Union Radio-Scientifique Internationale U.R.S.I. International Union of Radio Science

Monthly Newsletter of International URSI Commission J – Radio Astronomy

March 2021

Officers

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Vice-Chair:	Douglas Bock		Jacki Gilmore

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News Items - Greetings from the Chair!

- The Commission J Newsletter is back after several months in hibernation. Over that time the officers and GASS Session Conveners have been busy folding GASS2020 into GASS2021. At last count, Commission J received 202 submissions (oral and poster) for a nominal 118 oral time slots. At present, the abstracts are being reviewed. Within the few weeks, the GASS2021 program will begin to emerge, and the oral time slots for Commission J will be assigned. Thank you for supporting URSI GASS2021!

- URSI GASS2021 is being planned as a hybrid local / virtual event. Please visit the URSI GASS2021 website for details (https://www.ursi2021.org/).

- **We are actively searching for nominees for Vice Chair and Early Career Representatives of Commission J.** The application form for the Vice-Chair election: http://ursi.org/files/DownloadForms/Form%20Vice-Chair%20Election_2021.docx
  The application form for the Commission Early Career Representative election: http://ursi.org/files/DownloadForms/Form%20ECR%20Election_2021.docx
  Please notify me ASAP, and we will need all nomination materials by March 31st. Consider nominating yourself or others! Contact me if you have questions.

- Commission J has two entries in the URSI GASS2021 Student Paper Competition. Barnali Das with the paper "Coherent radio emission from main sequence pulsar: introducing a new stellar diagnostic" and Devojyoti Kansabanik with the paper "Unravelling the eclipse mechanism for black widow pulsar J1544+4937 using broad band radio spectrum."

- This month we have an interesting article by Sravani Vaddi and Anish Roshi on the last successful VLBI observations with the legacy Arecibo telescope. Thank you for your contribution to our Newsletter.

URSI Mission Statement

Radio science encompasses the knowledge and study of all aspects of electromagnetic fields and waves. The International Union of Radio Science (Union Radio-Scientifique Internationale), a non-governmental and non-profit organization under the International Council for Science, is responsible for stimulating and coordinating, on an international basis, studies, research, applications, scientific exchange, and communication in the fields of radio science.

Included within the objectives are the following:

- To encourage and promote international activity in radio science and its applications, for the benefit of humanity;
- To encourage the adoption of common methods of measurement, and the inter-comparison and standardization of the measuring instruments used in scientific work;
- To stimulate and co-ordinate studies of:
    - the scientific aspects of telecommunications using electromagnetic waves, guided and unguided;
    - the generation, emission, radiation, propagation, reception, and detection of fields and waves, and the processing of the signals embedded in them.
- To represent radio science to the general public, and to public and private organizations.

You may download a copy of the official URSI leaflet at https://www.ursi.org/content/pdf/URSI_Leaflet_English.pdf

Last VLBI Observations with the Legacy Arecibo Telescope

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The Arecibo Observatory (AO) is a multi-disciplinary research and education facility that provides a wide range of instrumentation for research and observation in the fields of astronomy, planetary, and atmospheric and space sciences. AO's principal research instrument was the 305-meter fixed spherical radio telescope capable of operating at multiple frequency bands using receivers and transmitters housed in a cable-mount steerable Gregorian dome.

In the early morning of August 10, 2020, one of the 18 cables suspending the 900-ton platform pulled out of the socket at one end and fell, tearing the telescope's primary reflector surface. Before appropriate repair plans could be implemented, three months later, on 6 November, one of the main cables snapped causing damage beyond repair. The National Science Foundation announced on November 19, 2020 that the telescope would be decommissioned. However, on December 1, 2020, before a controlled decommission could take place, the remaining cables snapped leading to the collapse of the platform into the 305-meter surface.

The legacy 305-meter telescope has been part of the very long baseline interferometer (VLBI) network from its earliest days and has made significant contributions to the VLBI science. Owing to its large collecting area, the 305-meter telescope provided an order of magnitude increase in sensitivity to the High Sensitivity Array (HSA), the European VLBI Network (EVN), and the Global Network. Arecibo's sensitivity was instrumental in resolving the Pleiades distance controversy with measurements of Pleiades radio stars (Melis et al. 2014). Arecibo participated in the space-based observation using RadioAstron, the 10-meter space radio telescope, giving a resolution of 26 microarcsec thereby revealing details of the core structures in 3C273 quasar (Kovalev et al., 2016). The first repeating FRB (FRB121102) was found at Arecibo (Spitler et al. 2014) and teaming up with the EVN network, FRB121102 could be localized with ~10 milli arcsec accuracy (Marcote et al. 2017).

