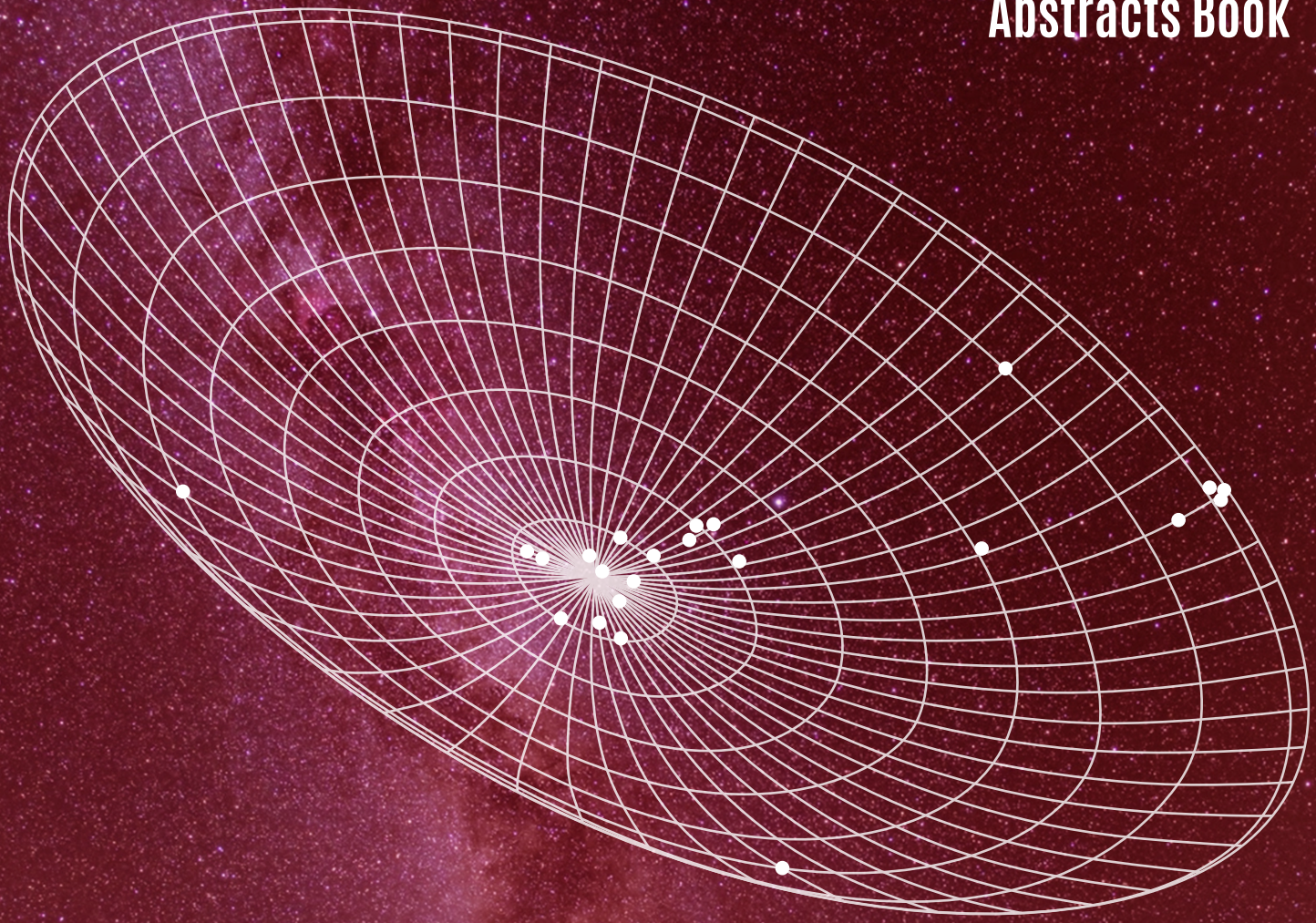
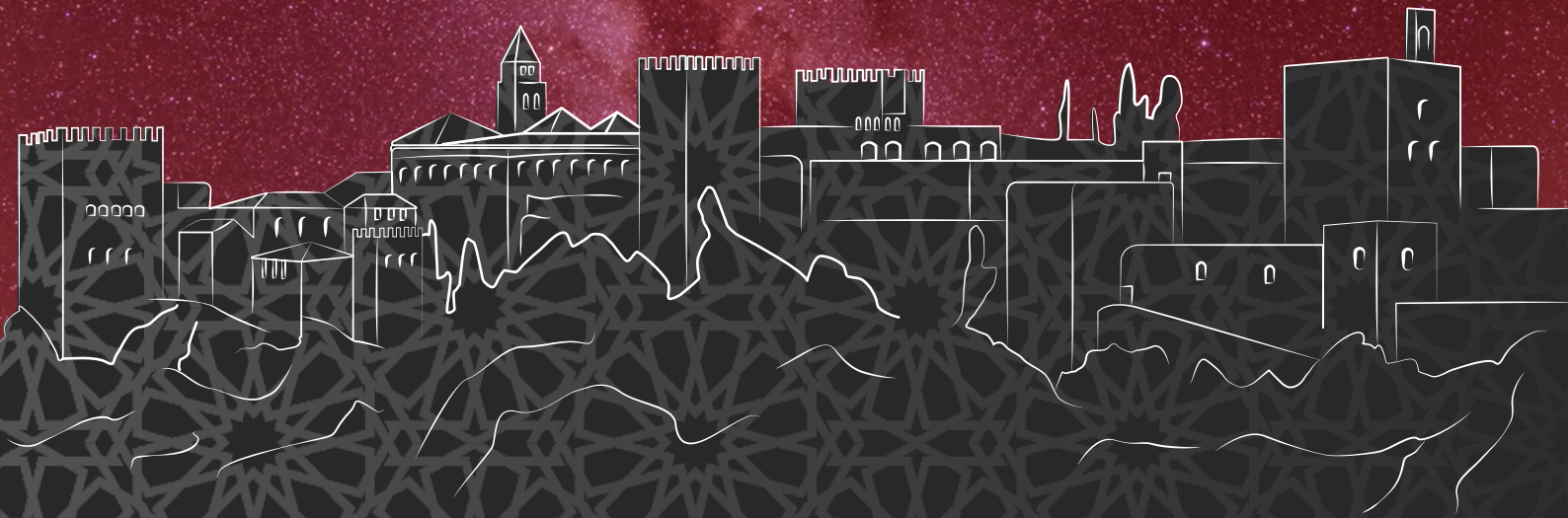
14th EVN Symposium & Users Meeting

Granada (Spain) 8 - 11 October 2018

Abstracts Book





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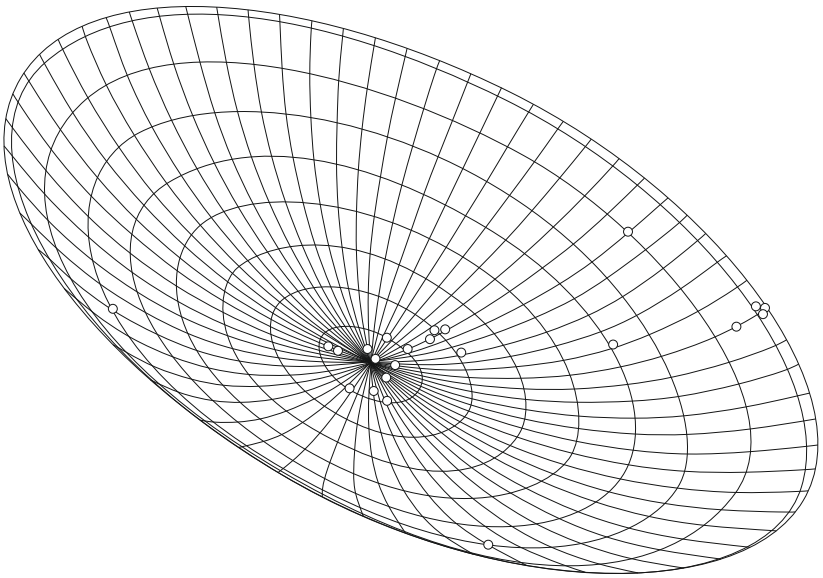
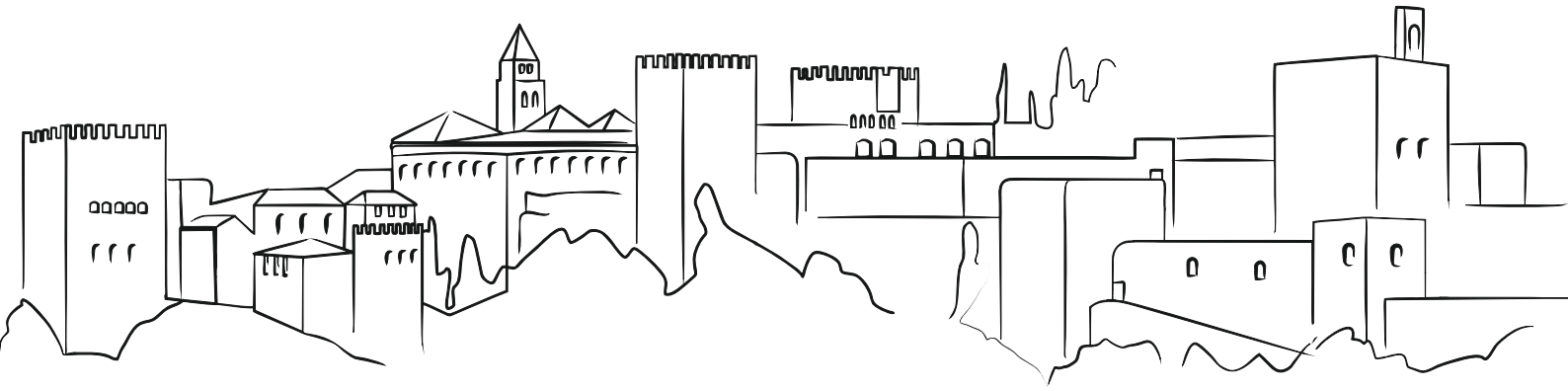
This event has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 (RadioNet)

Program





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Ayuntamiento de Granada

Sunday, 7th

20:00 **Early registration and welcome cocktail at *Cuarto Real de Santo Domingo*.**

Monday, 8th

08:00 **Registration opens**

09:00 - 09:30 **Opening by President of CSIC, Directors of IAA-CSIC and OAN-IGN, and Chair of EVN CBD** at Auditorium

Stellar Evolution Session 1 (Chair: F. Colomer) at Auditorium

09:30 - 10:00 **"Studies of stellar evolution using masers", A. Bartkiewicz (Review)**

10:00 - 10:15 **"Revealing magnetic fields towards massive protostars: a multi-wavelength approach using masers and dust", D. Dall'Olio**

10:15 - 10:30 **"Magnetic field measurements around massive young stellar objects with the EVN", G. Surcis**

10:30 - 10:45 **"KaVA Large Proposal for High-Mass Star-Formation Studies with Multiple Masers", T. Hirota**

10:45 - 11:00 **"High-mass star formation expored with maser VLBI & thermal (ALMA, JVLA) observations", L. Moscadeli**

11:00 - 11:30 **Coffee break**

AGN Session 1 (Chair: D. Gabuzda) at Auditorium

11:30 - 12:00 **"The sharpest view of blazar jets through space and mm-VLBI observations", J.L. Gómez (Review)**

12:00 - 12:15 **"Does Cygnus A harbor a binary black hole?", U. Bach**

12:15 - 12:30 **"Moving cores in MOJAVE sample", M. Lisakov**

12:30 - 12:45 **"RadioAstron survey completed: AGN cores at unprecedented angular resolution", Y. Kovalev**

12:45 - 13:00 **"Zooming in the jet formation site in AGN with RadioAstron", T. Savolainen**

13:00 - 13:15 **"Radioastron observations of the jet launch region in 3C84", G. Giovannini**

13:15 - 13:30 **"Innermost region of the blazar S5 0716714 from RadioAstron polarimetric observations at 22 GHz", E. Kravchenko**

13:30 - 15:00 **Lunch break**

Fast Transients, Neutron Stars & Pulsars (Chair: J. Moldon) at Auditorium

15:00 - 15:30 **"The localization of a repeating Fast Radio Burst", B. Marcote (Review)**

15:30 - 15:45 "Recent VLBI Results on SN 1986J and the Possibility of FRBs Originating from Inside the Expanding Ejecta of Supernovae", M. Bietenholz

15:45 - 16:00 "Unravelling pulsar scattering through VLBI", D. Simard

16:00 - 16:15 "Observing pulsars with ALMA: an unprecedented opportunity to explore the millimetre wavelength regime of pulsar emission", P. Torné

16:15 - 16:30 "Imaging pulsar echoes at low frequencies", O. Wucknitz

16:30 - 16:45 "Pulsar scintillometry on the Vela pulsar with the LBA", F. Kirsten

16:45 - 17:00 "The Large European Array for Pulsars: Experimental setup, now and future", K. Liu

17:00 - 17:30 **Coffee break**

17:30 - 18:30 **EVN Users Meeting, Chair: A. Polatidis (EVN PC Chair)**
"Welcome and updates from the EVN Program committee", A. Polatidis
"EVN User Support provided by JIVE", Z. Paragi
"Updates from the JIVE Correlator", B. Campbell
"Answer to questions from the community", EVN officers and personnel from JIVE (moderator A. Polatidis)

Social Activities

19:30 **EVN Symposium Football match at *Complejo Deportivo Núñez Blanca*.**

Tuesday, 9th

Starbursts, Low Luminosity AGN and Surveys (Chair: A. Alberdi) at Auditorium

09:00 - 09:30 "Continuum Observations of Starburst Galaxies", J. Conway (Review)

09:30 - 09:45 "Star-formation and accretion in the local Universe - LeMMING's an e-MERLIN survey", R. Beswick

09:45 - 10:00 "EVN imaging of the obscured nuclei of the LIRGI galaxies", N. Ramírez-Olivencia

10:00 - 10:15 "Searching for intermediate-mass black holes in NGC3310", M. Argo

10:15 - 10:30 "Studying galaxy evolution through cosmic time via the μJy radio population: early results from eMERGE DR1", T. Muxlow (on behalf of A. Thomson)

10:30 - 10:45 "Extragalactic wide-field surveys using the European VLBI Network", P. Barthel (on behalf of J. Radclife)

10:45 - 11:00 "SETI searches with the EVN", M. Garrett

11:00 - 11:30 **Coffee break**

	AGN Session 2 (Parallel) (Chair: S. Frey) at Auditorium	Stellar Evolution Session 2 (Parallel) (Chair: A. Bartkiewicz) at Faraday Room
11:30 - 11:45	"Extreme physics at extreme baselines", A. Lobanov	"Multiepoch observation of periodic methanol maser in G107.2985.63", M. Olech
11:45 - 12:00	"Polarimetric millimeter VLBI observations of 3C 84", J.-Y. Kim	"Parallaxes and proper motions of star-forming regions in the Sagittarius spiral arm", K. Rygl
12:00 - 12:15	"Tracing AGN feedback in powerful radio galaxies with VLBI", R. Schulz	"A study of the physical environments of evolved stars from the SiO and H2O masers", Y. Yun
12:15 - 12:30	"VLBI and the faint radio AGN population", N. Herrera-Ruiz	"NGC6334I - Tracing the Gas Motion During A Contemporaneous Maser Flare Event", J. Chibueze
12:30 - 12:45	"Three little radio galaxies in the early Universe", K. Gabanyi	"Measuring Magnetic Fields from Water Masers in the Synchrotron Protostellar Jet in W3(H2O)", C. Goddi
12:45 - 13:00	"Multi-frequency studies of the jet in the high-redshift quasar S5 0836+710", L. Vega-García.	"COBRaS: The e-MERLIN 21cm Legacy Survey of Cygnus OB2", D. Fenech
13:00 - 13:15	"Gravitational lensing at milliarcsecond resolution with global VLBI observations", C. Spingola	"Investigating Black hole formation using VLBI", P. Atri
13:15 - 13:30	"Insights into galaxy evolution with strong gravitational lensing", H. Stacey	
13:45 - 15:00	Lunch break	

Multi-Messenger and Multi-Wavelength (Chair: Z. Paragi) at Auditorium

15:00 - 15:30	"Multi messenger astronomy", M. Branchesi (Review)
15:30 - 15:45	"The Synergy between VLBI and Gaia astrometry", H. van Langevelde
15:45 - 16:00	"The radio view of Gravitational waves counterparts: GW/GRB170817", G. Ghirlanda
16:00 - 16:15	"A dust-enshrouded tidal disruption event with a resolved radio jet in a galaxy merger", M. Perez-Torres (on behalf of S. Mattila)
16:15 - 16:45	"Synergies between VLBI and high-resolution IR/optical interferometry", J. C. Guirado (Review)

16:45 - 17:15	"Synergies between CTA and VLBI", **M. Orienti (Review)**
17:15 - 17:45	**Coffee break**
17:45 - 18:30	EVN Vision Discussion, **T. Venturi**
	Social Activities
21:00 - 23:30	**Night visit to the *Alhambra* *Nazari Palaces*. Buses will pickup participants from the conference venue.**

Wednesday, 10th

09:00 - 09:30	"Precise Astrometry today and tomorrow, with Next-generation Observatories", **M. Rioja (Review, Plenary)** at Auditorium	
	AGN Session 3 (Parallel) (Chair: B. W. Sohn) at Auditorium	**Astrometry (Parallel) (Chair: P. Charlot) at Faraday Room**
09:30 - 09:45	"Evolution of AGN jets from multi-epoch core-shift studies", **A. Plavin**	"Where are you, Scutum? Tracking down a spiral arm with maser astrometry", **K. Immer**
09:45 - 10:00	"Exploring the non-linear motion of the parsec-scale jet of FSRQ 1633382", **H. Ro**	"Sensing the astrophysical influence within VLBI astrometric measurements of extragalactic radio-sources", **C. Gattano**
10:00 - 10:15	"Gamma-ray emission in radio galaxies under the VLBI scope", **R. Angioni**	"Einstein Equivalence Principle test with RadioAstron: preliminary results", **D. Litvinov**
10:15 - 10:30	"Resolving the Radio-Loudest Quasar known to date at z~6", **E. Momjian**	"Tying multiple Radio Wavelength Celestial Frames to the Gaia Optical Frame", **C, Jacobs**
10:30 - 10:45	"Asymmetric jet production in NGC1052", **A.-K. Baczko**	"Progress update of the VGOS radio telescope at Metsähovi Gedodetic Research Station", **G. Molera Calvés**
10:45 - 11:00	"Substantial winds from the accreting supermassive black hole in M87 revealed by Faraday rotation observations", **J. Park**	"VLBI and Doppler tracking of spacecraft for planetary atmospheric studies", **T. Bocanegra**
11:00 - 11:30	**Coffee break**	
	AGN Session 4 (Parallel) (Chair: S. Pushkarev) at Auditorium	**Stellar Evolution Session 3 (Parallel) (Chair: M. Lindqvist) at Faraday Room**

11:30 - 11:45	"What the iMOGABA tells us about Gamma-ray bright AGNs", S.S. Lee	"Jets from massive protostars: clues on their role in the formation process from masers and high resolution radio / NIR imaging", F. Bacciotti
11:45 - 12:00	"Toroidal magnetic fields and associated currents in AGN jets on kiloparsec scales", S. Knuettel	"Detailed SiO proper motion analysis: slow net expansion and a small correlation with the magnetic field", A. Richards
12:00 - 12:15	"Double nuclear structure discovered in 3C84", J. Oh	"Studies of galactic masers in RadioAstron space VLBI mission", A. Sovolev
12:15 - 12:30	"Radio structures in radio-quiet quasars with extremely powerful X-ray outflows", J. Yang	"Short-lived episodic outflow in a water fountain star", R. Burns (on behalf of G. Orosz)
12:30 - 12:45	"Global Millimeter VLBI Array Survey of Ultracompact Extragalactic Radio Sources at 86 GHz", D.G. Nair	"3D Models of Maser Flares", M. Gray
12:45 - 13:00	"Parameter study of a semi-analytical relativistic MHD jet model in comparison with recent VLBI observations", C. Ceccobello	"Resolving discrepancy in the pPN OH231", J.-F. Desmurs
13:00 - 13:15	"Use of VLBI/Gaia position offsets for AGN physics", L. Petrov	"Multi-epoch VLBI of a double maser super-burst", R. Burns
13:15 - 13:30	"Expanding VLBI in East Asia and AGN science", K. Hada	"Radio emission in ultracool dwarfs: the nearby triple system VHS 1256 – 1257", J. Climent
13:30 - 15:00	**Lunch break**	

Social Activities

13:30	**Visit to *IRAM 30m Telescope* for the 50 participants who registered. A bus will pickup participants from the conference venue. A lunch bag will be provided to have lunch at the mountain.**
18:30	**Public talk: "Agujeros negros: los límites del espacio y el tiempo", E. Ros (at the conference venue, in Spanish)**
20:30	**Conference dinner at *Palacio de Santa Paula*.**

Thursday, 11th

EHT and new VLBI Developments (Chair: B. Campbell) at Auditorium

09:00 - 09:30 "Imaging Black Holes", H. Falcke (Review)

09:30 - 09:45 "Probabilistic fringe-fitting and source model comparison", I. Natarajan

09:45 - 10:00 "CASA on the fringe", I. van Bemmel

10:00 - 10:15 "RPICARD: A CASA-based Calibration Pipeline for VLBI Data", M. Janssen

10:15 - 10:30 "BRAND - the next generation receiver for VLBI", W. Alef

10:30 - 10:45 "A development of compact triple band receiver for millimeter-wave radio astronomy", S.-T. Han

10:45 - 11:00 "Comparing remote atomic clocks via VLBI networks and fiber optic links: the LIFT/MetGeSp perspective", R. Ricci

11:00 - 11:30 **Coffee break**

High Sensitivity VLBI with SKA and other VLBI Arrays (Chair: P. de Vicente) at Auditorium

11:30 - 12:00 "The science impact of high sensitivity VLBI with SKA", C. García-Miró (Review)

12:00 - 12:15 "SKA-VLBI Key Science Programmes", Z. Paragi

12:15 - 12:30 "Investigations on MultiView VLBI for SKA", R. Dodson

12:30 - 12:45 "Activities of VERA and East Asian VLBI network", H. Kobayashi

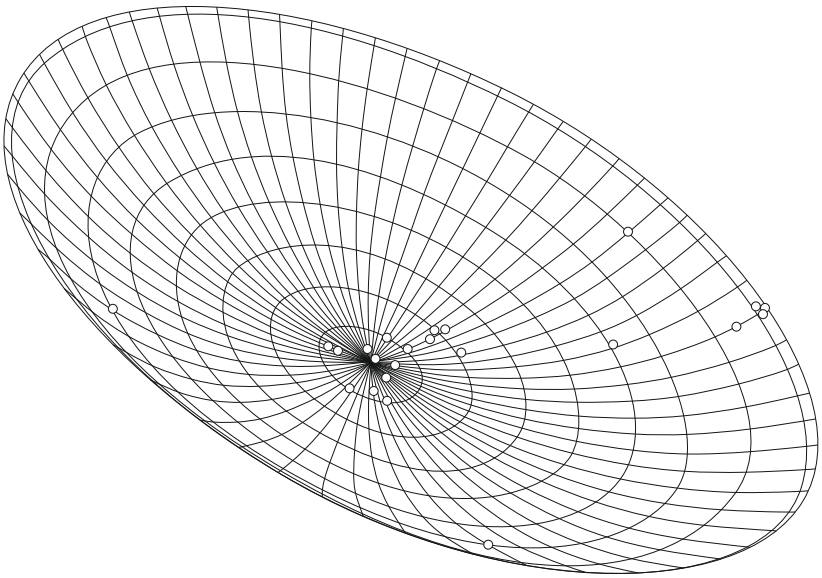
12:45 - 13:00 "Status of the Very Long Baseline Array", W. Brisken

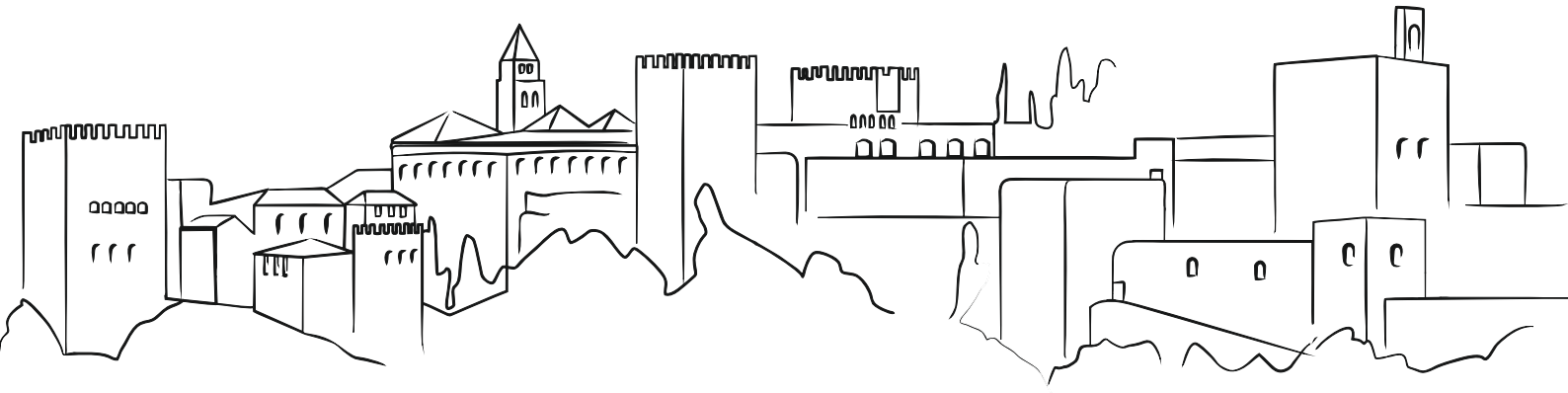
13:00 - 13:30 EVN Symposium 2018 Summary, T. Venturi and H. J. van Langevelde

13:30 - 15:00 **Lunch**

15:30 - 18:30 CASA-VLBI tutorial organized by JIVE (registration is required through this separate form). The tutorial will take place at the main auditorium of the IAA-CSIC.

