

Dissecting the Universe - Workshop on Results from High-Resolution VLBI

Monday 30 November 2015 - Wednesday 02 December 2015

Max-Planck-Institut für Radioastronomie, Bonn, Germany



Book of Abstracts

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Session II - mm-VLBI: the GMVA, nearby objects / 43**GMVA Observations of M87 and Status Report of the GLT Project**

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We will report results of GMVA observation of M 87 and progress of the Greenland Telescope Project. In order to investigate the innermost region of the M 87, we conducted GMVA observation in 2014. We revealed double ridge structure as is observed by VLBI at low frequency observations. The measured streamline is reasonably agreed with the previous observations at low frequency. We will discuss the origin of the jet based on this new derived streamline. In addition to that, we will give a short status report on the progress of the GLT project.

Session VIII - RadioAstron: Galactic and extragalactic masers, pulsars, & technique / 46**Water megamasers at high resolution**

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The frequency range and sensitivity of the RadioAstron system make it possible to detect a few of the most powerful extragalactic water MegaMasers. Single maser features have been detected in two well-known sources NGC4258 and NGC 3079 at baselines of 1.8 and 2.2 ED. These features represent a small part of the complex spectral signature of these sources. In this paper we present these results and determine their properties and their place of origin in the source. The detection of these components has also strong implications regarding the nature of the masering process and the environment. In addition, we will evaluate the possibility of detecting other lower power sources.

Session II - mm-VLBI: the GMVA, nearby objects / 5**Millimeter VLBI Observations of the Twin-Jet-System in NGC1052**

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The nearby twin-jet system in the low-luminosity active nucleus of NGC 1052 is an ideal target for mm-VLBI studies of jet formation on the smallest accessible scales. At cm-wavelength, NGC 1052 is well known for its prominent emission gap between the two jets, that is caused by free-free absorption in a circumnuclear torus. GMVA observations taken in October 2004 peer through the

absorber, revealing an isolated high brightness-temperature feature located between two fairly symmetric jets. A detailed analysis at 43 GHz identifies this central feature as the kinematic center of the source, and thus defines the location of the central engine. The varying jet-to-counterjet flux ratio and morphology of the two jets over 4 yr of VLBA data is difficult to explain under the assumption of an intrinsically symmetric bipolar jet system.

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First 3mm-VLBI imaging of the two-sided jet in Cygnus A: zooming into the launching region

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High resolution VLBI observations of relativistic jets are essential to constrain fundamental parameters of current jet formation models. At a distance of 249 Mpc, Cygnus A is a unique target for such studies, being the only powerful FRII radiogalaxy for which a detailed sub-parsec scale imaging of the base of both jet and counter-jet can be obtained. Observing at millimeter wavelengths unveils those regions which appear self-absorbed or free-free absorbed at longer wavelengths and enables an extremely sharp view of the nuclear regions to be obtained. We performed 3 and 7 mm Global VLBI observations, achieving ultra-high resolution imaging on scales down to 45 microarcseconds. With a spatial resolution of only ~ 200 Schwarzschild radii we could study the transverse size and structure at the onset of the two-sided flow through a pixel-based analysis. The flow appears already broad and stratified at the base, suggesting that the emission is produced by a slow outer sheath launched from the accretion disk.

Session X - VLBI science and technique, outlook / 0

New insight into AGN-jets: they are alive!

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Despite numerous and detailed studies of the jets of Active Galactic Nuclei (AGN) on pc-scales, many questions are still debated. The physical nature of the jet-components is one of the most prominent unsolved problems as is the launching mechanism of jets in AGN. An in-depth investigation of long-term archival VLBI and multi-wavelength data (several decades) in combination with the application of theoretical models allows detailed studies of the overall properties of jets. This enables us to discriminate between motion scenarios and to derive a more physical understanding of the nature and origin of jets in general. We will present and discuss recent results.

In collaboration with: S.-J. Qian, E. Kun, M. Karouzos, J. Roland, L. Gergely, M. Aller, H. Aller, W. Steffen, A. Witzel, et al.

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The connection between the mm VLBI jet and the gamma-ray emission in the blazar CTA102 and the radio galaxy 3C120

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We present multi-wavelength studies of the blazar CTA102 and the radio galaxy 3C120 during unprecedented γ -ray flares for both sources. The Fermi Large Area Telescope registered in September-October 2012 an extraordinary bright γ -ray outburst in the quasar CTA102, and between December 2012 and October 2014 a prolonged γ -ray activity in the radio galaxy 3C120. In both studies the analysis of Fermi data has been compared with a series of 43 GHz VLBA images from the VLBA-BU-BLAZAR program, providing the necessary spatial resolution to probe the parsec scale jet evolution during the high energy events. In the case of 3C120, in order to extend the observing period covered by radio data, we also used 15 GHz VLBA data from the MOJAVE sample. Although these two objects represent very different classes of AGN, we found they have similar properties during the γ -ray events. The γ -ray flares are associated with the passage of a new superluminal knot through the mm VLBI core, but not all ejections of new components lead to γ -ray events. Both in CTA102 and in 3C120, γ -ray events occurred only when the new components are moving in a direction closer to our line of sight. We locate the γ -ray dissipation zone a short distance downstream of the radio core but outside of the broad line region, suggesting synchrotron self-Compton scattering as the probable mechanism for the γ -ray production.

Session V - mm-VLBI: SgrA* at 3mm and 1mm, EHT / 15

New Developments with the Event Horizon Telescope

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The Event Horizon Telescope Collaboration is developing a very sensitive VLBI array for the millimeter and submillimeter wavelength regime. Its primary targets are the supermassive black holes in M87 and Sagittarius A*, for which it is already achieving an angular resolution finer than the diameter of the lensed photon ring predicted by general relativity. The EHT has also collected data over several years on blazars and other AGN sources at resolutions ranging from tens to hundreds of microarcseconds. This presentation will summarize recent scientific breakthroughs with the EHT along with the technical developments that will enable greater sensitivity and baseline coverage in the near future.

Session VI - RadioAstron: AGN and beyond / 22

Dissecting TeV blazars: Space VLBI study of the BL Lac source Markarian 501

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RadioAstron offers a unique opportunity to study the nuclear structure in nearby AGN with a spatial resolution of a few hundreds of Schwarzschild radii, allowing to probe the region of jet acceleration and collimation. We carried out perigee imaging of the nearby TeV BL Lac Markarian 501 at 6, and 1.3 cm, aiming to study in detail this BL Lac source and its peculiar jet. In this paper, we first review the basic features resulting from previous high angular resolution of the sources (including VSOP and GMVA observations): multiple bends, hints of limb brightening on scales between 0.1 and 20 mas, and lack of significant jet knot motions. Finally, we give details about the new Radioastron+EVN observations carried out in June 2015 and present the preliminary results after the recent successful correlation of the data.