In this article, we briefly present the VLBI system at AO, which completed the upgrade in early 2020, and the preliminary results from the last successful interferometric observations made with the 305-meter telescope using this upgraded system.

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VLBI system upgrade and commissioning in 2020

Early in the year 2020, the VLBI system at AO was upgraded with a next-generation VLBI backend system. The upgraded system allowed AO to be up-to-date with the new developments in VLBI technology. The upgrade comprises both hardware and software units. The hardware unit consists of (a) Roach Digital Back End (RDBE), a digital processing unit, and (b) Mark6 recorder that records the data coming from the RDBE. The software unit consists of (a) Field System (FS) that communicates with the RDBE, Mark6, and (b) the AO telescope control system (CIMA). Figure 1 shows a schematic of the VLBI backend system architecture with various units and their connectivity. These three units are connected to a switch using RJ45 ethernet cables which form the VLBI net. The RDBE communicates with the Mark6 over two 10 Gigabit Ethernet (GbE) ports. The FS and Mark6 are also connected to the AO LAN to communicate with CIMA and to electronically transfer the data to JIVE.

An RDBE is a module that takes analog IF signal, processes and formats it for recording. The hardware components of an RDBE are the Reconfigurable Open Architecture Computing Hardware (ROACH) board, Analog to Digital Converter (ADC) board, Analog Level Control (ALC) board, and a synthesizer/timing board. The input IF signal is in the frequency range 500 to 1000 MHz, which is sampled at the second Nyquist zone using the 8-bit ADC. The ADC operates at 1024 MHz. The power level of the input signal to the ADC can be adjusted with a programmable attenuator. The digital signal processing done in the RDBE depends on the type of firmware loaded, which are called personalities of the RDBE. There are two personalities currently available: the polyphase filter bank (PFB) and digital down converter (DDC). The software interface used to communicate to the RDBE is rdbe_server and it follows the VLBI standard software interface specification (VSI-S) communication protocol.

Mark6 is the next generation VLBI data recording and playback system. The upgrade increased the recording rate from 2 Gbps to 16 Gbps. It receives data from the RDBE and records it in removable disk drives which are controlled by disk controllers. Mark6 records data on to four disk packs where each pack consists of eight disks of 1 TB storage providing a total local storage of 32 TB. The data is recorded simultaneously to all the disks. Mark6 uses jive5ab recording software. The RDBE and Mark6 are controlled by the field system. The 1-GbE optical fibre to the e-VLBI network allows real time e-transfer of the observations to the correlator site in JIVE in e-EVN. Data for correlation for the VLBA observations are sent by shipping disk packs to VLBA.

