioAstron observations. Join me as I present these new results and discuss their implications.

Session VIII: Nuclei of radio loud AGN II – Chair: Michael Janssen / 75

Characterising the plasma properties and magnetic field orientation of OJ287 and its kpc jet knots at low radio frequencies with LOFAR-VLBI

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The BL Lacerta object OJ287 , located at z = 0.306 is a very unusual object, as it is suspected of hosting a binary black hole system which powers a relativistic blazar jet. New LOFAR observations of this source, reduced including its international baselines, have allowed us to match the resolution of instruments such as the VLA and Chandra, thereby resolving the knots in the kpc jet of OJ287. We study the evolution of the synchrotron spectrum evolution along the jet's length, and report the discovery of new jet components only detected at very low frequencies. Finally, we discuss current work studying the magnetic field structure in the large-scale jet of OJ287 through its measured polarisation properties.

Session VIII: Nuclei of radio loud AGN II – Chair: Michael Janssen / 47

Modelling the jet structure of the blazar NRAO 150 using mm-VLBI

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NRAO 150 is a prominent radio to millimetre emitting quasar at redshift $z = 1.52$. This source exhibits a particularly intriguing structure, as the jet is seen at an extremely small angle to the

line of sight. Previous Very Long Baseline Interferometry (VLBI) observations have revealed a fast counter-clockwise rotation of its innermost jet region. Owing to the high angular resolution provided by VLBI, we can probe relativistic jets at such small scales, in the vicinity of the central engine. In this work, we aim to study the morphology and kinematic behaviour of the jet of NRAO 150. The source was observed by the Global Millimeter VLBI Array (GMVA) at 86 GHz, and by the European VLBI Network (EVN) at 43 GHz and 22 GHz. The data was imaged in total intensity and geometric model fitting was applied, in order to perform a comprehensive analysis of the jet structure. We report a counter-clockwise jet rotation for one emission feature, which is consistent with previous VLBI studies. We also present a new kinematic model for this source and fit a helical model to the component's trajectory. The fit supports the assumption of a counter-clockwise jet rotation. Geometric projection effects also need to be taken into account, as the source points at a small angle to our line of sight. In this talk we will examine and discuss possible scenarios for these projection effects and interpret how they relate to the observed jet features.

Session X: X-ray binaries – Chair: Rob Beswick / 114

Beyond the Core: Unveiling Multiple Gamma-Ray Production Zones in Blazar 3C 454.3

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We present a multi-wavelength analysis of the gamma-ray emission mechanisms within blazar 3C 454.3. Using 12 years of gamma-ray data alongside multi-epoch VLBA observations at 15 and 43 GHz, we explore the correlation between jet features and gamma-ray activity. Our analysis reveals a significant correlation between gamma-ray flux and core emission at 43 GHz and 15 GHz, suggesting these core regions contribute substantially (37% and 30%, respectively) to the overall gamma-ray production. Furthermore, a quasi-stationary 43 GHz component at 4.6 pc and a mobile 43 GHz feature (0.8-2.3 pc, βapp = 9.9 ± 1.1 c) exhibit strong correlations with gamma-ray variations, contributing 18% and 26% to the high-energy emission, respectively. The observed co-variability across these extended jet regions strongly suggests Synchrotron Self-Compton (SSC) as the primary gamma-ray production mechanism. Our discovery of a high-speed component (βapp = 9.9 ± 1.1 c) contributing to gamma-ray emission significantly challenges existing theoretical models. Our findings highlight the potential presence of multiple, and potentially non-stationary, gamma-ray emitting regions within blazar jets, furthering our understanding of blazar complexity and SSC processes.

Session X: X-ray binaries – Chair: Rob Beswick / 108

Numerical simulations and radiative signatures of transient and episodic jets

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Observations of transient and episodic jets allow us to study jet formation and particle acceleration in real time. To better understand the possible physics behind these violent events we perform two-temperature 3D GRMHD simulations of accreting black holes. Our simulations start with an initial torus in hydrostatic equilibrium seeded with a magnetic field with alternating polarity. During the accretion process we trigger magnetic reconnection which leads to three distinct flow states: (i) an intermittent flow that passes from quiescent states to a flaring state, (ii) a quasi-steady-state with no jet, and (iii) an accretion state similar to a magnetically arrested configuration including a strong jet. In addition, our simulations lead to the formation of current sheets which provide ideal conditions for the acceleration of non-thermal particles. From the

GRMHD simulations we compute the polarised radiative transfer including light curves, broadband spectra, radio images a various frequencies and polarisation fractions. Finally our results can be compared to current and future observation of SgrA* or black hole binaries.

Session X: X-ray binaries – Chair: Rob Beswick / 99

Capturing the evolution of RS Ophiuchi's 2021 nova explosion with the European VLBI network

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Nova outbursts are powerful astronomical events occurring in binary star systems, where a white dwarf accumulates material from its companion star until a critical pressure and temperature are reached and trigger a thermonuclear outburst. In this talk we'll focus on the well known recurrent and symbiotic nova RS Ophiuchi (RS Oph) that experienced a new outburst in August 2021, representing the first nova ever detected at very-high energies (E>100 GeV). In this context, we present the results of a very long baseline interferometry (VLBI) monitoring with the European VLBI Network (EVN) at 1.65 and 5 GHz, performed from 14 to 65 days post-explosion. We characterized in great detail the evolving morphology of the expanding bipolar ejecta and determined the physical conditions of the surrounding medium. We estimated the expansion speed of the two elongated bipolar outflows, the white dwarf accretion rate, the mass loss rate of the companion star, the radial evolution of the surrounding medium density, as well as the properties of the density enhancement on the orbital plane.