Session VII - mm-VLBI: continuum, gamma-connection, spectral lines / 16

VLBI Studies of Star Forming Regions using Molecular Masers

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Owing to their compactness and high brightness, molecular masers are ideal targets for high-angular resolution VLBI. At cm wavelengths, intense maser transitions, in particular the 6.7 GHz CH₃OH and the 22.2 GHz H₂O lines, are extensively observed in high-mass star forming regions and provide unique diagnostic probes. Multi-epoch VLBI observations can provide the 3D kinematics of the circumstellar gas and sensitive polarimetric observations can yield the strength and structure of the magnetic field around forming stars on scales (10-1000 AU) not accessible with other techniques. At mm wavelengths, VLBI imaging of masers is largely unexplored, with the only exception of SiO transitions (at 43 GHz and 86 GHz), which enabled us to exceptionally resolve the launch and collimation region of an outflow from a compact disk in the closest known high-mass protostar. Maser transitions from methanol and water have also been detected at mm and submm wavelengths with single-dish telescopes (in the frequency range 80-700 GHz). Multi-frequency VLBI observations from cm to mm wavelengths would be very useful: I) to infer the physical conditions from maser line ratios (if they originate from the same gas); II) to map out more of the source structure, dynamics, and physical conditions (if they probe different portions of the circumstellar gas); III) to measure proper motions with higher accuracy on shorter time baselines at higher frequencies (owing to smaller synthesised beams). Prospects of imaging mm masers with VLBI will be discussed (time permitting).

Session I - RadioAstron / 39

The farthest view with overterrestrial baselines

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The unrivalled angular resolution of Space VLBI being coupled with the natural physical “zooming” properties of the expanding Universe make high-redshift compact radio sources a very valuable targets for observations at extremely long baselines. In this brief review I will revisit the legacy of the high-redshift project conducted with the VSOP about 15 years ago and present a report in progress on the ongoing RadioAstron project focused at sources at redshifts exceeding 3.

Session VI - RadioAstron: AGN and beyond / 2

Probing the innermost regions of AGN jets and their magnetic fields with RadioAstron

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We present polarimetric 1.3 cm RadioAstron, 7 mm VLBA, and 3 mm GMVA observations of a sample of blazars probing the innermost jet regions at tens of microarcseconds angular resolution. Comparison of the total and polarized emission across these wavebands allows to determine the magnetic field structure and strength in the vicinity of the central black hole through Faraday rotation analysis. It also allows to probe the brightness temperature, angular sizes, and spectra across and along the innermost jet to determine the physical parameters of the fluid (velocity field, energy density) and that of the non-thermal electron population. This information can be used to understand how AGN jets are formed, accelerated and collimated, what is the role played by the magnetic field in these processes.

Session III - mm-VLBI: AGN at 3mm / 42

What has VLBI at the highest resolutions taught us about the VLBI "core"?

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Blazars, being among the brightest objects known in the universe are an obvious choice for intensive monitoring with high frequency and highest spatial resolution VLBI. Typically, jets exhibit a "core-jet" structure with optically thin jet components being emitted from an assumed stationary optically thick (flat spectrum) VLBI core. As we observe at higher frequencies, we peer deeper and deeper into this self-absorbed region. Combining 7mm and 3mm VLBI imaging, we observe a multitude of effects, such as complex morphological structures with moving and quasi-stationary features; bent and stratified/displaced jet structures, pronounced spectral variations of the VLBI core which correlated with the broad-band flaring activity, and occasional evidence of jet components observed upstream of the brightest jet component, indicative of an at least partially resolved jet base at 3mm. These results lead us to suggest that the physical jet origin (jet apex) must be located upstream of the observed 3mm VLBI core, whose properties sometimes resemble a recollimation shock. The observed broad-band flaring would therefore be consistent with shock-shock interactions inside the core region. This has implications for the site of -ray production, suggesting a location near the VLBI core and within less than a few parsec of the physical jet base.

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The most compact H₂O maser spots and their locations in W3 IRS5

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The RadioAstron mission has succeeded in detection of Galactic and extragalactic H₂O masers in its ultimate angular resolution finer than 100 microarcseconds. The maser emission in extreme physical conditions will be explored in further image synthesis and astrometry. Here we present the H₂O masers in the massive-star forming region W3 IRS5 observed with the RadioAstron and the VERA (Japanese VLBI Exploration of Radio Astrometry). The former observations yielded detections of the masers in fringe spacings up to 40 microarcseconds. The brightness temperatures of the masers may be higher than 5×10^{13} K. The relative positions of the detected masers will be investigated in the forthcoming data of the imaging observations including group-delay calibration. The latter observations yielded the coordinates of the detected masers in the W3 IRS5 region. They were found in the clusters of masers where large line-of-sight velocity gradients were found. This suggests that the extremely bright masers are formed in shock fronts of the outflow interacting with the ambient gas clouds.

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A physical model for the radio and GeV emission from the microquasar LS I +61°303

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The stellar binary system LS I +61°303 consists of a Be star and a compact object (neutron star or black hole) in an eccentric orbit. Several authors predict periodic accretion with two peaks along such an eccentric orbit. Indeed, the orbital period of $P_1 = 26.4960 \pm 0.0028$ days has been found in the emission from the source at different wavelengths, but timing analysis of radio data, peaking only at orbital phases around apastron, results in two periods, P_1 and $P_2 = 26.92 \pm 0.07$ days, a period well compatible with the precession period of a relativistic jet determined from the analysis of the astrometry of VLBA images. In the GeV regime two outbursts are observed, one at periastron and one at apastron. While the apastron GeV peak shows the same timing characteristics as the radio outbursts, the periastron GeV peak appears to be only modulated by P_1 . To investigate on this peculiar timing behavior we extend a previously developed physical model of a self-absorbed relativistic jet to include inverse Compton scattering along the orbit (EIC and SSC), assuming two injections of relativistic particles, one at periastron and one at apastron. We present here our results and compare them to Fermi-LAT observations at 0.1-3 GeV.

Session V - mm-VLBI: SgrA* at 3mm and 1mm, EHT / 30**Detection and Implications of Horizon-Scale Polarization in Sgr A***Dr. JOHNSON, Michael¹¹ *Harvard-Smithsonian Center for Astrophysics***Corresponding Author(s):** mjohnson@cfa.harvard.edu

Magnetic fields play central roles in the accretion, emission, and outflow near black holes but have never been directly observed in this region. Because linear polarization of the bright synchrotron emission from galactic cores traces these magnetic fields, polarimetric interferometry with the Event Horizon Telescope (EHT) is capable of imaging the near-horizon fields. I will present the results of observations of Sgr A from the 2013 EHT campaign. These observations, the first to resolve the polarized emission from Sgr A at any wavelength, detect ordered magnetic fields with vigorous activity near the event horizon.