Talks





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BRAND - the next generation receiver for VLBI

W. Alef, G. Tuccar, M. Pantaleev, J. Flygare, J.A. López Pérez,
Félix Tercero, G. Schonderbeek, L. Bezrukovs

The aim of the BRAND EVN project is to build a very wide receiver prototype for primary focus with a frequency range from 1.5 GHz to 15.5 GHz In addition
we will investigate solutions for secondary focus telescopes.
The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]. We present
the status of the project which was started on January 1st, 2017 and is progressing smoothly: Feed, LNA, filters, major digital components, and some of the firmware are available now.

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Gamma-ray emission in radio galaxies under the VLBI scope

R. Angioni, E. Ros, M. Kadler, R. Ojha for the TANAMI and Fermi-LAT collaborations

We report on the first systematic VLBI and gamma-ray monitoring study of a representative sample of radio galaxies with strong compact radio emission, with the aim of exploring the intrinsic relationship between high-energy emission and pc-scale jet properties in active galactic nuclei (AGN). While a number of studies have firmly established a close relationship between the gamma-ray and radio properties of AGN in general, the samples considered are dominated by blazars, i.e. AGN featuring well-aligned, Doppler-boosting-dominated jets. This poses a challenge in disentangling the orientation-dependent effects from the intrinsic emission produced in AGN jets. Radio galaxies, on the other hand, have misaligned jets whose emission is much less affected by Doppler boosting. We find that the high-energy emission in the compact jets of radio galaxies is not strongly driven by orientation-dependent Doppler boosting effects, much unlike the situation in their blazar counterparts. However, a significant correlation between gamma-ray flux and radio flux still holds, suggesting a direct physical link between the intrinsic emission properties of AGN jets in the two wavebands. We base our study on the decade(s)-long VLBI monitoring provided by the TANAMI and MOJAVE programs, in combination with gamma-ray data from Fermi-LAT, and also report on the interplay between pc-scale jet kinematics and gamma-ray emission in key individual sources such as the classic FR II radio galaxy Pictor A and the peculiar AGN PKS 0521-36.

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Searching for intermediate mass black holes in NGC3310

Megan Argo (UCLan), Joseph Coppola (UCLan), Hannah Earnshaw (Caltech), Mar Mezcua (IEEC-CSIC), Tim Roberts (Durham)

Intermediate-mass black holes are theoretically predicted but observationally elusive, and evidence for them is often indirect. The nearby face-on spiral galaxy NGC3310 has hosted many supernovae in recent history, and recent Chandra observations have shown a group of strong off-nuclear x-ray sources that are coincident with radio emission seen in archival VLA and MERLIN observations. Their luminosity, spectrum and off-nuclear location make these sources excellent IMBH candidates. To investigate this possibility, we used combined EVN/e-MERLIN observations at both 1.4 and 5 GHz to look for compact radio emission and evidence of jet activity. I will show the results of these observations and the implications for IMBH parameter space.

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Investigating Black hole formation using VLBI

Pikky Atri, James Miller-Jones, Peter Jonker, Tom Maccarone, Gijs Nelemans, Gregory Sivakoff, Anastasios Tzioumis

Even though the first black hole (BH) was detected decades ago, the mechanism by which BHs form is not observationally well constrained. Theoretical models suggest that BHs are born when a massive star dies, either with or without a supernova explosion. BHs born with a supernova explosion should get strong natal kicks, whereas direct collapse BHs do not incur
such a kick. We are measuring the proper motions (few mas/yr) of BH X-ray binary (BHXB) systems during their hard states by using Very Long Baseline Interferometry (VLBI) networks all over the globe, including the European VLBI Network. Combining the proper motion with the radial velocity and distance to the system, the full three-dimensional space velocity can be obtained. The system can then be traced back in time through the Galactic potential to estimate the magnitude of the natal kick that could have put the binary system into its Galactocentric orbit. We are also folding into our analysis the few BHXB systems that are optically bright enough in quiescence for their proper motion to be measured by Gaia. A strong natal
kick could unbind a binary system present in the field or result in ejection of BHs from globular clusters, both of which decrease the probability of formation of a BH-BH binary. Thus, the BH natal kick distribution directly affects the predicted rates of BH-BH mergers. We aim at increasing the sample set of estimated natal kicks to obtain an observationally constrained
natal kick distribution. In this talk, I will present the natal kick analysis of several BHXB systems, including one system that was observed using the EVN (Swift J1753.5-0127).

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Jets from massive protostars: clues on their role in the formation process from masers and high resolution radio / NIR imaging

F. Bacciotti (1), F. Massi (1), L. Moscadelli (1), C. Arcidiacono (2)

(1) INAF-Osservatorio Astrofisico di Arcetri
(2) INAF-Osservatorio Astronomico di Bologna

Disks and jets are believed to deeply influence the early evolution of low-mass stars, but their role in high-mass (M > 7 Msun) star formation is still unclear. A close investigation of disk/jet systems in the high-mass regime can help establishing if high-mass stars emerge from a scaled-up version of the low-mass formation scenario. We selected a sample of 40 high-mass young stellar objects from the BeSSeL (Bar and Spiral Structure Legacy) survey, located at a distance d < 4 kpc, and conducted multi-epoch observations of water masers and multi-frequency radio continuum imaging with VLBI /JVLA at subarcsec resolution. In this way we have been able to investigate the initial 100 au of jets and winds accelerated by the driving source. Critical information on jet collimation and propagation, however, can only be obtained by linking the sub-arcsec structure to the outflowing gas pattern on scales of 10^2-10^5 au from the central star (up to 0.5-1 arcmin). To investigate this region, still heavily embedded, we carried out very deep sub-arcsecond imaging of a sub-sample of 6 targets in the H2 emission at 2.12 microns, which is a tracer of jet shocks, with the LUCI NIR cameras mounted at the Large Binocular Telescope (LBT). Here we present the results of our multi-wavelength observations of these 6 sources in maser, radio, and H2 emission. We detect H2 signatures associated to all the targeted compact radio sources, elongated in the same direction than the innermost radio emission. Our study confirms the presence of collimated jets in the vicinity of newly formed high-mass stars, pointing to a formation mechanism similar to the one of low-mass stars.

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Does Cygnus A harbor a binary black hole?

Uwe Bach, Bia Boccardi, Thomas Krichbaum, and Andrei Lobanov

Recently a new radio source was detected with the VLA in Cygnus A at a distance of about 460 parsec from the center. The source is not directly associated with the VLBI core and the jets, but coincides with a compact optical/near-IR source.
We detected the new source on sub-parsec scales with EVN observations at 1.3cm in March 2017 and 6cm and 18cm in May/June 2017. It appears compact and more luminous than any known radio super nova. The most plausible origin of the
emission is a recent onset of activity from a so far not detected secondary super-massive black hole (SMBH). It could be an extreme type of a super-nova, but the enormous luminosity and compactness on sub-parsec scales and the flat spectral index suggest that a secondary SMBH may exist in the immediate surroundings of the central engine in Cygnus A.
Here we present our EVN observations and discuss their implications. Secondary SMBH are expected to be ubiquitous in galaxies, but they remain difficult to detect, with only a few celebrated cases known so far. The discovery that this archetypical powerful FRII radio galaxy may be a binary SMBH could mean that SMBH binaries may be more common, and more important, than previously considered.

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Asymmetric jet production in NGC1052

A.-K. Baczko, R. Schulz, E. Ros, M. Kadler, M. Perucho, C. Fromm, J. Wilms

AGN with a twin-jet system are rare. Even more unusual are those which reveal asymmetries between both jets as well as being absorbed by a surrounding torus. The LINER NGC 1052, located at a close distance of about 20 Mpc, is a source that has both. Does this imply intrinsic asymmetry and even infer an asymmetric jet production? One indication towards this interpretation is the difference in speeds between both jets observed at 43 GHz (about 0.35c for the eastern jet and 0.57c for the western one).
We present multi-wavelength observations from 1.4 GHz up to 86GHz to probe regions on scales from milli-parsec up to several parsecs. In this way, free-free and synchrotron-self absorption can be examined in detail from a fully obscured inner area at low frequencies to a glowing central core in the jet forming regions at higher frequencies. Resolutions down to 50 micro arcseconds, thanks to RadioAstron and mm-VLBI, give us access to unknown regions in which we expect the formation of the twin-jet system.

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Studies of stellar evolution using masers

Anna Bartkiewicz

> Studies of maser emission with high angular resolution are one of the best tool for deriving kinematics and the physical conditions of regions that are hidden in the dense environment and are not reachable at other wavelength ranges. Therefore, the European VLBI Network is successfully used to investigate high-mass star forming regions and evolved stars. With the milliarcsecond resolution and sensitivity of a few mJy it provides valuable informations concerning astrometry, proper motions, magnetic field. I will summarize the recent observational progress on masers at the cm wavelengths and its input on the stellar evolution.

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star-formation and accretion in the local Universe - LeMMING's an e-MERLIN survey

R. Beswick, I. McHardy, R. Baldi, D. Williams, M. Argo, J. Westcott, T. Muxlow and the LeMMINGS consortia.

The e-MERLIN LeMMINGs (Legacy e-MERLIN Multi-band Imaging of Nearby Galaxies survey) is a high resolution radio imaging survey of ~300 galaxies in the local Universe, with a significant multi-wavelength follow-up campaign. The goals of this survey are to provide detailed characterisation of star-formation and accretion activity across a wide range of galaxy types, sizes, luminosities and environments. In this talk I will describe the project its status and the first wave of results from this survey, including a range of extremely deep targeted observations (e.g. Dullo et al 2018, Westcott et al, 2017, 2018, Rampadarath et al, 2018, Williams et al 2017) and the first of the large statistical results which characterise the compact radio emission from the sample (Baldi et al 2018).

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Recent VLBI Results on SN 1986J and the Possibility of FRBs Originating from Inside the Expanding Ejecta of Supernovae

Michael Bietenholz
Norbert Bartel

I present recent VLBI results on SN 1986J, which is one of only a handful of supernovae where the radio emission of the expanding ejecta can be resolved using VLBI. SN 1986J is unusual in that a compact synchrotron radio emitting component appeared in the centre of the expanding shell of ejecta about 14 yr after the explosion, and now dominates the VLBI image. The central component may be due to a newly formed pulsar wind nebula, or an accreting black hole, or it may be due to interaction of the supernova shock with a highly structured environment left over from a progenitor which was in a close binary system. I present our latest VLBI image of SN 1986J and discuss the constraints on the nature of the central component.

Although no Fast Radio Burst (FRB) has been observed from SN 1986J, its central component presents us with a unique opportunity to observe radio signals which have propagated through the ejecta of a young SN, which provides strong observational constraints on the propagation of FRB signals through such environments. We conclude that at least for Type II SNe, the SN environment remains opaque to FRB signals for several decades, by which time the dispersion measure produced by the ejecta is much smaller than typically seen for FRBs.

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VLBI and Doppler tracking of spacecraft for planetary atmospheric studies

Tatiana Bocanegra Bahamon

The Planetary Radio Interferometry and Doppler Experiment (PRIDE) is a technique that can enhance the science return of planetary missions. By shadow tracking the spacecraft signal using radio telescopes from different VLBI networks around the world, the PRIDE technique provides precise open-loop Doppler and near-field VLBI observables (Duev et al. 2012, Bocanegra-Bahamon et al. 2018a) to find the radial velocity of the spacecraft and its position in the plane of the sky. This information is not only important for navigation, but it can also be used for many science applications. One such case is the study of planetary atmospheres by means of radio occultation experiments.

The application of PRIDE for atmospheric studies has been demonstrated by observing ESA's Venus Express (VEX) and Mars Express (MEX) during multiple Venus and Mars occultation events (Bocanegra-Bahamon et al. 2018b). From these observations density, temperature and pressure profiles of Venus and Mars were derived to characterize the planets' ionosphere and neutral atmosphere. The noise budget of the observations indicated that the quality of the detections are comparable to those obtained with NASA's and ESA's deep space networks (Bocanegra-Bahamon et al. 2018a). With PRIDE, making use of open-loop Doppler data, EVN stations were able to sound deeper layers of Venus' thick atmosphere when compared to closed-loop Doppler data provided by ESA's New Norcia. With the wideband spectral analysis of PRIDE, we showed that even with small antennas, such as the 12-m AuScope's Katherine, the spacecraft signal can be detected below Venus' cloud layer.

Radio occultation experiments with PRIDE can exploit the advantage of having access to large radio telescopes from different VLBI networks. Additionally, due to the wide coverage of the networks, the setup can be optimized to ensure high SNR signal detections. This offers a great opportunity when conducting radio occultation experiments with limited SNR of planets or moons with thick atmospheres. Such is the case of radio occultation experiments in the Jovian system, for which the PRIDE team is preparing as one of the experiments selected by ESA for the JUpiter ICy moons Explorer mission (JUICE) mission.

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Multi messenger astronomy

M. Branchesi

On 2015 September 14, the first observations of gravitational waves from the coalescence of a binary system of black holes opened a new exploration of the transient sky. Gravitational-wave astronomy has become a reality. On 2017 August 17, the ground-breaking discovery of gravitational waves and electromagnetic signatures from the coalescence of a binary system of neutron stars marked a new era in multi-messenger astronomy. The talk will review the astrophysical implications of the observations made by the Advanced LIGO and Virgo detectors and the most extensive space- and ground-based follow-ups. Open questions, challenges and future prospects for multi-messenger observations, with particular emphasis on the role of radio observations will be discussed.

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Status of the Very Long Baseline Array

Walter Brisken

In this talk I will present the current status of the Very Long Baseline Array (VLBA), including technical status, Open Skies observing, and prospects for the upcoming decade. The next generation Very Large Array (ngVLA) and its implications for the VLBA will be covered. Additionally I will discuss the VLBA's role in larger networks such as the High Sensitivity Array, global VLBI with the EVN, and concepts for expanding global VLBI capabilities.

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Multi-epoch VLBI of a double maser super-burst

Ross Burns, Olga Bayandina, Mateusz Olech, Gabor Orosz, Huib van Langevelde, Katherina Immer, Willem Baan, Tomoya Hirota, Jungha Kim, Koichiro Sugiyama, Gabriele Surcis, Irina Val'tts, Nadya Shakhvorostova, Georgij Rudnitskij, Alexandr Volvach, Gordon MacLeod, James Chibueze, Pawel Wolak, Anna Bartkiewicz, Busaba Kramer, Alex Kraus, Karl Menten, Kazuhito Motogi, Kee-Tae Kim, Crystal Brogan, Todd Hunter, Stan Kurtz

In a rare and spectacular display, two well-known massive star forming regions W49N and G25.65, recently underwent maser 'super-burst' - their fluxes suddenly increasing above 30,000 and 18,000 Jy, respectively, several orders of magnitude above their usual values.
In quick-response, ToO observations with the EVN, VLBA and KaVA were obtained, during a 4 week campaign - producing high-cadence multi-epoch VLBI investigation of the maser emission. The combination of high-resolution, polarisation and flux monitoring during the burst provides one of the best accounts, to date, of the super burst phenomenon and its relevance to the investigation of massive star formation.

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Parameter study of a semi-analytical relativistic MHD jet model in comparison with recent VLBI observations

C. Ceccobello, W. Vlemmings, M.H.M.Heemskerk, Y. Cavecchi, S. Markoff, P. Polko and D. Meier

Jets are a largely common phenomenon and reveal themselves at different scales and redshifts, showing an extreme diversity in energetics, shapes and emission, in objects such as active galactic nuclei (AGN) and X-ray binaries (XRBs), as well as young stellar objects (YSOs) and gamma-ray bursts (GRBs).
Observations suggest that jets are an energetically important component, not only to the systems that host them, but also their larger surrounding environments, where they deposit a significant amount of energy that has been extracted from the accretion flow.
Therefore, understanding the mechanisms responsible for the formation and emission of jets is a fundamental problem to be addressed.
In this talk, I will present a new integration scheme to solve relativistic MHD equations describing collimated, relativistic outflows.
For the first time, jet solutions can be reconstructed from the disk mid-plane to downstream of the modified magnetosonic fast point, where there are hints of a recollimation shock.
These solutions show a range of jet dynamics (jet Lorentz factor ~ 1-10) and geometric properties (i.e. shock height ~ 10^3 - 10^8 Rg), which makes our model suitable for application to many different systems in which relativistic jets are launched. High-resolution multiband VLBI observations provide unprecedented details of the jet structure, constraining the jet geometry and, therefore, its dynamical properties, from the base up to the shock region.

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NGC6334I - Tracing the Gas Motion During A Contemporaneous Maser Flare Event

James O. Chibueze, Toshihiro Omodaka, Gordon MacLeod, Crystal Brogan and Todd Hunter

NGC6334I showed evidence of episodic accretion event observed as flare in multiple maser species (water, methanol and hydroxyl) and a brightening of the dust continuum emission in millimeter wavelength. Our multi-epoch water maser observations overlapped with this episodic event. Evidence of compact outflows and turbulent gas motion can me seen in the region. MM1 (a dominant millimeter source in the region) recently excited 6.7 GHz methanol masers, and these gas motion we see around it trace the earliest activities associated formation of the driving source in the region.

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Radio emission in ultracool dwarfs: the nearby triple system VHS 1256 − 1257

J.B. Climent, J. C. Guirado, R. Azulay , B. Gauza, M. A. Pérez-Torres, R. Rebolo and M.R. Zapatero-Osorio

Radio observations of ultracool stellar objects (late M, L and T objects) constitute a remarkable opportunity to investigate the magnetic activity of these objects and its influence on the formation of disks or planets.

The system VHS 1256-1257 is one of the candidates to improve the statistics of active cool objects. This young system (150-300 Myr) consists of a 0,1” equal-magnitude M7.5 brown dwarf binary and a planetary-mass L7 companion separated by 8’’. We observed this system with the Jansky Very Large Array and with the European VLBI Network at several frequency bands during 2015 and 2016.

We found weak but persistent radio emission spatially coincident with the main component of VHS 1256-1257. The spectral behavior of the detected radio emission suggests that the acting radiation mechanism would be non-thermal, gyrosynchrotron emission. This implies the presence of magnetic fields of the order of kGauss. In addition, we set a strong upper bound to the flux density of the L7 planetary companion. Future observations with different radio interferometers
to clarify the nature of VHS1256-1257 will be discussed.

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Continuum Observations of Starburst Galaxies

John Conway, Eskil Varenius, Miguel Perez-Torres

VLBI and LOFAR international baseline continuum observations of starburst galaxies are reviewed; concentrating in particular on the nearby well studied LIRG/ULIRG sources Arp299 and Arp220. Such observations reveal compact sources (radio supernovae, supernova remnants and AGN candidates), diffuse disk radio emission, galactic outflows and also trace the presence of thermal gas via observations of free-free absorption. Studying the compact supernovae within these sources can give information about stellar evolution in the extreme conditions found in LIRGs/ULIRGs including whether the stellar IMF follows standard values. The observed SNRs are the sites in which relativistic electrons and other particles are accelerated which in turn gives rise to the radio - star-formation rate correlation - which, although it is a vital tool used in astrophysics, is still poorly understood physically, especially within intense star-forming galaxies. Finally high resolution radio continuum observations of outflows from star-forming galaxies help trace mechanical feedback effects which can affect the evolution of galaxies and the regulation of star-formation.

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Revealing magnetic fields towards massive protostars: a multi-wavelength approach using masers and dust

Wouter Vlemmings, Gabriele Surcis

Magnetic fields play a significant role during star formation processes, hindering the fragmentation and the collapse of the parental cloud, and affecting the accretion mechanisms and feedback phenomena. However, several questions still need to be addressed to clarify the importance of magnetic fields at the onset of massive star formation, such as at what evolutionary stage their action becomes relevant, how strong they are, and at what spatial scales they act.
Furthermore, the magnetic field parameters are still poorly constrained especially at small scales, i.e. few astronomical units from the central object, where the accretion disc and the base of the outflow are located. Thus we need to probe magnetic fields at different scales, at different evolutionary steps and possibly with different tracers.
I will show that the magnetic field morphology around high-mass protostars can be successfully traced at different scales by observing maser and dust polarised emission. A confirmation that they are effective tools is indeed provided by our recent results from 6.7 GHz MERLIN observations of the massive protostar IRAS 18089-1732, where we found that the small-scale magnetic field probed by methanol masers is consistent with the large-scale magnetic field probed by dust.
Moreover I will present results obtained from our ALMA Band 7 polarisation observations of G9.62+0.20, which is a massive star-forming region with a sequence of cores at different evolutionary stages. We resolve several protostellar cores embedded in a bright and dusty filamentary structure. I will then discuss the magnetic field morphology in different cores and different evolutionary stages and I will compare its strength with previous estimates obtained by maser observations.

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Resolving discrepancy in the pPN OH231

Desmurs, J.-F.

OH231.8 is an archetypal pre-planetary nebulae (pPN). It's a binary system surrounding by bipolar outflows. In the past decades, it has been extensively studied, in particular, we performed several VLBI observations to obtained mas-resolution maps of the SiO (7mm) and H2O (1.3cm) maser emissions. H2O masers are found to be distributed in two areas along the symmetry axis of the nebulae oriented nearly north-south delineating a bipolar outflow, and their astrometric positions have been accurately measured. SiO masers, indicating the position of the Mira component of the binary system, form a structure perpendicular to the axis of the nebulae. The general picture of the source looks satisfactory, except for the relative position of the two masers. Surprisingly, SiO masers, have been tentatively placed 250 mas away (370 AU) from the apparent center of the outflow. Using the ALMA interferometer, we observed at mm wavelengths the SiO maser emission and accurately derived the position of the Mira component. Combining existing VLBA data and our new ALMA observations, we are now able to give a complete and detail description of the inner part of this amazing pPN.

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Investigations on MultiView VLBI for SKA

Richard Dodson

The SKA will deliver an order of magnitude increase in sensitivity, but most VLBI observations are limited by systematic errors. In these cases improved sensitivity offers no benefit. I will discuss one way of improving the accuracy of the VLBI calibration, where multiple simultaneous observations around the target are used to deduce the corrections required for the line of sight to the target: MultiView VLBI.

I will discuss simulations that helped us develop the strategy, estimates for applicability from ionospheric studies, results from real observations and projections into the types of science which can be attempted in the future. An example would be to measure the parallax of OH-masers in the LMC, which requires measurement errors of a few uas. For this the sensitivity of the SKA will provide the precision and MultiView will provide the accuracy.

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Imaging Black Holes

Heino Falcke

One of the most fundamental predictions of general relativity are black holes. Their defining feature is the event horizon, the surface that even light cannot escape. So far, we have never seen the event horizon, but this is about to change. Advanced computer simulations make clear predictions of how the shadow of black holes should look like and global interferometric radio observations with the Event Horizon Telescope are now trying to image the supermassive black hole in the center of our own Milky Way and the radio galaxy M87 for the very first time. The talk will give an overview of the ongoing research in this area.

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COBRaS: The e-MERLIN 21cm Legacy Survey of Cygnus OB2

D. Fenech, J. Morford, R. Prinja, J. Clark, R. Blomme, J. Yates, J. Drake, S. Eyres, A. Richards, I. Stevens, N. Wright, S. Dougherty, J. Pittard, H. Smith, J. Vink

The Cygnus OB2 association is located in the Galactic Cygnus X region at a distance of 1.4 kpc, making it one of the closest young massive stellar clusters. Cyg OB2 is not only very rich in stellar density but also in its diversity. It is known to contain a rich population of massive stars including almost 2600 OB stars, a large number of binaries and a considerable number of pre-main sequence stars.

We report on the first results from The Cyg OB2 Radio Survey (COBRaS), an e-MERLIN legacy project to provide a deep-field radio map of the Cygnus OB2 association. The project aims to enhance our understanding of stellar mass-loss and binary interactions and has been awarded a total allocation of 252 hrs at C-band
(5 GHz) and 42 hrs at L-band (1.6 GHz) to image the core of the cluster. I will present our key findings so far from the completed L-band observations and some of the unexpected surprises.

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Three little radio galaxies in the early Universe

K. Gabanyi, S. Frey, Z. Paragi, H. Cao, T. An, L. Gurvits, T. Sbarrato, K. Perger, K. Rozgonyi

There are indications that the number of known radio-loud quasars above redshift z=4 is much smaller than expected from the number of sources with relativistically beamed jets (i.e. blazars). To explain the apparent deficit in the misaligned (non-beamed) population of high-redshift jetted active galaxtic nuclei, various explanations are proposed. These involve heavy optical obscuration and significantly different bulk Lorentz factors in jets at early cosmological epochs. It is also possible that the number of blazars is smaller than we think. Our recent European VLBI Network (EVN) observations targeting z>4 blazar candidates revealed that as many as 3 sources do not show high brightness temperature radio emission characteristic to relativistic beaming in jets, but rather kpc-scale double structures. These intriguing objects have significant radio emission resolved out with the EVN, while they are compact on ~5-10 arcsec scale. New dual-frequency e-MERLIN observations of these three sources revealed a rich morphology, bending jets and hot spots with possible sites of interaction between the jets and the surrounding medium at sub-arcsecond angular scales.

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The science impact of high sensitivity VLBI with SKA

Cristina Garcia Miro

The Square Kilometre Array (SKA), reaching a collecting area of one square kilometre, will be the world's largest radio telescope. Result of a scientific collaboration between 10 countries (with more to join), it will consist of one Observatory with 2 telescopes located in different continents, Africa and Australia. The telescopes deployment is planned in two phases, but even in its first stage (SKA1) it will already enable transformational science in a broad range of scientific objectives. In particular for VLBI science it will contribute with a very sensitive element with access to the Southern Hemisphere. It will also drive technological advances for the future VLBI era, such as the inclusion of multi-beam radio telescopes in VLBI networks, and it will bring opportunities to modernise the VLBI global operational model. This contribution gives an update of the current status and timeline of the project, presently undergoing the Critical Design Reviews for the different components of the SKA1 Observatory.