Session X: X-ray binaries – Chair: Rob Beswick / 88

Discovering the quiet side of Black Hole X-ray Binaries: A Systematic Search in Radio Surveys

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Black hole X-ray binaries (BHXBs) are stellar-mass black holes in binary systems with stars, serving as laboratories for studying various astrophysical phenomena such as accretion-outflow mechanisms, jet launching processes, and binary evolution. With approximately 70 known systems in our Galaxy and 2-3 new discoveries annually, most studies focus on systems detected during outbursts when sudden changes in accretion rates illuminate them across the electromagnetic spectrum. This biases our understanding of BHXB behavior toward systems undergoing outbursts, whereas it is known that the systems spend most of their life in a quiescent, quiet state. In this talk, I'll demonstrate the effectiveness of measuring proper motions of variable radio sources from wide-field surveys to select compact Galactic targets and find potential quiescent BHXB candidates or other unknown radio transients. Using the Very Long Baseline Array (VLBA), we observed 33 highly variable radio sources, detecting 14 on one or more epochs, with no optical, X-ray or infrared counterparts found. Among the detected targets, we identified five Galactic candidates for quiescent BHXBs, while only one such system had been known prior to this study. This illustrates the potential of systematic searches in radio surveys, archival and upcoming, to expand the population of quiescent BHXBs and discover new types of exotic radio transients.

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X-ray binaries and stellar-mass black holes

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X-ray binaries provide nearby laboratories to study the launching and evolution of relativistic jets on human timescales. High angular resolution VLBI observations are critical in determining the motions of these jets, allowing us to track them back to their launch point and determine an ejection time. This can be compared with the contemporaneous X-ray behaviour to determine the causal connection between the changing geometry of the accretion flow and the evolving properties of the jets. However, the rapid variability of the jets in both brightness and morphology can in some cases violate the fundamental assumptions of aperture synthesis, precluding high-precision measurements of the jet properties. Recent algorithmic advances are allowing us to overcome these challenges, providing a wealth of new information on the properties of the jets. In this talk I will give an overview of recent progress in this field, explaining what we can learn from VLBI studies at different stages of an X-ray binary outburst. I will also discuss the use of X-ray binary jets as astrometric probes, allowing us to measure the proper motions and parallaxes of these systems. Together with systemic radial velocities determined from the optical band, these measurements can be used to calculate the binary's motion through the Galaxy, and hence place constraints on the formation of their black holes.

Session XI: Frequency management – Chair: Alan Roy / 125

Spectrum management and the EVN

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In recent years, the utilization of the radio spectrum has dramatically increased. Digital telecommunication applications, be it terrestrial cell-phone networks or new-space low-earth orbit satellite constellations, have not only acquired unprecedented amounts of spectrum but also use their frequencies everywhere on Earth. The consequences for radio astronomy and other scientific radio services are severe. A single cell-phone tower within hundreds of kilometers around a radio telescope can blind us and there is no place on Earth to escape the ubiquitous transmissions of satellite megaconstellations.
Since 1988, the Committee on Radio Astronomy Frequencies (CRAF) has been advocating for our rights to use the spectrum. We do this by participation in the national and international regulatory frameworks - which is a truly endless endeavor. Hundreds if not thousands of documents need to be processed every year. We not only contribute to regulatory texts, but even more importantly, perform spectrum compatibility calculations. In this presentation, I will summarize our latest activities with a focus on EVN operations.

Session XII: Young stellar objects – Chair: Anna Bartkiewicz / 24

Breaking news from high-mass star formation: recent VLBI contributions

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The formation process of high-mass stars (M > 8 Msun) is still unclear; this is mainly due to their fast evolution and large distances that make it very difficult to observe them in detail. However, many observational and theoretical efforts have been made in the last decades that have shed light on some aspects of the formation process. For instance, it has been shown that molecular outflows are essential during the formation process as much as the accretion disks, similarly to what happens during the formation of low-mass stars. Furthermore the magnetic field is considered playing an important role in the formation of massive young stellar objects

(YSOs), for instance in launching and shaping molecular outflows. I will briefly highlight some of the most recent results in the field, focusing mainly on those obtained through the VLBI. In particular, I will spend some time showing the results obtained with the EVN toward the high-mass star-forming region W75N(B). Several radio sources have been detected in this region, among them the massive YSOs VLA 1 and VLA 2 are thought to be in different evolutionary stages. In particular, VLA 1 is at the early stage of the photoionization and it is driving a thermal radio jet, while VLA 2 is a thermal, collimated ionized wind surrounded by a dusty disk or envelope. The 22 GHz water masers around both VLA 1 and VLA 2 have been monitored, in polarimetric mode, over a period of six years with the EVN. A complete picture of the region will be presented, including the most recent ALMA results.

Session XII: Young stellar objects – Chair: Anna Bartkiewicz / 110

The Orion Nebula Cluster as seen by VLBI

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Magnetically active low-mass young stars can produce nonthermal radio emission with brightness temperatures well above 10**6 K, which can be detected with the VLBI technique. The Orion Nebula Cluster (ONC) contains a rich population of young stars, where thousands are low-mass stars. Radio observations have shown that in the core of the ONC about 600 of these low-mass stars are radio emitters. We initiated a VLBA campaign to study all these radio stars at very high angular resolution and uncovered that more than 100 stars are nonthermal radio emitters (the largest population of this kind discovered so far). In this talk, I will present the observed sample and the astrometric and photometric properties of detected stars.

