# ON A POSSIBLE FUTURE NATIONAL RADIO ASTRONOMY FACILITY

*INTERIM DRAFT REPORT*
*April 2015*

## EXECUTIVE SUMMARY

The executive summary will be written for the final report, it would be premature to draft it in the interim report. It will summarize our main recommendations.

It will state that a responsible approach implies the preliminary growth of the community of potential users and it will define a first phase during which this task will be the first priority. The support given to it by our authorities will be determinant in defining the scope of the second phase. In this context, the executive summary will underline the importance of giving the Vietnamese research community adequate support to have access to frontline international facilities.

It will sketch the main steps of the second phase, starting with the precise definition of the proposed facility and will summarize the main arguments used to this aim: ability to federate and train the user community and foster its growth; ability to perform excellent research that can strengthen the position of the country on the international scene; ability to accelerate the development and progress of high tech industry and R&D.

It will show how astrophysics is today the most dynamic branch of natural sciences, gathering scientists from many other fields at the frontline of fundamental research, such as nuclear physics, particle physics, plasma physics, chemistry, photonics, life sciences and many others. It will give evidence for the need for Vietnamese science policy to select it among the few domains of modern science that it must develop in priority for Vietnamese science and technology to take off on the international scene.

It will present our evaluation of the required time and resources, financial and human; the figures quoted in the present interim report are only crude indications and will have to rest on significantly more solid bases in the final report.

It will underline the importance of the regional context and of seeking advice and support from foreign scientists having experience as well as informed and educated views on these issues. The astrophysics communities in the region, in particular in Korea, Japan and Taiwan, have explicitly expressed their support for the progress of astrophysics in Vietnam and offered their help to plead the case with our authorities. An international advisory committee should be set up to help, support and monitor such progress.

It will underline the fact that it addresses the VNSC directorate in answer to a request of theirs, asking for a study of the acquisition by Viet Nam of a possible national radio astronomy facility. In this context, it will not explicitly address the strategy that should be used to convince higher authorities of the soundness of such an initiative, but be satisfied with general statements of common sense, such as the importance of sparing the feelings of the scientific Vietnamese community by insisting on the spirit of partnership that should associate universities to the project and the spirit of service that would be implied by the centralization of resources and coordination in an environment that brings together science and technology.

It will take in due account the reactions that the present interim report will receive from the VNSC management. The present version has been shown to astronomers, both abroad and in Viet Nam, and takes their comments in proper account. In this context, the final report will explicitly comment on the importance of outreach in making astronomy popular in the public, at the same time as it will make a clear separation between outreach activities, resting in priority on TV programmes of quality, planetariums, science exhibitions and events, small optical telescopes, etc… and frontline research, explicitly addressed in the report.

# 1. GENERAL CONSIDERATIONS

In the general context of the creation of a Space Centre in Hoa Lac, near Ha Noi, the Department of Astrophysics (DAP) of the Viet Nam National Satellite Centre (VNSC) was asked to study possible radio telescope installations that Viet Nam might wish to acquire in the near future. Such a study being unconstrained by strict boundaries, a preliminary task is to spell out a number of arguments of general relevance. A first issue to be considered is to define which community such an installation is meant to serve and which tasks it is expected to achieve. A second issue to be addressed is to position such an installation in the national, regional and international contexts. A third issue must deal with the amount of resources that are required to acquire, operate, maintain and exploit the installation. The present introduction states some general considerations of relevance to these issues.

## *1.1 Astrophysics today*

While astrophysics is today the most dynamic field of physics, with three major fundamental unanswered questions at its core (dark energy, dark matter and inflation), it is almost absent from the research landscape of Viet Nam and embryonic in the cursus of its universities. The determination of the Government to make Viet Nam access a high position in the field of space science and technology is an incentive for devoting a major effort to develop astrophysics in the country in all its branches, theoretical, observational and instrumental and at all levels, academic, research and engineering. Modern frontline research in astrophysics is done using major installations, either ground based or aboard satellites, allowing for the exploration of the electromagnetic spectrum from radio to hard gamma ray wavelengths with high sensitivity and excellent resolutions, both spatial and spectral. The important resources involved in the construction of such installations have required collaborations between several countries, and the instruments are exploited on an international scale. Research in astrophysics is therefore requiring, in priority, resources allowing the community to propose observations and access data collected by such international installations and to take part in their analysis within international scientific collaborations.

