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# THE POTENTIAL USE OF THE 20-METER RADIO TELESCOPE PLANNED AT THE TIMAU NATIONAL OBSERVATORY

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*Abstract.* The importance of radio telescopes for astronomy, geodesy, and other disciplines has been demonstrated by the growing number of radio telescopes worldwide, including in South-East Asia. Timau National Observatory has also considered a radio telescope development program, which is expected to contribute both on a national and global scale. The diameter for the single dish is planned to be around 20-meter with a frequency range of 1-50 GHz. This paper outlines potential research for the planned radio telescope as a single dish as well as a part of future interferometer/VLBI collaboration. We collected several studies conducted with single antenna with a diameter of around 20-meter as a comparison to study its potential use as a single dish. As it is also essential to consider using an interferometer network, we also examined its capability as a part of VLBI, including the UV coverage and object simulation. Finally, it can be concluded that many studies can be conducted using the 20-m radio telescope as a single dish. Its location slightly below the equator can also play an important role in completing the global VLBI network.

*Key words*: instruments, astronomy, radio telescope.

## 1. INTRODUCTION

Radio telescopes have many essential roles in astronomy as complementary to optical and other wavelength telescopes. They have revealed many unsolved problems in the universe since they were first developed. The research using radio telescopes is growing, and it has given several contributions not only in the astronomical field but also to others, such as geodesy and atmospheric science. Currently, the research collaborations between institutions and countries are growing in terms of radio telescopes, notably for achieving higher angular resolution in the Very Long Baseline Interferometry (VLBI) technique. Several notable discoveries, such as the observation of blackhole shadow (Akiyama *et al.*, 2019) and the estimation of Earth's Orientation Parameters (Ziegler *et al.*, 2020), were successfully obtained through this technique.

VLBI collaboration in East Asian countries is rapidly growing, particularly between Japan with VLBI Exploration Radio Astrometry (VERA), South Korea with Korea VLBI Network (KVN), and China with Tianma and Nanshan antenna (Cui *et al.*, 2019). Meanwhile, there is also potential for collaboration between Southeast Asian countries such as Thailand, Indonesia, and Malaysia, which are currently developing radio telescopes. Indeed, in the near future, Indonesia has plans to construct several radio telescopes with one of them will be placed in Timau National Observatory (9° 35’ 50.2” S, 123° 56’ 48.5” E), East Nusa Tenggara (Mumpuni *et al.*, 2018; Hidayat *et al.*, 2022; Husna & Mumtahana, 2022). With the location around the equator where no VLBI antenna exists so far (Nurul Huda *et al.*, 2021), Indonesia can play an essential role in the future.

Currently, modern astronomy facilities are being established at Timau National Observatory (Mumpuni *et al.*, 2017, 2018). Mount Timau valley (altitude: 1532 m) has been chosen as a suitable observatory site based on its atmospheric condition in terms of clear sky fraction (Hidayat *et al.*, 2012) and radio interference measurements (Hidayat *et al.*, 2014; Sitompul *et al.*, 2021). The construction of the main 3.8-meter Ritchey–Chrétien optical telescope with segmented mirror and Nasmyth foci is ongoing. Several research topics are planned to be done, ranging from space weather, observation of variable stars, exoplanets, galactic and extragalactic star clusters, interstellar matter, the structure and dynamics of galaxies, and cosmological observations (Mumpuni *et al.*, 2018).