Session XII: Young stellar objects – Chair: Anna Bartkiewicz / 112

Dynamical Masses of Young Stellar Multiple Systems with the VLBA (DYNAMO-VLBA)

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Very Long Baseline Interferometry (VLBI) provides high angular resolution images and has been used for stellar astrometry for decades. In the DYNAMO-VLBA project, we utilize the Very Long Baseline Array (VLBA) to study tight binary and multiple pre-main-sequence stars, whose components have detectable radio emission and typical separations on the order of milli-arcseconds. Consequently, Gaia cannot provide information on their orbital parameters, making VLBA observations essential for ongoing study. We report dynamical mass measurements of the individual stars in the S1 system in Ophiuchus and EC95 in Serpens. S1 is the most luminous and massive stellar member of the nearby Ophiuchus star-forming region. We found that the primary component, S1A, has a mass of 4.11 ± 0.10 M⊙ , significantly less than the previously reported 6 M⊙, highlighting a discrepancy where the models corresponding to S1A's HR diagram location predict masses at least 25% higher than the dynamical mass. The secondary, S1B, has a mass of 0.831 ± 0.014 M⊙. Additionally, we detected the secondary component during periastron for the first time. In the triple system EC95 in the Serpens region, we measured the masses of EC95A and EC95B, finding 2.148 ± 0.097 M⊙ and 1.998 ± 0.116 M⊙, respectively. For the first time, we estimated the mass of EC95C to be 0.192 ± 0.545 M⊙ with a period of 179.3 ± 20.1 years. The dynamical mass estimations derived from VLBA data are free of assumptions on the physical parameters of the stars and could be used to test evolutionary models of pre-main-sequence stars.

Session XII: Young stellar objects – Chair: Anna Bartkiewicz / 14

Preliminary results of identifying the g-factor of 6.7 GHz methanol maser via polarization observations

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Cosmic masers enable us to estimate the magnetic field via the Zeeman effect, especially in high-mass star-forming regions where OH and methanol masers occur. We can measure the Zeeman-splitting of the maser lines and, knowing the Landé g-factor, determine the strength of the magnetic field. The g-factor is undoubtedly known for the excited OH maser, but for methanol masers, it is still under investigation because it is still unclear which of the eight hyperfine transitions (each with its own g-factor) dominates the 6.7 GHz maser emission. To resolve this issue, we conducted simultaneous observations of the 6.035 GHz exited OH and of the 6.7 GHz methanol maser emissions for two bright sources, for which maser emissions arise in the same spatio-kinematical regions and have clear Zeeman-splittings. Simultaneous observations of both maser lines allow us to compare the magnetic field estimated with the ex-OH masers with the Zeeman-splitting measured in the methanol maser line and to figure out the dominant hyperfine transition of the 6.7 GHz methanol maser. We will present preliminary results from the project EK052 (E22C002), which was observed in May 2023.

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6.7 GHz Methanol masers in the IRAS 20126+4104 during minimum and maximum activity

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IRAS 20126+4104 (G78.122+3.633) is a well-studied high-mass protostar that still presents unanswered questions, such as the cause of 6.7 GHz methanol maser short-term fluctuations (ranging from 5 to 60 days) and how individual maser cloudlets respond to transitions from long low-activity periods to long high-intensity periods. To address these questions, we are utilizing combined 6.7 GHz methanol maser monitoring efforts from the Irbene and Torun radio telescopes, along with milliarcsecond (mas) imaging capabilities of the European VLBI Network (EVN).
In this research project, we have obtained a second epoch of observations of this source, timed close to its activity maximum, in contrast to all other observations that were taken near its minima. Preliminary results suggest an increase in the projected linear size of maser cloudlets as their flux increases, as well as the appearance of new intense maser cloudlets near existing ones. Additionally few of most variable coudlets (2; 3 and 7) seems to be in a bit different position - there peak is a bit closer to a jet.
Additionally, in this observation project (EA067), we obtained the second-ever milliarcsecond images of G90.92+1.49 and G94.602−1.796.

Session XIII: FRB and Astrometry – Chair: Marcin Gawroński / 133

e-MERLIN and e-VLBI observations of Dyson Sphere Candidates

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Project Hephaistos recently identified seven M-dwarfs as possible Dyson Spheres (DS) candidates. We cross-matched the sources in archival radio survey catalogues and found that three of these candidates (A, B & G) have radio counterparts. The radio sources are offset from the Gaia stellar positions by ~ 4.9, ~ 0.4 and ~ 5.0 arcseconds (candidates A, B, and G respectively). We proposed (Tongtinan+ 2024) that Hot DOGs (Dust Obscured Galaxies) have contaminated the original Mid-IR measurements of the DS candidates. In June, we observed one of the DS candidates (G) with e-MERLIN and e-VLBI. e-MERLIN resolves the radio source associated with G into 3 components. The central component is detected by e-VLBI implying a brightness temperature > 10^6 K . These observations support our hypothesis that an obscured AGN contributes to the measured WISE W3 and W4 flux densities for candidate G, with the foreground star being a normal M-dwarf lying close to the AGN line of sight. We believe that most (if not all) of the Project Hephaistos DS candidates can be explained in this way.