## *1.2 Why a national facility?*

The acquisition of a national facility, while of lower priority, could however play an important role in the development of the field as a training ground for Vietnamese astrophysicists to become familiar with the techniques and methods used in the larger international installations. What is precisely meant by training ground depends on which community is being targeted. On one extreme, one can think of facilities accessible to undergraduate and graduate students at universities, which can be used for lab work and for observations that can produce graduate dissertations and master theses. The VNSC radio telescope, which is presently installed on top of the building of the University of Science and Technology of Ha Noi (USTH) and used for training its students, is such an example. On the other extreme, one can think of a single dish radio telescope, such as those operated by China, South Korea and Japan, incorporated within a very long baseline interferometer network and giving access to quality research at international level. In the first case, the aim is to attract young students to the field of space science and technology at an early stage; in the second case, it is to ease the gathering of a national research community around a tool that could bring prestige to the country and give a boost to its progress.

### *1.3 Why radio rather than optical?*

Such a training facility must be ground based for obvious reasons of convenience. Moreover, the very humid tropical climate of the country excludes optical telescopes: data from the meteorological stations of major Vietnamese airports show that the yearly average duty cycle of such instruments could not exceed 10% and would never allow for observations of sufficient quality for doing serious research. This fact has been recognised long ago and has been used to make a strong case for the development of radio astronomy in Viet Nam by Professor Nguyen Quang Rieu, the founding father of the field in the country. Indeed radio waves are essentially unaffected by attenuation in the atmosphere up to 10 or so GHz, above which the attenuation in water and air increases and requires millimetre and submillimetre installations to be operated at high altitudes. These general considerations limit therefore the scope of our investigation to radio astronomy installations operated above 1 cm wavelength or so (30 GHz) in spite of the scientific advantage of reaching smaller wave lengths where standard molecular lines emit. Some observations might still be done up to nearly 100 GHz (3 mm) when weather permits. Avoiding electromagnetic pollution pleads for remote locations, while efficiency to serve training pleads for proximity to universities and to the Hoa Lac Space Centre.

### *1.4 The main challenge: the workforce*

An important argument to take into proper account is the demand of the installation in terms of running budget and of the staff required for its proper operation and maintenance. The investment necessary for the acquisition of a scientific instrument is only part of the resources that need to be devoted to it over the years for a responsible and successful exploitation. It is not just a question of money, but also, may be mainly, a matter of competence. Examples of scientific facilities that are underused, or even unused, by lack of competent staff for their maintenance, operation and exploitation abound everywhere, in Viet Nam as much as abroad. Currently, the community of radio astrophysicists active in the country does not exceed 10 PhDs, concentrated around three nuclei: Professor Dinh Van Trung at Ha Noi’s Institute of Physics (VAST), Professor Phan Bao Ngoc at TPHCM International University and the VNSC Department of Astrophysics. All are implied in research using international facilities operated abroad on an international scale. Today, diverting a significant fraction of this workforce to the exploitation of a national facility is unrealistic. This illustrates how seriously the issue of properly staffing the proposed installation will have to be addressed, together with the issue of securing for it a large enough user community. It will be the main factor of relevance to the timing and scope of the project. From this point of view, VNSC offers an ideal framework for its management, concentrating in a same place both scientific and engineering competence.

## 2. THE ASEAN AND EAST ASIAN CONTEXT

Four countries, China, Japan, South Korea and Taiwan, stand out as operating (on their territories for the first three) installations of international standard. Of the other countries, Thailand is the most advanced while Indonesia and Malaysia are at a level comparable with Viet Nam. We briefly review the situation in each of these countries.

### *2.1 China*

Chinese astronomy is organised around the National Astronomy Observatories of China (NAOC), founded in 2001 in the wake of the reorganization of the Institutes of the Chinese Academy of Sciences, with a scientific staff of 950 full timers, of which 220 researchers-teachers training 190 PhD students and 240 master students. NAOC runs three major observatories and coordinates the scientific and training policies of the other Chinese observatories. They are part of many collaborations, in particular with the US, Argentina, Germany and France. They are particularly present on the radio astronomy scene with a large number of antennas and arrays operated in the centimetre to metre range, some of which are organised in a national very long baseline network and two of which are also part of the European Very Long Baseline Network. The highest frequency antenna is operated at 3 mm wavelength at Delingha (3200 m altitude). In addition to the installations listed below, a number of ambitious projects are contemplated, among which an 80 m radio telescope operated at 22 GHz (13 mm) for the 2020's and a space interferometer including two 10 m diameter antennas operated between 6 and 46 GHz (6.5 to 50 mm), for 2020.