Session X - VLBI science and technique, outlook / 56**The Discovery and Implications of Refractive Substructure for VLBI at the Highest Angular Resolutions**Dr. JOHNSON, Michael¹¹ *Harvard-Smithsonian Center for Astrophysics***Corresponding Author(s):** mjohnson@cfa.harvard.edu

At radio wavelengths, scattering in the interstellar medium distorts the appearance of astronomical sources. When averaged over a sufficiently long time, the scattering results in a blurred image of the source. However, the scattering has the opposite effect for individual observing epochs, introducing substructure in the image. Also, unlike angular and temporal broadening, which become weaker at higher observing frequencies, the imprint of substructure becomes stronger at higher frequencies. I will discuss the discovery of substructure in Sgr A* at 22 GHz, the implications of substructure for RadioAstron and the Event Horizon Telescope, and the potential for refractive substructure to improve studies of extreme brightness temperatures with VLBI.

Session III - mm-VLBI: AGN at 3mm / 6**Microarcsecond Structure of the Parsec Scale Jet of the Quasar 3C454.3****Author(s):** Dr. JORSTAD, Svetlana¹**Co-author(s):** Prof. MARSCHER, Alan ² ; Dr. AGUDO, Ivan ³ ; Dr. GOMEZ, Jose-Luis ³ ; Dr. LARIONOV, Valeri ⁴¹ *IAR, Boston University, Boston, USA*² *Boston University, Boston, USA*³ *Instituto de Astrofísica de Andalucía (CSIC), Granada, Spain*⁴ *St.-Petersburg State University, St.Petersburg, Russia***Corresponding Author(s):** jorstad@bu.edu

The Boston University group have been monitoring the parsec scale jet of the quasar 3C454.3 with the Very Long Baseline Array at 43 GHz since 1995 January. Thusfar, we have collected 128 total and polarized intensity images of the quasar with a high resolution of ~0.1 mas. I will discuss VLBI properties of the two prominent features in the innermost jet of 3C454.3, the VLBI core and quasi-stationary knot C located at ~0.6 mas from the core, and their evolution during two decades of observations, including a comparison between polarization behavior of the features and optical polarization variability of the quasar.

This research is funded in part by NASA Fermi Guest Investigator grant NNX14AQ58G and NASA Swift Guest Investigator grant NNX15AR34G.

Session VII - mm-VLBI: continuum, gamma-connection, spectral lines / 28**Jets from Water-Disk-Megamaser Galaxies****Author(s):** Ms. KAMALI, Fateme¹**Co-author(s):** Dr. HENKEL, Christian ¹ ; Dr. BRUNTHALER, Andreas ¹ ; Prof. MENTEN, Karl ¹¹ *MPI für Radioastronomie***Corresponding Author(s):** fkamali@mpifr-bonn.mpg.de

Detailed studies of the jet-accretion disk connection are essential for a better understanding of the formation and launch of the jets. Water disk masers in the very central region of active galaxies, with the circumnuclear disk being viewed edge-on, provide a unique sample of targets for studying the accretion disk surrounding the super massive black holes. In this work we investigate the accretion disk-jet paradigm by searching for nuclear jets from the active galaxies where the water disk maser emission has been observed from the accretion disk. A sample of 24 such galaxies was observed with the Karl G. Jansky Very Large Array (JVLA) at ka band and 87% of the sample showed the radio continuum emission at 3.5 sigma or higher level. The follow-up higher resolution observation of the detected sources with the Very Large Baseline interferometry will reveal the nature these compact radio emissions.

Session IX - mm-VLBI and the KVN / 53**Unlocking the secrets of PKS 1502+106. Synergies between mm-VLBI and single-dish monitoring****Dr. KARAMANAVIS, Vassilis**¹¹ *MPI für Radioastronomie***Corresponding Author(s):** vkaraman@mpifr-bonn.mpg.de

In August 2008, Fermi/LAT discovered the distant blazar PKS 1502+106 ($z=1.839$) showing a rapid and strong gamma-ray outburst followed by bright and variable flux over the next months. This activity at high energies triggered an intensive multi-wavelength campaign indicating that the outburst was accompanied by a significantly delayed counterpart at radio bands. Utilizing ultra-high angular resolution VLBI imaging at 43 and 86 GHz, we attempt to shed light on the physics of the jet flow right after this high-energy flare. Furthermore, we aim at localizing the gamma-ray emitting region. In this talk the findings of the mm-VLBI study using the Global Millimeter VLBI Array (GMVA) data between 2009 and 2012, will be presented. These imply an accelerating jet. The viewing angle towards the source differs between the inner and outer jet, with the former at ~ 3 degrees and the latter at ~ 1 degree, beyond the first milliarcsecond. A single component travelling within the bent jet of PKS 1502+106 can be associated with the pronounced flare both at high-energies and in radio bands.

Session IX - mm-VLBI and the KVN / 14**The Plasma Physics of Active Galactic Nuclei (PAGaN) project with KVN and KaVA****Author(s):** Mr. KIM, Jae-Young¹**Co-author(s):** Prof. TRIPPE, Sascha ² ; Dr. SOHN, Bong Won ³ ; Mr. OH, Junghwan ² ; Mr. PARK, Jong-Ho ² ; Dr. LEE, Sang-Sung ³ ; Mr. LEE, Taeseok ² ; Mr. KIM, Daewon ²¹ *MPI für Radioastronomie*² *Seoul National University, Korea*³ *Korea Astronomy and Space Science Institute, Korea***Corresponding Author(s):** jykim@mpifr-bonn.mpg.de

AGN with bright radio jets offer the opportunity to study the structure of and physical conditions in relativistic outflows. For such studies, multi-frequency and polarimetric VLBI observations are important as they directly probe particle densities, magnetic field geometries, and several other

parameters. In this talk, I will present results from first-epoch data obtained by the Korean VLBI Network (KVN) and KVN and VERA Array (KaVA) within the frame of the Plasma Physics of Active Galactic Nuclei (PAGaN) project, especially focusing on polarimetric results from KVN. We observed seven/eight AGN at frequencies of 22, 43, 86, and 129 GHz in dual polarization mode by KVN and at 22 and 43 GHz in single polarization only by KaVA, respectively. Our KVN observations constrain apparent brightness temperatures of jet components and radio cores in our sample to $> 10^{8.01}\text{K}$ and $> 10^{9.86}\text{K}$, respectively. Degrees of linear polarization m_L are relatively low overall: less than 10%. This indicates suppression of polarization by strong turbulence in the jets. We found an exceptionally high degree of polarization in a jet component of BL Lac at 43 GHz, with $m_L \sim 40\%$. Assuming a transverse shock front propagating downstream along the jet, the shock front being almost parallel to the line of sight can explain the high degree of polarization.

