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Observing at 1.4 GHz with the Sharjah New 40-m Radio Interferometer

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Abstract

As part of its educational program to introduce radio astronomy in its curriculum, the Sharjah Academy for Astronomy, Space Sciences, and Technology is constructing a 40-m radio interferometer to be used at 1.4 GHz, the frequency of neutral hydrogen emission. The system is made of three SPIDER 500A 5-meter telescopes. To avoid visibility redundancy, the three telescopes were placed at the vertices of a right scalene triangle with distances (sides of a scalene triangle) of 30, 40, and 50 meters. This array will be able to simulate the resolution of a 40-m diameter single-dish antenna, with a collecting area equal to an antenna of 8.7 meters in diameter. The synthesized beam in this configuration measures about 0.36 degrees (21.6 arc minutes). The project started with installing the first SPIDER 500A in mid-2019, and the remaining two by the end of 2019. Radio Observations at 1.4 GHz are essential. We plan to map the overall spiral structure of our galaxy by observing the Hydrogen line emission. It will also be possible to calculate the rotation curve of our galaxy to figure out the relative speed of each arm. With the arcminute resolution, we plan to do extensive surveys of the extended extragalactic radio sources. As part of the SETI program, we plan to use the radio interferometer to search for signals from potential extra-terrestrial civilizations since the 21 cm hydrogen line is considered a favorable frequency for communication. This paper will discuss the construction of the 40-m radio interferometer and the observing program that will be implemented once the array is fully functional.

Keywords: Interferometry; Antennas; Radio Sources; 1.4 GHz; 21 cm Hydrogen Line; Radio telescope.

1. Introduction

The Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST) 40-m radio interferometer is intended to be an educational observatory for teaching radio astronomy as part of the University of Sharjah program in space sciences, and also as a research tool for radio astronomers in the MENA world. Its primary observing frequency is 1.4 GHz (21 cm), the frequency of neutral hydrogen emission. This frequency is not absorbed by Earth's atmosphere, so it can easily pass to be captured by radio telescopes. Since hydrogen is the most abundant element in the universe, observations at 1.4 GHz are essential to start so many small research projects in radio astronomy such as to map the rotation curve of the

Milky Way galaxy, i.e., determine the velocity of the hydrogen clouds that lie along the spirals arm, do extensive radio surveys, calculate the mass of galaxies, study the dynamics of individual galaxies, or to be part of the SETI program. To various degrees, all celestial objects emit at this frequency. In this regard, the SAASST 40-m radio interferometer will be fully exploited to start different research projects.

The project started with the installation of the first SPIDER 500A in mid-2019. The SPIDER 500A is a 5-m dish made by PrimaLuceLab [1]. This 5-m radio telescope has a motorized altitude-azimuth mount that allows the radio dish to move from 0° – 90° in altitude and 0° – 360° in azimuth [2]. Since the radio waves coming from the celestial objects are relatively weak, large antennas are required to collect enough signal to study them, and also sensitive receiving equipment. In this regard, and to our first system, two more SPIDER 500A 5-meter telescopes were added to simulate a 40-m radio interferometer. Interferometry uses the ability to combine the signals from several antennas to simulate a larger one to achieve a greater resolution and with a cost much less than to build a single large antenna. Radio interferometers usually consist of parabolic dishes spread along a straight line, i.e., the One-Mile Telescope [3] or an array of one-dimensional antennas, i.e., the Molonglo Observatory Synthesis Telescope [4], or using a particular setup like the Very Large Array (VLA) where the dishes are spread along three arms in the shape of the letter "Y" [5]. All of the telescopes in a given array are widely separated and connected through either coaxial cable, optical fiber, and in some cases, transmission lines. Overall, the primary purpose is to increase the resolution through aperture synthesis [6]. The principle behinds this technique is to superpose the signals coming from the different telescopes on the basis that the same phase signals will add to each other while opposite phase signals will cancel out. This simulates a large telescope equivalent in resolution, but not in sensitivity to a single antenna whose diameter is equal to the baseline of the system, i.e., the distance of the antennas furthest apart in the array.