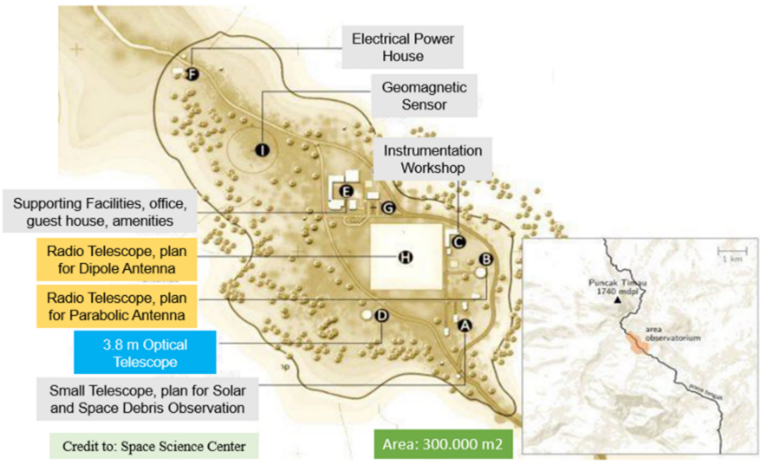


Fig. 1 – The master plan of Timau National Observatory with the number of astronomical facilities for multi-wavelength astronomy and space weather observation (Mumpuni *et al.*, 2017).

In the next step, Timau National Observatory will focus on developing radio telescopes. Two types of radio telescopes have been proposed: a 20-meter class telescope for higher frequency and a dipole interferometer array for lower frequency. In this work, we discuss the details of the future 20-meter class radio telescope at Timau National Observatory. The proposed frequency range for this telescope is between 1–50 GHz. We outline potential research for this future radio telescope as a single dish as well as a part of the VLBI network by collecting several references. We also studied its capability for the VLBI network by simulating the UV coverage and observing artificial objects through several VLBI configurations.

## 2. METHODS

There are two observation techniques mentioned in this work: single dish and interferometry. These two techniques will be used in the future 20-meter radio telescope at Timau National Observatory. Both techniques have their necessity and different purposes for observation. The major difference between both techniques is the angular resolution achievement, which can be described with the diffraction limit equation: $\theta = 1.22\lambda/D$ (Cordon & Ransom, 2016). D represents the diameter (in meters) of the telescope in single dish mode, $\lambda$ is the wavelength in meters, and $\theta$ means the angular resolution in radians. In contrast with the single dish, interferometry combines two or more radio telescopes to achieve better resolution, $\theta$. In this case, D means the longest distance of the antennas (baseline). VLBI is an example of the interferometry technique in radio telescopes. The following two subsections discuss a brief description of single-dish and interferometry modes. In this paper, we use a different approach to study the possibility of future radio telescopes using both techniques.

### 2.1. SINGLE DISH DATA COLLECTION

In the case of the single-dish technique, we prefer to do the literature review in order to understand the advantage of this technique in the future radio telescope. We have collected information from hundreds of radio telescopes worldwide, including the radio telescopes used for interferometer/VLBI. We selected the information by focusing only on the telescopes with a diameter range between 18 and 26 meters. We also restricted the information by limiting the telescopes that can be used in a single-dish mode. The details of this selection method for this literature review can be found in Husna & Mumtahana (2022). By doing these restrictions, we reviewed 11 reference antennas: Onsala 20-m, Onsala 25-m, Simeiz 22-m, HartRAO 26-m, Mopra 22-m, Paul Plishner Radio Astronomy and Space Sciences Center (PPRASSC) 18-m, Australia Telescope Compact Array (ATCA) 22-m, VERA antenna (Iriki, Mizusawa, Ishigakijima, Ogasawara) 20-m, KVN antenna (Ulsan, Yonsei, Jeju) 20-m, Shenshan