Session XIII: FRB and Astrometry – Chair: Marcin Gawroński / 123

VLBI and Gaia: rivalry turned into synergy

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The launch of the Gaia mission has paved a way to millisecond-scale optical position measurements, reaching and exceeding accuracy attainable by radio VLBI. These advances do not make radio astrometry obsolete. Instead, multiwavelength measurements open fundamentally new opportunities, impossible with either VLBI or Gaia alone. In this talk, I will explore these opportunities and implications for further astrometry improvements, as well as for probing AGN physics. I will highlight current results and upcoming studies on the jet properties and the disk-jet connection. The near future will bring an even tighter VLBI-Gaia synergy, especially with new Gaia releases and variability measurements.

Session XIII: FRB and Astrometry – Chair: Marcin Gawroński / 113

Geodesy at K band with the European VLBI Network

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The European VLBI Network (EVN) has been used in geodesy mode at K band for the purpose of determining the geodetic positions of non-geodetic EVN telescopes (i.e. without S/X receivers). The work was initiated within the context of the EC-funded JUMPING JIVE project (2017-2021). For this purpose, a number of high-quality sources spread over the sky and belonging to the third realization of the International Celestial Reference Frame (ICRF3) have been targeted. The data have allowed us to estimate the positions of the non-geodetic EVN telescopes in the ITRF2020, the terrestrial reference frame currently in use, with cm level precision. Additionally, high-resolution images of the observed ICRF3 sources have been derived. A specificity of the images is that they show increased resolution compared to those derived from the Very Long Baseline Array. The presentation will detail these results.

Session XIII: FRB and Astrometry – Chair: Marcin Gawroński / 64

Advances in Fast Radio Burst Localization with VLBI: Insights from Recent Developments

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Fast Radio Bursts (FRBs) have emerged as one of the most enigmatic phenomena in modern astrophysics, characterized by their millisecond-duration flashes of extreme luminosity originating from cosmological distances. Despite significant progress in the field, the exact nature and progenitors of FRBs remain elusive. Our group has made substantial advancements in the precise localization of FRBs using Very Long Baseline Interferometry (VLBI), leveraging the unparalleled resolution and sensitivity of the European VLBI Network (EVN). These efforts have enabled us to localize the millisecond-duration bursts to milliarcsecond precision, and directly image the persistent radio sources associated with some FRBs. These findings provided critical insights into their environments and potential progenitors, such as young magnetars, superluminous supernovae, and massive black hole systems. In this talk, I will present the latest results from our VLBI observations within the PRECISE and AstroFlash/EuroFlash activities. By combining multi-wavelength data and theoretical modeling, we have been able to differentiate between various formation channels and evolutionary stages of FRB sources. Our findings not only shed light on the physical conditions required to produce these bursts but also pave the way for future research with next-generation facilities. This work represents a significant step forward in understanding the origins and mechanisms of FRBs, contributing to the broader field of astrophysics and cosmology.

Session XIV: Astrometry – Chair: Eduardo Ros / 50

Densification of VLBI radio sources around the JUICE spacecraft trajectory during its Venus flyby

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The European Space Agency's (ESA) large-class mission Jupiter Icy Moons Explorer (JUICE) was launched on 2023 April 14, and started its interplanetary journey towards the Jovian system. The primary science goal of the mission is a complex study of the icy Galilean moons of Jupiter, Ganymede, Europa, and Callisto. One of the eleven scientific experiments of JUICE is the Planetary Radio Interferometry and Doppler Experiment (PRIDE). Without a specific on-board payload, PRIDE will use the communication system of the spacecraft to determine its accurate position with respect to bright extragalactic radio sources, through phase-referencing very long baseline interferometry (VLBI) observations, preferably in the in-beam mode. Our main goal is to find suitable new reference sources around JUICE's trajectory to support its navigation on the way to and in the Jovian system. As there is approximately only one known reference source per 2.5 square degrees alongside the Ecliptic and thus the trajectory of JUICE, finding new sources and densifying the reference frame is an important amplification of PRIDE. To identify suitable in-beam reference sources, test and tune-up data reduction methodology and algorithms, and assess the quality and accuracy of the JUICE state vector determination, we planned several VLBI experiments using the European VLBI Network (EVN), the Australian

Long Baseline Array (LBA), and a global VLBI network. Here we present the results of our latest experiment. These observations will serve as a pilot study for finding new potential reference sources close to the trajectory of JUICE during its upcoming Venus flyby in August 2025. The X-band observations were carried out using 12 antennae of the EVN in February 2024, targeting 9 weak sources selected from the VLA Sky Survey and the mJIVE-20 collection, and 3 bright sources from the Radio Fundamental Catalog (RFC). Our aims are to detect new in-beam phase reference calibrators among the 9 in-beam targets, and to link the RFC sources into the International Celestial Reference Frame.

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Imaging VGOS observations and modeling source structure effects

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The new generation of geodetic Very Long Baseline Interferometry (VLBI), VLBI Global Observing System (VGOS), is now regularly observing to produce the best geodetic VLBI data, with a thermal noise level of about 3 ps. It now approaches to the designed observing strategy, i.e., scan lengths of on average 10 seconds and switching time of about 20 seconds. However, the systematic errors due to the angular structure of the radio sources are becoming prominent in these high-precision VGOS observations. It is important to understand, study, and monitor these systematic errors. Project Astrogeodesy (also a new research group at the GFZ), funded by European Research Council, aims to developing a data processing/calibrating pipeline to model these systematic errors. Improvements have been made to derive images of the source structure – and subsequently model it with a small number of Gaussian components – through closure imaging at the four bands (3 – 14 GHz) directly from VGOS observations on a regular basis. We will report on our imaging results and the current research activities about source structure in VGOS observations.