The main science programs cover traditional decimetre astronomy, including lunar exploration, Galactic surveys, pulsar observations, SNR searches, etc. The CSRH studies solar activity and solar flares, while Delingha concentrates on molecular lines. The antennas included in very long baseline arrays are also implied in geodesic studies.

| *Name* | *diam (m)* | *wl (mm)* | *# ant* | *alt* | *start* | *VLBI* |
|---|---|---|---|---|---|---|
| *Nanshan* | *25* | *13-180* | *1* | *2080* | *1994* | *China, EAVN* |
| *Miyun MRT* | *50* | *36-500* | *1* | *155* | *2006* | *China* |
| *Miyun MSRT* | *9* | *1300* | *28* | *155* | *1985* | |
| *Sheshan* | *25* | *13-180* | *1* | *5* | *1987* | *China, EAVN* |
| *Sheshan Tianma* | *65* | *6-210* | *1* | *5* | *2009* | |
| *Kunming* | *40* | *33-140* | *1* | *1985* | *2006* | *China* |
| *FAST* | *500* | *100-4300* | *1* | *1000* | *>2016* | |
| *21CMA Ulastai* | *2m long* | *210* | *10287* | *2500* | *2007* | |
| *Delingha* | *13.7* | *3* | *1* | *3200* | *1999* | |
| *QTT Qintai* | *110* | *2.5-1000* | *1* | *2000* | *2017* | |
| *CSRH Heliograph* | *4.5* | *150-750* | *40* | *1365* | *2010* | |
| | *2* | *20-150* | *60* | | *2013* | |

## *2.2 Japan*

Japanese astronomy is organized under the National Astronomical Observatory of Japan (NAOJ), which was established in 1988 by uniting three former observatories. In addition to 200 contract staffs supporting each individual campus, NAOJ has a staff of 260, including over 160 teachers and researchers; it trains ~70 PhD and master students and hosts ~35 postdoc fellows. It operates a major radio astronomy installation in Nobeyama, and a four-antenna millimetre wave very long baseline interferometer, VERA. Nobeyama hosts a 45 m diameter antenna for galaxy studies and a solar observatory equipped with radioheliographs and polarimeters. VERA uses a dual-beam technique to correct for atmospheric turbulences and achieves record precision in astrometry from masers in the Galaxy. Recently, NAOJ started operation on the ALMA site of a sub-millimetre 10 m antenna, ASTE, in collaboration with Chile and Japanese universities.

Together with NAOJ, Japan operates the Japanese VLBI Network (JVN), a collaborative project of universities and institutes, which includes six antennas in addition to the VERA antennas with diameters between 11 and 64 m operated at centimetre wavelengths. They study protostellar disks and outflows, AGN jets, etc.

Japan joined ALMA in 2004 and committed to building 16 dishes in the centre of the array. NAOJ hosts the East Asia ALMA regional centre.

| *Name* | *diam (m)* | *wl (mm)* | *# ant* | *alt* | *start* | *VLBI* |
|---|---|---|---|---|---|---|
| *VERA (Mizusawa, Iriki, Ogasawara, Ishigaki)* | *20* | *7-150* | *4* | *2-beam* | *2003* | *KaVA, EAVN* |
| *Usuda, Kashima, Tsukuba, Tomakomai, Gifu, Yamaguchi* | *64, 34, 32, 11, 11, 32* | *14-45* | *6* | *low* | *2005* | *JVN (with VERA), EAVN* |
| *Nobeyama* | *45* | *2-15* | *1* | | *1985* | |
| *Radioheliograph* | *0.8* | *17* | *84* | *1350* | *1992* | |
| *Polarimeter* | | *32-300* | *8* | | *1994* | |
| *ASTE* | *10* | *0.4-1.1* | *1* | *4800* | *2012* | |

## *2.3 South Korea*

Radio astronomy in South Korea started to rapidly develop since the construction of the first 13.7 m radio telescope (TRAO) in 1986. Since 1974, Korean astronomy is organized under the Korean Astronomy and Space Science Institute (KASI). In addition to TRAO, it operates three 21 m antennas forming the Korean VLBI Network (KVN, longest baseline of ~500 km), alone in the world to work at millimetre wavelengths. TRAO is operated as a single dish but can also be part of the KVN. KVN uses an innovative multi-channel quasi-optical beam transportation system, allowing for simultaneous observation at four frequencies.

KVN research includes the formation and death of stars (water, SiO and methanol masers), the structure and dynamics of the Galaxy, AGN studies, spectral and temporal properties of transient sources (bursting SFRs, γ-ray flaring AGNs, variable compact radio sources, etc.). Observations are remotely conducted at the KVN Array Operation Centre in KASI but single dish observations can also be conducted at each radio observatory.