*Table 1*

List of antennas and their parameters for VLBI simulation

| Antenna Location | D (m) | Lat (°) | Long (°) | Alt (m) | X (km) | Y (km) | Z (km) |
|---|---|---|---|---|---|---|---|
| Timau | 20 | -9.597 | 123.947 | 1313 | -3512.939 | 5218.509 | -1056.544 |
| Parepare1, 2 | 6.1, 3.5 | -3.978 | 119.650 | 75 | -3147.753 | 5529.81 | -439.483 |
| Biak | 3 | -1.174 | 136.100 | 47 | -4594.923 | 4421.654 | -129.860 |
| Rancabungur1, 2 | 11, 3 | -6.535 | 106.700 | 151 | -1821.127 | 6069.802 | -721.145 |
| Rumpin | 15.4 | -6.371 | 106.631 | 68 | -1814.353 | 6073.869 | -703.138 |
| Jatiluhur1, 2 | 32, 18 | -6.522 | 107.411 | 131 | -1896.320 | 6046.884 | -719.707 |
| Bosscha | 13 | -6.824 | 107.617 | 1280 | -1917.168 | 6033.431 | -753.012 |
| Thailand | 40 | 18.864 | 99.217 | 396 | -967.146 | 5960.431 | -2049.319 |
| Malaysia | 13 | 3.399 | 101.589 | 72 | -1279.077 | 6237.259 | 375.7170 |
| KVN-Seoul | 21 | 37.562 | 126.943 | 121.7 | -3042.616 | 4046.056 | 3867.180 |
| KVN-Ulsan | 21 | 35.542 | 129.251 | 161.4 | -3287.481 | 4023.533 | 3687.030 |
| KVN-Jeju | 21 | 33.288 | 126.461 | 441.3 | -3171.814 | 4292.568 | 3480.879 |
| VERA- Mizusawa | 20 | 39.133 | 141.132 | 75.6 | -3857.244 | 3108.782 | 4003.899 |
| VERA-Iriki | 20 | 31.747 | 130.440 | 541.6 | -3521.719 | 4132.174 | 3336.994 |
| VERA-Ishigakijima | 20 | 24.412 | 124.171 | 222.9 | -3264.08 | 4808.182 | 2619.997 |
| VERA-Ogaswara | 20 | 27.091 | 142.216 | 38.5 | -4490.898 | 4808.056 | 2887.214 |
| Urumqi | 32 | 43.865 | 87.571 | 2080 | 228.310 | 3481.490 | 4367.064 |
| Shanghai | 25 | 31.097 | 121.191 | 100 | -2831686 | -4675.733 | 3275.327 |

25-m, and Nanshan 25-m. Some of them use the receiver within the range of our future radio telescope.

### 2.2. DATA AND SIMULATION METHODS FOR VLBI

In contrast with the single dish mode, we performed some simulations to understand the potential of the radio telescope when using interferometry mode, notably for VLBI. The imaging quality of VLBI highly depends on the density and UV path distribution in the UV plane. The tracks are established by 2-D projections of the various baseline configurations on a plane perpendicular to the source's direction. We use two tools for the simulation: ASL Imager (Zhao *et al.*, 2018) and VNSIM (Likhachev *et al.*, 2020).

As seen on Table 1, 18 antenna locations with various diameters were selected for this simulation. Here we converted the geographic coordinate and altitude of the VLBI antenna to the Earth-Centered, Earth Fixed (ECEF) X-Y-Z values. The first 7 rows on Table 1 show the candidate location of future Indonesian antennas, including

Timau. The antennas at Parepare, Biak, Rancabungur, and Rumpin were simulated since we plan to convert the decommissioned remote sensing satellite in those areas to radio telescopes. The antennas at Jatiluhur are also in the process of the conversion project (Nurul Huda *et al.*, 2021). The configuration and the Bosscha antenna will initiate the national VLBI collaboration. Other antennas listed in Table 1 are located outside Indonesia. Two of those antennas belong to Malaysia and Thailand. Together with Indonesia, they can be used as a representative of the future so-called Southeast Asia VLBI Network (SEAVN). Furthermore, the VLBI antennas joining East Asia VLBI Network (EAVN) are also included in our simulation, i.e., Korean KVN, Japanese VERA, Chinese Urumqi, and Shanghai (Cui *et al.*, 2019).

## 3. POTENTIAL RESEARCH AS A SINGLE DISH

We note that the frequency range of the planned radio telescope is around 1–50 GHz. Therefore, the observation wavelength spans between 0.3 and 0.006 meters. From the equation in section 2, the angular resolution of this 20-m single dish is estimated from 1.25 to 62.90 arcminutes. However, it depends on the future receiver that will be implemented in this radio telescope. From the reference study listed in subsection 2.1, we finally obtain the scientific case overview through a 20-m single dish. We noticed several telescopes used the receiver within the range of our future radio telescope (1–50 GHz).