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VLBI Observations of compact sources in the Galactic Plane

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The GLOSTAR galactic plane survey conducted with the VLA and Effelsberg telescopes led to the detection of thousands of compact continuum sources in the Galactic Plane with sizes of less than one arcsecond. We observed 1782 of these compact sources in the galactic longitude range from 28 to 36 degrees with the VLBA to investigate the fraction of sources which are detectable with VLBI and to distinguish between galactic and extragalactic sources based on their proper motions. By measuring scatter broadened source sizes as a function of frequency we also gain invaluable insights into the scattering properties of the interstellar medium. Here we will report on first results from this survey, placing sources among the most heavily scattered AGN known to date, which indicate much stronger and more widespread scattering than anticipated.

Session XIV: Astrometry – Chair: Eduardo Ros / 33

Source-frequency Phase-referencing Observations of AGNs with EAVN and Yebes

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We report results from the first successful simultaneous 22/43 GHz dual-frequency observing campaign with a joint array of the KVN, VERA, and Yebes 40m RT in 2018.
Simultaneous receiving makes it straightforward to apply frequency phase transfer (FPT) and source frequency phase referencing (SFPR) methods, which are essential for overcoming the main challenges of mm-VLBI observations and achieving astrometry.
Our analysis confirms the coherence time at 43 GHz was extended to tens of minutes after applying FPT from 22 GHz on all baselines to Yebes. These results mark the longest baseline to date (10,138 km) for the successful application of this method.
Combined with the regularized maximum likelihood (RML) imaging methods, we have achieved unprecedented angular resolutions of the observed targets.
The SFPR data also enabled us to measure the core shift of the targets and explore the magnetic field properties. Thanks to the long baseline lengths and the high-fidelity RML images, we are able to obtain core shift measurements with high precision, reaching 17∼30 microarcseconds.

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Toward Tracking SMBH Binary Orbits: Pilot K/Q Simultaneous Observation Using KVN and Yebes-40m Telescope

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We present the results of a pilot observation testing the performance of Frequency Phase Transfer (FPT) and Source/Frequency Phase Referencing (SFPR) at 22 and 43 GHz using the Korean VLBI Network (KVN) and the Yebes-40m telescope in Spain, with a baseline length of ∼9,000 km. The ultimate goal of this project is to monitor the orbital motion of supermassive black hole binaries (SMBHBs) using high-precision VLBI astrometry, which requires a precision of a few micro-arcseconds. We find that the FPTed visibility phase at 43 GHz on Yebes-KVN baselines shows a significant improvement in coherence time compared to the non-FPT phase, demonstrating that FPT is effective even with long baselines. We also present preliminary SFPR maps showing the feasibility of high astrometric precision within 10 μas. We discuss remaining issues, such as the time evolution of residual phases at long baselines, and outline future observation plans for long baseline SFPR, including multi-frequency antennas up to 86 GHz.

Session XIV: Astrometry – Chair: Eduardo Ros / 63

VLBI astrometry for OH/IR stars and Period-Luminosity relation in very long period range

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We will present astrometric VLBI studies for OH/IR stars conducted with the Japanese VLBI array VERA (VLBI Exploration of Radio Astrometry). Using several OH/IR stars, we have been explored period-luminosity relation (PLR) in the quite long pulsation period range ($\geq$1000 d). A preliminary result of the new PLR will be presented. We will emphasize advantages of VLBI in parallax measurements of dust-obscured stars, and complementarity between VLBI and Gaia will also be mentioned.
In a late stage of stellar evolution with initial masses of $0.8-10M_{\odot}$, they spend time as Asymptotic Giant Branch (AGB) stars. Mira variables are thought to be in early phase of the AGB exhibiting a PLR, which is a well known tool for distance estimation. As they evolve, they will be surrounded by dust shells. Then, due to detection of OH masers and IR excess, they will be recognized as OH/IR stars. Due to extinction by circumstellar dust, parallax measurements of the OH/IR stars in optical bands are difficult. However, VLBI astrometry for H_2O masers associated with the OH/IR stars are effective to measure their parallaxes. Since OH/IR stars with thick dust shells tend to show quite long pulsation periods ($P \geq$1000 days), extensions of the PLR to longer period range may provide new distance estimator for the OH/IR stars. Since they are more massive than typical Mira variables, they can also be used in the study of Galactic dynamics.
At the EVN symposium 2016, we reported the start of new research targeting the OH/IR stars with very long periods. Now, eight years later, we have been observed OH/IR stars with periods of 500-1500 days. We present current status of our studies using an OH/IR star NSV17351 together with parallaxes of other sources. A prelimialy result of the PLR of $M_{\rm bol} = (-3.31\pm0.08)\log P + (-3.94\pm0.20)$ was obtained considering spectral energy distributions (SEDs) of the sources.

Session XV: VLBI perspectives I – Chair: Michael Lindqvist / 124

Current and future developments for the EVN

Prof. GARRINGTON, Simon[1]

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This talk will review the current status of the EVN and some of the developments and enhancements which are already going ahead including adding new telescopes, increasing bandwidth, developing new data processing modes and new correlator hardware, as well as aiming to increase the flexibility of observing in response to evolving scientific demands, especially for transient and multi-messenger astronomy. Beyond these 'evolutionary' developments, it is also important to consider how the EVN can work together with the SKAO and other new telescopes in Africa and elsewhere in a new era of global VLBI. Concepts for new networks of smaller radio telescopes (possibly in clusters) on various scales in Europe are now being actively planned by multiple groups. Provided these initiatives can be suitably integrated, a new EVN which can be more efficiently optimised for future scientific demands with more telescopes, wider fields, wider bandwidths and continuous observing could be envisaged.