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The Kinematics of M81 and M82 Galaxies

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The proper motion measurements combined with the the radial velocities, are important tools for our understanding of the dynamics and evolution of galaxies in a group environment. One of our nearest group is the M81 group at a distance of 3.63 ± 0.34 Mpc. It is a fascinating interacting galaxy system containing galaxies M81, M82 and NGC 3077. This work present the proper motions of M81 and M82 galaxies, derived from the VLBI radio observations. The observations were conducted in three epochs between 2007 and 2009 at X- (8.4 GHz), U- (15.3 GHz) and K-band (22.2 GHz). On one hand, the M81 proper motion relative to Milky Way was derived from background quasars (0945+6924, 0948+6848, 1004+6936). This was done by fitting a rectilinear motion to the position offsets of the quasars. After correcting the peculiar motion of the Sun and the rotation of the Milky Way, we obtain a proper motion relative to the Milky Way of $1.5 \pm 10.0 \mu\text{as yr}^{-1}$ ($196 \pm 172 \text{ km s}^{-1}$) towards the East and $-20.1 \pm 4.0 \mu\text{as yr}^{-1}$ ($-346 \pm 69 \text{ km s}^{-1}$) towards the North. On the other hand, the proper motion of M82 galaxy is derived from observations of two H₂O masers in the opposite side of its dynamic center. After correcting for the internal rotation, this measurements yields a proper motion relative to M81 of $5.6 \pm 4.2 \mu\text{as yr}^{-1}$ ($94.6 \pm 71 \text{ km s}^{-1}$) towards the East and $3.5 \pm 4.1 \mu\text{as yr}^{-1}$ ($59.2 \pm 69 \text{ km s}^{-1}$) towards the North. Since M82 is embedded in the dark matter halo of M81, it can be considered bound, we therefore derive a lower limit of the mass of M81 to be $3.05 \times 10^{11} M_{\odot}$.

Session IV - RadioAstron: AGN at high brightness temperatures / 32

RadioAstron survey of AGN cores at extreme angular resolutions

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The RadioAstron AGN survey is performed by the space radio telescope Spektr-R and many sensitive ground radio telescopes in Russia, Europe, Asia, USA, South Africa, Australia, Japan at 18, 6, and 1.3 cm and has already detected about 140 AGNs at projected spacings up to 27 Earth diameters. Formal resolution as high as 14 microarcsec has been achieved for AGNs observed at 22 GHz. Current status and results of the RadioAstron AGN survey program will be summarized including statistics of measurements of very high brightness temperatures in AGN cores and physical implications of these findings. On behalf of the RadioAstron AGN Survey Team

Session I - RadioAstron / 31**RadioAstron Mission Overview**Dr. KOVALEV, Yuri¹¹ *Astro Space Center of Lebedev Physical Institute***Corresponding Author(s):** yyk@asc.rssi.ru

The RadioAstron Space VLBI mission utilizes the 10-m radio telescope on board the dedicated Spektr-R spacecraft to observe cosmic radio sources with an unprecedented angular resolution at 92, 18, 6 and 1.3 cm. The longest baseline of the space-ground interferometer is about 350,000 km. We will review in the talk basic parameters and capabilities of the space radio telescope Spektr-R and RadioAstron Space VLB interferometer as well as principles of organization of its science program.

Session IX - mm-VLBI and the KVN / 18**Global 3-mm VLBI observations with Korean VLBI Network toward bright AGN jets****Author(s):** Dr. KOYAMA, Shoko¹**Co-author(s):** Prof. ROS, Eduardo ² ; Dr. KRICHBAUM, Thomas P. ¹ ; Dr. JUNG, Taehyun ³ ; Dr. HODGSON, Jeffrey ¹ ; Prof. MARSCHER, Alan ⁴¹ *MPI für Radioastronomie*² *MPI für Radioastronomie & Univ. València*³ *Korea Astronomy and Space Science Institute*⁴ *Boston University***Corresponding Author(s):** skoyama@mpifr-bonn.mpg.de

Relativistic outflows in AGNs are ultimately powered by gravitational energy conversion by super-massive black holes. Recent mm-VLBI observations reveal in an increasing number of objects a misalignment of the jet position angles between innermost and outer jet regions. A combination of the 3 antennas of the Korean VLBI Network (KVN) with the Global 3-mm VLBI Array (GMVA) enhances the uv-coverage and imaging capabilities and extends the east-west resolution with baseline length of up to 9000 km. With its short inner-Korean baseline spacings, the KVN also facilitates a more accurate amplitude calibration of the global array and furthermore improves the detectability of extended and partially resolved structure. Here, we will report on first 3mm VLBI images of OJ 287, 3C 273, and 0716+714, which were obtained in a GMVA plus KVN pilot experiment at 3-mm in 2012 May.

Session II - mm-VLBI: the GMVA, nearby objects / 40**The Global Millimetre VLBI array: technique and science**Dr. KRICHBAUM, Thomas P.¹¹ *MPI für Radioastronomie***Corresponding Author(s):** tkrichbaum@mpifr-bonn.mpg.de

I will describe the Global Millimetre VLBI Array and I will introduce major technical advancements in progress.

Session VIII - RadioAstron: Galactic and extragalactic masers, pulsars, & technique / 24**Accurate shifts measurements for AGN multifrequency VLBI maps**

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Determining relative shift between VLBI maps on different frequencies is the typical task arising in spectral index and core shift measurements. This shift can be found using a 2D cross-correlation of the maps with optically thick regions excluded. However the masking procedure is still performed manually, which can lead to uncertainties due to human driven choice that dominate in the total error budget and can not be properly estimated. We propose and discuss a method for unique identification of the optically thick parts of the jet and calculation of the maps shift.

Session VII - mm-VLBI: continuum, gamma-connection, spectral lines / 25

Comprehensive study of a gamma-ray to radio connection in 3C273

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In late 2009 quasar 3C273 experienced a series of strong gamma-ray flares which triggered our 6 cm - 7 mm VLBA follow up observations. We added to our 4 multifrequency epochs four years of 7 mm data in order to trace kinematics of newborn components.

The connection between gamma-ray and mm-wavelength variability is complex in 3C273 and there is no one-to-one correspondence in the lightcurves. If one connects the most prominent peaks in gamma-ray and in 7 mm VLBI core lightcurves, the latter lags the former by ~110 days. This would imply that the site of gamma-ray emission is located several parsecs upstream of the apparent jet base at 7 mm, close to the apex of the jet. This would be consistent with the distance from jet apex to the 7 mm core derived from the core shift analysis and supported by small time scale variability of gamma-ray emission. We found several components ejected during the active gamma-ray state and tie up one with the major gamma-ray flare.

We analysed frequency dependant core position to derive value of the magnetic field of the 7 mm VLBI core which turned out to be almost invariable over the 5 month period. Therefore we attributed the rising flux density mostly to injection of new energetic particles.

We scrutinized distribution of the two-frequency spectral index along the jet direction in the core region and found that the transition zone from optically thick to optically thin emission could be reliably resolved with VLBA observations and therefore is intrinsic to the jet.