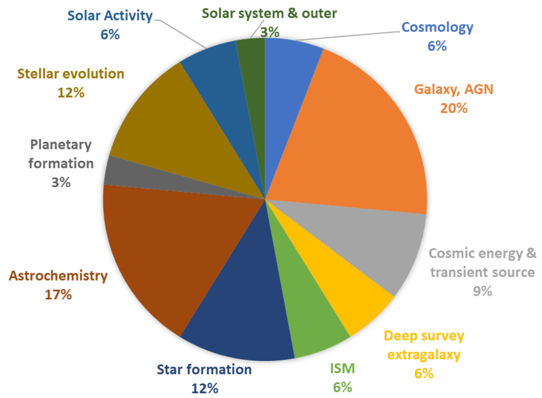


Fig. 2 – Research areas conducted by single dish observation from the chosen 11 telescopes by literature review.

Figure 2 illustrates the research area obtained from the literature study. Many research areas can be done using a 20-meter class telescope ranging from Sun, Solar system, and Planetary formation to Galaxy & Active Galactic Nuclei (AGN) as well as Cosmology. We found that the majority of the references are studies of Galaxy

& AGN (20%), while there is a relatively small percentage for Planetary formation and solar system. The research area with our telescope is not limited to this result, as it only reviewed 11 telescope references with various frequencies. However, we can use this as a benchmark and an overview study of research potential for the future 20-meter class radio telescope working as a single-dish.

#### 4. SIMULATION OF VLBI OBSERVATION

In the first work, here we conduct a VLBI simulation that observes an object called NGC253 (RA 0:47:33.20399, DEC -25:17:17.942) on August 4, 2022, within an observation length of 24 hours and frequency 1420 MHz. We focus on UV coverage since it can determine the quality of the VLBI observational image. Good quality VLBI observation has a dense distribution of UV plots. The simulation was done using four antenna configurations listed in Table 1.

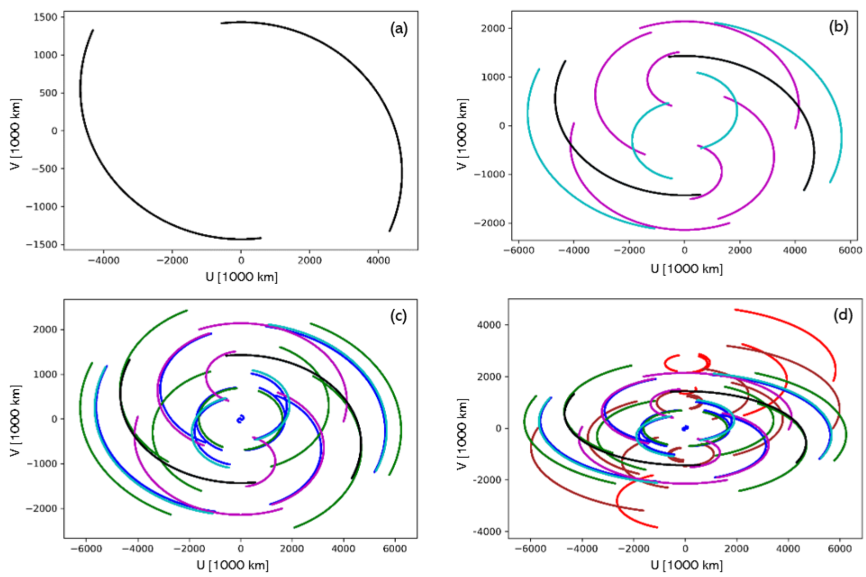


Fig. 3 – The expected UV-coverage (1000 km) from 24 hours observation for the source in the declination -25◦. Each panel shows UV coverage for several antennas combinations: (a) Timau + Parepare, (b) Timau + Parepare + Rancabungur + Rumpin, (c) Timau + Parepare + Rancabungur + Rumpin + Bosscha + Jatiluhur, (d) All Indonesian antennas + Malaysia + Thailand.

Figure 3 shows the result of the UV coverage simulation. The different colored lines represents the antenna configuration. It is clearly shown that more antennas give better UV coverage. The first configuration (Figure 3-a) has bad UV coverage since we only use two antennas (Timau and Parepare). The UV coverage is improved if we add other Indonesian antennas consisting of Rancabungur, Rumpin, Jatiluhur, and Bosscha in the simulation (see Figures 3-b and 3-c). As shown in Figure 3-d, the improvement would be much better if Malaysia and Thailand participated in the observation.