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SETI searches with the EVN

Michael Garrett

The Search for Extra-terrestrial Intelligence (SETI) has recently undergone a major rejuvenation with initiatives like the Breakthrough Listen project, conducting new systematic surveys of the nearest stars and galaxies. These observations focus on the use of the largest single-dish radio telescopes in the world, analysing the raw output voltage data with very fine time and frequency resolution. For arrays such as MeerKAT and the ATA, beam-forming techniques are used to place a few beams on top of specific targets e.g. exoplanets. Employing interferometry techniques for SETI searches on distributed arrays offers some interesting advantages over traditional beam-forming techniques. Some of these advantages are well known, including the strong suppression of RFI signals in cross-correlated data (e.g. Ramparadath et al.). Less well appreciated is that multiple baselines also provide an important level of redundancy that improves the level of confidence in detecting faint signals that may also be one-off, non-repeating, transient events. Another advantage is that modern software correlators permit us to detect signals across the full primary beam of the individual elements of the array, permitting hundreds of known (and unknown) targets to be observed simultaneously using wide-field techniques developed for VLBI. Note that such an approach naturally delivers data with good time and frequency resolution as required for SETI searches. Finally, in the event that a SETI candidate is discovered, radio interferometers distributed on scales of 1000's of km will also be able to pin-point the location of these signals with milliarcsecond precision – this may be crucial in understanding the characteristics of the platform on which the transmitter is fixed, and potentially the nature of the civilisation responsible for generating the signal. We present some of the advantages distributed interferometers can represent, by presenting a short analysis of spectral-line VLBI data drawn from the EVN archive.

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Sensing the astrophysical influence within VLBI astrometric measurements of extragalactic radio-sources

César Gattano and Patrick Charlot

The radio-sources observed by geodetic-VLBI are Active Galactic Nuclei [AGN]. Most of them show instabilities in their astrometric position time series, more or less strong depending on the source (generally in the order of 0.1-1 milli-arcsecond). Those instabilities may be caused by astrophysical phenomena occurring in the central VLBI region of those objects. Astrometric variations correlated with variability (of the radio-flux) argues in this sense. On this basis, we have begun to characterize the signal included in the available VLBI position time series. First, a general statistical study reveals tendencies on physical parameters (e.g. magnitudes) if the source is astrometrically stable or unstable. Second, a geometrical analysis of those time series reveals that, frequently, a preferred direction stands out from the instabilities. But, for some sources, two directions are distinguished. The first scenario is consistent with regular emergence of knots from the VLBI core, hence causing shifts of the radio emission centroid. The second scenario may give clues to the presence of a second black hole within the AGN that have its own activity offset from that of the first black hole. Finally, taking the Gaia Data Release 2 into account for optical counterparts, we finally compare those directions with the orientation given by the radio-optical position offset. We distinguish between sources, those of which radio-astrometric variations are aligned with the radio-optical offset from those of which this angular deviation is perpendicular. In the future, understanding the underlying physics of AGN will be essential for the realisation of future versions of the International Celestial Reference Frame because of the need to identify sources which materialize the most stable directions of the Universe.

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The radio view of Gravitational waves counterparts: GW/GRB170817

G. Ghirlanda

Radio observations of the electromagnetic emission of gravitational wave events has proved unique to detect the faint slowly evolving signal. Radio detections distributed between 10 and 150 days after the BNS merger have shown that flux rises slowly with time. This evidence could be consistent with either a jet, seen off-axis, whose energy and bulk velocity decrease going off—axis or by a mildly relativistic nearly isotropic fireball (a cocoon). The latter could be still produced by a jet which has deposited much of its energy into the BNS ejecta. While it is hard to disentangle between these two scenarios based only on the source luminosity evolution, high resolution radio imaging (obtained within a global-VLBI project) hold the key to discuss solve the puzzle.

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Radioastron observations of the jet launch region in 3C84

G. Giovannini, T. Savolainen, M. Orienti, M. Nakamura, H. Nagai et al.

I will present and discuss a study on the sub-pc scale of the radio galaxy 3C 84, based on space VLBI observations obtained with RadioAstron at 22 GHz.
High resolution images allow to investigate the jet origin and its
properties. Moreover I will compare these data with previous published images and with recent VLBA observations at 43 GHz.

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Measuring Magnetic Fields from Water Masers in the Synchrotron Protostellar Jet in W3(H2O)

Goddi, C.; Surcis, G.; Moscadelli, L.; Imai, H.; Vlemmings, W. H. T.; van Langevelde, H. J.; Sanna, A.

Magnetic fields are invoked to launch, drive, and shape jets in both low- and high-mass protostars, but observational data on the spatial scales required to assess their role in the protostellar mass-loss process is still scarce.
We report full polarimetric VLBA observations of water masers towards the Turner-Welch Object in the W3(OH) high-mass star forming complex. This object drives a synchrotron jet, which is quite exceptional for a high-mass protostar, and is associated with a strongly polarized water maser source, W3(H2O), making it an optimal target to investigate the role of magnetic fields on the innermost scales of protostellar disk-jet systems.
The linearly polarized emission from water masers provides clues on the orientation of the local magnetic field, while the measurement of the Zeeman splitting from circular polarization provides its strength. The water masers trace a bipolar, biconical outflow at the center of the synchrotron jet. Although on scales of a few thousand AU the magnetic field inferred from the masers is on average orientated along the flow axis, on smaller scales (10s to 100s of AU), we have revealed a misalignment between the magnetic field and the velocity vectors, which arises from the compression of the field component along the shock front.
Our measurements support a scenario where the magnetic field would evolve from having a dominant component parallel to the outflow velocity in the pre-shock gas, with field strengths of the order of a few tens of mG (at densities of 10^7 cm^-3), to being mainly dominated by the perpendicular component of order of a few hundred of mG in the post-shock gas where the water masers are excited (at densities of 10^9 cm^-3).
The general implication is that in the undisturbed (i.e. not-shocked) circumstellar gas, the flow velocities would follow closely the magnetic field lines, while in the gas shocked by the prostostellar jet the magnetic field would be re-configured to be parallel to the shock front.

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3D Models of Maser Flares

M.D. Gray, S. Etoka, J. Baggott, J. Westlake

Fully 3D models of astrophysical maser clouds at VLBI scale are used to test several scenarios for the generation of astrophysical maser flares. These include geometrical situations, such as rotation of prolate and oblate spheroidal clouds and superimposition of clouds in the line of sight, as well as parameter variations, such as changes in pump and loss rates, and in the level of the amplified background radiation. Light curves produced by the models are compared with extensive observational data on flaring in TypeII methanol masers to test the likelihood of the different scenarios.

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Synergies between VLBI and high-resolution IR/optical interferometry

Guirado, J.C.

Combined interferometric observations at different wavelengths probe different regions of numerous astrophysical scenarios. Optical and infrared interferometry is going through major advances in terms of resolution and sensitivity, providing ample room for synergy with
radio facilities. I will report on present and future possibilities of joint radio and optical-IR interferometric observations, which will help to enhance studies on different fields as, among others, pre-main sequence stars and their protoplanetary disks, evolved stars, binary stars, and extragalactic objects.

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Expanding VLBI in East Asia and AGN science

Kazuhiro Hada (on behalf of KaVA/EAVN AGN Science Working Group)

The international VLBI collaboration in East Asia is rapidly growing. Besides the successful integration of KVN and VERA (KaVA), now the network is expanding into China. This forms so-called the East Asian VLBI Network (EAVN) and stimulates the activities of joint science promotion among researchers in this area.

One of the primary science goals of KaVA/EAVN is to understand the physics of accretion and ejection in active galactic nuclei (AGN) and associated high-energy phenomena. The capability of quasi-full-year operation of KaVA/EAVN is suitable for monitoring the detailed structural evolutions (and multi-frequency mm polarization for KVN) of relativistic jets. This allows us to address some major questions about jets such as the acceleration mechanisms, connection to gamma-ray flares and magnetic-field properties.

Some of key AGN programs are project-led and promoted by the KaVA/EAVN AGN Science Working Group. This includes a massive monitoring program of SgrA* and M87 near in time to the EHT campaign, EAVN+Italy global VLBI (“EATING” VLBI) observations of powerful jets, as well as monitoring of some more individual sources. In this contribution, I will overview the ongoing expansion of EAVN array and glowing activities on AGN studies based on KaVA/EAVN.

(Maybe my talk would be suitable for either AGN or VLBI Arrays. I leave the allocation to SOC)

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A development of compact triple band receiver for millimeter-wave radio astronomy

Seog-Tae Han

We have developed a compact triple-band receiver which enables simultaneous observations in the three frequency intervals K(18–26 GHz) band, Q(35–50 GHz) band, and W(85–115 GHz) band. The quasi-optics design enables the triple-band receiver to fit into a single cryostat with some of the mirrors and dichroic filters outside the cryostat. The expected
size of total receiver system is 640 mm(W) x 940 mm(L) x 350–400 mm(H) including
the optical circuit. When compared with the present KVN optical bench of size
2600 mm x 2300 mm x 60 mm, the designed system is significantly more compact
and is tailorable for use in telescopes with a small receiver cabin.

The receiver performance and test observation results will be presented.
We have shown that it is possible to design a quasi-optical circuit that has simultaneous observation capability for three frequency bands, and that ultimately this concept may lead to development of much more compact multi-frequency receiver systems for mm-wave and sub-mm radio telescopes.

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VLBI and the faint radio AGN population

N. Herrera Ruiz, E. Middelberg, A. Deller and R. P. Norris

The VLBI technique is a powerful tool to separate AGN from star-forming galaxies. For this reason, we have carried out wide-field VLBI observations of the COSMOS field, characterised by an extensive amount of ancillary data, to study the faint radio AGN population. We have observed around 3000 radio sources with the VLBA and around 200 of them with the VLBA together with the GBT, additionally. We have detected 468 radio sources with the VLBA and 35 with the VLBA+GBT. All the observations were carried out at 1.4 GHz. In this overview I would like to present the observations, the calibration and the main results of the project as well as few individual interesting sources.

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KaVA Large Proposal for High-Mass Star-Formation Studies with Multiple Masers

Tomoya HIROTA, Kee-Tae KIM, KaVA Star Formation Science Working Group

We have started a systematic observational study of the 22 GHz water masers and 44 GHz class I methanol masers in high-mass star-forming regions as a four-year KaVA (KVN and VERA Array) large program since 2016. The primary aim of our project is to investigate dynamical evolution of high-mass young stellar objects (HM-YSOs) and their circumstellar structures by observing spatial distributions and 3D velocity fields of water and methanol maser features. For statistical studies, we first selected 87 HM-YSOs in various evolutionary phases, based on the catalogues and single-dish surveys of the 22 GHz water masers, 44 GHz class I methanol masers, and 6.7 GHz class II methanol masers. Most of the targets are associated with multiple maser species. From these initial samples, we selected 23 water maser sources and 19 methanol maser sources, for which VLBI data were not available in 2016 and 2017, to check detectability with KaVA and variability of maser features. All the 44 GHz methanol maser sources have been observed for the first time with VLBI. As a result of the first year observations, we selected 16 water maser sources to conduct monitoring observations to measure proper motions in the second year. All of these sources show multiple maser features with various distributions such as linearly elongated structures, compact shell-like structures, and more complex distributions, suggesting variety of outflow structures. In addition, we also selected 3 methanol maser sources to measure the proper motions for the first time with VLBI. Observations have been started since 2018 March and still on-going. By combining follow-up observations with VERA (astrometry), Japanese VLBI Network (6.7 GHz class II methanol masers), ALMA (thermal molecular lines and continuum), and single-dish telescopes (various molecular lines), we will investigate physical properties and 3D dynamical structures of disk, jet, outflow, UCHII, and infalling envelope, and their relationship with the evolutionary phases of HM-YSOs.
In this talk, we will present current status of our KaVA large program and initial results from the first year observations and ALMA cycle 3 follow-up observations.

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Where are you, Scutum? Tracking down a spiral arm with maser astrometry

K. Immer, J. Li, M. Reid

Edwin Hubble showed in 1926 that galaxies can be classified into three groups depending on their shape: ellipticals, spirals and irregulars. We know that our own Galaxy has a spiral shape. However, the details of the galactic structure like the number of spiral arms or their exact location are still under debate. In this talk, I will present recent efforts to unveil the structure of our Milky Way, a complicated endeavour due to our position in the Galaxy.
I will show how parallax observations of maser sources in star-forming regions are used to pinpoint the location of the Scutum spiral arm and how we determine its pitch angle(s).

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Tying multiple Radio Wavelength Celestial Frames to the Gaia Optical Frame

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Very Long baseline Interferometry (VLBI) at 3.6 cm wavelength has for several decades been the only source of sub-milliarsecond (mas) accurate celestial reference frames. The last decade has seen high accuracy VLBI work extended to 1.2 cm and 0.9 cm wavelengths which now provide independent data sets for testing reference frame accuracy. These efforts are now joined by the Gaia Data Release #2 frame at optical wavelengths providing for the first time results from a totally independent technique and thus a more stringent test of the true accuracy of celestial frames.

With four frames now available, this paper will inter-compare all the frames and attempt to set bounds on the accuracy of each frame. While precision of the tie between frames is approximately 10 to 20 μas, we already see sign of systematic errors. In particular, the north-south imbalance in VLBI networks leaves VLBI frames vulnerable to zonal errors. We will discuss our efforts to control those errors so that astrophysical offsets between the optical and radio centroids will be exposed for scientific study at unprecedented levels of accuracy which may enable new insights into the processes within AGNs.

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RPICARD: A CASA-based Calibration Pipeline for VLBI Data

M. Janssen, I. van Bemmel, C. Goddi, M. Kettenis, I. Marti-Vidal, D. van Rossum, D. Small, and H. Falcke

Currently, HOPS and AIPS are the primary choices for the time-consuming process of (millimeter) very long baseline interferometry (VLBI) data calibration. However, for a full end-to-end pipeline, they either lack the ability to perform
easily scriptable incremental calibration or do not provide full control over the workflow with the ability to manipulate and edit calibration solutions directly. CASA offers all these abilities, together with a secure development future and an intuitive python interface, which is very attractive for young radio astronomers. Inspired by the recent addition of a global fringe-fitter, the capability to convert fits-idi files to measurement sets, and amplitude calibration routines based on antab metadata, we have developed a fully automated CASA-based VLBI data reduction pipeline.
The pipeline will be able to handle data from multiple arrays: EHT, GMVA, VLBA and the EVN in the first release. Polarization and phase-referencing calibration are supported and a spectral line mode will be added in the future. The large bandwidths of future radio observatories ask for a scalable reduction software. Within CASA, a message passing interface is used for speedup. The most significant gain is obtained for the time-consuming fringe-fitting task as each scan be processed in parallel.

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Polarimetric millimeter VLBI observations of 3C 84

J. -Y. Kim, T. P. Krichbaum, A. P. Marscher, S. G. Jorstad, I. Agudo, C. Thum, J. A. Hodgson, N. R. MacDonald, E. Ros, R. -S. Lu, M. Bremer, P. de Vicente, M. Lindqvist, S. Trippe, and J. A. Zensus

Synchrotron radiation from AGN jets can be linearly polarized up to ~70% in theory. However, the observed degree of linear polarization is usually much lower. The weak linear polarization could to be due to (i) highly tangled magnetic fields in a turbulent plasma, (ii) high Faraday rotation and (iii) blending of polarized sub-components within the observing beam. The bright radio-galaxy 3C 84 (Perseus A, NGC 1275), which is located at the center of the Perseus Cluster is almost unpolarized at cm-wavelength, but features a complex morphology from sub-pc to pc scales. We performed deep polarization VLBI imaging using the Global mm-VLBI Array (GMVA) at 86 GHz including the 100m Green Bank Telescope. We obtain new images of 3C84 with a very high angular and spatial resolution of 50 uas (250 Rs), which resolves the center of the galaxy where two-sided relativistic jets are formed. We also analyze quasi-simultaneous multi-wavelength data from the VLBA (15 and 43 GHz) and ALMA (97.5, 233.0, and 343.5 GHz) observations. In this talk, we report detection of significant linear polarization in the VLBI core at frequencies > 43GHz and also a very high RM of ~10^(5-6) rad/m^2 in the central region. The physical implications will be discussed.

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Pulsar scintillometry on the Vela pulsar with the LBA

Franz Kirsten

The ionized interstellar medium scatters the spatially coherent signal of pulsars, leading to multi-path propagation evident as scintillation in the observer's plane. In a dynamic spectrum, i.e. the flux density distribution as a function of frequency and time, scintillation becomes apparent as a criss-cross pattern of intensity variations. In the 2D power spectrum of the dynamic spectrum -- the so-called secondary spectrum -- the power is distributed along a parabola through the origin. The curvature and shape of this parabola give us insights about the distance of the scatterer and the level of anisotropy in the scattering medium. If observed with VLBI, one can use the phase information in the secondary spectrum to map out the scattering screen. Combined with the distance to the scattering screen, this map can be used to perform high precision astrometry of the pulsar itself.
In a recent campaign we observed the bright, strongly scattered Vela pulsar at 1.6 GHz with the Long Baseline Array. We clearly detect the parabolic structures in the secondary spectra of both visibility amplitudes and phases. In this talk I will present the results from this campaign and discuss the conclusions we draw given the distance and screen orientation that we find.

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Toroidal magnetic fields and associated currents in AGN jets on kiloparsec scales

Sebastian Knuettel, Denise Gabuzda

Helical fields are generally accepted as the main magnetic field configuration for the launching of astrophysical jets, but it is still unclear how they effect the jet collimation and what role they play on the largest jet scales (if they persist to such distances from the central AGN). The synchrotron emission from these jets can be highly linearly polarised, making the behaviour of the polarised radiation a useful and reliable tool in examining the magnetic field environment of these jets. The observed polarization angle is effected by Faraday rotation, which is depends on the local electron density and line-of-sight magnetic field component. Observations at multiple wavelengths can be used to construct Faraday-rotation images, which provide information about the distribution of both these properties. A significant gradient in the RM transverse to the jet direction may indicate a corresponding gradient in the line-of-sight magnetic field, implying a toroidal or helical magnetic field, which would, in turn, imply the presence of an associated electrical current in the jet. Such an analysis has been done on VLBI scales using observations at centimetre wavelengths, however, relatively few studies have probed the kiloparsec scale jets. The detection of such large scale gradients can reliably demonstrate that helical or toroidal fields can persist to large distances from the central AGN. We present kiloparsec-scale Faraday rotation maps for several AGNs, including NGC 6251, based on archival data from the Very Large Array. NGC 6251 shows statistically significant transverse RM gradients across its kiloparsec scale jet structure that implies an outward current. This adds to previous detections of significant transverse Faraday rotation gradients across large-scale jets,which have all corresponded to outward currents (Christodoulou et al 2016, Knuettel et al 2017). Together with results for AGN jets on parsec scales, which imply inward currents (Gabuzda et al 2018), this suggests that the jets have a current/magnetic field configuration similar to that of a co-axial cable.

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Activities of VERA and East Asian VLBI network

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VERA, which has four VLBI station in Japan with 2-beam system, started science observations from 2004. It aims to measure the parallax and proper motions for Galactic maser sources. VERA have succeeded to determine trigonometric distance and proper motions for more than 100 objects. Including VLBA and EVN results, Galactic constants are revised to reliable value. We will presents future plan of VERA as well.
East Asian VLBI network, EAVN, is organized as a combination of Japanese VLBI network, Korean VLBI network and Chinese VLBI network, which has around 20 stations in total. VERA, which is the 2-beam phase referencing array in Japan, and KVN, which is the multi-frequency phase referencing array, are combined as KaVA. KaVA is carrying out three large programs and open use for world-wide users. And Japan and Korea have developed a large VLBI correlator facility in Daejun, Korea, which has 16 station correlation with 8Gbps input per station. From 2018, EAVN has started to call for proposals with the combination of KaVA and Tianma 65-m in Shanghai. EAVN is growing to involve other Chinese telescopes, Nanshan 25m and Yunnan 40m. We will present the status and science results of EAVN and future view including world-array and SKA combination.

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RadioAstron survey completed: AGN cores at unprecedented angular resolution

Y. Y. Kovalev for the RadioAstron AGN survey team

The Space Very Long Baseline Interferometer RadioAstron has performed a survey of 248 radio-loud active galactic nuclei at 18, 6, and 1.3 cm at projected spacings up to 350,000 km. Significant detections at space-ground baselines were found for 164 AGNs. Formal resolution as high as 11 microarcsec has been achieved. Apparent brightness temperature up to about or higher than 10^14 K was found in cores of observed active galactic nuclei. These measurements challenge our understanding of the non-thermal continuum emission in the vicinity of supermassive black holes. Physical implications of these findings will be discussed. While the survey was dedicated to total intensity measurements, we have also discovered that fractional linearly polarized correlated flux density significantly increases with long SVLBI projected spacings. This suggests the presence of ultra-compact regions with ordered magnetic field, most probably within the core of those quasars. Considerations regarding future Space VLBI missions will be also presented.

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Innermost region of the blazar S5 0716+714 from RadioAsron polarimetric observations at 22 GHz

Evgeniya .V. Kravchenko, Jose L. Gomez, Yuri Y. Kovalev, Andrei P. Lobanov, Marcello Giroletti on behalf of the Polarization KSP team

We present results of μas radio polarimetric imaging of one of the most studied BL Lac object S5 0716+714, observed with the RadioAstron space-VLBI mission. The source is well known because of its extreme and rapid variability through the whole electromagnetic spectrum. S5 0716+714 gamma-ray activity is strongly related to the inner jet morphology, which together with the short-scale variations at radio and optical bands makes the blazar the best candidate for an intrinsic origin of its intra-day variability (IDV).
Our EVN/Global VLBI observations of the source was made with the 10-m space radio antenna and eleven ground stations on 2015 January 3-4 at 22 GHz. The projected baselines reached 4-6 Earth's diameters in length, resulted in angular resolution of 24 μas, the highest for the studied source to-date.
The S5 0716+714 image revealed unprecedented elongation of the apparent base of jet within innermost 0.2 μas in direction, almost perpendicular to the larger-scale flow.
This is consistent with the temporal variations of the inner jet direction with the amplitude of about 60 degrees, resulted from our analysis of multi-epoch observations of the blazar within the VLBA-BU-BLAZAR monitoring program at 43 GHz. We suggest, that this fine-scale region of the S5 0716+714 jet may be responsible for the IDV and flaring activity of the source.
The source exhibits large-scale magnetic field, perpendicular to the jet flow, which is consistent with its helical geometry. We detect compact linearly polarized component in the innermost 0.2 μas of the jet, which coincides well with the position of a stationary feature, seen in other studies, and points on possible association with the recollimation shock.

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What the iMOGABA tells us about Gamma-ray bright AGNs

Sang-Sung Lee and the iMOGABA team

The interferometric monitoring of gamma-ray bright AGNs (iMOGABA) program aims at revealing the origins of the gamma-ray flares that are often detected in active galactic nuclei (AGNs). We would like to talk about what we have learned about the Gamma-ray bright AGNs based on the recent results of the KVN Key Science Program: the iMGOABA. The talk will include a) the source properties of the whole samples obtained from a single-epoch observation, and b) some of scientific highlights for the iMOGAGBA on specific sources. From those highlighted works, we find that the Gamma-ray bright AGNs become fainter at higher frequencies, yielding optically thin spectra at mm wavelengths. Based on the studies on specific sources, taking into account the synchrotron self-absorption model of the relativistic jet, we are able to estimate the magnetic field strength in the mas emission region during the observing period. More scientific highlights and future prospects of the KVN KSP are discussed.

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Moving cores in MOJAVE sample

Mikhail Lisakov

A common way to study kinematics of a jet is to presume that its apparent core is stationary and could be used as a reference point. It was shown recently that in several sources the movement of the apparent core could be detected with both astrometric and self-referencing techniques. With our new method applied to the MOJAVE sample, we have detected that the motion is significant for many sources and, for some, could be explained by changing opacity at the apparent core during a radio flare. Further on, the method could be used for improving both kinematic measurements in AGN jets and astrometric measurements.

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Einstein Equivalence Principle test with RadioAstron: preliminary results

N. Bartel, M. Bietenholz, A. Biriukov, D. Dirkx, A. Filetkin, G. Granato, L. Gurvits, A. Gusev, V. Kulagin, N. Nunes, V. Rudenko, M. Zakhvatkin, et al.

We report on preliminary results of the gravitational redshift test performed with the space radio telescope RadioAstron, which has been in a highly eccentric orbit around the Earth since 2011. We probed the flow of time on board, which varies while RadioAstron passes through the varying gravitational potential of the Earth, by recording the spacecraft's downlink signal synchronized to its on-board H-maser. A total of 17 successful experiments were performed, each comprised of several observations carried out at various distances between the spacecraft and the Earth. The experiment requires us to extract the tiny gravitational redshift signal from the mixture of much larger effects, including the nonrelativistic Doppler, ionospheric and tropospheric frequency shifts, higher-order kinematic effects of special relativity, Earth tides, and various instrumental effects. Preliminary analysis of the data of two experiments gives us a fractional accuracy of the relevant Einstein Equivalence Principle violation parameter of 2×10^{-4}, which is comparable to that obtained by Gravity Probe A. We argue that the accuracy of our result so far is likely dominated by that of the ionospheric frequency shift and discuss prospects for improving this result further. We also present the results of a simulations study of other factors contributing to the experiment accuracy, including the frequency measurement noise, uncertainty of the on-board H-maser frequency bias, solar radiation pressure, ground stations' positions, etc. We found that, apart from the propagation media, the major contribution to the experiment accuracy is due to the frequency measurement noise and the on-board H-maser frequency bias.