Session XV: VLBI perspectives I – Chair: Michael Lindqvist / 83

RADIOBLOCKS impact for the EVN

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RADIOBLOCKS is a European Commission-funded project that aims to go beyond state-of-the-art technological solutions to increase the sensitivity, field of view and bandwidth of radio astronomy infrastructures. Although these developments address aspects for almost all radio astronomical infrastructures along the entire data chain, VLBI will benefit from their results and deliverables.
RADIOBLOCKS is divided into tasks that work on different parts of the signal chain. One task is dedicated to Novel Detectors and Components to address the developments of improved cryogenic LNAs and SiS mixers, among others. This will allow large bandwidths and simultaneous observations at different, largely separated frequencies to study the emission of sources at increased sensitivity. The Digital Receivers task will develop and demonstrate receivers that produce large data streams capable of RFI mitigation, including cryoPAFs and a prototype VLBI backend that will allow broadband and multi-frequency observations. Data Transport and Correlation is another important part of the signal chain: one task is therefore dedicated to processing the data produced by the new receiver systems. It will develop a collection of efficient, high-performance signal processing blocks using commercially available hardware accelerator platforms such as FPGAs, tensor core-enabled GPUs for correlations, and off-the-shelf Ethernet network switches for high-speed data transfer. The last block of the signal chain deals with the implementation of a generic Data Processing Tool Kit to handle the post-processing of large data streams. This includes fringe fitting, advanced data processing algorithms to handle data with sparse visibility and simulations to extend the EHT tools for cm-VLBI or study different SKA-VLBI observing scenarios.
In this talk, we will show the progress of RADIOBLOCKS after its first year and highlight the developments that will have an impact on the VLBI of the future.

Session XV: VLBI perspectives I – Chair: Michael Lindqvist / 34

Bayesian calibration and imaging in VLBI

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Calibration and imaging are closely interconnected in very long baseline interferometry (VLBI). The conventional CLEAN algorithm has been widely employed for imaging, self-calibration, and polarization calibration. However, forward modeling and Bayesian imaging algorithms have recently outperformed CLEAN, and these new imaging methods can also be utilized for various aspects of data calibration. This talk describes a new approach we have developed for extending the Bayesian imaging framework RESOLVE to include self-calibration and polarization calibration of VLBI data. Applications of this approach to imaging of 43 GHz VLBA and 86 GHz GMVA+ALMA observations of M87 show that high-resolution images and antenna-based gain solutions with uncertainty estimation can be obtained. Ongoing developments of Bayesian

polarization calibration and imaging will be illustrated with the example of analysis of 15 GHz MOJAVE data for 3C273. Based on this analysis, we conclude that the Bayesian approach can be successfully extended to include the elements of self-calibration and instrumental polarization, thus allowing for robust, high fidelity recovery of pivotal structural characteristics of the emitting regions, including, for the examples mentioned above, the faint, extended jet emission and the photon ring in M87 and the internal structure of the total intensity and polarized emission in jet in 3C273. These results provide strong evidence for the Bayesian calibration and imaging approach to be very well suitable for image reconstruction from VLBI data.

Session XV: VLBI perspectives I – Chair: Michael Lindqvist / 93

Latest developments in wide-field VLBI

Dr. RADCLIFFE, Jack[1]

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In the past few decades, radio surveys have provided us with unique insights into many areas of astrophysics such as star formation, supernovae, active galactic nuclei, pulsars, cosmology and much more. A key aspect of these surveys is the technique of Very Long Baseline Interferometry (VLBI) which can provide some of the highest resolutions possible in astronomy. This method has been crucial in understanding the inner workings of galaxies such as AGN-star-formation feedback, dark-matter substructures in gravitational lenses, and providing the first two direct images of a black hole shadow.
VLBI has been typically limited where the largest surveys require many years of observations to build up an extensive sample. However, computational improvements have enabled us to map multiple sources within a single VLBI survey and push into the lower frequency regime through the International LOFAR telescope. In this talk, I will talk about the scientific and technical discoveries arising from such surveys and focus on the bright future of VLBI surveys. This includes the transition from the current modus operandi of a small number of surveys of a few 'famous' deep fields to a ubiquitous VLBI survey instrument. I will conclude the talk by talking about the upcoming developments in VLBI, such as the incorporation of SKA and MeerKAT, ultra-wideband receivers, and GPU-accelerated correlation and calibration.