For the SAASST 40-m radio interferometer and to avoid visibility redundancy, the three telescopes were placed at the vertices of a right scalene triangle with distances (sides of a scalene triangle) of 30, 40, and 50 meters. This array will be able to simulate the resolution of a 40-m diameter single-dish antenna, with a collecting area equal to an antenna of 8.7 meters in diameter. The synthesized beam in this configuration measures about 0.36 degrees (21.6 arc minutes).

Section 2 of the paper describes the construction of the 40-m radio interferometer and presents some simulations of the array. In Section 3, we present the anticipated observing program. The last section summarizes the paper and gives our final thoughts on the system.

2. Construction

2.1 Setup of the Telescopes

The Sharjah 40-m Radio Interferometer is located at Lat. 25° 17' 05.21" and Long. 55° 27' 50.28", 25 m above sea level. It is the first-ever interferometer in the MENA region. The system was officially inaugurated on June 14, 2020. The interferometer was completed in three main phases: (i) installing the telescope platform, (ii) assembling the first SPIDER 500A radio telescope, and (iii) assembling another two SPIDER 500A radio telescopes.

The three telescopes are placed at distances of 30, 40, and 50 m at the vertices of a scalene right triangle. The interferometer is located on the eastern side of the Sharjah Academy for Astronomy, Space Sciences, and Technology (see Fig. 1) to ensure easy access for maintenance and control. This site showed no significant artificial interference on the digital analyzer at 1420 MHz during pre-testing [3].

Fig. 1. Sharjah 40-m Radio interferometer at Sharjah Academy for Astronomy, Space Sciences, and Technology.

Each SPIDER 500A radio telescope, made by the Italian company PrimaLuceLab, is based on an alt-az configuration that has four primary functional components, the reflector dish, the antenna, the receiver, and the amplifier. Each telescope has an angular resolution of 3 degrees, but when combined to form the three-element interferometer, the angular resolution is about 0.36 degrees at 1.4 GHz. This is adequate enough to detect a large number of galactic and extragalactic sources.

Each 5-m reflector dish (WEB500-5) is made of a fine aluminum mesh to ensure maximum collecting area and stability with minimum weight. The dish is designed with unique rear support to maintain rigidity on the mount, effectiveness of the pointing system, and perfect parabolic shape with a maximum error of less than a twentieth of a wavelength.

One of the vital components of a radio telescope is the feed horn, which transmits the incoming radio waves to the receiver. The SPIDER 500A is equipped with the H-FEED feed horn operating at 1420 MHz. It is designed to minimize side lobes and spillover effects and maximum illumination of the primary reflector, which allows a high gain from the 5-m reflector dish. It is maintained by four-sided rigid support minimizing obstruction and maximum performance. The feed horn consists of two Low Noise Amplifiers (LNA), allowing the reception of dual-polarization.

Each reflector dish sits on a weatherproof computerized mount and is fully steerable around the azimuth (0 to 360 degrees) and elevation (0 to 90 degrees) axes. The rotation around the two axes is remotely controlled by the software RadioUniversePRO.

The WP-400 mount is equipped with an electronic security system that overwrites the user and "parks" the telescope for the antenna to point towards the zenith if the wind exceeds 50 km/h. This position ensures maximum stability. The antenna, along with the mount, stands on a C400-Heavy steel pier, ensuring a concrete foundation.

The H1420-One superheterodyne receiver consists of a double conversion (up/down) and a 50 MHz bandwidth (RF = 1395 – 1445 MHz) 14-bit analog to digital converter. It operates on 1024 channels (each 61 kHz) displayed and processed in real-time by the RadioUniversePRO software. Because of the high gain and low electronic noise of the receiver, radio sources can be observed with a theoretical flow of at least 5 Jy [8].

Each telescope comes with a radio astronomy flux calibrator, ultrasonic wind sensor (RCPU-USWIND) controlled by the RadioUniversePRO software, and an All-sky camera 180-degree lens.

All three receivers are placed in individual cabinets along with the RCPU-400 power units and RCPU-USWIND wind sensor unit in a bunker 3-m underground (see Fig. 2).

Fig. 2. control room underground with all receivers and control units.