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The Large European Array for Pulsars: Experimental setup, now and future

Kuo Liu

Pulsar observations with interferometric technique have been widely explored and deployed in the recent years thanks to the vastly developing digital-signal-processing hardware. In most cases, these observations are performed with the pathfinders to the next generation of radio telescope. In this talk, I will present a brief introduction to the Large European Array for Pulsars, a unique pulsar observing infrastructure established within the European Pulsar Timing Array collaboration. I will introduce its experimental design, observing strategy and data acqusition systems. I will also describe the data processing pipeline developed specifically for this project in order to optimize the data quality of the outcome. In addition, I will show the scientific results obtained from the project so far, and briefly prospect for its plan in the near future.

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Extreme physics at extreme baselines

Andrei Lobanov

It is widely accepted that the maximum brightness of cosmic synchrotron sources should be ultimately determined by energy losses due to inverse Compton scattering, thus limiting the effective (brightness) temperature of incoherent synchrotron radiation to about one trillion degrees. However, a number of recent measurements made with ground and space VLBI have indicated that cosmic synchrotron emitters may actually dramatically exceed this limit. The observed violations of the inverse Compton limit suggest that extreme physical conditions may be present in the innermost regions relativistic jets on scales below about 1000 gravitational radii. This may signal the presence of significantly non-stationary processes, exotic particle energy distributions, or exceptionally strong and ordered magnetic fields in the close vicinity of supermassive black holes. Recent results in this field and their potential impact on our understanding of physics of jets and black holes will be discussed.

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The localization of a repeating Fast Radio Burst

B. Marcote

Fast Radio Bursts (FRBs) are transient sources that emit a single radio pulse with a duration of only a few milliseconds. They were firstly discovered ten years ago, and nowadays we have detected tens of these events. However, their physical origin remains unclear, and a number of scenarios even larger than the number of known FRBs has been proposed during these years.

The detection of multiple bursts in FRB 121102 excluded all the cataclysmic scenarios, at least for this particular FRB. The presence of these repeating bursts allowed us to perform a precise localization of the source with the Karl G. Jansky Very Large Array (VLA) and the European VLBI Network (EVN). Optical observations with Keck, Gemini and HST unveiled the host to be a low-metallicity star-forming dwarf galaxy located at a redshift of 0.193. The EVN results showed that the bursts are co-located (within a projected separation of < 40 pc) to a compact and persistent radio source with a size of 0.7 pc and located within a star-forming region.

This environment resembles the ones where superluminous supernovae or long-duration gamma-ray bursts are produced. Although the nature of this persistent source and the origin of the bursts remain unknown, the scenarios considering a neutron star/magnetar energizing a young superluminous supernova, or a system with a pulsar/magnetar in the vicinity of a massive black hole are the most plausible ones to date.

More recent observations have shown that the bursts from FRB 121102 are almost 100% linearly polarized at an unexpectedly high and variable Faraday rotation measure, that had been observed to date only in vicinities of massive/supermassive black holes. The bursts are thus likely produced from a neutron star in such environment, although the system can still be explained by a young neutron star embedded in a highly magnetized pulsar wind nebula or supernova remnant.

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A dust-enshrouded tidal disruption event with a resolved radio jet in a galaxy merger.

Mattila et al.

We present the discovery of an energetic nuclear transient in the central region of Arp299-B, which together with Arp299-A forms one of the most luminous and
nearby mergers. The nuclear transient radiated at least 1.5E+52 erg in theinfrared but remained elusive at optical and X-ray wavelengths.

We interpret its properties to arise from a stellar tidal disruption event (TDE)of a massive (2-6 solar masses) star that passed close to the supermassive black
hole. Very-long-baseline interferometry monitoring over a decade, using mainly EVN and eEVN observations, shows unambiguous evidence for an evolving jet-like morphology, expanding a subluminal speeds. This is the first case of a confirmed resolved radio jet in a TDE ever, thus validating theoretical predictions.

Our observations indicate that much of the emission from the TDE must have been reprocessed by dense gas, and re-radiated at infrared wavelengths by dust, suggesting a possible way for reducing the tension between theoretical
luminosity predictions and observations of TDEs in galaxies. Such TDEs from relatively massive, newly formed stars could provide a large radiative feedback, especially at higher redshifts where galaxy mergers are more common.

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Progress update of the VGOS radio telescope at Metsähovi Gedodetic Research Station

Guifré Molera Calvés, Nataliya Zubko, Jyri Näränen

The three-year project on building a VGOS radio telescope system at the Metsähovi Geodetic Research Station, Finland, is progressing as planned. The manufacturing of the telescope is completed by MT Mechatronics GmbH and it was delivered on-site in June 2018. Telescope assembly and installation has been going on during the summer 2018. The installation site was ready for the telescope arrival with the telescope foundation and the anchor ring for the telescope steel pedestal already on site. The finalization of the telescope installation should conclude by the ends of October. The construction of the signal chain components is also moving forward. The installation and integration of the signal chain components is scheduled for the autumn 2018. It is expected to have first observational tests in the beginning of 2019. In this presentation we give the latest project status and describe the next steps for the Metsähovi VGOS system.

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Resolving the Radio-Loudest Quasar known to date at z~6

Emmanuel Momjian (NRAO)
Chris Carilli (NRAO)
Eduardo Banados (Carnegie)
Fabian Walter (MPIA)
Bram Venemans (MPIA)

We present the discovery and the follow up Very Long Baseline Interferometry (VLBI) imaging of the z=5.84 radio-loud quasar PSO J352-15 at 23.9 x 11.3 mas resolution (139 x 66 pc). This quasar has the highest radio-to-optical flux density ratio (R > 1000) at such a redshift, making it the radio-loudest source known to date near z ~ 6. The VLBI observations at 1.54 GHz resolve this quasar into multiple components with an overall linear extent of 1.62 kpc (0.28") and a total flux density of 6.6 +/- 0.4 mJy, which is about half of the emission measured at a much lower angular resolution. The morphology of the source is compatible with either a radio core with a one sided jet, or a Compact or a Medium-size Symmetric Object (CSO/MSO). If the source is a CSO/MSO, and assuming an advance speed of 0.2c, then the estimated kinematic age is ~ 10^4 yr. We discuss the VLBI results in the context of quasar-mode feedback during the earliest formation of Active Galactic Nuclei (AGN) and the most massive galaxies. We also present the potential of carrying out H 21 cm absorption studies toward this quasar to detect the neutral IGM, as well as studying the apparent proper motion of the jet components at such high redshifts.

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High-mass star formation expored with maser VLBI & thermal (ALMA, JVLA) observations

Luca Moscadelli, Alberto Sanna, Riccardo Cesaroni, Ciriaco Goddi

Intense methanol and water maser transitions are commonly observed towards high-mass young stellar objects (YSO). Multi-epoch VLBI observations allow us to determine maser positions and 3-D velocities with an accuracy of about 1~mas and 1~km/s, respectively. Presently, JVLA cm and ALMA mm observations can determine the spatial distribution and (line of sight) kinematics of the thermal (continuum and line) emission around the forming star with unprecedented sensitivity (~10 microJy and ~1 mJy for continuum and line, respectively) and angular resolution (0.05-0.2 arcsec). Combining maser VLBI and thermal interferometric datasets is the most accurate way to determine the physical conditions and unveil the dynamical structures (disks, jets, expanding/infalling shells) associated with massive star formation. This talk presents the results of this technique for three high-mass YSOs: G16.59-0.05, G23.01-0.41 and G24.78+0.08, whose maser emission has been extensively monitored with VLBI and for which we have recently obtained new JVLA and ALMA data.

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Global Millimeter VLBI Array Survey of Ultracompact Extragalactic Radio Sources at 86 GHz

D.G. Nair, A.P. Lobanov, T.P. Krichbaum, E. Ros, J.A. Zensus,rnY.Y. Kovalev, S.-S. Lee7, F. Mertens, Y. Hagiwara, M. Bremer,rnM. Lindqvist, and P. de Vicente

We present results from a large global 86 GHz VLBI survey of 162 compact radio sources was conducted in 2010–2011 using the Global Millimeter VLBI Array (GMVA). For 138 objects, the survey provides the first ever VLBI images made at 86 GHz. The survey data are applied for studying jet physics down to smallest angular (~50 microarcseconds) and linear scales. Brightness temperature measurements made from the survey data have been applied to estimate the intrinsic brightness temperature at the jet base (VLBI core) and in the nearest moving jet components. These measurements have been modelled by a basic population scenario with a constant Lorentz factor for the entire source sample. From this modelling, the core brightness is found to be limited by the inverse Compton losses, while equipartition and adiabatic expansion govern the observed evolution of the moving jet components. Combining the survey estimates of brightness temperature with data obtained at lower frequencies, we have also studied jet acceleration on scales of ~100-10000 gravitational radii, showing that an MHD mechanism is most likely responsible for accelerating the jet plasma on these scales.

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Probabilistic fringe-fitting and source model comparison

Iniyan Natarajan, Roger Deane, Zsolt Paragi, Oleg Smirnov, Ilse van Bemmel, Des Small

Probability theory provides a uniquely valid set of rules for plausible reasoning, which enables us to apply it with greater flexibility to problems of scientific inference. Here, we take a probabilistic approach to fringe-fitting, in which we solve for time and frequency dependent phase variations introduced in VLBI observations by the interstellar medium and the Earth's atmosphere, by modelling them using the Radio Interferometry Measurement Equation (RIME) formalism. We also simultaneously estimate source structure and perform model selection between simple parametrised source models using Bayesian hypothesis testing. We test our method on Event Horizon Telescope (EHT) simulations with tropospheric phase corruptions introduced. We also explore ways in which this formalism may be applied to problems in astrometry and geodesy.

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Double nuclear structure discovered in 3C84

Junghwan Oh, Jeffrey A. Hodgson, Sascha Trippe, Sang-Sung Lee, Thomas Krichbaum, Jae-Young Kim, Bindu Rani

3C84 is a nearby active galaxy, where we can directly image the launching region of the jet. We observed the source with the Global millimeter VLBI Array (GMVA) with better than 50 micro-arc-sec resolution over 8 years. These observations revealed a consistent double nuclear structure separated by ~700 Schwarzschild radii, with the region being too broad and too bright to be the true jet base anchored in an accretion disk. We find a significant correlation between the brightness temperature and relative position angle of double nuclear components. We interpret this as being due to the expansion and cooling of a synchrotron emitting jet sheath. The cooling timescales appeared to be typical of blazar-like emission. We find a direct evidence non-relativistic kinematics in the region very close to the black hole.

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Multiepoch observation of periodic methanol maser in G107.298+5.639

Mateusz Olech, Marian Szymczak

In recent years a small group of methanol maser sources showing periodic variability have been identified. There is ongoing discussion on causes of this type of behavior, but none of the explanations are satisfactory. Discovery of source G107.298+5.639 showing alternating and periodic flares of 6.7GHz methanol and 22GHz water vapor masers can give us a clue to processes leading to observed periodicity. Recently we confirmed OH maser periodicity in this object. Result of multiepoch EVN observations of methanol emission in G107.298, comparison with single epoch 22GHz water and 1.6GHz OH maser observations and discussion of possible mechanism will be presented.

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Synergies between CTA and VLBI

M. Orienti on behalf of the CTA Consortium

Gamma rays are produced by the most powerful and often explosive physical processes in the Universe. Understanding the origin and role of relativistic cosmic particles in galactic and extragalactic objects is among the key issue that will be addressed by the Cherenkov Telescope Array (CTA). With its huge improvement in sensitivity, angular resolution, energy range, and flexibility of operation, CTA will provide a step forward in our understanding of the gamma-ray emission in transients and active galactic nuclei (AGN).

At the other extreme of the spectrum, radio Very Long Baseline Interferometry (VLBI), with its milliarcsecond imaging and polarimetric capabilities have long been the key tool in studying the relativistic outflows that are the likely sites of gamma-ray production in AGN. Furthermore, VLBI ultra-precise astrometry will be fundamental for the study of transient phenomena.

In this contribution I will present an overview on the characteristics of CTA and on the science at high energy. Then, I will focus on the synergies between CTA and VLBI.

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Short-lived episodic outflow in a water fountain star

Gabor Orosz, Jose F. Gomez, Hiroshi Imai, Daniel Tafoya, Jose M. Torrelles, Ross A. Burns, Pau Frau, Martin A. Guerrero, Luis F. Miranda, Miguel A. Perez-Torres, Gerardo Ramos-Larios, J. Ricardo Rizzo, Olga Suarez, Lucero Uscanga

Water fountains are evolved stars that show early stages of collimated mass loss during the transition from the asymptotic giant branch, providing valuable insight into the formation and shaping of asymmetric planetary nebulae. In this talk, we introduce a peculiar water fountain star, IRAS 18113-2503, and show the results of a multi-epoch VLBI campaign to unveil the spatial and 3D kinematic structure of its water masers. Our observations reveal three pairs of high-velocity (150-300 km/s) bipolar bow shocks on a scale of 180 mas (2000 au). We find, for the first time, an exponentially decelerating system of episodic ejections in a water fountain, with a periodicity of ~10 years. Using a simple kinematic model, we derive some physical properties of the jet, its source and surroundings, and show that the observations may best be explained by a close binary system of ~10 au separation.

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SKA-VLBI Key Science Programmes

Zsolt Paragi

A significant fraction of the observing time with the two phase-I SKA components (SKA1-LOW & SKA1-MID) will be spent on Key Science Projects led by member country scientists. The various SKA Science Working Groups, including the VLBI Focus Group are in the process of defining KSPs that are aligned with the High Priority Science Objectives of the SKA. At the moment it is not clear how the special observing mode of SKA-VLBI - when the SKA1 components are phased-up and included in VLBI networks - could be incorporated in KSPs. Our VLBI community needs to be prepared by the time the KSP proposal calls are expected (early 2020s). I will talk about the various unique potential science cases and outline the possibilities for us to engage in SKA KSPs.

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Substantial winds from the accreting supermassive black hole in M87 revealed by Faraday rotation observations

Jongho Park, Kazuhiro Hada, Motoki Kino, Masanori Nakamura, Hyunwook Ro, Sascha Trippe

Active galactic nuclei (AGNs) often produce highly collimated relativistic jets, one of the most energetic phenomena in the Universe. Theoretical models predict that AGN jets can be accelerated to nearly speed-of-light by magnetic fields, if they are confined by an external medium. Winds, nonrelativistic un-collimated gas outflows launched from accretion flows onto the supermassive black holes in AGNs, are primary candidates for this medium. Recent observations have indeed revealed a gradual collimation and acceleration of the jet in M87, a nearby AGN that possesses a black hole with a mass of three to six billion Suns which provides a unique opportunity to investigate the region under the influence of the black holes gravity. However, it has not been possible to either probe the external medium by observations or verify the general picture of jet collimation and acceleration. Here we report radio observations of Faraday rotation (the rotation of the plane of polarization by intervening magnetic fields) in the M87 jet, where information on the external medium (which is not directly observable) is imprinted. The Faraday rotation systematically decreases with increasing distance from the black hole from 5,000 to 200,000 Schwarzschild radii, in good agreement with the gas density being inversely proportional to the distance. This behavior matches the theoretically expected signature of moderately magnetized winds, which can naturally serve as the external confining medium. The sign of the Faraday rotation is predominantly negative, suggesting that jet and accretion axis are misaligned and the jet emission exposes only one side of the toroidal magnetic fields in the winds. Our results demonstrate that winds are indeed a key element of the black hole inflow-outflow system.

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Use of VLBI/Gaia position offsets for AGN physics

Petrov, L., Plavin A., Kovalev, Y.Y.

It was shown by Kovalev et al. (2017) and Petrov & Kovalev (2017a,b) that VLBI/Gaia DR1 position offsets are not entirely random, but have a preferable direction along the parsec-scale jet. This anisotropy of VLBI/Gaia position offsets is interpreted as a manifestation of presence of mas-scale optical jets cospatial to radio jets. Based on this explanation, a number of predictions has been made. Analysis of VLBI/Gaia DR2 has confirmed predictions and thus, supports this interpretation. We will discuss how new observables, projections of the VLBI/Gaia offsets on jet direction and on the direction perpendicular ot jet, can be used to get inference of AGN properties.

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Evolution of AGN jets from multiepoch core-shift studies

Alexander Plavin, Yuri Y. Kovalev, Alexander Pushkarev, Andrey Lobanov

The observed position of the jet base ("core") in radio-loud active galactic nuclei changes with frequency ("core shift" effect) because of synchrotron self-absorption. Studying this effect enables us to reconstruct properties of the jet regions close to the central engine. We present new results based on multi epoch core shift measurements in 40 AGNs. Each of them has been observed with global VLBI at 2 and 8 GHz over more than ten epochs from 1994 to 2016. The core shifts are determined using a specially developed automatic procedure to minimize possible biases. Our measurements show that the offsets between the core positions at 2 and 8 GHz are typically about 0.5 mas, and they vary in time with a typical magnitude of 0.4 mas and maximum variations reaching up to 0.8 mas. The temporal variations show a strong dependence between the core position and its flux density, suggesting that changes in both are likely to be related to nuclear flares injecting a denser plasma into the flow. We deduce that the density of relativistic particles flowing through the core regions significantly increases during these flares, while the magnetic field strength and plasma speed do not change substantially. We show that the expected inverse frequency dependence for the shift cannot hold at all times, especially during strong activity periods. This effect has to be taken into account when using core shift measurements to infer various jet parameters and to increase the absolute astrometric accuracy.

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Extragalactic wide-field surveys using the European VLBI Network

J. Radcliffe, M. Garrett, P. Barthel, T. Muxlow, R. Beswick, A. Deller

In this talk, I will present current result from the largest and most intensive wide-field VLBI project ever undertaken with the European VLBI Network which targets the highly studied GOODS-N field. This talk will be split into two parts:

Part 1 will outline the technical progress developed over the project, namely direction-dependent calibration (Radcliffe+16, Moldon, Radcliffe+in prep.), and a new primary beam correction scheme for the highly heterogeneous EVN (Keimpema & Radcliffe+in prep., Radcliffe+18a) both of which are now publicly available.

Part 2 will outline the first results of this VLBI survey, revealing 31 faint radio sources, across 0.5 square degrees, down to uJy flux densities (Radcliffe+18a). We will illustrate that we may be detecting hints of a new population of core-dominated radio sources (see also Herrera-Ruiz+17,18) which required by empirical simulations (Whittam+17), and are also observed in low-luminosity objects in the local universe (Baldi+18). In addition, we hope to present the first results using the EVN-eMERLIN hybrid array which can, for the first time, probe the interplay between nuclear starburst and AGN activity by being simultaneously sensitive to kpc and sub-kpc scales at z>0.2. VLBI need not just be a simple extragalactic ‘AGN finder’ anymore.

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EVN imaging of the obscured nuclei of the LIRGI galaxies

Naím Ramírez-Olivencia
Miguel Ángel Pérez-Torres
Antxon Alberdi Odriozola
Eskil Carencias
John Conway

We present preliminary results of our ongoing work on the Luminous Infrared Galaxies Inventory (LIRGI). LIRGI is an eMERLIN legacy project to study 42 of the most IR luminous ((logL_IR/L_sun) > 11.4) local (D < 250 Mpc) U/LIRGs with high-angular resolution at 6 and 18 cm. Most of those U/LIRGs are merger or post-merger systems, and all of them have properties of area star formation densities, gas and radiation densities similar to star-forming galaxies at high redshift. Thus, characterizing them locally, with high angular resolution, will be very useful when studying the high-redshift, unresolved star-forming galaxies.

As a complementary step in this study, we initiated a similar effort with the EVN, and observations at 6 and 21 cm were carried out. The main aim of those observations is to unveil the dominant heating mechanism in the central regions of those galaxies (AGN, starburst, or both). Thanks to the sensitivity of the EVN and its mas-angular resolution,we have been able to detect and characterize the nature of the compact objects responsible for the radio emission. In this presentation we will show some of the most remarkable examples both in the eMERLIN and EVN observations.

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Comparing remote atomic clocks via VLBI networks and fiber optic links: the LIFT/MetGeSp perspective

Roberto Ricci, M. Negusini, F. Perini, M. Roma, C. Bortolotti, G. Maccaferri, M. Stagni, R. Ambrosini, D. Calonico, C. Clivati, A. Tampellini

Very Long Baseline Interferometry experiments require an extremely precise synchronization between the atomic clocks keeping the time and frequency standards at radiotelescope observatories. Recently the availability of fiber optic links from a few radio observatories and their national metrological institutes has made possible the streaming of extremely stable frequency standards via optical atomic clocks (even two order of magnitudes better than Rubidium or Hydrogen maser standards).
Firstly, I will present the infrastructure of the Italian Link for Frequency and Time (LIFT) and results of the MetGesp project aimed at finally creating a common clock between two of the antennas of the VLBI Italian Network. Secondly, I will show the results of VLBI experiments in which the rms phase noise was used to accurately compare the synchronicity of atomic clocks located at a few EVN sites (Medicina, Noto, Yebes, Torun, Metsahovi). VLBI clock timing proves a valid alternative to satellite-based techniques such as Global Navigation Satellite System or Two-Way Satellite Frequency and Time Transfer.

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Detailed SiO proper motion analysis: slow net expansion and a small correlation with the magnetic field

Khudhair Assaf (Univ. Wasit, Iraq); Bill Cotton (NRAO, USA); Phil Diamond (SKA, UK); Sandra Etoka (Univ. Manchester, UK); Malcolm Gray (Univ. Manchester, UK); Elizabeth Humphreys (ALMA, Chile/Germany); Anita Richards (Univ. Manchester, UK); Markus Wittkowski (ESO, Germany)

A detailed analysis of 23 epochs (covering two stellar cycles) of monitoring R Cas SiO J=1-0 v=1 masers showed 184 maser features (an average of 20% per epoch) could be matched over between 3 and 13 epochs. The largest number of matches occur in the early part of each cycle, following the maser brightness trends, which are roughly as predicted. The proper motions can be tangential, radial, intermediate or change direction, but overall the net direction is expansion corresponding to ~0.4(0.1) km/s. This would take ~67 year to cross the SiO maser shell, giving a mass loss rate similar to other estimates in the literature. A small proportion of feature pairs in successive epochs have significant polarization and polarization angles consistent to within pi/8 rad. A small excess of this subsample have proper motion vectors within 22.5 deg of parallel to the inferred magnetic field direction (2sigma significance) but this is in radial expansion for less than half of these. The magnetic field strength provides a force comparable to the kinetic and thermal energy densities and could influence their directions, but it does not appear to be driving the majority of motions of gas clumps. The SiO masers typically emanate from a shell within 2-5 optical stellar radii, which is also the region where the radio photosphere becomes optically thick at 1.3 - 6 cm wavelength, and where molecular or dust emission can be traced by IR interferometry. Recent advances in techniques and e-MERLIN K-band observations will allow improved coordination between maser and continuum/IR observations in the investigation of how exactly mass is lost from stars.

NB to be presented by Assaf if able to attend, otherwise Richards. Thank-you.

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Precise Astrometry today and tomorrow, with Next-generation Observatories.

Maria J. Rioja

High precision astrometry provides the foundation to resolve many fundamental problems in astrophysics. The application of astrometric studies spans a wide range of fields, and has undergone enormous growth in recent years. This is as a consequence of the increasing measurement precision and wide applicability, which is due to the development of new techniques.
Forthcoming observatories have the potential to further increase the astrometric precision providing there is a matching improvement in the methods to correct for systematic errors.
The EVN and other observatories are providing demonstrations of these and are acting as pathfinders for instruments such as the SKA and ngVLA.
I will review the state of the art astrometry nowadays and the perspectives for the coming facilities.

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Exploring the non-linear motion of the parsec-scale jet of FSRQ 1633+382

Hyunwook Ro, Bong Won Sohn, Aeree Chung, Thomas P. Krichbaum

Physics of relativistic jet in Active Galactic Nuclei (AGNs) is one of the prominent questions in astrophysics that has not been resolved to date. Particularly, the launching mechanism of the jet which occurs near the supermassive black hole is still poorly understood. FSRQ 1633+382 (z = 1.814), a powerful AGN with a prominent radio jet, is one of the best laboratories to study the innermost jet in detail. In this study, we have investigated kinematics of parsec-scale jet of FSRQ 1633+382 using Very Long Baseline Array (VLBA) data from 1994 to 2017. We found that at some point the radial distances of the propagating jet components are temporarily stopped. This indicates that the inner jet of FSRQ 1633+382 changes their direction multiple times. We applied a helical trajectory model to the non-linear motion and extracted the physical properties of the motion. Since the trajectory of the jet component reflects the topology of the magnetic field, our results suggest the presence of twisted magnetic field lines which are arisen from a magnetized accretion disk or a rotating supermassive black hole.

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Parallaxes and proper motions of star forming regions in the Sagittarius spiral arm

K. L. J. Rygl, Y. Wu, M. J. Reid, A. Brunthaler, K. M. Menten

The spiral structure of our own Galaxy is still not very well known due to our location within the Galactic disk that causes any spiral structure to be superimposed within the line of sight. While kinematics can largely disentangle the various spiral arms, kinematic distances are not accurate enough for precise spiral structure studies. We measure the parallaxes and proper motions of water and 6.7GHz methanol masers associated to star-forming regions in the Sagittarius spiral arm, up to the tangential point at Galactic longitudes of 49 degrees, as part of the BeSSeL program. By combining this new astrometric data with previous measurements, we can study the distribution of masers in this spiral arm to improve measures of the arm height, width, and pitch angle. As the Sagittarius arm is one of the closest spiral arms to the Sun, the parallax uncertainties are relatively small, and we can begin to trace the three dimensional structure and velocities of the star forming regions in the arm and compare that to spiral arm models and observations of other (face-on) galaxies.