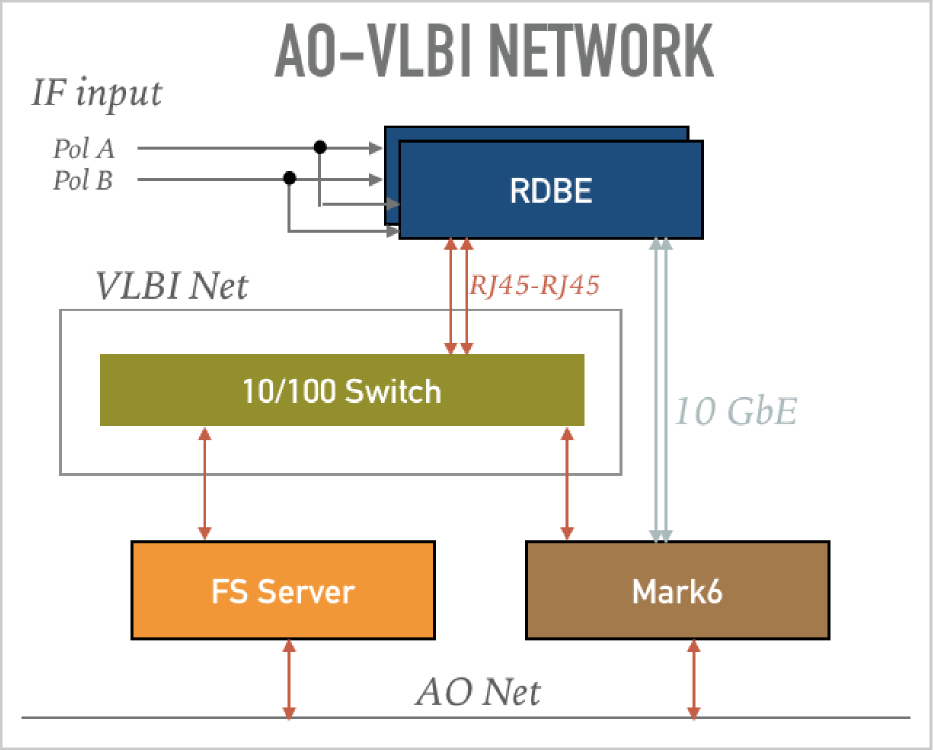

Fig 1: A block diagram of the AO VLBI system. The signals from the telescope are connected to the RDBE. The RDBE, Mark6, and the field system server are interconnected through ethernet links as shown. The server and Mark6 system are connected to the AO LAN for transferring the data through the internet.

Software for VLBI observation monitoring

A python program was developed to initialize and continually monitor the status of the backend recording system for a VLBI observing run. The program connects to the two RDBEs (RDBE2 and RDBE4) and spawns multiple threads to display in three panels: (a) the ADC output RMS values, (b) the status of the clock synchronization bit, and (c) the quantization threshold for the 2-bit quantization (see Figure 2). Experimentally we determined an RMS value of 20 units provided by RDBE will toggle 4 bits of the ADC, giving enough head room to process strong, transient radio frequency interference without saturating the converters. Therefore the attenuators in the RDBEs are initialized such that the RMS in the display is close to 20. The RMS value is read every 5 seconds and is displayed. The top right panel displays the status of synchronization between the data observable time clock and the FS time. The panel displays a filled red circle when there is a synchronization error and remains green otherwise. The bottom panel shows the quantization levels of the four digital down converters when the RDBEs are programmed with DDC personality. The program retrieves the threshold values for each DDC and adjusts them to be within tolerance of the expected threshold values. The tolerance level is a configurable input parameter. A logger is created every time the program is executed and keeps track of information, errors, and warnings that occur when the program is executed.