Session XVI: VLBI perspectives II – Chair: Zsolt Paragi / 22

TNRO: A Beacon for Southeast Asia's VLBI Advancement and Role in Global VLBI Networks

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In 2017, the National Astronomical Research Institute of Thailand (NARIT) launched a national flagship project with the empyreal goal of capacity building and technology development through the construction of national radio telescopes for radio astronomy and geodesy. To achieve this, NARIT has established the Thai National Radio Astronomy Observatory (TNRO), in Chiangmai, the northern part of Thailand. At this observatory, two radio telescopes have been constructed: one is a 40-m Thai National Radio Telescope (TNRT) in collaboration with Yebes Observatory, Max Planck Institute for Radio Astronomy, and Jodrell Bank Centre for Astrophysics, and another one is a 13- m VGOS radio telescope as its co-location in collaboration with Shanghai Astronomical Observatory. The 40-m TNRT is the largest telescope for radio astronomy in Southeast Asia, offering flexible operation across a wide frequency range of 0.3-115 GHz. This capability enables significant contributions to time-domain astronomy and allows for comprehensive surveys across various scientific research fields, as outlined in a recently published white paper. Collaborating with VLBI arrays in the world, such as the European VLBI Network (EVN), the TNRT will drastically enhance the imaging quality and performance due to its unique geographical location. This advancement marks a significant step for both radio astronomy and geodetic VLBI studies. In this presentation, we will review the progress of TNRO, including the Call for Proposals initiated in October 2023, and the preparations for VLBI observations, highlighted by the first fringe detection in the L-band. Additionally, we will discuss the future expansion of TNRO through the construction of additional VGOS stations and the vision for establishing forthcoming regional VLBI networks based on TNRT. This includes the Thai National VLBI Array and Southeast Asia VLBI Network, in collaboration with Indonesia, Malaysia, and Vietnam.

Session XVI: VLBI perspectives II – Chair: Zsolt Paragi / 7

Commissioning of the BRAND receiver at Effelsberg

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The BRAND receiver is a new system mainly intended for the EVN that covers the remarkably broad contiguous frequency range of 1.5 GHz to 15.5 GHz. It includes all required components of the entire signal path from the cryogenic frontend, feed, amplifiers, hybrids, the 56 Gsps sampler up to the VLBI backend and is intended for VLBI and single-dish work. This band coverage offers flexibility for redshifted spectral lines, sensitivity and frequency agility in the EVN.
In this talk I will present work recently carried out as part of my master thesis to integrate the BRAND components into a prototype system to be installed in the Effelsberg 100-m telescope, which continues the development from the RadioNet BRAND-EVN project. The Effelsberg prototype will enable - for the first time - on-sky measurements with a new generation of very broad-band receivers. This will allow to assess the real-world performance in various scenarios, e.g. astronomical as well as geodetic VLBI and single-dish applications and should help inform the decision-making about future EVN capabilities. The work presented is based on technical tests on the cryogenic-, IF-, and data-acquisition system in Bonn and Effelsberg. On-sky tests include single dish spectroscopy, pulsar observations, and VLBI and I will present results as available.

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Enhancing VLBI capabilities: recent achievements and future upgrades of the INAF radio telescopes

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Small and flexible VLBI arrays, as exemplified by the successful EVN-lite operational model, can produce significant scientific outcomes. INAF, the Italian National Institute of Astrophysics,

operates such an interferometer, comprising three dishes with a total collecting area equivalent to an 80m radio telescope and baselines up to 950 km, supported by a software correlator in Bologna. This facility can serve as a complementary resource to the full-size EVN. I will present recent observational results in the areas of active galactic nuclei and astrophysical transients, showcasing the current capabilities. Additionally, I will discuss ongoing upgrades, including the installation of compact triple-band receivers for millimeter-wave observations and plans for broadband receivers. I will highlight the potential for multi-wavelength and multi-messenger studies, and especially the possible synergies with neutrino and gravitational wave detectors.

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The Global Millimetre VLBI Array: Current Capabilities and Future Enhancements

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The Global Millimetre VLBI Array (GMVA) represents the most extensive array for high-resolution observations at 3.5 mm wavelengths. The mm-VLBI technique has reached a state of maturity and is now delivering cutting-edge results (e.g., the combined image of the black hole shadow and the jet in Messier 87 published by Lu et al. in April 2023). A leap forward is planned with upcoming advancements, including multi-band receivers which will allow the frequency-phase transfer technique to be used, mitigating atmospheric phase fluctuations and improving image fidelity by one order of magnitude in terms of signal-to-noise ratio in the observations. A new generation of digital baseband converters yields a big increase the data bit rate, allowing for more efficient data processing and higher quality observations. Furthermore, the expansion of the network with new telescopes, such as the phased ALMA and the forthcoming APEX, is continuously enhancing the Fourier sampling and therefore the resulting image fidelity. These technological advancements and network expansions will significantly boost the GMVA's observational power, paving the way for new discoveries in millimetre-wave astronomy over the next years, connecting the European VLBI Network and global cm-wavelength down to 7mm with the Event Horizon Telescope observations at shorter wavelengths.

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LEVERAGE - Concept for a long-baseline extension in next-generation VLBI experiments and rapid-response array

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The next decades of radio astronomy will be dominated by large facilities of superior sensitivity. Between 1GHz and 15GHz, strong synergies can be developed between the next-generation Very Large Array (ngVLA) and the Square Kilometre Array (SKA), specifically the SKA-mid. Towards higher frequencies, the ngVLA will be able to co-observe with other frontline facilities including the EVN (at 1-43 GHz), and the GMVA (at 43-86 GHz). In this talk, we will discuss the possibility of enhancing these synergies with an array of mid-to-high frequency radio antennas in Germany to be operated as a stand-alone facility, as well as a complement to the ngVLA, SKA-mid, EVN, and GMVA in VLBI and studies of transients. LEVERAGE is a concept for an array of two to four radio-antenna stations operating in the mid-to-high frequency range (up to 120GHz) with baselines between 500km and 1000km, which will significantly enhance the science capabilities of both the SKA and ngVLA in terms of submilliarcsecond-scale image reconstruction and flexibility in reacting to short transient events. Moreover, the LEVERAGE concept offers high efficiency as a stand-alone instrument and can be optimized to localize and follow-up radio transients with a faster reaction time than the larger next-generation facilities. The facility may support special modes that are difficult to realize on the full large next-generation facilities or are going beyond their scope such as long uninterrupted integrations, high-cadence observations, long-term monitoring or broader simultaneous frequency coverage.