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Zooming in the jet formation site in AGN with RadioAstron

Tuomas Savolainen for the RadioAstron Nearby AGN key science program team

During the past five years, RadioAstron Nearby AGN Key Science Program team has carried out multiple space-VLBI imaging experiments on nearby radio galaxies M87, 3C84 and Cen A with an aim to study the structure of their jet formation sites. The obtained images significantly exceed the resolution achieved in ground-based experiments revealing new details of the jet formation site and of the interplay between the jet and the ambient medium. For example, in 3C84 we have detected a surprisingly wide edge-brightened jet merely a few hundred gravitational radii from the central engine, a "mini-cocoon" around the recently restarted parsec-scale jet, and high brightness temperatures that are at or above the inverse Compton catastrophe limit. Furthermore, we have been able resolve the internal structure of the jet acceleration and collimation zone in M87. I will give an overview of the main results from the key science program and also briefly discuss an ultra-high resolution campaign, in which we observed two quasars over the whole RadioAstron orbit yielding detections down to a fringe spacing of 12 microarcseconds.

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Tracing AGN feedback in powerful radio galaxies with VLBI

Robert Schulz, Raffaella Morganti, Kristina Nyland, Zsolt Paragi, Elizabeth Mahony, Tom Oosterloo

The jets of powerful radio galaxies are known to play a vital role in regulating the gas distribution of the host galaxy as they push through the interstellar medium (ISM). Evidence for this feedback mechanism includes observations of fast outflows of neutral atomic hydrogen (HI) gas detected in absorption in a number of radio galaxies. However, detailed information on the complex interplay on parsec-scales is still extremely limited, but can be retrieved using Very Long Baseline Interferometry (VLBI). We have been conducting a study to locate and characterize the outflow of HI gas on parsec scales in a small, but diverse sample of young and recently restarted radio galaxies. In this talk, I will compare the differences and similarities of the properties of the HI outflows in our sample which indicate that the selected sources could represent different stages of evolution in jet-ISM interaction. Our results also provide important input for theoretical models and show the need for future larger sample studies with VLBI that enable a more detailed statistical analysis.

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Unravelling pulsar scattering through VLBI

Dana Simard and Ue-Li Pen

The scattering of pulsar emission by cold plasma throughout the interstellar medium complicates precise timing measurements and limits the use of pulsars as probes of fundamental physics. In simple cases, the scattering can be attributed to a single screen localized along the line-of-sight to the pulsar, and VLBI can take advantage of the fact that the spatial flux distribution is due to scattering of coherent pulsar emission to measure the distance to the scattering screen and the distribution of images on the screen. However, in many cases the scattering environment is more complex, and many screens with different orientations and distances contribute. I will review how VLBI can be used to map single screens before discussing how we can separate screens by combining visibilities with cross-correlations of autocorrelations. I will show how this technique can improve our interpretation of VLBI observations of PSR B0329+54, known to be affected by at least 4 scattering screens. Characterizing these scattering structures opens windows to unravelling the nature of these compact lenses in the ISM, which may be related to small-scale magnetic structures, removing the effects of scattering from pulsar timing observations, and using the coherent scattered images to obtain unprecedented spatial precision at the pulsar itself.

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Studies of galactic masers in RadioAstron space VLBI mission

A.M. Sobolev and RadioAstron maser team

Observations of the masers in the RadioAstron (RA) mission yielded detections of fringes for a number of sources in both H2O and OH maser transitions. Several sources display numerous ultra-compact details. This proves that implementation of the space VLBI technique for maser studies is possible technically and is not always prevented by the interstellar scattering, maser beaming and other effects related to formation, transfer and detection of the cosmic maser emission.
The sharpest “direct” linear resolution <4.e11 cm was achieved in observations of the maser in Orion.

RA detected the smallest structures ever observed in a Galactic maser. Analysis of the data >2.e14 K, and the line widths are 0.5 km/s. Most of the flux density (~ 90 per cent) is contained in a halo of diameter 1 mas. We discuss possible interpretations for the compact structure.

Very compact features with angular sizes not exceeding about 20 – 60 micro-arcseconds represent only a few per cent of the maser flux registered with the single-dish instruments. Estimates of the brightness temperatures of the ultra-compact features provide the values ranging from 1.e14 to 1.e16 K. We discuss possible nature of the ultra-compact structures which can appear due to the saturation effects, presence of the strong ultra-compact source on background and existence of the long correlation paths, e.g. turbulent velocity correlations.

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Gravitational lensing at milliarcsecond resolution with global VLBI observations

Cristiana Spingola

Gravitational lensing is a powerful tool for quantifying the mass content and distribution in distant galaxies. By using milliarcsecond angular resolution observations of radio-loud gravitationally lensed sources it is also possible to detect and quantify small deviations from a smooth mass density distribution. With this aim, we use 1.65 GHz global VLBI observations of the gravitationally lensed radio source MG J0751+2716 (at z = 3.2). The background radio source is highly resolved in the tangential and radial directions, showing evidence of both compact and extended structure (core-jet morphology) across several gravitational arcs that are 200 to 600 mas in size. By identifying compact sub-components in the multiple images, we constrain the mass distribution of the foreground z = 0.35 gravitational lens using analytic models for the main deflector and for the members of the galaxy group. The mass models with and without the group find an inner mass-density slope steeper than isothermal for the main lensing galaxy, which is consistent with the two-phase galaxy formation scenario. Moreover, we find randomly distributed image position residuals of about 3 mas. These residuals are much larger that the intrinsic astrometric uncertainties (40 μas on average), suggesting that at the mas level, the assumption of a smooth mass distribution fails, requiring additional structure in the model.

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Insights into galaxy evolution with strong gravitational lensing

Hannah Stacey, John McKean

Investigating the connection between star formation and AGN growth in the high redshift Universe is challenging due to limitations in sensitivity and resolution of observational data. Previous studies have revealed high levels of star formation in quasar host galaxies, but studies of individual quasars have inevitably focused on a few bright sources. By targeting quasars that are gravitationally lensed we probe intrinsically lower luminosities, allowing us to study more typical quasars and construct a more complete sample of the population.

We have derived FIR luminosities and SFRs for the 104 gravitationally-lensed quasars observed with Herschel/SPIRE, the largest such sample ever studied. We find evidence for dust-obscured star formation in 66% of the sample, a result is in line with current models of quasar evolution and suggests that most quasars exist in a transitional phase between a dusty star-forming galaxy and AGN-dominated system.

Using the radio-infrared correlation, we differentiate radio-bright and radio-faint quasars and compare their FIR emission. With this method, we identify a population of optically-selected quasars with a radio excess which suggests they have low-power radio jets. We highlight the importance of VLBI to measure compact emission and understand the emission mechanisms, and hence AGN feedback mechanisms, at play in these objects.

A full understanding of our results requires detailed, multifrequency observations of individual objects. In this respect, high-resolution follow-up of lensed quasars from within our sample will be important as it will allow the radio jets, heated dust and molecular gas to be mapped on small angular scales. In addition to the Herschel study, we present preliminary results of our high-resolution studies of dust, molecular gas and radio emission which will be reconstructed on scales of 10-200 parsecs in combination with sophisticated gravitational lens modelling techniques. With our results, we demonstrate that gravitational lensing can provide important insights into the evolutionary process at cosmologically-interesting redshifts.

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Magnetic field measurements around massive young stellar objects with the EVN.

G.Surcis, W. Vlemmings, H.J. van Langevelde

Although the observational and theoretical progresses of the last years, the formation process of high-mass stars (M>8 M_sun) is still unclear. This is mainly due to their fast evolution and large distances that make difficult to observe, with large details, a sufficient amount of massive young stellar objects (YSOs) at each evolutionary stages. However, in the last 10 years some pieces of information regarding the gas motion and the magnetic field close to the YSOs have been gathered by observing and analyzing the maser emission of mainly water and methanol molecules. In particular, we have performed full polarization observations of 6.7 GHz methanol masers and/or 22 GHz water maser with the European VLBI Network (EVN) towards a large number of sources in order to provide measurements of magnetic fields orientation and strength at milliarcsecond resolution around massive protostars. These pieces of information can be obtained at this high angular resolution only by observing and analyzing the polarized emission of masers. From the linearly and circularly polarized emissions we can determine the orientation and the strength of the magnetic fields, respectively.
In my talk I will present the updated statistics about the alignment of the magnetic fields with the bipolar outflows ejected from the massive protostars obtained by observing the linearly polarized emission of 6.7 GHz methanol maser. In addition, and for the first time, we will provide the magnetic field strength measured from the Zeeman-splitting of methanol maser by using the very recent determination of the Landé g-factors for the methanol maser transitions (Lankhaar et al. 2018, Nature Astronomy, 2, 145). Furthermore, I will briefly show the up-to-date results of the monitoring project (still ongoing) of the kinematics of the 22 GHz water masers, and its link with the magnetic field, detected in the massive star-forming region W75N(B).

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Studying galaxy evolution through cosmic time via the μJy radio population: early results from eMERGE DR1

Alasdair Thomson, Tom Muxlow, Rob Beswick, Jack Radcliffe, Nick Wrigley, Ian Smail, Ian McHardy, Rob Ivison, Isabella Prandoni

eMERGE is a multi-tiered legacy survey being carried out with eMERLIN and the VLA at 1.5GHz and 6GHz. Exploiting the unique combination of high sensitivity and high angular resolution provided by radio interferometry, these observations will provide a powerful, obscuration-independent tool for tracing intense star-formation and AGN activity in galaxies out to z~5.

In our first data release (DR1), we present eMERGE Tier 1, a 12-arcmin pointing centred on GOODS-N, imaged at 1.5GHz with the VLA and eMERLIN at ~270mas resolution down to an rms sensitivity of ~1.5μJy/beam, along with 6GHz imaging from the VLA at ~0.5” resolution and comparable sensitivity. This unique radio survey – unrivalled in its combination of depth, areal coverage and angular resolution in the pre-SKA era – allows us to localise and separate extended star-forming regions, nuclear starbursts and compact AGN core/jet systems in galaxies over the past two-thirds of cosmic history, a crucial requirement of tracing the apparently simultaneous growths of the stellar populations and central black holes in massive galaxies.

In this talk I will highlight some early science results from eMERGE DR1, including the first reliable angular size distribution for a large (>200) sample of ~μJy radio galaxies (providing a crucial benchmark for studies of the sub-μJy population of “main sequence” galaxies out to high redshift, which will be undertaken by SKA in the next decade), as well as a characterisation of the multi-frequency radio properties of dusty starburst galaxies at z=2-3. Ongoing eMERGE observations will eventually quadruple the area of Tier 1 (to 30') and double the sensitivity (to ~1uJy/beam) at 1.5GHz, while planned eMERLIN observations at 6GHz will reach ~40mas resolution (~300pc at z=2) at ~1μJy/beam, providing the resolution and sensitivity necessary to search for star-formation occurring in dense giant molecular clouds at cosmic noon.

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Observing pulsars with ALMA: an unprecedented opportunity to explore the millimetre wavelength regime of pulsar emission

Pablo Torne, Kuo Liu

The millimetre wavelength spectral window of pulsars has barely been explored, being the lack of sensitive-enough instruments one of the main reasons. However, new broad-band receivers at the IRAM 30-m, and the recently commissioned phased mode of the Atacama Large Millimeter Array (ALMA), which delivers the approximate sensitivity of an 80-m single dish, have opened an unprecedented opportunity to investigate pulsars in this unexplored frequency regime. In this talk, I will present the results from our observations of a sample of pulsars both with the 30-m and with ALMA in its phased mode. These include the integrated pulse profile of Vela obtained with ALMA at a record-high radio frequency and its polarisation properties at multiple frequency bands. In addition, we will discuss the noise properties of the ALMA dataset and comment on the capability of using the 30-m and phased-ALMA to search for new pulsars.

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CASA on the fringe

Ilse van Bemmel, Des Small, Mark Kettenis, Arpad Szomoru, George Moellenbrock

JIVE is dedicated to lowering the threshold for using VLBI as an observational tool in a broad selection of astronomical topics. This includes the development of new software tools for VLBI data processing in the CASA package. In this talk I will introduce the new fringefit task and highlight additional new tasks and changes to existing tasks. In addition, the development, verification and future plans for the CASA VLBI toolkit will be discussed. This will serve as a general introduction to the tutorial at the end of the symposium.

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The Synergy between VLBI and Gaia astrometry

Huib van Langevelde, Luis Quiroga-Nunez, and members of the Bessel and Baade teams

With the publication of Gaia DR2, 1.3 billion stars now have public parallax and proper motion measurements. In this contribution we compare the results for sources that have both optical and radio measurements, showing that one has to be cautious in particular when using Gaia data for large, variable and bright AGB stars. Moreover, there are still a number of applications where VLBI astrometry yields unique constraints for astrophysical problems in Galactic astronomy, even though the number of objects with Gaia astrometry is much larger than the number of Galactic sources with VLBI astrometry. The stars in the BAaDE sample can uniquely constrain the dynamics and stellar content of the bulge and bar of the Milky Way. We are analysing pilot VLBI observations of the SiO masers associated with such Mir-like stars. The BeSSel project not only provides parallax and proper motions at much larger distances than Gaia can reach, but it also uniquely samples the spiral arms of the Galaxy. With the advent of the SKA this can be extended to weaker sources, notably for the Southern hemisphere where the inner Galaxy can be sampled as we show in simulations of the Galactic population of methanol masers.

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Multi-frequency studies of the jet in the high-redshift quasar S5 0836+710

L. Vega-Garcia, A.P. Lobanov, M. Perucho, C.M.Fromm

We present a multi-frequency analysis of the jet in 0836+710 using global VLBI data in combination with RadioAstron space-VLBI observations. We take advantage of a rich data set including five frequencies to perform a detailed spectral analysis of the source, including maps of spectral index and synchrotron turnover frequency. To complement this, we performed a kinematics analysis using public multi-epoch data from long-term VLBI monitoring programs. Finally, using numerical simulations we investigate the presence of asymmetries in the jet structure observed in the 22 GHz RadioAstron image, and its possible links with jet rotation or jet viewing angle.

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Imaging pulsar echoes at low frequencies

Olaf Wucknitz

Interstellar scattering is known to broaden distant objects spatially and temporally. The latter aspect is difficult to analyse, unless the signals carry their own time stamps. Pulsars are so kind to do us this favour. Typically the signature is a broadened image with little or no substructure and a similarly smooth exponential scattering tail in the profile. The case of B1508+55 is special: The profile shows additional components that are moving relative to the main pulse with time. We use low-frequency VLBI to test the hypothesis that these components are actually such scattering-induced echoes, by trying to detect the expected angular offset.
Using international stations and the phased-up core of the LOFAR array, we can do interferometry with high resolution in time and space. This talk presents a selection of results from an ongoing large-scale monitoring campaign. We can not only detect the offset, but even image a full string of echoes, and relate the positions with delays. What we find is apparently consistent with scattering by highly aligned components in a single screen. Further investigations will help us to understand more details of the scattering process.

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Radio structures in radio-quiet quasars with extremely powerful X-ray outflows

Jun YANG (Onsala Space Observatory, Sweden), Tao AN (Shanghai Astronomical Observatory, China), and Zsolt Paragi (JIVE, Netherlands)

When active galactic nuclei have accretion rates close to their Eddington limits, radiatively driven outflows at mildly relativistic velocities in a quite large aperture would be launched. Some powerful wind-like outflows may produce strong shocks and thus have significant non-thermal emission. The outflow-driven radio emission may be detectable in some radio-quiet quasars with extremely powerful and long-lived X-ray outflows and remarkably high bolometric luminosities. To investigate the speculation, we performed very-long-baseline interferometric (VLBI) observations of three optically luminous quasars (PDS 456, IRAS F11119+3257, PG 1211+143). In our VLBI images, all these quasars have relatively extended structures. With respect to their accurate Gaia positions, we find that their radio cores are either quite faint or undetected. Assuming that the radio cores also host wind-like outflows, we provide upper limits on their radio luminosities. Furthermore, there are two-sided jets observed on sub-kpc scales in PDS 456 and IRAS F11119+3257. This provides the strong evidence for the episodic jet activity at the state of very high accretion rate.

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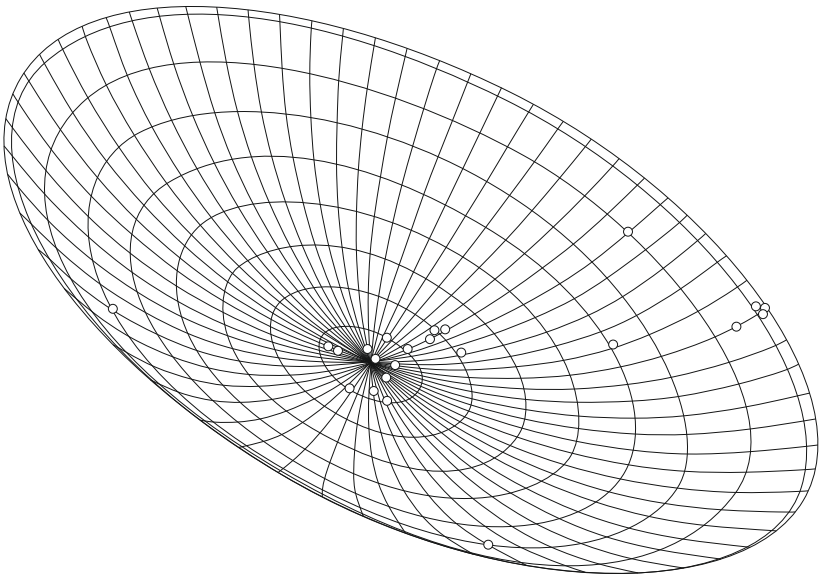
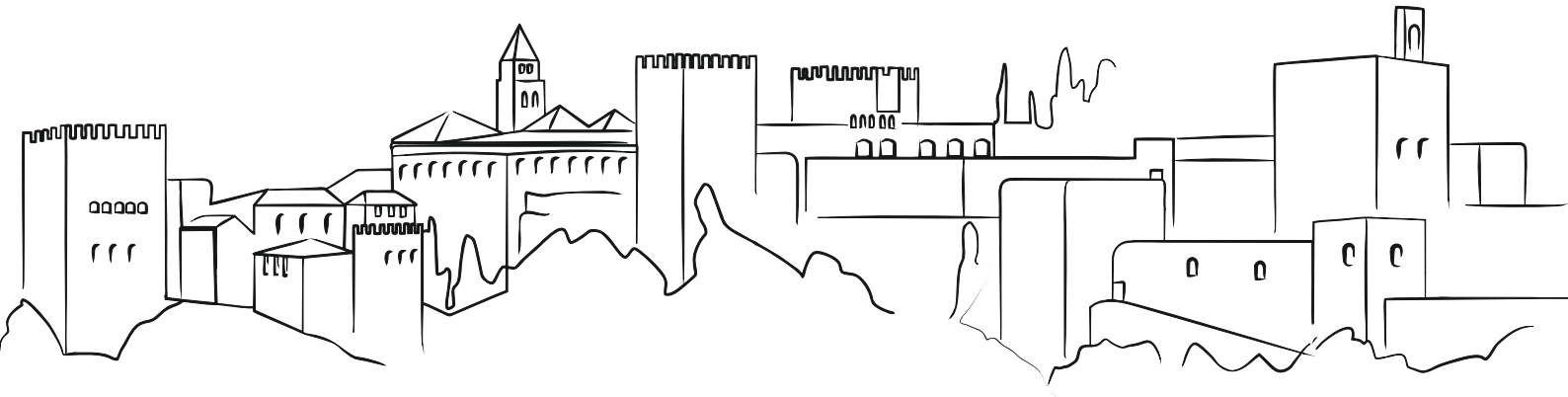
A study of the physical environments of evolved stars from the SiO and H2O masers

Youngjoo Yun, Se-Hyung Cho, Richard Dodson, María J. Rioja

We present the long-term observational results of the H2O and SiO masers emitted from the circumstellar envelopes (CSEs) of the evolved stars. Korean VLBI Network (KVN) has observed the stellar masers at four frequency-bands (K, Q, W and D bands) simultaneously since August 2014. The relative spatial distributions between the H2O and SiO masers are precisely determined from the source frequency phase referencing (SFPR) method, which are closely related to the individual masing conditions induced by the physical environments of the inner and outer parts of the CSEs of the evolved stars. The temporal variability of not only the spatial distribution but also the intensity of the stellar masers enable us to trace the physical characteristics of the CSEs along the stellar phase. From our results, the multi-frequency observation of KVN is proved to be powerful to investigate the physical environments and the evolutionary process of the evolved stars.

Posters





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DBBC3 the new wide-band backend for VLBI

G. Tuccari, W. Alef, S. Dornbusch, R. Haas, K-A Johansson, H. Rottmann, M. Wunderlich

The DBBC3 VLBI digital backend is the successor of the most widely adapted VLBI backend DBBC2. The DBBC3 offers much wider bandwidth, integrated Ethernet output, and three different firmwares for observing have been implemented now: Direct Sampling Conversion (DSC), arbitrary selection of bands (OCT), Digital Down Conversion (DDC).
These modes cover all the requirements of astronomical, VGOS and legacy geodetic VLBI of the present, but also of the near future. In addition the DBBC3 offers unsurpassed compatibility to the relatively large number of
other existing VLBI backends.

A number of test observation have been conducted in the last months to achieve the best performance for the VGOS modes, and a similar test is planned for the EVN network. A number of DBBC3 systems has been deployed and more
are currently under construction, with a number of 4GHz bands ranging from 2 up to 8 with resulting output data-rates from 32 Gbps to 128 Gbps.

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Origin And Evolution Of Multi-Band Variability In The Radio Source 4C 38.41

Juan-Carlos Algaba, Sang-Sung Lee, Bindu Rani, Dae-Won Kim, Motoki Kino, Jeffrey Hodgson, Guang-Yao Zhao, Do-Young Byun, Mark Gurwell, Sin-Cheol Kang, Jae-Young Kim, Jeong-Sook Kim, Soon-Wook Kim, Jong-Ho Park, Sascha Trippe, Kiyoaki Wajima

The flat spectrum radio quasar 4C 38.41 showed a significant increase of its radio flux density during the period 2012 March - 2015 August which correlates with gamma-ray flaring activity. Multi-frequency simultaneous VLBI observations were conducted as part of the interferometric monitoring of gamma-ray bright active galactic nuclei (iMOGABA) program and supplemented with additional monitoring observations at various bands across the electromagnetic spectrum. The epochs of the maxima for the two largest gamma-ray flares coincide with the ejection of two respective new VLBI components and the evolution of the physical properties seem to be in agreement with the shock-in-jet model. Derived synchrotron self absorption magnetic fields, of the order of 0.1 mG, do not seem to dramatically change during the flares, and are much smaller, by a factor 10,000, than the estimated equipartition magnetic fields, indicating that the source of the flare may be associated with a particle dominated emitting region. Analysis on the physical properties of the ejected components is performed, suggesting an evolution along the jet.

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Resolving the Geometry of the Innermost Relativistic Jets in Active Galactic Nuclei

J. C. Algaba, M. Namakura, K. Asada, S. S. Lee

In the current paradigm, it is believed that the compact VLBI radio core of radio-loud active galactic nuclei (AGNs) represents the innermost upstream regions of relativistic outflows. These regions of AGN jets have generally been modeled by a conical outflow with a roughly constant opening angle and flow speed. Nonetheless, some works suggest that a parabolic geometry would be more appropriate to fit the high energy spectral distribution properties and it has been recently found that, at least in some nearby radio galaxies, the geometry of the innermost regions of the jet is parabolic. We compile here multi-frequency core sizes of archival data to investigate the typically unresolved upstream regions of the jet geometry of a sample of 56 radio-loud AGNs. Data combined from the sources considered here are not consistent with the classic picture of a conical jet starting in the vicinity of the super-massive black hole (SMBH), and may exclude a pure parabolic outflow solution, but rather suggest an intermediate solution with quasi-parabolic streams, which are frequently seen in numerical simulations. Inspection of the large opening angles near the SMBH and the range of the Lorentz factors derived from our results support our analyses. Our result suggests that the conical jet paradigm in AGNs needs to be re-examined by millimeter/sub-millimeter VLBI observations.

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A new IAU Working Group for communicating radio astronomy

Megan Argo and the C2WG

At the IAU General Assembly in Vienna in August 2018, Commission C2 (Communicating Astronomy with the Public) will agree a number of new Working Groups within the commission, one of the proposed new Working Groups is “Communicating Radio Astronomy”. With the coming Square Kilometre Array, the development of the African VLBI Network, and efforts to convert defunct communication antennas to radio telescopes ongoing in SE Asia and South America, radio astronomy science and technology is booming. The aim of this WG is to connect communicators around the world in order to foster international collaboration, discuss the particular challenges of communicating radio astronomy, and to share successes and best practise. This contribution will outline the scope and goals of this WG, and explain how you can get involved.

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Multi-epoch VLBI images to study the ICRF-3 Defining Sources in the Southern Hemisphere

Sayan Basu, Dr. Aletha de Witt, Dr. Jonathan Quick

Very long baseline interferometric (VLBI) observations of extragalactic radio sources at 2.3 and 8.4 GHz are used to construct and maintain a quasi-inertial reference frame known as the International Celestial Reference Frame (ICRF). Among the 3414 ICRF-2 sources, 295 sources of the highest astrometric quality are used to define the stability of the ICRF axes. Multi-epoch, high-resolution imaging is particularly important as these quasars or reference sources that make up the ICRF often show extended emission on milli-arcsecond (mas) scales, with jet structures appearing and disappearing on timescales of months to years. Reference sources with extended structures are poorly suited for high-accuracy reference-frame use unless the source structure and variability can be taken into account. In order to maintain the ICRF with the highest accuracy, these reference sources and in particular the defining sources should be monitored on a regular basis.