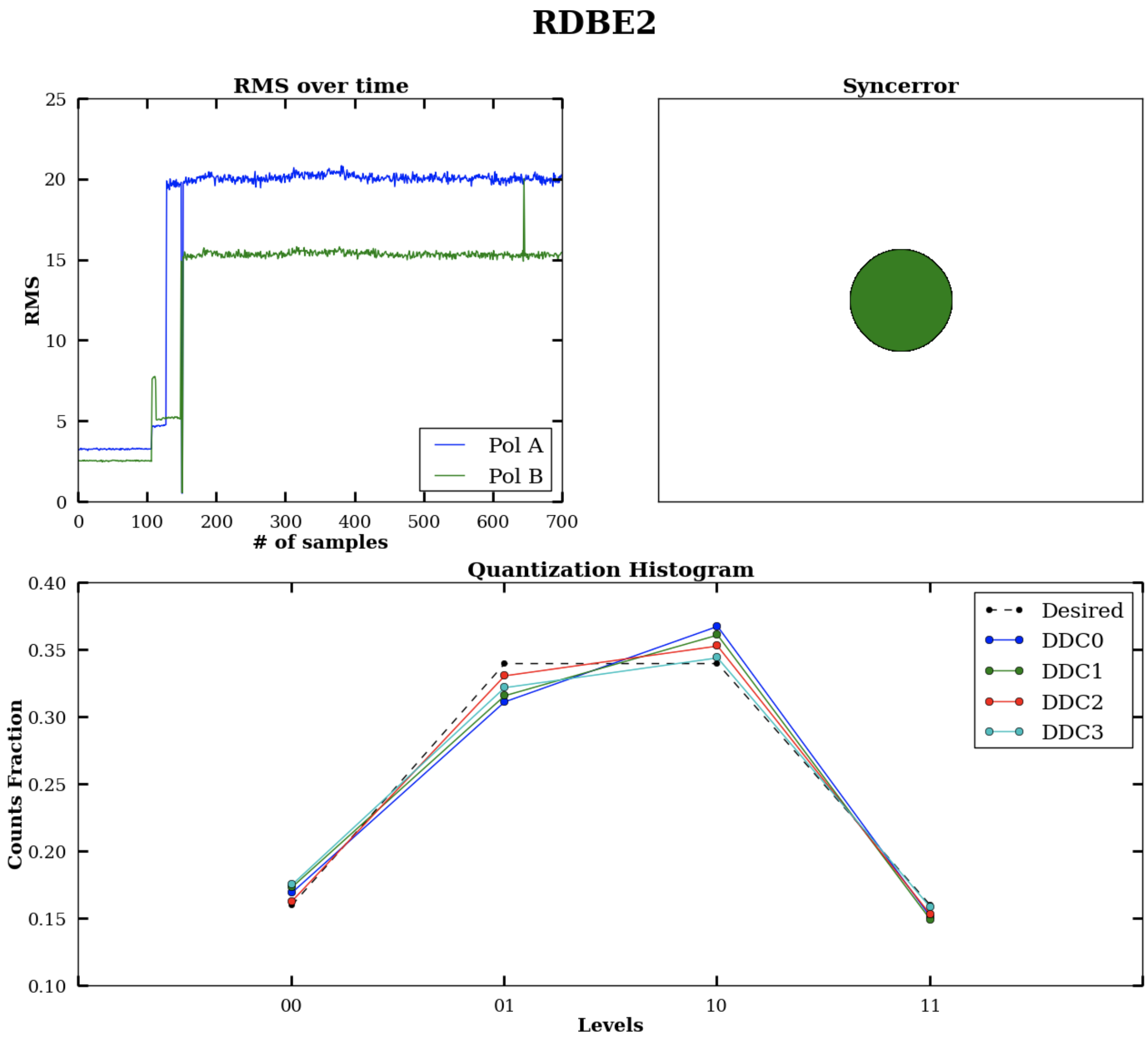

Fig 2: A sample display of the VLBI monitoring program for one of the RDBEs (RDBE2). The display has three panels. Top left panel shows the RMS of the RDBE over time. The software reads the RMS values from RDBEs and sets the attenuators in them to initialize the value to 20 at the beginning of the observations. The top right panel shows the synchronization status. The bottom panel shows a histogram of the signals in the 4 states after 2-bit quantization of the four DDCs. The desired threshold level for quantization with minimum distortion is also displayed.

High sensitivity EVN+Arecibo science results

We highlight here preliminary results from the last successful observations made with the upgraded VLBI system at the AO. Specifically, the detection of the radio core of the weakest nucleus in a dual active galactic nucleus system MRK463 with the EVN+Arecibo network. In these observations, it is seen that the inclusion of an Arecibo telescope kind of system can play a major role in mapping the weakly emitting radio source.

Very long baseline interferometry (VLBI) offers a resolution that is useful to study small spatial scales such as regions close to a black hole. When coupled with a large aperture telescope, one can additionally obtain high sensitivity. We used the European VLBI Network (EVN) to study nuclear activity in four dual active galactic nuclei (DAGNs). A DAGN is a galaxy that hosts two actively accreting supermassive black holes (SBH) and is believed to be a galaxy merger remnant. Studies of DAGNs play an important role in our understanding of the formation and evolution of SBHs. The demographics of these systems are helpful in obtaining constraints on the typical frequency of galaxy mergers which is important for the gravitational wave search as well as in theoretical modeling of galaxy formation and evolution.

Fig 3: SDSS composite optical image of MRK463. The eastern and western nuclei are marked.

MRK463E is an interesting DAGN in our sample (see SDSS color composite figure on the right). It is located at a distance of ~200 kpc and is one of the nearest DAGN systems to us. In fact, it is a luminous infrared galaxy. It was classified as a DAGN based on optical spectrum (Koss et al. 2012) and X-ray observations (Bianchi et al. 2008). The nuclei are separated by ~ 3.9 kpc. Given its distance and the nuclear separation, it serves as an important laboratory to study: (i) the growth of the two SBHs and how they impact the host galaxy in their dual AGN phase, and (ii) how it compares with what is observed in “single AGN” systems.

While the radio nature of the above AGN is established for the eastern nucleus, the nature of the western nucleus remains unclear primarily because its radio emission is about 2 orders of magnitude fainter compared to the eastern core. The goals of our VLBI observations are to study the morphology and spectral nature of both nuclei in order to understand how they evolve in the common envelope of gas that is feeding both the black holes. Since the western core was weak in radio, we tapped the unparalleled sensitivity of the Arecibo 305m telescope and included it as one of the stations with the EVN.