Next, we did the simulation for an artificial point source object located in RA: 23h6m1s and DEC: 8d37m15s. We used two configurations. In the first configuration, we only consider EAVN antennas in the simulation (Figure 4 left). Then we combine EAVN with all Indonesian antennas, including the future antenna in Timau, for our second configuration (Figure 4 right). The top panel of Figure 4 shows the expected UV coverage (1000 km) from 24 hours of observation. EAVN antennas are depicted in a blue line, while additional Indonesian antennas are illustrated with a red line.

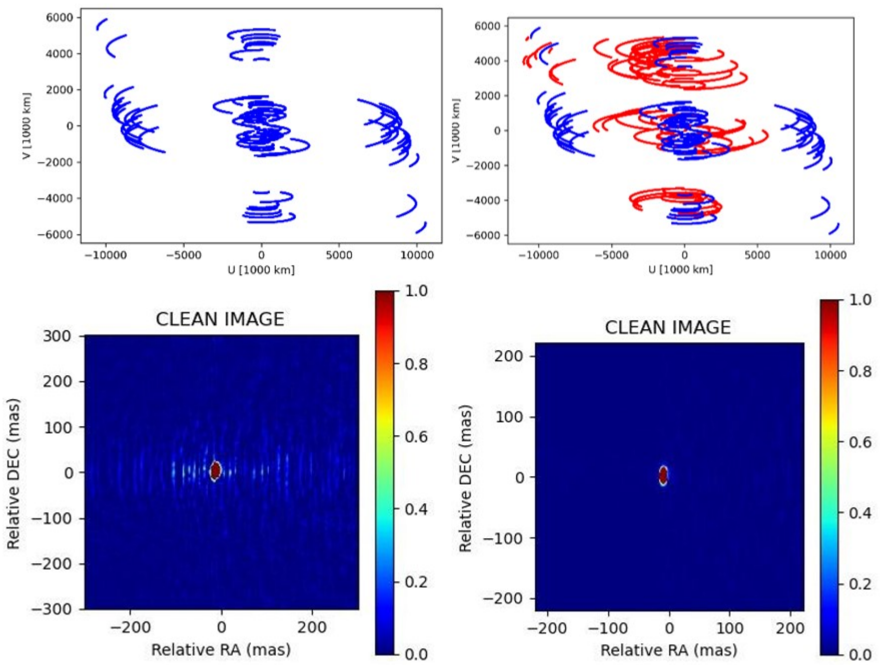


Fig. 4 – Top panel: Results on UV coverage simulation using EAVN with a blue line (left) and EAVN + Indonesian antennas with a red line (right). Bottom panel: Results on point source simulation from each configuration above.

As shown in Figure 4 bottom panel, Indonesian antennas have a vital role in producing better observation images. It is quite understandable since the UV coverage improves by including Indonesian antennas in the observation.

## 5. DISCUSSION AND SUMMARY

The future 20-m radio telescope in Timau National Observatory will be the first modern medium-large size radio telescope built in Indonesia. Indeed, there are several prominent scientific motivations for interdisciplinary fields, such as capacity building, global cooperation, unique scientific observation, as well as the opportunity for education and training. Besides scientific research such as astronomy, geodesy, and atmospheric science, the radio telescope development program can naturally enhance skills, experiences, and technology. Collaboration is important from the initial process, such as design and product, construction, component detailing, and characterization. Once the instrument is set up and does its first light, global cooperation will certainly await to achieve many research goals.

In this study, we have some insight into what kind of research can be conducted with a 20-meter antenna dish at 1-50 GHz frequency. The potential use as a single dish from the literature review proposed several research themes from the solar system to cosmology. Further research will compromise with the selection of the receiver system. Nevertheless, this study is expected to be the guideline for formulating the key science program of the proposed radio telescope. Meanwhile, the important role of the future radio telescope as the VLBI antenna was clearly seen in the result. By adding the Indonesian antennas, better results can be achieved. Our antenna location will be of the greatest interest due to the lack of stations near the equatorial region.

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