In the Southern Hemisphere due to the limited number of radio telescopes it is difficult to run dedicated imaging programmes of these extragalactic radio sources, to both monitor existing ICRF sources and to identify new potential candidate ICRF sources. An effort was required to identify an experiment that can be used to produce multi-epoch VLBI images of the ICRF defining sources below a declination of -30 degrees, in order to study the source morphology. We present such results from the Celestial Reference Frame Deep South (CRDS) geodetic/astrometric VLBI sessions where VLBI images of all 76 ICRF defining sources below a declination of -30 degrees were produced. We also present first VLBI images of new sources that were included in the observing schedule to study their suitability as reference frame sources for the next generation celestial reference frame, the ICRF-3.

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Bursting H2O maser source G25.65+1.05: from single-dish to space VLBI

Olga Bayandina, Alexey Alakoz, Ross Burns, Stan Kurtz, Evgeny Lekht, Georgij Rudnitskij, Nadezhda Shakhvorostova, Michael Shyrov, Irina Val'tts, Alexandr Volvach and Larisa Volvach on behalf of the Maser Monitoring Organization (M2O)

In 2017-18 the source of outstanding H2O maser bursts G25.65+1.05 (RAFGL7009S) have been intensively studied with a wide range of baselines – from compact array (JVLA) and ground VLBI (EVN) to space VLBI (RadioAstron mission supported by VLBA and EVN telescopes) - the report aims to show the results of these observations. The source is one of only three Galactic water masers together with W49N and OriKL that are known to flare to the level of 10^5 (Tb ~ 10^17 K). Strong flares of H2O maser in it were first discovered in long-term single-dish monitorings with 22-m telescopes of Pushchino and Crimean Astrophysical Observatories and only recently were followed by interferometric observations. We present the first ever comprehensive compact array overview on a maser activity in the source; the fine spatial structure EVN study of bursting H2O maser; finally the record resolution signal detection in RadioAstron observations with space-ground baselines (RA-Torun and RA- HartRAO) of 8.6 - 9.3 Earth Diameters (ED) and angular resolution of 23 μas, which corresponds to the liner size of emitting region of about 0.05 AU (assuming the distance to the source of 2.08 kpc). The high intensity of the burst provides a large dynamic range for the analysis of the parameters of compact structures that are detected in the source on ground-ground and space-ground baselines.

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AGN intra-day and inter-day variability studies on VIRAC radio telescopes

Vladislavs Bezrukovs, Mikhail Rybov, Artem Suhkarev, Arturs Orbidans, Marcis Bleiders

Starting from year 2017, the radio telescopes of the Ventspils International Radio Astronomy Centre (VIRAC) are used to study the intra-day and inter-day variability of various types of active galactic nuclei. These studies are based on a generalization of the results of a 40-year monitoring of the fluxes of extragalactic radio sources conducted at the Michigan Radio Astronomy Observatory in the USA using wavelet and Fourier analysis performed at the Odessa Observatory of the Radio Astronomy Institute of the National Academy of Sciences of Ukraine. On their basis, a catalogue was created for the properties of the variability of extragalactic radio sources.

The extension of the temporal spectrum of flux changes to inter-diurnal and diurnal scales is carried out on VIRAC radio telescopes RT-32 and RT-16 respectively with 32 and 16 meters' antennas. The intra-day variability in the calibration source 3C295 (Seyfert galaxy of type II) is detected and preliminary results presented in the poster for discussion.

Observations of a number of other radio sources (3C 273, 3C 454.3, OJ 287, BL Lac) are suspected for these types of variability and scheduled for monitoring observations.

The poster discuss possibility for observations of these promising objects during VLBI sessions by EVN and simultaneous long-term total flux monitoring using VIRAC antennas. The temporal changes in fluxes linked with VLBI maps opens opportunity to determine the nature of the physical processes that form fast flux changes of various types of active galactic nuclei.

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Towards a determination of H0 in JVAS B1030+074: a detection of the VLBI jet in both images

Biggs, A. D.

We have recently measured the time delay between the two images of the gravitational lens system JVAS B1030+074 using archival VLA monitoring data. Impressive polarization variability gives a value of 146 +/- 6 days for this long sought-after parameter. In principle, it is now possible to determine H0 with this lens and focus must turn to improving the lens model. VLBI can potentially provide modelling constraints if the lensed source contains a radio jet, but although a prominent example is seen in the brighter image, its counterpart in the fainter (and therefore smaller) image has never been convincingly detected. We have performed our own analysis of the existing VLBI 1.7-GHz data and demonstrate that in fact the jet in image B is observable and see similar structures in multiple epochs. We also discuss prospects for detecting the third image in this system.

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Physical parameters of the near-Earth asteroids from radar observations

Yu. S. Bondarenko, D. A. Marshalov, Yu. D. Medvedev, D. E. Vavilov, M. B. Zotov and A. G. Mikhailov

The Institute of Applied Astronomy in cooperation with the Jet Propulsion Laboratory and Goldstone Deep Space Communications Complex regularly conduct intercontinental bistatic radar observations of near-Earth asteroids using 70-m antenna (DSS-14) to transmit 8560 MHz (3.5 cm) signal and 32-m radio telescopes (RT-32) of “Quasar” VLBI network in Svetloe, Zelenchukskaya and Badary observatories to receive the echoes. To carry out such observations, the existing receiving, conversion and recording systems have been adapted and special software for radar observation scheduling and echo signal data processing has been developed. Since 2015, echoes from 2011 UW158, 2003 TL4, 2003 YT1, 2014 JO25, 2003 BD44, 3122 Florence and 2017 VR12 asteroids have been registered. The continuous wave echo power spectra of these asteroids were obtained and their analysis was carried out. We estimated the size, rotation period, radar albedo and circular polarization ratio of these asteroids.

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OJ287: Deciphering the "Rosetta stone of blazars"

S. Britzen, C. Fendt, G. Witzel, S.-J. Qian, I.N. Pashchenko, O. Kurtanidze, M. Zajacek, G. Martinez, V. Karas, M. Aller, H. Aller, A. Eckart, K. Nilsson, P. Arevalo, J. Cuadra, M. Subroweit, and A. Witzel

OJ287 is the best candidate Active Galactic Nucleus (AGN) for hosting a supermassive binary black hole (SMBBH) at very close separation. We present a re-analysis of 120 Very Long Baseline Array (VLBA) observations (at 15 GHz, MOJAVE survey) covering the time between Apr. 1995 and Apr. 2017. We find that the OJ287 radio jet is precessing on a timescale of ~ 22 yr. In addition, our data are consistent with a jet-axis rotation on a yearly timescale. We model the precession (24±2 yr) and combined motion of jet precession and jet-axis rotation. The jet dynamics and flux-density light curves can be understood in terms of geometrical effects. Disturbances of an accretion disk caused by a plunging black hole do not seem necessary to explain the observed variability. Although the SMBBH model does not seem necessary to explain the observed variability, a SMBBH or Lense-Thirring precession (disk around single black hole) seem to be required to explain the timescale of the precessing motion.

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OH EGOs: Hydroxyl masers in Extended Green Objects

Ross A. Burns, Olga Bayandina, Gabor Orosz, Huib van Langevelde, Hiroshi Imai, Richard Dodson, Maria Rioja

Extended green objects (EGOs) are a class of high-mass protostar characterised by active outflows seen in Spitzer data. The launching mechanism of outflows in massive embedded objects remains one of the key puzzles of massive star formation theory as it is thought to reflect characteristics of the accretion process. A sample of EGOs exhibiting OH masers were identified by VLA observations, raising the possibility of probing the magnetic fields at the launching region. This contribution introduces new high-resolution full-Stokes EVN observations of OH masers in EGOs targeting the launching region of outflows in high-mass protostars.

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M2O-VLBI: The VLBI branch of the Maser Monitoring Organisation

Ross Burns, Olga Bayandina, Mateusz Olech, Gabor Orosz, Huib van Langevelde, Katherina Immer, Willem Baan, Tomoya Hirota, Jungha Kim, Koichiro Sugiyama, Gabriele Surcis, Irina Val'tts, Nadya Shakhvorostova, Georgij Rudnitskij, Alexandr Volvach, Gordon MacLeod, James Chibueze, Pawel Wolak, Anna Bartkiewicz, Busaba Kramer, Alex Kraus, Karl Menten, Kazuhito Motogi, Kee-Tae Kim, Crystal Brogan, Todd Hunter, Stan Kurtz

During the 2017 IAU maser symposium in Cagliari two well known maser sources went 'super burst'. The single-dish Maser Monitoring Organisation (M2O) reported sudden enhancements in the emission of two well known maser sources, both reaching fluxes above 15,000 Jy within a few hours. In response, a team was assembled for the purpose of following up maser super burst events using quick-response VLBI imaging to disseminate the origin of such behavior. This poster describes the first activities of the M2O-VLBI, its members and the future plan for investigating the maser super burst phenomenon.

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The Current Status and Wideband Upgrades of the KVN

Do-Young Byun, Se-Jin Oh, Seog-Tae Han, Do-Heung Je, Moon-Hee Chung, Min-Gyu Song and Seog Oh Wi

Recently KVN equipped with broadband samplers OCTAD that supports aggregated data rates up to 32Gbps. It consist of four A/D converters and digital down-converters that support various bandwidth modes. Using the newly introduced broadband samplers together with existing data acquisition system, simultaneous observation of four frequencies with full polarization is possible.
On the other hand, upgrade work is in progress to expand frequency range of current KVN receiver. As a first step, K-band receivers are upgraded to have 18-26 GHz input range in 2018 and upgrade of 86GHz receiver for 85-116 GHz will be followed by next year. The recent status and wide band upgrade plan of the KVN system are introduced.

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Delving Deeper into Blazar Cores with 3mm GMVA Polarimetric Observations

Alan Marscher, Svetlana Jorstad, Jose L. Gomez, Nicholas MacDonald, Thomas Krichbaum, Biagina Boccardi, Efthalia Traianou, Ivan Agudo

In order to investigate the high energy emission and jet formation in blazars, we study a sample of gamma-ray bright AGN in a combined 7mm / 3mm Vlbi monitoring program. Here we present total and linearly polarized GMVA images of a sample of blazars from the VLBA-BU-BLAZAR program, obtained from May 2016 to March 2017. The lower opacity at 3 mm and high angular resolution, of the order of 50 microarcseconds, allow us to measure the angular sizes of the most compact features, which can be compared with those observed at 7 mm with the VLBA for the determination of the jet's physical parameters.
Moreover, Faraday rotation and spectral index analysis between the two frequencies (3 and 7mm) provide us information about the three-dimensional structure of the magnetic field with unprecedented angular resolution.

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Magnetic Field, Kinematic and Physical Properties of G351.417+0.645 from high resolution observation of OH masers using LBA

Thanapol Chanapote, Richard Dodson, Maria Rioja, Kitiyanee Asanok, James Green, Busaba Hutawarakorn Kramer

We observed OH masers towards the high-mass star-forming region G351.417+0.645 at ground- (1665- and 1667-MHz main lines and 1720-MHz satellite line) and excited-state (6030 and 6035 MHz) using the Australian Long Baseline Array (LBA) in 2012. High resolution of LBA enabled us to precisely measure magnetic field and kinematic properties and trace physical properties of this source. There are 21 and 23 Zeeman pairs detected at ground and excited states respectively providing magnetic field measurements between -6.4 and +4.4 mG. We found the same trend of a reversal of magnetic field from 1665- and 6035-MHz transitions. In comparison with previous LBA observation in 2001, there is no change in magnetic field strength and direction and radial velocity. We calculated internal proper motion with respect to the brightest features between those epochs (2001 and 2012) and found small downward motion from 50% of all the same maser features. Moreover, we also inferred the physical properties of this source from the coincidence of OH transitions at different location by comparing with the current OH models.

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ICRF3, the new realization of the International Celestial Reference Frame

P. Charlot, on behalf on the ICRF3 Working Group

This talk will give an overview of the new realization of the International Celestial Reference Frame, ICRF3, to be presented for adoption by the IAU General Assembly in August 2018. ICRF3 is aimed at replacing the second realization of the International Celestial Reference Frame, ICRF2, in use since 2010. ICRF3 has been generated by a Working Group of the IAU appointed in 2012. It is based on state-of-the-art astronomical and geophysical modeling and takes advantage of the wealth of VLBI data acquired on various observing networks (IVS, VLBA, DSN,…) since 2009 when ICRF2 was built. Compared to ICRF2, ICRF3 represents a significant improvement in terms of source characterization, position accuracy and total number of sources. About twice as many observations have entered ICRF3 compared to ICRF2. ICRF3 comprise source positions at three radio frequencies, 8.4 GHz, 22 GHz and 32 GHz. It is meant to be the reference for alignment of the Gaia optical frame onto the International Celestial Reference System with the highest accuracy.

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High-precision VLBI astrometry of radio stars

Wen Chen, Fengchun Shu, Min Wang

We will use the Chinese VLBI Network and Long Baseline Array to observe some radio stars to link with these stars in the Gaia Celestial Reference (GCRF) and VLBI reference frames. In this work, radio star positions are estimated to be accurate at the 10 mas level, with position errors approaching a few milliarcseconds for some of the stars observed.

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Simultaneous Monitoring Observations of Evolved Stars Using KVN 4 Bands II.

Se-Hyung Cho, Youngjoo Yun and KVN Evolved Star WG Members

We have performed simultaneous time monitoring observations of 22.2 GHz H2O and 43.1/42.8/86.2/129.3 GHz SiO masers toward 16 KVN Key Science Project(KSP) sources of evolved stars at the first stage of the KSP. We aim at investigating spatial structure and dynamical effect from SiO to 22.2 GHz H2O maser regions associated with a mass-loss process and development of asymmetry in circumstellar envelopes. Since 2015A observing season, astrometrically registered maps of SiO and H2O masers were obtained toward nine KSP sources using the source frequency phase referencing method. Here we report the KSP results of evolved stars focused on these successful SFPR sources.

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Measuring the Core Shift of Sgr A*

Ilje Cho, Bong Won Sohn, Taehyun Jung, Motoki Kino, Guang-Yao Zhao, Ivan Agudo, Maria Rioja, Richard Dodson, Kazuhiro Hada

The Galactic center, Sagittarius A* (Sgr A*), is the closest supermassive black hole (SMBH) and provides a great opportunity to study the origin of mm/sub-mm emission. Currently, two competing models have been suggested: the base of the jet and a radiatively inefficient accretion flow (RIAF). Measuring the frequency dependent core shift which the radio core moves toward the central SMBH with increasing frequency when the structure is elongated (e.g., conical jet) is an important tool to test this.

The Korean VLBI Network (KVN) is one of the best VLBI arrays to study the core shift, thanks to its quasi-optics system at four frequencies (i.e., 22 ,43, 86 and 129 GHz) so that it enables to correct the phase of target source at higher frequency using the calibrator's phase at lower frequency, so called source frequency phase referencing (SFPR; Rioja & Dodson, 2011). Then the relative astrometric measurements can be recovered.

We have conducted several observations for Sgr A* using KVN, and found not only the positional shift of its center at different frequencies but also an unexpected systematic phase slope which has not been clearly shown in the higher declination sources. We present our efforts to remove the residual phase trend and to constrain the other positional uncertainties so that we can obtain the intrinsic core shift of Sgr A*.

In addition, we conducted VLBA observations closely scheduled to the event horizon telescope (EHT) observations at 1 mm in April 2018. It aims to measure the core shift in parallel with KVN and compare it with the asymmetric structure of Sgr A* which may be resolved through EHT observations.

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(JUMPING) JIVE: Recent Developments

Giuseppe Cimo'

The primary task of JIVE – the Joint Institute for VLBI ERIC – is to operate a data processor and support the operations of the European VLBI Network (EVN), as well as provide support to the world-wide EVN user community. Aligned with these efforts, the European Commission, within the Horizon2020 framework, has funded the JUMPING JIVE project with the goal of bringing VLBI into the next decade and confirming JIVE and the EVN as globally recognized centres of excellence in astronomy. In this talk, I will be presented some recent activities at JIVE, highlighting in particular a number of exciting scientific and technological results, and describing the efforts of (JUMPING) JIVE in paving the future of VLBI in Europe and beyond.

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ASTERICS and the challenges of Multi-Messenger Astrophysics

Giuseppe Cimo'

Multi-messenger astrophysics is a field rich in opportunities but also challenges. It requires collaboration and coordination within a global network of facilities. The scientific drive towards combining and aligning data from different facilities in order to comprehensively study multi-messenger and transient events requires interoperability between hybrid data streams with unprecedented time synchronization across locations distributed across the Earth. The current observational strategies need to be adapted to take into account commensal operations. Practically, new approaches to computing and data analysis by means of machine learning have to be implemented because of the data volume and the issues of complex scheduling of hundreds of antennas operating at different regimes. Aligned with this vision, the European Commission approved (in the framework Horizon 2020) the ASTERICS initiative -ASTronomy ESFRI and Research Infrastructure CluSter- to collect knowledge and experiences from astronomy, astrophysics and particle physics and foster synergies among existing research infrastructures and scientific communities, with the ambition of seeing them interoperate as an integrated, multi-wavelength and multi-messenger facility. In my contribution, I will present the efforts of the ASTERICS cluster towards the interoperability of the next generation of astronomical and (astro)particle physics facilities.

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EAVN observations along with EHT for M87 in 2017

Yuzhu, Cui; Kazuhiro, Hada; Honma, Mareki on behalf of EAVN science work group

The radio galaxy M87 offers a privileged opportunity to probe the jet launching and formation scales thanks to the proximity and large mass of the central black hole. This makes M87 a prime target for the Event Horizon Telescope (EHT) along with SgrA*. In April 2017, M87 was for the first time observed by EHT+ALMA. This may allow the first imaging of the black hole shadow and jet-launching regions at scales of a few Schwarzschild radii. However, due to the sparse uv-coverage of the EHT, a proper interpretation of the EHT image (emission features surrounding the shadow) may require contemporaneous complementary observations at the lower frequencies that provides the higher fidelity jet images. Here we report results from detailed EAVN 22/43GHz monitoring observations of M87 that were performed from January to May 2017 (so-called the "EAVN campaign 2017"), covering well the EHT-2017 observing window. We obtained data for a total of >15 epochs, and for each session 7-15 telescopes joined from East Asia, boosting the sensitivity and imaging capability compared to KaVA. These data will uniquely monitor the detailed structural evolution of the jet, velocity fields and possible component ejections near in time to the EHT period.

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6668-MHz Methanol maser exploration of the W51 SFR complex beyond W51 main

Sandra Etoka
CoI: Malcolm Gray & Gary Fuller

W51 is one of the most massive giant molecular clouds in the Galaxy. It contains two giant HII regions labelled W51A and W51B which are themselves resolved into smaller components. In W51A, the most luminous sites are the two protocluster regions, so-called IRS2 and e1/e2. These regions, known to harbour maser emission from various species, show clear evidence of embedded young massive forming stellar objects. Our initial investigation of the region through MERLIN observations revealed intense and complex Class-II 6.668-GHz methanol maser activity towards W51 Main, associated with the e1/e2 protocluster. Here we present the second part of the investigation of this SFR complex which revealed
the presence of 6.668-GHz methanol maser activity in several regions including W51 IRS2/North with indication that the masers are excited by multiple objects potentially at different stages of evolution.

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Milliarcsecond monitoring of supernova remnants in M82

D. Fenech, R. Beswick, T. W.B. Muxlow, M. Argo

M82 is considered the archetypal starburst galaxy and at a distance of ~3.6\,Mpc is one of the closest examples of its kind. It therefore provides a unique opportunity to study a star-forming environment in detail and particularly the discrete products of star-formation such as supernova remnants (SNR) and HII regions.
We will present multi-epoch millarcsecond resolution monitoring of the most compact supernova remnants in M82. This will include global VLBI imaging of two of the most compact sources and their evolution over two decades, as well as the first monitoring results of the transient source.

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VLBI monitoring of two distant quasars as a showcase for 'EVN Lite'

S. Frey, O. Titov, A. Melnikov, P. de Vicente, F. Shu

Two prominent quasars at extremely high redshifts, J0906+6930 (z=5.47) and J2102+6015 (z=4.57) have been monitored with an ad-hoc array of five VLBI stations (Badary, Svetloe, Zelenchukskaya, Yebes, and Sheshan) at 2.3 and 8.6 GHz in the past two years. The primary purpose of this series of 24-hour astrometric-style experiments was to investigate possible changes of the accurate source positions over time. Moreover, the apparent non-variability of the objects allowed us to combine data obtained at multiple epochs and produce the best-quality VLBI images of the quasars at these observing frequencies available so far. Here we present the results of both the imaging and the preliminary astrometric analysis. We argue that this type of observations could be attractive for the proposed 'EVN Lite' concept in the future where a subset of EVN telescopes would observe more frequently than the regular EVN sessions.

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The rise and fall of a binary AGN candidate: the story of PSO J334.2028+1.4075

P. Benke, S. Frey, K. Gabányi, L. Gurvits, Z. Paragi, T. An, E. Kun, P. Mohan, D. Cseh

Apparently periodic optical variations of the luminous high-redshift (z=2.06) quasar PSO J334.2028+1.4075 (FBQS J2216+0124) led Liu et al. (2015) to interpret the variability as the orbital period of a binary supermassive black hole (SMBH) residing in a single circumbinary accretion disk. The proposed orbital separation was around 0.006 pc, and the possible inspiral time about 7 years in the rest frame of the quasar. Such objects would be of high interest as the difficult-to-find end products of binary SMBH evolution, and potential sources of low-frequency gravitational waves. However, extending the time baseline of the variability study, Liu et al. (2016) later found that the periodicity of PSO J334.2028+1.4075 does not remain persistent. Foord et al. (2017) did not find evidence for the binary active galactic nucleus scenario based on Chandra X-ray observations. The object has also been studied in detail in the radio (Mooley et al. 2018) with the Karl G. Jansky Very Large Array (VLA) and the Very Long Baseline Array (VLBA), revealing a lobe-dominated quasar at kpc scales, and possibly a precessing jet, which may retain PSO J334.2028+1.4075 as a binary SMBH candidate. Here we report on our 1.7-GHz observation with the European VLBI Network (EVN) which complements the high-resolution VLBA data taken at higher frequencies, and discuss the current knowledge about the nature of this interesting object.

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Total and linearly polarized synchrotron emission from overpressured magnetized relativistic jets

Antonio Fuentes, José L. Gómez, José M. Martí, Manel Perucho

We present relativistic magnetohydrodynamic (RMHD) simulations of stationary overpressured magnetized relativistic jets, which are characterized by their dominant type of energy: internal, kinetic, or magnetic. Each model is threaded by a helical magnetic field with a pitch angle of 45º and features a series of recollimation shocks produced by the initial pressure mismatch, whose strength and number varies as a function of the dominant type of energy. We perform a study of the polarization signatures from these models by integrating the radiative transfer equations for synchrotron radiation using as inputs the RMHD solutions. These simulations show a top-down emission asymmetry produced by the helical magnetic field and a progressive confinement of the emission into a jet spine as the magnetization increases and the internal energy of the non-thermal population is considered to be a constant fraction of the thermal one. Bright stationary components associated with the recollimation shocks appear, presenting a relative intensity modulated by the Doppler boosting ratio between the pre-shock and post-shock states. Small viewing angles show a roughly bimodal distribution in the polarization angle, due to the helical structure of the magnetic field, which is also responsible for the highly stratified degree of linear polarization across the jet width. In addition, small variations of the order of 26º are observed in the polarization angle of the stationary components, which can be used to identify recollimation shocks in astrophysical jets.

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High-resolution VLBI imaging of the gamma-ray blazar candidate J1331+2932

A. Gemes, K. Gabanyi, S. Frey, T. An, Z. Paragi

Active galactic nuclei are the most luminous persistent (non-transient) objects in the Universe. They are bright in the entire electromagnetic spectrum. Blazars are a special class where the jets point nearly to our line of sight. Because of this special geometry and the bulk relativistic motion of the plasma in the jet, their radiation is enhanced by relativistic beaming. The majority of celestial objects detected in gamma-rays are blazars. However, finding their counterparts in other wavebands is often challenging. Here we present the results of our 5-GHz European VLBI Network (EVN) observation of the radio source J1331+2932, a candidate blazar found while searching for possible gamma-ray emission from the stellar binary system DG CVn (Loh et al. 2017). The highest-resolution radio interferometric measurements provide the ultimate tool to confirm the blazar nature of a radio source by imaging compact radio jet structure with Doppler-boosted radio emission, and give the most accurate celestial coordinates as well.

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First Results of 6-21cm VLBA Observations of the MOJAVE-II AGNs

D. C. Gabuzda, S. Knuettel, A. B. Pushkarev, F. Richardson, M. Spillane, J. Kyprianou

We are in the process of obtaining VLBA polarisation data for the 191 MOJAVE-II Active Galactic Nuclei at 5.0, 2.3, 1.7 and 1.4 GHz (wavelengths of 6, 13, 18 and 21cm). These observations will enable studies of the evolution of the intensity and magnetic-field structures of these AGN jets as they propagate from parsec to kiloparsec scales, as well as studies of the thermal plasma present in the vicinity of the jets on these scales, manifest via Faraday rotation. These data are very sensitive to Faraday rotation due to the long "lever arm" between 6 and 21cm. A wide range of other multi-wavelength studies can also be carried out using these data. First results from this project will be presented, highlighting the high sensitivity of the data to intensity, linear polarization and Faraday rotation structures on a range of scales; the typical uncertainties in the Faraday rotation are no more than 1-2 rad/m^2.

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High frequency component contribution to the ICRF-3

C. Garcia-Miro, C. S. Jacobs, S. Horiuchi, J.E. Clark, M. Mercolino, I. Sotuela, L.A. White

This contribution gives an update on the realisation of the NASA/JPL Celestial Reference Frame at X/Ka frequencies, its contribution to the future ICRF-3, and comparisons with recent Gaia DR-2 Optical Reference Frame.

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3C 84 and a solution to the "Doppler crisis"?