The first SPIDER500A was installed on April 25, 2019, followed by the other two telescopes on December 19, 2019. Each telescope took three days to be fully assembled. Each pier was installed on the concrete base using high strength bolts. The reflector dish was assembled on site along with the feed horn and support systems. Once this was completed, the mount was fixed on the pier, and the reflector dish was fixed on the mount. The coaxial cables were then connected from the feed horn to the receivers underground.

All three telescopes were thoroughly tested for mechanical errors and any damage caused by transportation by connecting them to a test software and rotating the telescope 360 degrees along the azimuth and 90 degrees along the elevation. This calibration procedure ensured the cables were correctly connected to the receivers and did not hinder the antenna movement. The mount was aligned along the North for the precise location of sources during observation.

After testing the telescopes, we ran different observations of different radio sources. Figure 3 shows a radio map of the Sun taken by one of SPIDER 500A radio telescopes with a resolution of about 3 degrees.

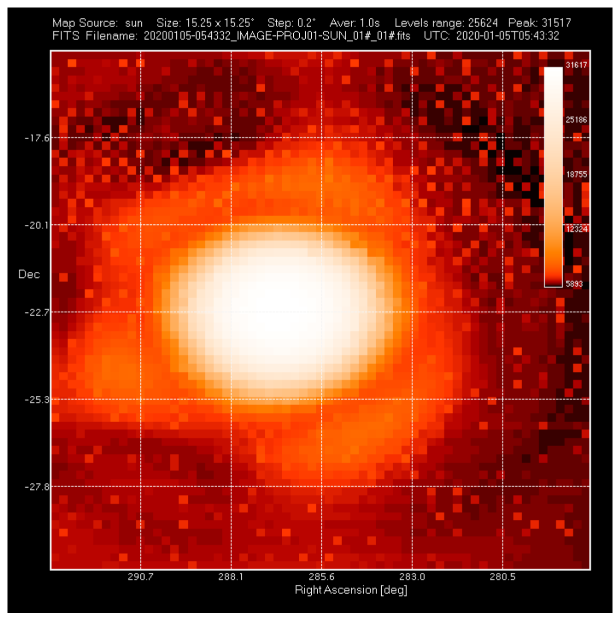

Fig. 3. Radio map of the Sun created on Jan 5, 2020 using SPIDER 500A. The map is 63x63 pixels. The white color represents region of maximum radio emission, the Sun.

2.2 Simulation of Cygnus A

To check on the capabilities of the SAASST 40-m radio interferometer, we ran some simulations based on the National Radio Astronomy Observatory simulation application [9]. The quality of the radio image that any radio interferometer obtains depends on various factors. If the telescopes are well distant from each other, the radio image is sharper. The opposite makes the radio image brighter. To meet our present funding constraint, we only considered in this first phase to install three antennas. More are planned in the future for a larger array. By placing more telescopes, you get more radio signals and hence a better image. The observing time is also a prime factor. For longer observing time, the image becomes better. The arrangement of the different telescopes that make the array is also another essential factor in the quality of the radio image.

To do the simulations, we have chosen the brightest radio source Cygnus A. This source is classified as an FR II radio source [10] and showcases two jets in opposite directions from the galaxy's center [11]. Hotspots mark the end portions of the jets well within the two radio lobes of Cygnus. These hot spots are formed when material from the jets collides with the surrounding intergalactic medium [12].

Figures 4-6 show several simulations of an array of three telescopes in different configurations. The observing time for each configuration was set for one hour, the maximum time allowed by the simulation application.

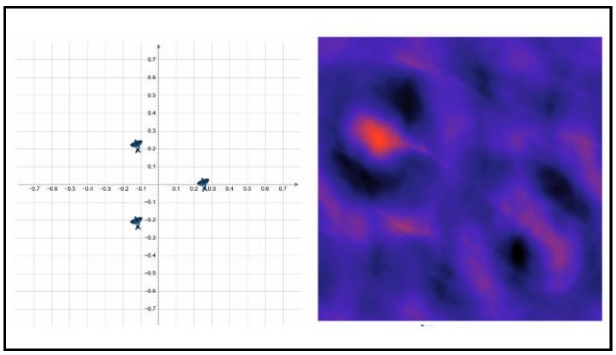

Fig. 4. Medium Circle configuration – The three telescopes are distributed around a circle shape configuration. Each antenna is equally spaced from the center. Both radio lobes are observed along with the jet.