The observations of four dual AGN were taken using the high sensitivity EVN+Arecibo configuration in June 2020, during the most covid-affected EVN session, when some antennas were unable to participate because of local restrictions. While 13 antennas participated for the session, visibilities from only six antennas are available. The receiver was set up with 8 subbands. Each subband had a bandwidth of 16 MHz and subdivided into 32 spectral channels. The integration time was 2 s. We used phase-referencing for observations of weaker sources. Since both the cores fall within the primary beam, we used multi phase-center and post-process the data during correlation. In such a setup, multiple source observations can be obtained in a single pointing by correlating at different positions. This source was observed for 177 min. The inclusion of the high-sensitivity Arecibo telescope reduced the integration time of the observation for a given noise level by about 30%, in comparison with previous observations of the same source.

Fig. 4 shows the radio map of the eastern and western cores. The eastern core is detected in our EVN+Arecibo observations at an SNR of 400 and the western core is detected at an 18 sigma level. The FWHM of the beam is 75x16 mas equivalent to a spatial resolution of 75-16 pc at a distance of 233 Mpc. The integrated flux density of the eastern core-jet structure is 75.2 mJy and peak flux density is 24 (+/- 0.2) mJy/beam. The large-scale (~ 10 arcsec) total flux density of the source is 322.5 mJy (Mazzarella et al. 1991), which indicates that about 23% of the flux density is detected at the VLBI scale. The size of the VLBI core-jet is 111.8 mas which corresponds to 114.5 pc. The flux density of the western core is 3.75 mJy and the peak flux density is 1.2 (+/- 0.2) mJy/beam.

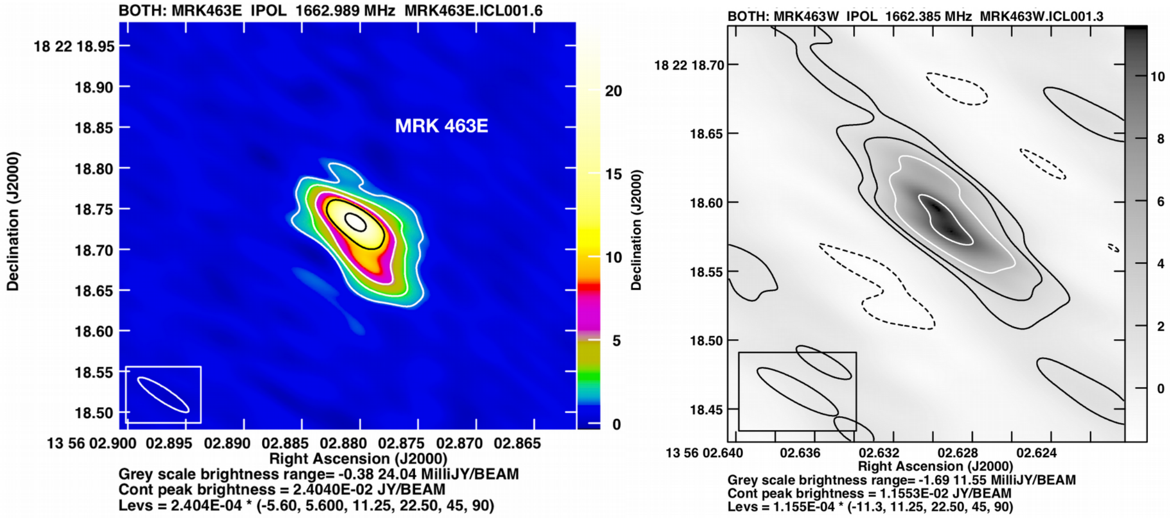

Fig 4 : EVN+Arecibo radio map of MRK463E at 18 cm (left) showing the core-jet structure and the detection of MRK463W (right). The contours shown are at 90, 45, 22.5, 11.25, and -11.25 percent of the peak value.

Future

AO will continue to take part in the VLBI network using the 12-meter telescope available at AO. The current plan is to equip the 12m telescope with a 2.3 to 14 GHz cryogenic receiver and interface the system with the 305-meter telescope's VLBI backend. In addition, efforts have been started for a next generation Arecibo telescope (Roshi et al. 2021), which will be capable of participating in VLBI observations and will provide a factor of 2 improvement in sensitivity compared to the HSA network and increased frequency coverage from 0.2 to 30 GHz.

Acknowledgment

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