Jeffrey Hodgson, Bindu Rani, Janghwan Oh, Sascha Trippe

The inner parsecs of the radio core of 3C 84 is a complex region with multiple bright regions that are moving at various speeds and in many directions. Nevertheless, the apparent motions of these components are typically subluminal and yet 3C 84 is one of the brightest Gamma-ray sources, having also been detected at TeV energies, leading to the question of how such high energies can be created without significant Doppler boosting. We performed a wavelet kinematic analysis of 3C 84 using high resolution 7 mm VLBA data. We find behaviour that is reminiscent of a Gamma-ray burst, with faster traveling shocks catching up with slower moving shocks before hitting the external medium, correlated with high energy flaring. We propose this mechanism as a solution to the “Doppler crisis”. We find tentative evidence that the mechanism producing the GeV and TeV flaring could be magnetic reconnections.

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Investigating dark matter properties with flux-ratio anomalies in radio-loud strongly lensed quasars

Jen-Wei Hsueh

Flux-ratio anomalies in strongly lensed quasars provide a promising approach to probe dark substructure abundance in distant galaxies. Two decades after the first major analysis, more lenses with significantly better data quality are available with modern interferometry such as VLBI. A matching improvement in the analysis process is therefore needed in order to investigate detailed dark matter properties. Recent studies have shown that, besides dark substructure there are two additional components that can cause flux ratio anomalies:
baryonic structures in lens galaxies and line-of-sight objects.
These two factors are not taken into account in most of the previous analyses of flux-ratios in lensed quasar systems.
I will present our results from a joint analysis on the latest data from radio and mid-infrared flux measurements. Importantly, we consider both baryonic disk and line-of-sight signals in our analysis process. Our results demonstrate a new analysis strategy for upcoming large samples from SKA, JWST and future surveys.

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MASK: Multi-frequency AGN Survey with the KVN

Taehyun Jung, Gunagyao Zhao, Minsun Kim, Ilje Cho, Bong Won Sohn, Jeong Ae Lee, Dawoon Jeong, Kiyoaki Wajima, Do-Young Byun, Woojin Kim, Jan Wagner

A simultaneous multi-frequency VLBI system of the Korean VLBI Network (KVN) with its powerful phase calibration technique, FPT (frequency phase transfer), has shown that the atmospheric fluctuations can be effectively calibrated, resulting in much longer integration time of VLBI data. Based on this aspect, we present the results of multifrequency AGN survey with the KVN (MASK), performed as a KVN legacy program to densify an existing VLBI catalog of extragalactic radio sources at 22/43/86/129 GHz.

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Probing the Faraday screen in the nuclear region of 3C84

Minchul Kam, Sascha Trippe

We present the result of the multi-frequency polarimetric observations to explore the environment of 3C 84 in the center of giant elliptical galaxy NGC 1275. We used the Korea VLBI Network (KVN) at 22, 43, 86, and 129 GHz as part of our Plasma-physics of Active Galactic Nuclei (PAGaN) project and Very Long Baseline Array (VLBA) archival data at 43 GHz. At the VLBI core, the linear polarization is extremely weak whereas it is relatively strong at a hotspot in the jet. By using the 256 MHz bandwidth of VLBA at 43 GHz, we detected the rotation measure (RM) at the core. Surprisingly, the core shows both positive and negative RM and its absolute value is lower than the expectation. This is inconsistent with previous results from the Submillimter Array (SMA) and the Combined Array for Research in Millimeter wavelength Astronomy (CARMA) observation at 220 and 340 GHz whose RM were always positive. To explain this, we suggest two possible scenarios. One is that EVPA rotations are saturated because the Faraday screen is internal to the jet. The other one is that the Faraday screen is hot accretion flow. To probe the origin of the Faraday rotation at the core, we proposed KVN observation at 86, 90, 94, 129, 138, and 144 GHz.

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Interferometric Monitoring of Gamma-ray Bright AGNs: J1159+2914

Sincheol Kang, Sang-Sung Lee, Do-Young Byun, Jeffrey Hodgson, and Jee-Won Lee

We present the results of multi-epoch monitoring of a blazar J1159+2914, one of the targets of a Very Long Baseline Interferometry (VLBI) monitoring program : Interferometric MOnitoring of GAmma-ray Bright AGNs (iMOGABA), as a Korean VLBI Network (KVN) Key Science Program (KSP). The observations were conducted simultaneously at 22, 43, 86, and 129 GHz, for 4 years from December 2012 to December 2016. Obtained total fluxes range between 0.26 and 2.88 Jy at all frequencies with a mean rms noise of 0.026 Jy. We also used the 15 and 230 GHz data observed by Owens Valley Radio Observatory and Sub-Millimeter Array. In order to analyze the characteristics of variabilities, we estimated variability timescales from 15 GHz data, using three different functions, structure function, Gaussian distribution function, and exponential function. Also in order to study the multi-frequency correlations, we compared the
light curve of 15 GHz with that of 22, 43, and 86 GHz, using cross-correlation analysis. Moreover we estimated B-field strength using core sizes from VLBA 43 GHz data, turnover frequency and maximum total flux from KVN data, and variability timescales from OVRO data, in order to study the variability of B-field nearby the radio emission region.

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Methanol maser polarization toward a massive star forming region, G10.34-0.14, using the KVN and the ALMA telescopes

Ji-hyun Kang, (KASI)
Do-Young Byun, Kee-Tae Kim, Jongsoo Kim, Aran Lyo, Woojin Kwon (KASI)
Mi-Kyung Kim (NAOJ)
Wouter Vlemmings, Boy Lankhaar (Onsala Observatory)
and Gabriele Surcis (INAF-Cagliari)

We present the linear polarization results of the KVN VLBI and the ALMA observations of the 44 GHz and the 95 GHz Class I methanol maser transition lines toward a massive star forming region, G10.34-0.14. The ALMA data show three mm continuum sources in this region. We identified about 30 maser features together with the 20000 AU-sized thermal methanol outflow. Some strongest masers show a few percent of linear polarization. Their polarization properties are consistent to the VLBI polarimetric observations performed with the KVN telescope, in spite of two orders of magnitude scale differences, indicating that the masing regions have consistent magnetic field environments over these scale lengths (6 AU to 600 AU).

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Analyzing VLBI interferometer characteristics using zero-baseline lab prototype and RASFX correlator

Y. Vekshin, V. Ken, V. Chernov, A. Evstigneev, E. Khvostov

The zero-baseline radio interferometer model based on the radio telescope RT-13 tri-band and ultra-wideband receivers, broadband data acquisition system (BRAS), and RASFX correlator was assembled in the IAA RAS in 2017. We carried out more than 100 sessions with the following setup: one channel with 512 MHz bandwidth, 2-bit sampling, X band (7.0-9.5 GHz). The session duration varied from single 5..20-minute scan up to 2.5 hour consisted of 300 10-seconds scans. To simulate celestial source the noise generator signal was injected to receivers through cryo unit directional coupler. Obtained with RASFX correlator fringe characteristics were analyzed: signal-to-noise ratio, delay, delay rate, fringe-phase and its standard deviations. The phase stability of the receiving systems was measured using R&S vector network analyzer, results were compared with PCal measurements. Allan deviation was calculated to find the character of phase and delay variations. The sinusoidal ripple of fringe delay due to the frequency inaccuracy of LO and overlapping spectra from Nyquist zones was revealed. It is shown that digital filtering of the band edges reduces the measured delay variation.

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Exploring the Nature of the 2016 γ-ray Emission in the Blazar 1749+096

Dae-Won Kim, Sascha Trippe, Sang-Sung Lee, Jae-Young Kim, Juan-Carlos Algaba, Jeffrey Hodgson, Jongho Park, Motoki Kino, Guang-Yao Zhao, Kiyoaki Wajima, Jee Won Lee, Sincheol Kang

Recent Fermi-Large Area Telescope (LAT) light curves indicate an active γ-ray state spanning about five months from June 2016 to October 2016 in the BL Lac object 1749+096 (OT 081). During this period, we find two notable γ-ray events: an exceptionally strong outburst followed by a significant enhancement (local peak). In this study, we analyze multi-waveband light curves (radio, optical, X-ray, and γ-ray) plus very-long baseline interferometry (VLBI) data to investigate the nature of the γ-ray events. The γ-ray outburst coincides with flux maxima at longer wavelengths. We find a spectral hardening of the γ-ray photon index during the γ-ray outburst. The photon index shows a transition from a softer-when-brighter to a harder-when-brighter trend at around 1.8 × 10−7 ph cm−2 s−1. We see indication that both the γ-ray outburst and the subsequent enhancement precede the propagation of a polarized knot in a region near the VLBI core. The highest polarized intensity, 230 mJy, and an electric vector position angle rotation, by ~32◦, are detected about 12 days after the γ-ray outburst.
We conclude that both γ-ray events are caused by the propagation of a disturbance along the jet. We discuss possible scenarios to explain the observed results for each γ-ray event.

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KVN Observation of Microquasars Simultaneously at K, Q, W and D Bands

Soon-Wook Kim (Korea Astronomy and Space Science Institute)
Jeong-Sook Kim (Korea Astronomy and Space Science Institute)

The Korea VLBI Network (KVN) is operated by the Korea Astronomy and Space Science Institute. The KVN consists of three 21-m antennas and, in each antenna, the multi-channel receiver system is equipped. The baseline length ranges from 305 to 476 km. The KVN can simultaneously measure K, Q, W and D bands, currently at the rate up to 8 Gbps. One of the advantageous KVN facilities is its fast response to the rapid transients. The microquasar, jet-ejecting X-ray binary system, is one of such targets. We present a recent activity of the KVN observations of microquasars. In the KVN VLBI observations, the rapid, intraday variability and associated jet imaging of a few microquasars have been obtained. The KVN has been also operated for the single-dish observations, independently in each antenna. In the KVN single-dish observations of microquasars, both long-term monitorings of the flux density as well as polarization have been carried out to obtain the variability characteristics of microquasars in daily-averaged or shorter time-scales. The operation at 32 Gbps or higher rate is also being tested, and more microquasars with a lower flux density would be observed in the near future. Furthermore, the on-going Extended KVN Project to install three more antennas, together with a high rate of 64 to 128 Gbps, would improve the sensitivity to imaging microquasars.

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KVN Surveys of Water and Class I Methanol Masers toward High-mass YSOs

Kee-Tae Kim, Chang-Hee Kim, Won-Ju Kim, Hyunwoo Kang, Ji-Hyun Kang, Do-Young Byun, Chung Sik Oh, and the KVN star formation group

We carried out simultaneous single-dish surveys of 22 GHz water and 44/95 GHz class I methanol masers toward more than 1000 high-mass YSOs in different evolutionary stages using the KVN (Korean VLBI Network) 21-m telescopes. Our sample consists of infrared dark cloud (IRDC) cores, high-mass protostellar objects (HMPOs), and ultracompact HII regions (UCHIIs). We also conducted a linear polarization survey of about 40 strong (>50 Jy) 44/95 GHz methanol maser sources. In this talk, we will present the main results of these KVN maser surveys as follows.

The detection rates of the observed masers tend to increase as the central objects evolve. This is contrary to the trends found in low- and intermediate-mass star-forming regions. Thus, the occurrence of these masers might depend on the surrounding environments as well as on the evolution of the central object. We detected many new water and class I methanol maser sources. The 44 GHz methanol masers have much narrower distributions than 22 GHz water masers in the relative peak velocity and velocity range, while associated 6.7GHz class II methanol masers have distributions intermediate between the two. The 95 GHz methanol masers were always detected in the 44 GHz methanol maser sources. The two maser transitions have the same peak velocities and show significant correlations in the peak velocity, peak flux density, isotropic luminosity, and linear polarization flux and angle. This indicates that they are likely produced in the same sites by the same mechanisms.

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Linking radio variability and kinematics in the extragalactic jets.

A. Kutkin, I. Pashchenko, K. Sokolovsky, M. Aller, H. Aller

Multi-frequency time delays between AGN radio outbursts probe a plasma speed in the core region. We derive the kinematics of 14 AGN using the time delays and the core shifts measurements. In blazars, these speeds are several times higher than that inferred from kinematics of the VLBI components. At the same time the measurements are consistent for radio galaxies. Possible reasons for this discrepancy are discussed.

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Solving the puzzling kinematics of flat spectrum radio quasar 1928+738

Kunwoo Lee, Jongho Park, Sascha Trippe

A recent study has discovered a fundamental relation between the long-term (Doppler-corrected) variability timescales of radio-loud AGN at cm wavelengths and the accretion rate. However, one source, 1928+738, out of ≈ 40 sources is substantially deviated from the relation. This might be because there is an ambiguity in Doppler factor of this source in the literature: the values from two different studies are different by more than a factor of 3 even though their methodology are quite similar to each other. We extracted the recent 15 GHz VLBA data (MOJAVE monitoring program) to obtain the Doppler factor by an independent method. Interestingly, we obtained increasing apparent velocities and increasing Doppler factors as function of distance from core, which indicates that bending of the jet toward our line of sight might contribute to the quite complicated kinematics for this source; the jet viewing angles decrease from ≈ 30 to ≈ 0 degrees. However, it seems that the assumption we used for estimating the Doppler factor does not hold at 15 GHz due to relatively long radiative cooling timescales since the bending of jet by almost 30 degrees is quite unrealistic. Therefore we have monitored 1928+738 ≈ 2 years with KaVA at 43 GHz. We aim to investigate (i) the accurate value of the Doppler factor of 1928+738 to confirm that whether this source is an outlier in the relation between variability timescale and accretion rate or not and (ii) whether the increasing apparent velocity as a function of distance from the core is related to jet bending toward our line of sight or not. Here we present our preliminary results.

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Radio and gamma-ray variability of S5 0716+714

Jee Won Lee, Bong Won Sohn, Filippo D'ammando

We present results of single-dish monitoring observation in flux density of BL Lac object S5 0716+714 at broad radio frequencies from 8 to 230 GHz using the data of UMRAO (8 GHz), OVRO (15 GHz), KVN (22 and 43 GHz), CARMA (95 GHz), and SMA (230 GHz). The single-dish observations were conducted over 4 years from 2010 November to 2014 June with a high cadence of several days. In this observing period, we detected significant flux variability at all frequencies and identified six local peaks. We tested shock-in-jet model and measured magnetic field from the evolution of spectral parameters for individual peaks. Furthermore, we discuss the correlation between gamma-ray and radio emission.

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Jet Kinematics of the Quasar 4C +21.35 from KaVA Observations

Taeseok Lee, Sascha Trippe, Motoki Kino, Bong Won Sohn, Jongho Park, Junghwan Oh, Kazuhiro Hada, Kotaro Niinuma, Hyunwook Ro, Taehyun Jung, Guan-Yao Zhao, Sang-Sung Lee, Juan-Carlos Algaba, Kazunori Akiyama, Kiyoaki Wajima, Satoko Sawada-Satoh, Fumie Tazaki, Ilje Cho, Jeffrey Hodgson, Jeong Ae Lee, Yoshiaki Hagiwara, Mareki Honma, Shoko Koyama, Tao An, Yuzhu Cui, Hyemin Yoo, Noriyuki Kawaguchi, Duk-Gyoo Roh, Se-Jin Oh, Jae-Hwan Yeom, Dong-Kyu Jung, Chungsik Oh, Hyo-Ryoung Kim, Ju-Yeon Hwang, Do-Young Byun, Se-Hyung Cho, Hyun-Goo Kim, Hideyuki Kobayashi, Katsunori M. Shibata, Zhiqiang Shen, Wu Jiang

We present the jet kinematics of the flat spectrum radio quasar (FSRQ) 4C +21.35 using time-resolved KVN and VERA array (KaVA) radio maps obtained from September 2014 to July 2016. During the observing campaigns, observations were performed bi-weekly at 22 and 43 GHz quasi-simultaneously. At 22 GHz, we identified three jet components near the core with apparent speeds from (7.5 ± 0.1)c to (13.2 ± 0.2)c. It is found that the timing of the ejection of the new component detected in 2016 coincides with the γ-ray flare in November 2014.At 43 GHz, we found four inner jet (<3 mas) components with speeds from (1.8 ± 0.1)c to (6.7±0.4)c. Jet component speeds tend to be higher with increasing distances from the core.

We compared our data with archival Very Long Baseline Array (VLBA) data from the Boston University (BU) 43 GHz and the Monitoring Of Jets in Active galactic nuclei with VLBA Experiments (MOJAVE) 15.4 GHz monitoring programs. Whereas MOJAVE data and our data are in a good agreement, jet speeds obtained from the BU Program data in the same time period are about twice as high as the ones we obtain from the KaVA data. The discrepancy at 43 GHz indicates that radio arrays with different angular resolution identify and trace different jet features even when the data are obtained at the same frequency and at the same time. The flux densities of jet components decay exponentially, in agreement with a synchrotron cooling time scale of ~1 year. Using known Doppler factor (~5) and electron Lorentz factor values (~9 000), we estimate the magnetic field strength to be ~2–4 μT.When adopting a jet viewing angle of 5◦, the intrinsic jet speed is of order 0.99c.

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Interstellar Scintillation Monitoring of the RadioAstron Blazars

J. Liu, T. P. Krichbaum, H. E. Bignall, X. Liu, A.Kraus, Y. Y. Kovalev, K. V. Sokolovsky, E. Angelakis, J. A. Zensus

The RadioAstron space radio telescope provides a unique opportunity to study the extreme brightness temperatures (TB) in AGNs with unprecedented long baselines of up to 28 Earth diameters. Since interstellar scintillation may affect the visibilities observed with space VLBI, a complementary ground-based flux density monitoring of the RadioAstron targets, which is performed near in time to the VLBI observation, could be beneficial. The combination/comparison with the SVLBI data can help to unravel the relative influence of source intrinsic and interstellar scintillation induced effects, which in the end may alter the conclusions on the TB measurements from SVLBI. Since 2014 we conducted a flux density monitoring to search for Intraday Variability (IDV) of RadioAstron targets with the Effelsberg 100m radio telescope. In this talk, I will present the statistical results of the Effelsberg monitoring and discuss the possible effects of ISS on the SVLBI data.

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From Electrons to Janskys: Synthetic Imaging of 3D Relativistic Jet Simulations

Nicholas MacDonald, Carolina Casadio, Ioannis Myserlis, Kenichi Nishikawa, Alan Marscher, & Svetlana Jorstad

I will present a suite of synthetic full Stokes synchrotron emission maps created via polarized radiative transfer through 3D relativistic jet simulations. In particular, I model the linear and circular polarized synchrotron emission emanating from three distinct numerical jet models: a relativistic Particle-in-Cell (PIC) jet simulation, a relativistic Magnetohyrdodynamic (RMHD) jet simulation, and the Turbulent Extreme Multi-Zone (TEMZ) model of blazar emission. The synthetic polarized emission maps of these jet models are created via ray-tracing and include the effects of optical depth, relativistic aberration, Faraday rotation, Faraday conversion, slow-light interpolation, and beam convolution. Direct comparison of these synthetic ray-traced images to mm-wave VLBI jet observations highlight the strengths (and weaknesses) in the ability of these various numerical schemes to capture the salient physics present in relativistic jets while also reproducing the observed synchrotron emission. I will also present a parallel study involving VLBI image stacking at 15 & 43 GHz (in Stokes I, Q, and U) aimed at discerning (through stacked RM analysis) the nature of the ambient medium (i.e. the Faraday screen(s)) surrounding blazar jets. These measurements will in turn be used to refine future relativistic jet simulations.

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The Evolution of Extreme Scintillator: PKS B1144-379

N. M. M. Said, S. P. Ellingsen, S. S. Shabala, J. N. McCallum, H. E. Bignall, C. Reynolds

We have examined rapid variability in the radio flux density of the BL Lac object PKS B1144−379 observed at 6.5 GHz, with the University of Tasmania's Ceduna radio telescope. High-cadence monitoring of this extreme scintillator was carried out between 2003 and 2011. We have used structure functions created from the time series to determine the source characteristic timescale. The best-fitting annual cycle model for each year suggests that the scintillation pattern has an anisotropic structure. We find the annual cycle in the interstellar scintillation timescale only prominent for certain years where other evidence suggests that the core is compact.

The modulation index of the target source and its total mean flux density show an anticorrelation. From our measurements we calculate that the core angular size varies between 10-30 μas (0.08- 0.23 parsecs). The core component is found to be at its most compact size during two flares in the total flux density, which were observed in 2005 and 2008. The source angular sizes we determine are consistent with the compactness inferred from very long baseline interferometry (VLBI). We conclude that the long-term variability in the radio flux density of PKS B1144-379 are due to intrinsic variations and affect our ability to measure an annual cycle in its variability time scale. This long-term monitoring has significantly enhanced our understanding of the evolution of this extreme scintillator.

Key words: ISM: structure - quasars: galaxies - AGN

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RASFX and DiFX: The Comparison of Geodetic VLBI Processing Results

Voitsekh Ken, Alexey Melnikov

GPU-based software correlator RASFX has been developed for geodetic processing of the VLBI observations in the IAA RAS in 2014. It includes HPC cluster and software, and outputs the calculated group delays to the NGS card files.
In this work we present the comparison of group delays from RASFX correlator to the group delays obtained from DiFX correlator output using PIMA software.
We found that the differences of the UT1-UTC measures from both correlators are mainly due to the different realisation of mathematical computations of the post-processing algorithms. The data converter was developed which allowed to use PIMA to post-process the RASFX data instead of native software. A series of intensive sessions were processed using this new routine.

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The geometric distance and binary orbit of PSR B1259-63

J. Moldon, J. C. A. Miller-Jones, A. T. Deller, R. M. Shannon, R. Dodson, M. Ribo, G. Dubus, S. Johnston, J. M. Paredes, S. M. Ransom, J. A. Tomsick

The pulsar/massive star binary system PSR B1259-63/LS 2883 is one of the best-studied gamma-ray binaries, a class of systems whose bright gamma-ray flaring can provide important insights into high-energy physics. Using the Australian Long Baseline Array we conducted very long baseline interferometric observations of the pulsar inside the binary over 4.4 years, fully sampling the 3.4-year orbital period. The motion of PSR B1259-63 on the sky reflects its orbital motion, the proper motion of the system, and its parallax signature. Taking our findings together with previous results from pulsar timing observations, all seven orbital elements for the system are now fully determined. Our geometric parallax provides the first model-independent distance to the system. The system distance is used to lock the isotropic gamma-ray luminosity during gamma-ray flares. We use our measurement of the inclination of the orbit to constrain the mass of the stellar companion. Our measured distance and proper motion are consistent with the system having originated in the Cen OB1 association and receiving a modest natal kick. The orientation of the orbit on the plane of the sky matches the direction of motion of the X-ray synchrotron-emitting knot observed by the Chandra.

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The new e-MERLIN CASA pipeline

J. Moldon, J.F. Radcliffe

VLBI has traditionally been a field for which significant specialization has been needed to understand and process data in order to obtain robust scientific results. That means that an expert "VLBI friend" is still essential for many astronomers, even radio astronomers, that want to use high resolution radio interferometers due to common fear to work with VLBI data. Also, although AIPS has been a robust tool to process any kind of VLBI data for the last decades and interfaces like ParselTongue have made it more friendly, the reality is that new generations of students are more used and willing to develop their data calibration, analysis and scientific workflow using more modern and flexible tools. In that context the Jodrell Bank Centre for Astrophysics is developing the e-MERLIN CASA pipeline (eMCP), a set of tools to calibrate e-MERLIN data based on python and CASA. The pipeline provides an easy way to use standard and optimized calibration strategies, progressively flag data (including automatic RFI flagging) and automatically generate diagnostic plots to understand problems with the data. One of the emphasis is data reduction repeatability so full calibration can be reproduced easily, especially for large data sets. Also, its modularity will allow the community to implement new strategies or improve the existent ones.

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Study of ICME by spacecraft radio signals

Guifré Molera Calvés, Esa Kallio, Giuseppe Cimo, Tatiana Bocanegra Bahamon, Dmitry Duev

Tracking radio communication signals from planetary spacecraft with ground-based telescopes offers, among others, the possibility to study the electron density and the interplanetary scintillation of the solar wind. Observations of the telemetry link of spacecraft have been conducted regularly with ground antennae from the European Very Long Baseline Interferometry Network (EVN), aiming to characterize the propagation of radio signals in the solar wind at different solar elongations and distances from the Sun. We have detected and studies the Mars Express spacecraft radio signal phase fluctuations while, based on a 3-D heliosphere plasma simulation, an interplanetary coronal mass ejection (ICME) crossed the radio path during one of our observations on 6 April 2015. Our measurements showed that the Doppler measurements and phase scintillation indices increased by a factor of 4 during the passage of the ICME. The method presented here confirms that the phase scintillation technique based on spacecraft signals provides information of the properties and propagation of the ICMEs in the heliosphere and can be used to detect and monitor the presence of ICMEs in the near future.

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Examining the jet of blazar 3C 273 at low frequencies using the International LOFAR Telescope

Sean Mooney, John Quinn, Leah Morabito

I will present observations of blazar 3C 273 made with the International LOFAR Telescope, which consists of groups of antennas clustered into stations which are spread throughout Europe.

Blazars are active galactic nuclei which have relativistic jets aligned towards Earth. While blazars are known to emit broadband radiation spanning the full electromagnetic spectrum, mapping the low-frequency (< 200 MHz) radio emission has proven challenging in the past due to the resolution and sensitivity which was available with the previous generation of radio telescopes. Advancements are now being made on this front due, in part, to telescopes such as LOFAR.

3C273 is the focus of our research. 3C273 has historical significance (it was the first identified quasar) and it is perhaps the most heavily-researched blazar to date. While the low-frequency emission is likely to be synchrotron radiation, there is still debate over which mechanisms produce the high-energy emission. Some models suggest that the X-ray emission is produced by the inverse-Compton scattering of cosmic microwave background photons (IC/CMB) off relativistic electrons. It is also possible that the high-energy emission is predominantly the result of the synchrotron photons being up-scattered by the relativistic electrons (SSC). By mapping the low-energy electron population and combining our results with multiwavelength data, we can assess the role that the low-energy electron population plays with respect to the production of the high-energy emission. Specifically, our results can test the viability of the IC/CMB and SSC models.