Session IV - RadioAstron: AGN at high brightness temperatures / 33

Extreme physics at extreme baselines

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Present developments in radio interferometry with spaceborne antennas and at millimetre wavelengths drive the field of study into a truly unexplored domain of baseline lengths and fringe spacings. The ongoing VLBI efforts at 1 mm have pushed this limit to ~8 Gigalambdas, and RadioAstron measurements have reached up to ~15 Gigalambdas, which signifies more than a factor of four increase of the fringe spacings probed by interferometric measurements. Venturing into this previously uncharted territory has already revealed several new physical aspects of radio emission from AGN and pulsars, including fine substructure of the scattering material and very

high brightness temperatures well in excess of the canonical inverse Compton limit. Explanations of the latter observations in particular may require invoking extreme physics marked by pair creation in strong magnetic fields in the immediate vicinity of the central engine in AGN. A possible outline of this physics may already have been foreshadowed by the recent RadioAstron and EHT measurements which enabled placing robust limits on brightness temperature on smallest angular and linear scales to be made directly from interferometric visibilities. Potential implications of these measurements for the physical nature of the central engine in AGN will be considered here, together with further prospects for extending this type of study to full imaging of AGN radio emission at a microarcsecond resolution.

Session V - mm-VLBI: SgrA* at 3mm and 1mm, EHT / 8

Anatomy of the horizon-scale structure of Sagittarius A* with a resolution of ~ 3 Schwarzschild radii

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Significant progress in millimeter VLBI has recently been made with the Event Horizon Telescope project, which aims to resolve strong field General Relativistic (GR) signatures in nearby supermassive black holes (in particular Sgr A* and M87). Adding APEX to the inner American array now allows to image the Galactic center (Sgr A*) with a resolution of ~ 3 Schwarzschild radii. Strong evidence is found for a non-pointlike non-Gaussian brightness distribution, which will be discussed in this talk. With the expected improvement in the array performance, future observations could lead to direct detection of strong GR signatures, e.g., the black hole shadow.

Session III - mm-VLBI: AGN at 3mm / 7

Millimeter-wave VLBI of Blazar Jets

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Millimeter-wave VLBI is the only technique that directly images the relativistic jets of blazars. The author will present and discuss recent results of monitoring of gamma-ray bright blazars with the VLBA (VLBA-BU-BLAZAR program) and GMVA, as well as prospects for 1 mm VLBI. Polarization and relative timing of events at higher frequencies with changes in polarization and structure at millimeter wavelengths provide information needed to test and guide models for the jet emission across the electromagnetic spectrum. This presentation will review what we have learned thus far from such studies.

The rough self-similarity of blazar jets at centimeter wavelengths breaks down at shorter wavelengths. The mm-wave “core” marks the location where the nature of the jet changes relative to more downstream regions. There are a number of hypotheses for what the core represents: (1) the actual base of the jet, (2) a standing shock, a region where (3) turbulence or (4) magnetic reconnection accelerates electrons, or (5) the section of the jet where the acceleration to a high bulk Lorentz factor ends. These hypotheses can be tested through spatially resolved polarized intensity imaging with mm-VLBI, since at short millimeter wavelengths there is little or no synchrotron self-absorption to hide the true structure. In order to illustrate the power of such observations, the author will present simulated polarized intensity images of a particular model for the core that he is developing, in which plasma with a combination of turbulent and helical magnetic field crosses a cone-shaped standing shock. This will reveal the dependence of the observed polarization pattern on the ratio of helical to turbulent field.

This research is supported in part by NASA through Fermi Guest Investigator grant NNX14AQ58G.

Session IX - mm-VLBI and the KVN / 12

Dynamics in acceleration and collimation regions of relativistic jets in black hole accretion disk system

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Thanks to high-angular resolution by mm-VLBI observations, now we can observe the relativistic jets up to the very vicinity of jet formation site in the black hole accretion disk system. In this presentation, I will review and summarize the dynamics in acceleration and collimation regions of relativistic jets in black hole accretion disk system from theoretical and numerical point of view. First, I will present the physical properties of stationary recollimation shocks in the relativistic jets from recent relativistic MHD simulations and briefly show the application to BL Lac observation by RadioAstron. Second, I will show the radiation properties of jet formation site in black hole accretion disk system from the results of coupling of general relativistic radiation transfer calculation with the GRMHD simulations.

Session V - mm-VLBI: SgrA* at 3mm and 1mm, EHT / 21

Closure phase measurements of Sgr A* at 3mm

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Located at the dynamical center of our Galaxy, the black hole candidate Sagittarius A* (Sgr A*) is an ideal target for studying the structure, emission, and dynamics close to an event horizon with high-resolution VLBI. We present the first results of 3mm observations of Sgr A* and NRAO 530 performed with the VLBA, GBT and LMT on May 2015. Thanks to an unprecedented sensitivity and the use of a new analysis method, we find evidence for non-zero closure phases in Sgr A* in comparison with NRAO 530, which hints at asymmetric source structure at the wavelengths.

Session III - mm-VLBI: AGN at 3mm / 1

86 GHz VLBI survey of Ultra compact radio emission in Active Galactic Nuclei

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Abstract: Very Long Baseline Interferometry (VLBI) Observations at 86 GHz reach a resolution of about 50 microarcseconds and sample the scales as small as $10^3 - 10^4$ Schwartzchild radii of the central black hole in Active Galactic Nuclei (AGN), and uncover the jet regions where acceleration and collimation of the relativistic flow takes place. Synchrotron radiation becomes optically thin at millimetre wavelengths ; making it possible to look deeper into the core and inner jets of AGN which is invisible at cm and longer wavelengths due to self absorption or free-free absorption by the torus. We present here results from a large global VLBI survey of 168 ultracompact radio sources at 86 GHz conducted in 2010 - 2011. All the sources were detected and 163 sources were imaged ; increasing by a factor of ~ 2 the total number of AGN imaged with VLBI at 86 GHz. We use gaussian modelfitting to represent the structure of the observed sources. The modelfitting yields estimates of the brightness temperature (T_b) of the VLBI bright core (base) of the jet and inner jet components of AGN, taking into account the resolution limits of the data at 3mm. We also compare the brightness temperature of the VLBI cores from this 86 GHz survey with similar estimates from the MOJAVE VLBI surveys at 15 GHz. We also compare the brightness temperatures obtained from the model fits with estimates of the brightness temperature limits made directly from the visibility data. For objects with sufficient structural detail detected, we investigate the effect of adiabatic energy losses on the evolution of brightness temperature along the jet.

Session II - mm-VLBI: the GMVA, nearby objects / 44

Magnetohydrodynamic Model of the M87 Jet Based on VLBI Observations

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M87, possibly the most studied relativistic jet in active radio galaxies, has been spatially resolved from ten to tens of millions of Schwarzschild radii; it gives a unique opportunity for understanding an AGN jet from birth to termination. Several key issues in AGN jets can be extensively discussed based on multi-frequency radio observations and magnetohydrodynamic (MHD) jet theories toward M87. One of our remarkable findings in M87 is the “jet break”, a structural change from parabolic to conical geometry, which coincides to a transition from increasing to decreasing in observed proper motions. In this talk, we discuss about the jet break as a fundamental property in AGNs under the interplay with the SMBH growth and evolution of early-type galaxies.