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First Closing Address

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Symposium Summary

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Past, present, and future of VERA

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We constructed the Japanese VLBI network VERA (VLBI Exploration of Radio Astrometry) in early 2000s, which consists of four 20-m antennas with the maximum baseline length of 2300 km. The primary goal of VERA was to determine the 3D structure of the Milky Way Galaxy through VLBI astrometry (Honma et al. 2012, 2015), by measuring trigonometric annual parallaxes and proper motions of Galactic radio sources up to 10 kpc distances (Nagayama et al. 2020, Oyama et al. 2024). For this purpose, we developed the unique dual-beam receiving system with which target Galactic (mostly 22 GHz H_2O and 43 GHz SiO maser sources) and reference extra-galactic sources with separation angles within 2.2 degrees can be observed simultaneously (Honma et al. 2008). VERA as the Galactic astrometry project was completed in 2020 and the resultant catalog paper was published (VERA collaboration, Hirota et al. 2020).
Currently, VERA is open for VLCOP (VERA Large-scale Collaborative Programs) mainly led by the Japanese domestic communities contributing to array operation and instrumental developments. VERA has been collaborating with the Korean VLBI Network (KVN) just after the construction of both arrays in mid-2000's, and regular common-use observations have been conducted with KaVA (KVN and VERA Array) since 2014. Furthermore, some Chinese telescopes have been contributing to establish EAVN (East Asian VLBI Network), and it has also been open for common-use programs since 2018.
For the future plan, we are considering possibilities to expand collaborations with other networks such as South-east Asian VLBI Network, EVN, global VLBI alliance, and SKA-VLBI.
In this presentation, we will review past accomplishment, current status and possible future plan of VERA.

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East Asian VLBI Network: Scientific Accomplishments in the First Six Years and Progresses in International Collaboration

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The East Asian VLBI Network (EAVN) has been launched as a new international VLBI array in collaboration with four institutes in China, Korea, and Japan in 2018 by expanding capabilities of the KVN and VERA array (KaVA). EAVN collaboration was expanded with inviting three new partner institutes in 2021, resulting in becoming one of the biggest VLBI arrays in the world. Current EAVN consists of 17 radio telescopes and three correlators, and is operated mainly at three frequency bands, 6.7, 22, and 43 GHz with the longest baseline length of about 5100 km. One of distinct capabilities of EAVN is multi-frequency simultaneous data reception at ten telescopes, which enable us to employ the frequency phase transfer technique to obtain better sensitivity at higher observing frequencies. EAVN has conducted 962 observing sessions (160 sessions/yr) with the total observing time of 6370 hours (1060 hr/yr) as of the end of the 2024A semester, and 55 articles using observing data by KaVA/EAVN have been published in refereed journals. On the basis of scientific accomplishments made by EAVN and geographical uniqueness, we are actively conducting global-scale VLBI experiments by collaborating with overseas VLBI arrays. Those activities may provide some hints for considering future growth into the Global VLBI Alliance (GVA). The talk mainly covers overview of EAVN, various scientific accomplishments and international collaborations made by EAVN in the first six years. I would also like to discuss possible future growth into GVA.

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Current developments with the LBA

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The Long Baseline Array (LBA) is the only Southern Hemisphere VLBI network, operated as a collaboration between CSIRO, the University of Tasmania, HartRAO, and SpaceOps New Zealand. The LBA has an "open sky" policy and observes for typically 25 days per year, with most of this time scheduled in four or five intensive sessions, interspersed with single observations as required. Most experiments are conducted at frequencies between 1.4 and 22 GHz, although ATCA and Mopra can observe at 43 and 86 GHz. Experiments are correlated by CSIRO staff using the DiFX software correlator running on a supercomputer at the Pawsey Supercomputing Centre in Perth. In this talk, I will discuss the current capabilities of the LBA, as well as current and planned developments for the individual antennas, such as "Ultra-wideband" receivers and a cryogenically cooled phased array feed for the Parkes Murriyang telescopes, and a new GPU-based digital backend for the ATCA. In the era of the SKA, the LBA will be positioned to play a major role in VLBI follow-up of discoveries and will continue to play a significant role in global VLBI science.

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PKS 1335-127 EHT Observations for multi-wavelength analysis

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The Flat Spectrum Radio Quasar PKS 1335-127, situated at a redshift of z=0.539, is among the most extensively studied blazars. This research aims to compare the jet features observed in gamma-rays and radio wavelengths during the 2018 and 2021 observation campaigns by the Event Horizon Telescope (EHT). Notably, a possible flare was detected in June 2020 in gamma-rays, marked by a significant increase in optical brightness by approximately 1.5 to 2 magnitudes. Leveraging the robust UV-coverage and high signal-to-noise ratio data from the 2018 and 2021 EHT observations campaigns, we are conducting a detailed multi-wavelength analysis to examine the variability and emission origins of the jet on microarcsecond scales. We aim to investigate the jet's characteristics at gamma-rays and radio wavelengths, to provide deeper insights into the mechanisms driving jet emission and variability in PKS 1335-127. This study underscores the importance of simultaneous multi-wavelength imaging in understanding the dynamic behavior of blazar jets and contributes to the broader knowledge of blazar physics.