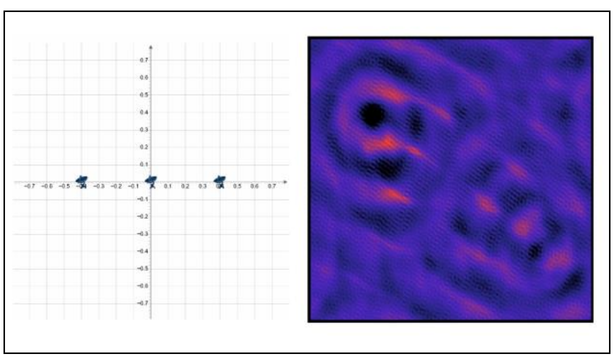

Fig. 5. One-Arm Configuration - The three telescopes are distributed along a one-arm segment. The antennas are equally spaced. The radio image is not as good as in Figure 4. We see the appearance of some radio fringes.

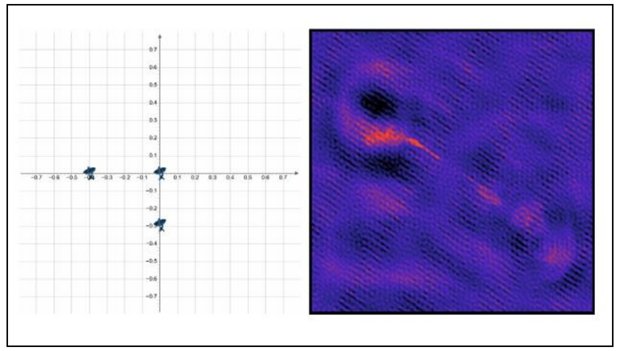

Fig. 6. SAASST Triangle Configuration – The three telescopes are placed at the vertices of a right triangle. The radio image looks much better than in the two previous configurations, even though in Figure 4, the image is smoother.

The simulations show that the triangle configuration gives a good UV coverage of Cygnus A. With calibration, the image can be further cleaned to show the radio lobes and jets in clearer details. The SAASST 40-m radio interferometer has good radio capabilities to observe any radio source in its range.

3. Observation Program

Since hydrogen is the most abundant element in the universe and because of the resulting 21 cm line, radio observations at 1.4 GHz are essential to understand the overall structure of our universe. The SAASST 40-m radio interferometer has an angular resolution of 21.6 arcminutes at this frequency. Hence, this new array will be able to perform 1.4-GHz radio continuum observations of hundreds of extended radio galaxies that are missed by large radio interferometers. We will be able to map the radio morphologies to produce high-quality images that can be used to derive the physical parameters of these sources. We can also obtain the total flux of these extended radio sources. We have already mentioned starting small research projects to map the rotation curve of the Milky Way galaxy to determine the velocity of the hydrogen clouds that lie along the spirals arm. The array can also do extensive radio surveys, calculate the mass of galaxies, study the dynamics of individual galaxies, or to be part of the SETI program. We are starting a program to do an extensive radio survey of all the different objects of our solar system, i.e., the Moon and Jupiter. A list of 72 extended radio sources has been compiled to start our first extensive radio survey using our 40-m radio interferometer. The angular sizes of these sources are between 0.1 to 0.5 degrees. The new array will be able to resolve most of these sources.

4. Conclusions

The 40-m radio interferometer at the Sharjah Academy for Astronomy, Space Sciences, and Technology is a unique system in the MENA world. As discussed above, its simulation of Cygnus A shows good UV coverage. Further development of the system is still underway, as the development of the multi-million channel backend, the interferometer correlator, and the upgrade of the RF cables to fiber optics. This will make the array fully functional to tackle its substantial observing program. Once this is accomplished, there is a plan to add six more antennas to make a more extensive array with a baseline of 400 km. Soon, the array will be linked to worldwide arrays to be part of the Very Long Baseline Interferometry. This SAASST new radio observatory will be a great asset to the new MSc. program in Astronomy and Space Sciences that has been recently launched at the University of Sharjah. Through the "Radio Astronomy" course of the program, students will have all the tools to do research in the radio domain by using the 40-m radio interferometer once fully operational.

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