Session VI - RadioAstron: AGN and beyond / 37

Radio and gamma-ray properties of the nearby radio galaxy 3C 84

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We present results of multifrequency high resolution Very Long Baseline Interferometry (VLBI) observations of the nearby radio galaxy 3C 84. This object is one of the closest and thus best-studied misaligned active galactic nuclei. Despite gamma-ray silent during the EGRET-era, 3C84 has been detected during high-energy flares by Fermi and MAGIC telescopes. Recent high-resolution observations point out a limb-brightened structure on parsec scale. In this talk we present an overview of this peculiar object, and we discuss the connection between the radio and gamma-ray properties.

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/ 19

Assessing uncertainties of VLBI results

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Reliable estimates of the uncertainties of VLBI results are essential for quantifying their significance. We propose to use the bootstrap for obtaining such estimates. This well known and widely used method handles spatial correlation in image domain and accounts for nonuniformity and non gaussian nature of visibility noise on different baselines in uv-domain. The resulting estimates depend on quality of model - feature that is absent in any other methods used so far. Method allows to quantify uncertainty of the measured pixel/region flux, frequency dependent core-shift, visibility model components parameters, etc. - any function of the observed visibilities, as well as simple and straightforward formulation of the significance criteria becomes available (eg. for transverse Faraday rotation measure (RM) gradients). We apply this method to typical problems arising in VLBI observation of AGN jets - quantifying significance of RM gradients, finding uncertainties of frequency-dependent core shift and visibility model component parameters and compare them with other methods.

Session IV - RadioAstron: AGN at high brightness temperatures / 23

High-resolution observations of 0836+710 and jet physics.

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Recent space VLBI observations with Radioastron have allowed us to image the jet in the quasar 0836+710 with great detail. The combination of these results with previous space and ground VLBI observations show a very detailed picture of the jet structure. It confirms the interpretation of the visible radio-jet as high-pressure regions with higher emissivity at GHz frequencies within a wider flow. The analysis of our results will tackle the properties of these regions and their relation to the underlying jet flow. In this contribution I will discuss the physical processes that could explain such configuration of the jet emissivity.

Session VIII - RadioAstron: Galactic and extragalactic masers, pulsars, & technique
/ 47**Quasar 0529+483 on Space-Earth baselines: brightness temperature and scattering substructure from RadioAstron observations****Author(s):** Dr. PILIPENKO, Sergey¹**Co-author(s):** RADIOASTRON AGN SURVEY TEAM, The²¹ *ASC LPI*² *RadioAstron AGN Survey Team***Corresponding Author(s):** spilipenko@asc.rssi.ru

Quasar 0529+483 is one of 28 extragalactic sources detected on projected baselines longer than 200 000 km at 4.8 and 1.7 GHz with ground-space interferometer RadioAstron as a part of the AGN survey program. Its correlated flux density at the longest baselines was found to be a few percent of the peak flux density and cannot be explained by a simple single Gaussian model which fits the data at shorter baselines. We interpret this as a manifestation of the substructure created by the refractive scattering on the interstellar medium predicted by Johnson & Gwinn (2015). We estimate the source frame brightness temperature 5×10^{12} K at 5 GHz. From the refractive substructure properties we estimate that the intrinsic source size at 5 GHz is 0.25×0.1 mas, while the angular broadening is 0.1 mas. At 1.7 GHz the intrinsic source size is likely to be smaller than the broadening size, 1 mas.

Presented on behalf of the RadioAstron AGN Survey Team

Session I - RadioAstron / 13**Current status of Millimetron space observatory****Author(s):** Dr. PILIPENKO, Sergey¹**Co-author(s):** Prof. KARDASHEV, Nikolay¹; Prof. NOVIKOV, Igor¹; Dr. LIKHACHEVA, Larisa¹; Dr. DE GRAAUW, Mattheus¹; Dr. LIKHACHEV, Sergey¹; Dr. LUKASH, Vladimir¹; Dr. KOSTENKO, Vladimir¹¹ *P.N. Lebedev Physical Institute RAS***Corresponding Author(s):** spilipenko@asc.rssi.ru

Millimetron is a planned 10-meter class space telescope for the far infrared to millimeter wavelengths (approx. 20 microns to 1 cm). It will operate in two modes. First one, the single dish mode, will cover wavelengths which are poorly accessible from the Earth's surface. With its high sensitivity reached due to active cooling of the telescope mirrors, Millimetron in this mode will observe interstellar medium in galaxies at the epoch of reionization, search for water in the atmospheres of Solar system bodies and in protoplanetary disks and study many other weak sources. On the longer wavelengths Millimetron will be able to work as an arm of a space-Earth interferometer with baselines up to 1.5 million kilometers, allowing to probe astrophysical objects with an unprecedented angular resolution. In this talk the current status of Millimetron development and its scientific goals will be summarized.

Session X - VLBI science and technique, outlook / 26**Silhouettes of parsec-scale AGN jets****Author(s):** Dr. PUSHKAREV, Alexander¹**Co-author(s):** Prof. LISTER, Matthew L.²; Dr. KOVALEV, Yuri³; Dr. SAVOLAINEN, Tuomas⁴¹ *Crimean Astrophysical Observatory*² *Purdue University*³ *ASC LPI*⁴ *Aalto Univ. & MPI für Radioastronomie*

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We used 15 GHz VLBA observations of 373 sources having at least 5 epochs within a 20-yr time interval 1994–2015 from the MOJAVE program and/or its predecessor, the 2 cm VLBA Survey. For each source we produced a corresponding stacked image averaging all available epochs for a better reconstruction of the cross section of the flow. We have analyzed jet profiles transverse to the local jet ridge line and derived both apparent and intrinsic opening angles of the parsec-scale outflows. The sources detected by the Fermi Large Area Telescope during the first 48 months of operation show wider apparent jet opening angle and smaller viewing angles on a very high level of significance supporting our early findings. Analyzing transverse shapes of the outflows we found that most AGN outflows have conical geometry at parsec scales, though there are also sources that exhibit active jet collimation.

Session X - VLBI science and technique, outlook / 48

Exploring the magnetic field configuration close to central engines

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The high radio frequency polarization imaging of non-thermal emission from AGN is a direct way to probe the magnetic field strength and structure in the immediate vicinity of SMBHs and is crucial in testing the jet-launching scenario. To explore the the magnetic field configuration at the base of jets in blazars, I took advantage of the full polarization capabilities of the GMVA (Global Millimeter VLBI Array). With an angular resolution of $\sim 50\mu\text{as}$, one could reach scales down to $\sim 720 R_s$ (for a 10^9 solar mass black hole). In this talk, I will show the preliminary results of our study on BL Lac.

Refreshments and Discussion / 52

Discussion in small groups and preparation of final, plenary discussion

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Discussion.