We are conducting high-resolution observations of 3C273 using both the LOFAR High Band Antennas (HBA, 100--240 MHz) and Low Band Antennas (LBA, 10--90 MHz). The observations were made using the international LOFAR stations in order to achieve sub-arcsecond angular resolution. Analysing a bright (67 Jy at 178 MHz) source with the international stations, coupled with the the low declination (+02°) of this source and its proximity to other bright sources (Virgo A) makes the data analysis technically challenging.

We have preliminary results with the HBA data at present and the LBA data reduction is underway.

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The Role of the EVN in our Understanding of High-redshift Star-formation Activity and Low-Luminosity AGN Systems through Integrated Imaging across Wide Spatial Scales

Dr Tom Muxlow (JBCA), Mr Jack Radcliffe (Kapteyn, Groningen), Dr Robert Beswick (JBCA), Dr Alasdair Thomson (JBCA), Dr Nick Wrigley (JBCA)

The development of deep high-resolution radio imaging has allowed astronomers to separate and characterise the AGN and star-formation activity in both the local and distant Universe, allowing obscuration-free derivation of the star-formation rate density evolution over cosmic time. Crucially, the high sensitivity of the EVN, with many additional telescopes worldwide and increased correlation bandwidths can now be used to image faint AGN activity within star-forming galaxies (SFG) and thus investigate AGN feedback in such systems. In addition, integrated imaging including both VLA and e-MERLIN short and intermediate spacing data, is allowing seamless detailed imaging on angular scales from arcseconds to mas on the evolving populations of SFGs and AGN systems to μJy sensitivity.

With the upcoming e-MERGE GOODS-N survey DR-1 initial data and image releases, the EVN together with e-Merlin and the VLA can be used to investigate the faint embedded AGN-jet systems and their interactions in both nearby star-forming galaxies and those far more luminous systems at high redshift, many of which contain nuclear starbursts only partially resolved by e-MERLIN. In particular deep high angular resolution imaging of star-forming systems in GOODS-N are used to characterise both the SFG population, together with the heterogeneous nature of the 'Radio-Quiet' AGN systems which dominate the AGN radio population at faint flux density levels below S1.4GHz~100μJy; and the evolving nature of the remaining 'Radio-Loud' sources at μJy flux density levels where the small core-dominated radio structures are found to be confined to within the host galaxy and contain almost equal numbers of one- and two-sided extended structures. This new class of 'Radio-Loud' AGNs may be the first detections (at the luminous end of the class) of the high-redshift equivalent to the local Universe low luminosity 'FR0' structures identified by (Baldi+16, Baldi+18) which are the most common form of radio-loud AGN systems seen locally.

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High-resolution study of the inner jet of M87 at 8 and 15 GHz

A. S. Nikonov, Y. Y. Kovalev

We present high-resolution dual frequency study of the inner radio jet of M87. The Very Long Baseline Array, one antenna of the Very Large Array and the Effelsberg telescope were used to obtain inner jet images with sub-milliarcsecond resolution at 8 and 15 GHz. Synthesized images with dynamic range higher than 14,000:1 clearly show a limb-brightened structure and a faint counter-feature. The reconstructed spectral index image shows flattening of the
spectrum along the spine of the resolved jet. This indicates higher pressure or higher energy of emitting particles associated with a higher plasma speed supporting the spine-sheath model. It has been suggested that the faint most eastern feature might be the true jet base rather than the counter jet. However, we have measured the spectrum to be characteristic of an optically thin jet, not an opaque core.

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Bias of core shift effect measurement in the blazars jets

Pashchenko I.N., Kutkin A.M.

The inhomogeneous model of a blazar jet predicts a shift of its apparent base with observations frequency. Measurements of this effect provide an important information about the physical conditions and structure of the innermost jet regions.
We propose methods to account for the systematic errors specific to the core shift measurement approach based on a cross-correlation of multifrequency VLBI images. We also estimate the bias of a core shift estimation due to approximating the real source structure with a simple model represented by a gaussian templates. We use the artificial data sets created using real VLBI data and inhomogeneous jet model evaluated on a grid of the parameters obtained from the simulation of the flux-limited sample. We found that the core shifts are typically overestimated by a factor of few. Thus, the magnetic field strength inferred from these measurements is also overestimated. We consider the influence of this bias on deriving various jet parameters and discuss the possibility to account for the bias using the observed data at hand.

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Inferring parameters of AGN jets using Bayesian analysis of VLBI data with inhomogeneous jet model

Pashchenko I.N., Plavin A.V.

Inhomogeneous jet model successfully explains frequency dependent core shift effect observed in AGN jets with VLBI. We propose to fit it to the observed interferometric visibilities directly using computational methods of the Bayesian statistics. We discuss useful reparametrizations and compare different fitting techniques. Both approximate analytical and exact numerical treatment of the inhomogeneous model are considered. We test the proposed approach using artificially generated data in the context of a parameter estimation and model selection and finally apply method to the real VLBI data.

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Results from RadioAstron polarization observations of 3C345

F. M. Pötzl, E. Ros, A. P. Lobanov, J. A. Zensus, on behalf of the RadioAstron KSP "AGN Polarization"

Supermassive black holes (SMBHs) in the centres of radio-loud active galactic nuclei (AGN) produce collimated relativistic outflows (jets). Space-VLBI observations within the RadioAstron key science program on AGN polarization provide images at an unprecedented resolution, which enables us to study the magnetic field strength and morphology in the innermost regions of AGN jets. We present here images from 1.6 GHz RadioAstron and 5, 8 and 15 GHz ground VLBI observations of the sub-parsec scale jet in the powerful blazar 3C345, revealing the complex jet structure and polarization on scales down to ~50 microarcseconds. We show a preliminary analysis of these images and discuss potential implications of the structures observed to the jet launching and collimation processes taking place on these scales.

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Relation between continuum radio spectra and parsec-scale properties of extragalactic radio sources

Popkov, A.V.; Kovalev, Y.Y.; Petrov, L.

We present the results of a joint analysis of VLBI and total continuum radio spectra measurements for the complete sample of 502 extragalactic radio sources with declination >+75 degrees and NVSS flux density > 0.2 Jy at 1.4 GHz. We use data of our VLBA Northern Polar Cap Survey observed at 13 and 3.6 cm as well as instantaneous 2-22 GHz broad-band spectra measured at RATAN-600. Parsec scales detections, size, compactness, brightness and spectral index are compared versus shapes of integrated continuum spectra (flat, steep, peaked, etc.) for the observed complete sample. We discuss the fraction and properties of archetypal blazars, CSS, and GPS targets within the population of extragalactic radio sources and make predictions of a fraction of detections expected for future blind VLBI surveys.

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Multi-frequency study of the gamma-ray flaring BL Lac object 2233-148 in 2009-2012

A.B. Pushkarev, M.S. Butuzova, Y.Y. Kovalev

We study jet physics of the BL Lac object 2233-148 making use of synergy of observational data sets in the radio and gamma-ray energy domains. The four-epoch multi-frequency (4-43 GHz) VLBA observations were triggered by a flare in gamma-rays registered by the Fermi-LAT on April 24, 2010. We also used 15 GHz monitoring data from the MOJAVE and OVRO programs. We have found that (i) jet shape of the source is conical on scales probed by our VLBA observations setting a lower limit on its unknown redshift, (ii) nuclear opacity is dominated by synchrotron self-absorption, (iii) turnover frequency of the synchrotron spectrum of the VLBI core shifts towards lower frequencies, and (iv) the corresponding speed of the flare propagation down the jet is significantly higher comparing to results from traditional kinematics based on tracking bright jet features.

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Exploring optimal sub-arraying strategies for MeerKAT-VLBI

Nkululeko Qwabe, Roger Deane

MeerKAT is a South African radio interferometer that will be the most sensitive in its class until the operation of the Square Kilometre Array mid-frequency array. Like SKA1-mid, MeerKAT's receptors are configured in a dense core as well as more extended spiral arms to provide higher angular resolution. The inclusion of the MeerKAT array into global VLBI networks will add significant sensitivity to existing VLBI networks, especially in the longest baselines of >7000 km and strengthen the role of the Hartebeeshoek Radio Astronomy Observatory (HartRAO) through better sampling and higher sensitivity in this part of the uv-plane. MeerKAT-VLBI will also extend VLBI coverage in the southern hemisphere which will be expanded even further by the African VLBI Network (AVN). MeerKAT's ability to be split into sub-arrays and simultaneously generate interferometric and tied-array output provides the opportunity to further increase its high expected scientific output. This flexibility will be important for many science programmes, including VLBI experiments where a subset of antennas may potentially participate with the AVN, EVN and LBA. Through a suite of simulations of VLBI arrays including MeerKAT, as well as the stand-alone interferometric and phased up performance of MeerKAT, this project explores optimal solutions for a range of potential MeerKAT-VLBI and MeerKAT projects. We aim to systematically explore the scientific, technical, and financial trade-offs of MeerKAT sub-arrays and commensal observations, which is ultimately aimed at maximising the scientific utility of both MeerKAT and the VLBI networks it forms part of.

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Fourier-Plane Modeling of the Jet in the Nucleus of the Galaxy M81

Arvind Ramessur, Michael F. Bietenholz, Lerothodi L. Leeuw

The mildly active nuclear region in the galaxy M81 (henceforth, M81*) is one of the nearest low-luminosity active galactic nuclei (LLAGN) whose structure is marginally resolved when probed with Very Long Baseline Interferometry (VLBI). Motivated by the way resolved radio sources usually appear on the smallest scales, i.e., a core with a one-sided jet structure, we developed a strictly one-sided, asymmetric triangular model, which we call ASYM, with brightness distribution along a line segment on the sky, with maximum brightness at one end of the segment fading linearly to zero at the other end. The ASYM model is compared and contrasted with an elliptical Gaussian model (hereafter, GAUS), by fitting existing VLBI data of M81* at 39 epochs between 1993 and 2003 at 8.4 and 5.0 GHz with the two models. Contrary to what we envisioned, we find that for 77% of our epochs, a simple GAUS model fits the visibility data of M81* at 8.4 GHz better (i.e., has a lower reduced $\chi 2$) than the ASYM model. We conclude that M81* is not strictly a one-sided, asymmetric jetted source; as is thought to be the case for the majority of AGN observed at VLBI scales. Our results imply that M81* is mostly symmetrical with a significant jet counterpart which cannot be overlooked.

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Ultra-compact structures in galactic masers observed in the Radioastron project.

N.N. Shakhvorostova, A.M. Sobolev, A.V. Alakoz

We present estimates of brightness temperature for galactic masers in star-forming regions Orion KL, Cepheus A, W3 OH, W3 IRS5 and W49 N detected at space baselines in the Radioastron project. Very compact features with angular sizes of ~20-60 μas were detected in these regions with corresponding linear sizes of ~4-10 million km. These features represent only a few per cent of the maser flux registered with the single-dish instruments. Brightness temperatures range from 1e13 up to 1e16 K.

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Development of KVN information system

Jae Sik Shin, Taehyun Jung, Do-Young Byun

The different operating methods and characteristics of the VLBI system in each country and the various feedback data issued during the observation process are very important information in the processing of observation data. However, the operation efficiency is reduced when standardized procedures and methods for sharing information in real-time are absent. In the case of KVN, the overall operation was analyzed step by step to improve productivity of VLBI observation data reduction, and web based application has been developed and applied. The data generated at each operation stage is stored in database and provided to PI, researcher, and operator in real time. In particular, the information in this system has been utilized in KVN and KaVA data correlation processing, saving time and money. In the future, this system will be expanded in conjunction with KVN data archiving.

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First galactic maser interferometric observations in Irbene - Torun baseline

Ivar Shmeld, Vladislavs Bezrukovs, Jānis Šteinbergs, Artis Aberfelds, Marcis Blediers, Artūrs Orbidāns, Karina Šķirmante, Marcin Gawroński, Roman Feiler

Ventspils International Radio Astronomy Centre (VIRAC, Latvia) operates with two radio telescopes RT-16 and RT-32 accordingly with 16 and 32 m fully steerable Cassegrain type antennas. The main receiving systems of both telescopes are cryogenic receivers with 4.5 – 8.8 GHz frequency range, additionally radio telescope RT-32 equipped with L band receiver. On the both antennas data registration units are suitable for interferometric observations. The Nicolaus Copernicus University Department of Radio Astronomy in Torun, Poland, operates 32 m radio telescope, which also works in similar bands - L, C and M and regularly participate in the VLBI observations. VIRAC also has a high performance computer cluster with installed SFXC software correlator developed at JIVE.

We propose to use all three radio telescopes as regional interferometer for galactic maser observations. The possible advances of such observations would be exact coordinates of new maser sources and matching the maser sources with IR sources from GAIA catalogue. Some large-scale structures in maser sources also could be considered and measured. Participation of one or two additional European radio telescopes is very welcome and will be considered in the future, which enhance this local interferometric network with mapping ability.

In this poster we highlight the results of first VLBI test observations with baseline Irbene – Torun. Overview of VIRAC current level in the software developments related to the VLBI data processing is also given.

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EATING VLBI and KVN-Yebes observations of AGN jets

B. W. Sohn, G. Giovannini, M. Giroletti, M. Kino, K. Hada, S. Koyama, M. Orienti, M. Honma, H. Nagai, T. Oyama, R. Lico, S. Oh, G. Zhao, P. Cassaro, A. Orfei, M. Stagn,i T. H. Jung, H. Ro, J. Kim, M., P. Vincente, Rioja, R. Dodson,

Firstly, we introduce EATING VLBI, East Asia To Italy: Nearly Global VLBI, we have the opportunity to perform observations using the Italian VLBI telecopes together
with the KVN and VERA arrays (KaVA). An important point of this project is the high resolution observation of AGN using KaVA and the Italian telescopes together, i.e. Nearly Global VLBI. The addition of the Italian telescopes is necessary to increase the angular resolution to obtain detailed images. In this proposal we request two epoch observations
of three AGNs with a strong interest by the Korean, Italian and Japanese research groups: 3C 84, Mrk 501 and TXS 0506+056. These powerful sources are characterized by the presence of resolved jets with a limb-brightened structure. The origin of this structure it is not yet clear and present models suggest a possible connection with the Gamma-ray
emission detected from AGN. To increase the knowledge on these sources and jet physics, we are asking two epochs of joint observations at 22 GHz with the KaVA and VLBIT array.
Secondly, we present KVN+Yebes SFPR observation (Rioja et al. 2015) of FSRQ 1633+382 in order to probe core position change of the source. We have monitored FSRQ (OVV) 1633+382 with VLBA + Eelsberg (2002-2005) at 22, 43 and 86 GHz and KaVA (2014-2017) at 22 and 43 GHz for sensitive imaging of its jet structure. Along with the rich structural
evolution of the jet which will be reported separately, we found two intriguing 'stable' components along the jet. Those two 'stable' components of FSRQ 1633+382 have unusual features which we can not easily associate with the standing shock explanation. In order to narrow down the possible answers, we propose SFPR KVN+Yebes astrometric observation. SFPR astrometry capability of KVN & Yebes is essential to probe or to distinguish between physical position change and frequency-shift of the core.

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Resolving the Innermost Jet Region of Radio Quasars 3C454.3 and OJ287

Traianou T., Krichbaum T.P., Casadio C., Marscher A., Jorstad S., Angelakis E., Kim J., Agudo I., Lister M., Zensus A.J.

Blazars are among the most powerful and variable known astrophysical objects. The very long baseline interferometry (VLBI) technique at short mm-wavelengths (mm-VLBI) allows us to look deeply into the heart of these compact objects and probe the physical processes that occur in the vicinity of the central engine. In this talk, we will present new results from (i) a kinematic and polarization study of the quasar 3C454.3 over 10 years, and (ii) new quasi-simultaneous multi-frequency 15-86 GHz VLBI imaging observations of OJ287, which were performed contemporaneous to RadioAstron observations at K-band. The millimeter-wave data of 3C454.3 reveal the appearance and propagation of new jet components. The results will be further discussed in this talk.

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Frequency-dependent core shift in ultracompact quasars

P. A. Voytsik, A. B. Pushkarev, A. V. Plavin, Y. Y. Kovalev, A. P. Lobanov, A. V. Ipatov

We present results of a pilot project to measure apparent frequency-dependent core shift effect in ultracompact quasars by the phase referencing method. EVN observations including the Quasar network at 1.7, 2.3, 5.0, 8.4 GHz were successfully carried out in October 2008 covering 24 active galactic nuclei. Maps of intensity distribution were reconstructed at all four frequencies. A new method has been developed for measuring the shift based on observations of close triplets of radio sources by means of relative astrometry. We demonstrate that this method is capable to reach the stated goal for ultracompact sources. A more traditional method of self-referencing to optically thin jets is not applicable for them. High sensitivity and high quality of UV-coverage is crucial for achieving required accuracy of the measurements. Significant shifts are found in 9 out of 24 targets. Mean values of the core shift for frequencies 1.7, 2.3, and 5.0 GHz relative to the highest frequency of 8.4 GHz are 1.8, 1.2, and 0.2 mas, respectively. The distance between apparent core position at 8.4 GHz and the jet origin as well as magnetic field strength at the 1-pc distance from the true jet origin are estimated for a subset of targets. Typical values appear to be 2 pc and 1.2 G, respectively.

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Compact star formation products in the nearby galaxies IC10 and NGC1569

J. Westcott, E. Brinks, R. Beswick

Large scale Radio Continuum (RC) emission from normal galaxies consists of two key components: thermal RC from compact HII regions that have been carved out by massive stars during their main sequence lifetime, and non-thermal RC generated by Cosmic Ray electrons (CRe) that have been accelerated in supernova shock fronts when these stars end their lives as core-collapse supernovae. In order to study (Hyper-)compact HII regions and supernova remnants (SNR) in nearby galaxies, observations at high linear, i.e. parsec scale resolution are required.

In this talk, I will present high-resolution (0.3" at 20 cm) e-MERLIN observations of the post-starburst dwarf irregular galaxies IC10 and NGC1569, to investigate the compact star formation products from the most recent star formation phase. We detect 11 compact sources in IC10, of which 3 are classified as compact HII regions. We do not detect any SNR within IC10, which is attributed to e-MERLIN actually resolving out SNRs at the distance of IC10 (D = 0.7 Mpc).

In NGC1569, I will focus my discussion on the compact SNR, NGC1569-38. We find that NGC1569-38 is resolved in our e-MERLIN observations yet is compact enough for the instrument to recover all of the emission originating from it. We show how lower resolution VLA observations suffer from significant contamination from the ISM surrounding the SNR entering the larger (typically 1.4") VLA beam. We derive an age for the SNR based on the e-MERLIN observations and derive a magnetic field strength of order 0.5 mG, in line with that found in Galactic SNR. Our results demonstrate the need for high-resolution observations at a range of frequencies to catalogue, analyse, and characterise star formation products in galaxies within the local volume.

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New Zealands Continued VLBI Development

Stuart Weston, Tim Natusch, Sergei Gulyaev

We present the recent developments and capabilities of the New Zealand radio telescopes to the EVN community having in mind the opportunity of using our facilities as part of the EVN. In addition we present the Radio Interferometer New Zealand (RINZ) which consists of two antennas (12m and 30m) at Warkworth in X-band separated by 200 meters. We have recently successfully conducted VLBI with Shao/China using the 2Gbps mode of the DBBC, and started a program of monitoring Intra-day variation (IDV) of compact radio sources using RINZ for an Australia -- New Zealand project at 2 Gbps to obtain higher sensitivity. The RINZ data is correlated locally using DiFX with the Long White Cloud Correlator (LWCC), building our own self-reliance. We are now in the process of moving to the DBBC-Fila10G-flexbuf setup with the aim of retiring the Mk5's within the next 12 months. The 30m is now working with the DBBC-Fila10G-Flexbuf configuration, the 12m will follow shortly.

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Searching for Galactic Center Pulsars with the Very Large Array

Robert Wharton

The Karl G. Jansky Very Large Array (VLA) is an extremely sensitive and versatile instrument that is particularly well suited for searching for pulsars in the Galactic center. I will give a brief overview of the different types of pulsar observing possible with the VLA and then discuss how we are using these new pulsar modes for Galactic center pulsar searches. Finally, I will give some preliminary results and discuss applications for next generation pulsar surveys.

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Interstellar scintillation observations for PSR B0355+54

Yonghua Xu,Kejia Lee,Longfei Hao

In this paper, we report our investigation of pulsar scintillation phenomena by monitoring PSR B0355+54 at 2.25GHz for three successive months using the Kunming 40-m radio telescope. We measured the dynamic spectrum, the two-dimensional correlation function and the secondary spectrum. These observations have a high signal-to-noise ratio (S/N ≥ 100). We detected scintillation arcs, which are rarely observable using such a small telescope. The submicrosecond scale width of the scintillation arc indicates that the transverse scale of the structures on the scattering screen is as compact as astronomical unit size. Our monitoring shows that the scintillation bandwidth, the time-scale and the arc curvature of PSR B0355+54 were varyingtemporally.Aplausibleexplanationwouldneedtoinvokeamultiple-scattering-screen or multiple-scattering-structure scenario, in which different screens or ray paths dominate the scintillation process at different epochs.

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Simultaneous VLBI monitoring observations of H2O and SiO masers toward VX Sagittarii

DH Yoon, SH Cho, YJ Yun & other KSP members

The red supergiant VX Sagittarii is a strong emitter of both H2O and SiO masers which trace a dynamic of the circumstellar envelope. However, previous VLBI observations of H2O and SiO masers have been performed separately, which make it difficult to spatially trace the outward transfer of the material consecutively from the SiO to H2O maser regions. In addition, previous VLBI observations were limited to mainly low frequencies less than 86 GHz. Therefore, we performed simultaneous monitoring observations of 22.2 GHz H2O and 43.1/42.8/86.2/129.3 GHz SiO masers toward VX Sgr using the Korean VLBI Network. We obtained the VLBI images at 25 epochs from Nov. 2014 to Apr. 2018 together with the single-dish data at 27 epochs. Here, we present the variations of spatial distributions and kinematics in these maser lines according to stellar pulsation. The broken features of SiO ring structure and peak intensity maximum of corresponding optical maximum at a certain epoch will be included.

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Sgr A* observations with KaVA and EAVN

Zhao, G.-Y.; Kino, M.; Akiyama, K.; Sohn, B. W.; Jung, T.; Cho, I.-J.; Jiang, W.; Shen, Z.-Q.; and the KaVA/EAVN AGN working group

In this presentation, we will summarize recent observational results of Sgr A* obtained with KaVA Long-term monitoring at 7 mm which is part of the KaVA/EAVN AGN large program. The KaVA array provides an excellent (u,v)-coverage for Sgr A* observations, especially alone the minor axis direction. The source is in a relatively quiescent status during our KaVA monitoring. No sign of G2 encounter has been detected so far, which supports the predictions of delayed or no activity from the close encounter. We found the sizes of Sgr A* is very stable during the several years of monitoring, which enables us to put tight constraints on the physical parameters of the scattering screen. We also show that joint observations at 13 and 7 mm with more stations in the East Asia region and the KaVA array (EAVN) can further enhance the image quality (uv-coverage, sensitivity) and more explorations could be possible.

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The Power of Simultaneous Multi-frequency Observations for mm-VLBI: Beyond Frequency Phase Transfer

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Atmospheric propagation effects at millimeter wavelengths can significantly alter the phases of radio signals and reduce the coherence time, putting tight constraints on high-frequency Very Long Baseline Interferometry (VLBI) observations. In previous works, it has been shown that non-dispersive (e.g., tropospheric) effects can be calibrated with the frequency phase transfer (FPT) technique. The coherence time can thus be significantly extended. Ionospheric effects, which can still be significant, remain however uncalibrated after FPT as well as the instrumental effects. In this work, we implement a further phase transfer between two FPT residuals (i.e., so-called FPT-square) to calibrate the ionospheric effects based on their frequency dependence. We show that after FPT-square, the coherence time at 3 mm can be further extended beyond 8 hr and the residual phase errors can be sufficiently canceled by applying the calibration of another source, which can have a large angular separation from the target (> 20^\circ) and significant temporal gaps. Calibrations for all-sky distributed sources with a few calibrators are also possible after FPT-square. One of the strengths and uniqueness of this calibration strategy is the suitability for high-frequency all-sky survey observations including very weak sources. We discuss the introduction of a pulse calibration system in the future to calibrate the remaining instrumental effects, allowing the possibility of imaging the source structure at high frequencies with FPT-square, where all phases are fully calibrated without involving any additional sources.

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Dwingeloo Telescope returns to VLBI

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The Cleopatra workpackage of the ASTERICS project aims to address the common challenge of time and frequency distribution in distributed instruments and multi-messenger astronomy. We have made improvements to the open hardware 'White Rabbit' time and frequency distribution system to achieve better reach, stability and phase noise. Moreover, we are able to use White Rabbit over public fiber, co-existing with other traffic on different wavelengths. To demonstrate the achieved performance, we are conducting VLBI observations using the venerable Dwingeloo telescope, which will soon receive the Hydrogen maser reference from the Westerbork Synthesis telescope, transported over 165km of fiber in the SURFnet network.
The Dwingeloo telescope is a 25m dish that at its opening in 1956 was the largest fully steerable dish in the world. It participated in some of the earliest VLBI observations in Europe. Nowadays it is run by volunteers of the CAMRAS foundation who have, with great support of its owner ASTRON, restored and rejuvenated the instrument. The volunteers regularly perform single dish observations of pulsars and the hydrogen line of our own and other galaxies. Using off-the-shelf software-defined-radio hardware, and the open-source GnuRadio program, we've recently achieved our first fringes between Westerbork, Jodrell Bank and Dwingeloo.