Session VII - mm-VLBI: continuum, gamma-connection, spectral lines / 51

Oblique shocks in polarised sources revealed by GMVA observations

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Polarisation studies using mm-VLBI probe the intrinsic linear polarization of relativistic outflows at sub-parsec scales, how uniform is the magnetic field geometry and how does it evolve with time, as well as the presence of recollimation shocks near the core region, and structural changes at the innermost jet. We present preliminary results of the first GMVA observations of highly variable,

polarised sources. The first epoch images at 7mm and 3mm wavelengths of this observational program correspond to the quasars 4C+39.25 and 1055+018.

Session VI - RadioAstron: AGN and beyond / 34

Gravitational redshift experiment with RadioAstron: current status, perspectives, and VLBI applications

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A unique test of general relativity is possible with the space radio telescope RadioAstron. The ultra-stable on-board hydrogen maser frequency standard and the highly eccentric orbit make RadioAstron an ideal instrument for probing the gravitational redshift effect. The large gravitational potential variation, occurring on the time scale of ~ 24 hr, causes a large variation of the on-board H-maser clock rate, which can be detected via comparison with frequency standards installed at various ground radio astronomical observatories. In order to perform this comparison the RadioAstron spacecraft is tracked by ground radio telescopes equipped with 8.4 or 15 GHz receivers, and its downlink signal is recorded by standard VLBI equipment. The well-established algorithms, developed originally for PRIDE (Planetary Radio Interferometry and Doppler Experiment) are used to accurately recover the frequency of the recorded signal, while the 1st-order Doppler shift and atmospheric disturbances are compensated for by a technique similar to that of phase referencing and based on interleaving 1-way and 2-way modes of operation of the spacecraft radio links. Additional tropospheric and ionospheric calibration are obtained from on-site WVR (Water Vapour Radiometer) and GNSS (Global Navigation Satellite Systems) receivers available at the majority of the EVN and IVS stations participating in the experiment. We expect the accuracy of the test to reach a value of $\sim 2 \times 10^{-5}$, thus improving the currently best result of the Gravity Probe A mission [1] by a factor of 10.

Session I - RadioAstron / 9

Pulsar Studies with RadioAstron

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On behalf of the Radioastron pulsar group this report presents an overview of the studies which were done with the Radioastron space radio telescope during the first four years of mission operation, including the early and key science programs. Space-VLBI observations of pulsars with the highest angular resolution revealed the new interstellar plasma scattering effects, such as, resolving the substructure in the scattering disk. Diameters of scattering disks were measured for several pulsars and the distances to the effective scattering screens were estimated. Layers of scattering plasma were detected to be located relatively close to the Sun (10-100 pc). Such layers might be responsible for fast flux variations of compact extragalactic radio sources. A new insight on the interstellar scattering was demonstrated by study of the instantaneous visibilities which were measured with the Space-VLBI observations of giant pulses from the Crab pulsar.

Session VIII - RadioAstron: Galactic and extragalactic masers, pulsars, & technique / 11**Primary data processing in Space-VLBI missions. ASC Correlator.****Author(s):** ANDRIANOV, Andrey¹**Co-author(s):** Mr. GUIRIN, Igor¹ ; Mr. KOSTENKO, Vladimir¹ ; Mr. ZHAROV, Vladimir² ; Mr. LIKHACHEV, Sergey¹ ; Ms. SHATSKAYA, Marina¹ ; Dr. RUDNITSKIY, Alexey¹¹ *ASC LPI*² *Lomonosov Moscow State University, Sternberg Astronomical Institute***Corresponding Author(s):** almax1024@gmail.com

The “Radioastron” space mission is the unique project of Russian Space Agency (Roscosmos) and Russian Academy of Sciences to investigate the Universe by means VLBI principles implementation with “Spektr-R” space satellite. “Spektr-R” onboard 10-m radio telescope has been operating since 15 November, 2011 as the Space element of the space-ground interferometer at the orbit with its apogee up to 350000 km. The first and the basic step in VLBI observations data processing is correlation. Space-VLBI brings new requirements in correlation process due to significant uncertainties in delay model for space telescope. Radioastron mission correlator is a part of ASL (Astro Space Locator) software package for Windows environment developed in Astro Space Center (ASC) of Lebedev Physical Institute. In this report the main features and operational procedures of the ASC Correlator are described with the emphasis on the Space-VLBI data-processing differences compared to the ground VLBI. Also, a description of time delay and its derivatives calculation algorithm is presented in this report, as well as the procedure of correction for these parameters. This approach is critical for the correlation of space-ground interferometer data. In this report we also show the importance of the orbit accuracy and correlator requirements for the future Space-VLBI missions, such as the “Millimetron” project.

Session VI - RadioAstron: AGN and beyond / 20**The Nuclear Structure in Nearby AGN at 3-500 Schwarzschild Radii Resolution****Author(s):** Dr. SAVOLAINEN, Tuomas¹**Co-author(s):** Prof. GIOVANNINI, Gabriele² ; Dr. ORIENTI, Monica³ ; Dr. HODGSON, Jeffrey⁴ ; Dr. KOVALEV, Yuri Y.⁵ ; Dr. BRUNI, Gabriele⁴ ; Dr. GIROLETTI, Marcello³ ; Dr. HADA, Kazuhiro⁶ ; Dr. KINO, Motoki⁷ ; Dr. KRICHBAUM, Thomas P.⁴ ; Dr. LOBANOV, Andrei P.⁴ ; Dr. LEE, Sang-Sung⁷ ; Dr. NAGAI, Hiroshi⁸ ; Dr. REYNOLDS, Cormac⁹ ; Prof. SOHN, Bong-Won⁷ ; Dr. SOKOLOVSKY, Kirill¹⁰ ; Mr. VOITSIK, Peter¹⁰ ; Prof. ZENSUS, J. Anton⁴¹ *Aalto Univ. & MPI für Radioastronomie*² *Bologna Univ. & IRA-INAFA*³ *IRA-INAFA*⁴ *MPI für Radioastronomie*⁵ *ASC LPI & MPI für Radioastronomie*⁶ *NAOJ & IRA-INAFA*⁷ *KASI*⁸ *NAOJ*⁹ *ICRAR*¹⁰ *ASC LPI***Corresponding Author(s):** tukasa@mpifr-bonn.mpg.de

The ultra-high angular resolution of RadioAstron space-VLBI observations provides an opportunity to study the relativistic jet structure in nearby radio galaxies at a spatial resolution of only a few to a few hundreds of Schwarzschild radii at centimeter wavelengths. Such observations complement the ground-based mm-VLBI experiments in probing the jet acceleration and collimation zone and offer a unique view of the internal jet structure. The RadioAstron Nearby AGN Key Science Program has carried out space-VLBI imaging of three bright, nearby radio galaxies - M87,

Centaurus A and 3C84. We present here an update on the results from this program. We have successfully detected 3C84 on space baselines up to 7 Earth diameters at 6 and 1.3 cm, while M87 was detected on baselines up to 3 Earth diameters at 18 and 6 cm and up to 1 Earth diameter at 1.3 cm. The innermost parsec of the radio galaxy 3C84 has been imaged at both observing bands - with the 1.3 cm data yielding one of the highest resolution space-VLBI images ever made. We will discuss the structures visible in these images, including the jet formation site and a parsec-scale hot spot.

Session II - mm-VLBI: the GMVA, nearby objects / 17

mm-VLBI Observations of the Active Galaxy 3C 111 in Outburst

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In 2007, the nearby ($z=0.049$) broad line radio galaxy 3C 111 exhibited a major flux density outburst. Three GMVA millimetre-VLBI observations at 86 GHz covering one year were conducted and allow us to study this outburst with unprecedented image fidelity at highest resolution of ~ 0.050 mas (~ 0.05 pc). The outburst led to the appearance of a complex series of plasma components forming an intriguing bent structure, being ejected at varying position angles. Within 1 pc from the jet base, ejections vary in position angle and components move with an apparent velocity of $\sim 3 - 4c$, significantly slower than the maximum velocity observed with cm-VLBI on scales beyond 1 mas.

Session VIII - RadioAstron: Galactic and extragalactic masers, pulsars, & technique / 45

Development of Processing Centers from Radioastron to Millimetron Projects

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The problems of implementation and operation of the Data Processing Center for the Radioastron Project as well as the problem of implementation of the Data Center for Millimetron project are considered. The main features of these SVLBI projects are large flow of information, big volume of data and computing power. The solving of this problems is organization of Data Processing Center or Data Center with suitable engineering infrastructure, commutation tools, channels and computer technique. The main tasks of Processing Center of Radioastron Project are collection, storage, calculation and distribution of information. Also the problems of high-speed data required for the exchange of large volumes of astronomical observations are considered. Also perspectives and plans of implementation of Data Center for Millimetron project are shown.

Session VIII - RadioAstron: Galactic and extragalactic masers, pulsars, & technique / 38**Studies of masers in star forming regions of our Galaxy and megamasers in external galaxies within RadioAstron space-VLBI project****Author(s):** Dr. SOBOLEV, Andrej M.¹**Co-author(s):** Dr. ALAKOZ, Alexey² ; Prof. BAAN, Willem³ ; Dr. IMAI, Hiroshi⁴¹ *Ural Federal University*² *ASC LPI*³ *ASTRON*⁴ *Kagoshima University***Corresponding Author(s):** andrej.sobolev@urfu.ru

Observations of the masers in the course of RadioAstron mission yielded detections of fringes for a number of sources in both water and hydroxyl maser transitions. Some 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.

For the first time cosmic water maser emission was detected with projected baselines exceeding Earth Diameter. It was detected in a number of star forming regions in the Galaxy and megamaser galaxy NGC 4258. Fringes from the water maser sources were detected on baselines exceeding 5 Earth Diameters (>65,000 km). This means that the angular resolution better than 40 microarcsec was directly achieved in the cosmic maser observations. The sharpest “direct” linear resolution better than 4 million kilometers was achieved in observations of the maser in Orion. Modelling of the data on Cep A water maser indicates that the source contains features with the sizes smaller than that of the Sun. Difference in velocities of these features corresponds to velocity gradient exceeding highest known values by 1-1.5 orders of magnitude.

So, the major step from milli- to micro-arcsecond resolution in maser studies is done. Existence of the features with extremely small angular sizes is established. Further implementations of the space VLBI maser instrument for studies of the nature of cosmic objects, studies of interaction of extremely high radiation field with molecular material and studies of the matter on the line of sight are planned.

Session V - mm-VLBI: SgrA* at 3mm and 1mm, EHT / 55**JIVE role in BlackHoleCam****Author(s):** Dr. VAN BEMMEL, Ilse¹**Co-author(s):** Dr. KETTENIS, Mark¹ ; Dr. SMALL, Des¹ ; Dr. SZOMORU, Arpad¹¹ *JIVE***Corresponding Author(s):** bemmel@jive.eu

Here we provide a brief overview of the role of JIVE in the BlackHoleCam project. Our efforts in developing software that will open up the field of millimeter VLBI for astronomers outside of the radio community and simplify operations and verification checks at the telescopes are described.

Session IV - RadioAstron: AGN at high brightness temperatures / 4**Multiband RadioAstron imaging of 0836+710****Author(s):** Ms. VEGA GARCÍA, Laura¹**Co-author(s):** Dr. LOBANOV, Andrei P.¹ ; Dr. PERUCHO, Manel² ; Dr. BRUNI, Gabriele¹¹ *MPI für Radioastronomie*

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Space VLBI observations with RadioAstron provide an extraordinary improvement of angular resolution. In this talk, I will present the results obtained from RadioAstron imaging of the quasar 0836+710 at L, C, and K bands. The images of 0836+710 show a wealth of structure on scales ranging from 0.2 to 150 milliarcseconds, which enables detailed studies of shocks and plasma instability development in the jet. Our preliminary analysis shows that the observed structure is consistent with a jet which has a lower density than the surrounding medium and propagates with a Mach number of ~ 6 . Further modelling of the internal structure of the flow should yield a more detailed physical picture of the jet propagation.

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RadioAstron AGN survey: statistics of sources detections

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The largest key science program of the RadioAstron mission is the survey of strong active galactic nuclei (AGN) at the highest angular resolution. The main goal of the survey is to study physics of AGN cores by observing AGN up to the longest RadioAstron projected baselines and measuring the geometries and brightness temperatures of the cores. To date AGN emission is successfully detected from about 140 sources at SVLBI baselines up to 27 Earth diameters. We present source detection statistics at three frequency bands 1.7, 5, and 22 GHz. We rigorously determine and apply the probability of SVLBI false detection based on the accumulated strong and unbiased statistics. The fringe fitting results are used to independently determine an accuracy of the Spektr-R orbit determination. We also show that detection rate does not depend on the distance to the space radio telescope while it does depend, as expected from the AGN jet geometry, on the projected distance.

Session I - RadioAstron / 50

Welcome Address and Introductory Remarks

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Welcome Address and Introductory Remarks

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ASL Software Package: VLBI data reduction and imaging.

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Astro Space Locator (ASL) software package is focused on post-correlation analysis of the data obtained by the aperture synthesis method with Very Long Baseline Interferometry (VLBI)

including Space-VLBI). The VLBI method of aperture synthesis is based on the visibility function measurements by separated telescopes.

ASL allows the user to perform the operation fringe synthesis and averaging (evaluation of the visibility function), visual editing, one-dimensional signal data processing (for each baseline, frequency and polarization), amplitude calibration, self-calibration for phase and amplitude. This software package allows performing all basic procedures for the image synthesis, including the main solution finding, methods of cleaning and self-calibration, and also allows the user to look at the in-between and final processing results in tabular and graphical form.