In 2010, KVN and the Japanese VLBI network (VERA) joined to form KaVA with a longest baseline of 2300 km. KVN, together with Japan and China, form the East Asian VLBI Network (EAVN) with 19 antennas at 22 GHz (14 mm) or 9 antennas at 43 GHz (7 mm). In 2014, KASI joined ALMA and became one of the three East Asia Regional Centres (ARC) together with Japan and Taiwan.

KASI Radio Astronomy Division counts five research groups totalling 65 staff (21 in radio astronomy research group, 11 in TRAO group, 21 in KVN group, 8 in radio technology development and 4 for the ALMA node). The Korea Astronomy Society counts ~700 members of which half attend annual meetings. This includes ~100 faculty members from universities and ~100 from KASI, with some 250 graduate students.

| *Name* | *diam (m)* | *wl (mm)* | *# ant* | *alt* | *start* | *VLBI* |
|---|---|---|---|---|---|---|
| *Yonsei/Seoul* | | | *1* | *260* | | |
| *Ulsan* | *21* | *2.3-13.6* | *1* | *120* | *2008* | *KVN, KaVA,EAVN* |
| *Jeju/Tamna* | | | *1* | *320* | | |
| *TRAO/Daejeon* | *13.7* | *2-3* | *1* | *110* | *1986* | |

## *2.4 Taiwan*

While having no installation of its own in the country, Taiwan is an important actor of radio astronomy research in East Asia. The community includes some 60 scientists and 10 engineers and technical staff. They are organized under ASIAA (Academia Sinica Institute of Astronomy & Astrophysics). They collaborate with western teams and contribute both financially and technically to the projects in which they take part, taking advantage of their expertise in electronics. They operate the Sub-Millimetre Array (SMA) in collaboration with the Smithsonian (SAO/Cambridge) on Mauna Kea (Hawaii), an array of eight 6 m diameter antennas tuned between 230 and 690 GHz (0.4-1.3 mm). The science is at the frontline of contemporary astrophysics, including observations of galaxies, nearby or remote, the study of star formation and of evolved stars, observations of the early Universe, exoplanets, etc.

They built and operate near the SMA a very compact assembly (6 m diameter) of millimetre wave detectors, AMiBA, aimed at the study of the CMB anisotropy and of galaxy clusters.

They plan to install in Greenland a prototype ALMA antenna given to them by the US to be part of a three node VLBI network at mm wavelength aimed at the study of super massive black holes. This antenna could be operated at 0.3 mm wavelength in single dish mode. Taiwan joined ALMA-Japan in 2005 and ALMA-North America in 2007.

<table>
<tr><th>Name</th><th>diam (m)</th><th>wl (mm)</th><th># ant</th><th>alt</th><th>start</th><th>VLBI</th></tr>
<tr><td>SMA/Mauna Kea</td><td>6</td><td>0.4-1.3</td><td>8</td><td>4200</td><td>2003</td><td>SubmmVLBI</td></tr>
<tr><td rowspan="2">AMiBA 7 & 13<br>Mauna Loa</td><td>0.6</td><td rowspan="2">3-3.5</td><td>7</td><td rowspan="2">3400</td><td>2006</td><td></td></tr>
<tr><td>1.2</td><td>13</td><td>2009</td><td></td></tr>
<tr><td>GLT/Greenland</td><td>12</td><td>0.3-1.3</td><td>1</td><td>3200</td><td>2017</td><td>SubmmVLBI</td></tr>
</table>

## *2.5 Other countries*

*Thailand*. In 2004, the foundation of the National Astronomy Research Institute of Thailand (NARIT) marked the determination of the country to become an important actor of astronomy and astrophysics research in South-east Asia. Their first priority has been to create the Thai National Observatory equipped with a 2.4 m optical telescope at 2450 m altitude, which is in a transition period from commissioning new instruments to start real observations and has not produced any publication yet (other than instrumental). The weather conditions allow for observing during at least part of the night about 3 nights out of 4. Their science group counts seven scientists who publish work done in collaboration with foreign teams using international facilities. While having ambitious projects for the future and investing important resources to develop astronomy and astrophysics not only in the country but also in the region, modern Thai astronomy and astrophysics research has not yet really taken off. In radio astronomy they have constructed a 3 m diameter dish tuned on the HI line but not steerable. The Thai Radio Astronomer Research network counts 10 members of which 5 are active. They are currently constructing a 4.5 m radio telescope that will be operated from decimetre to centimetre wavelengths. On the long term, they have plans for a very long baseline interferometer of three 20 m diameter dishes operated up to 100 GHz (3 mm) when weather permits.

*Indonesia*. Astronomy in Indonesia is concentrated in the Bosscha observatory (Bandung). Radio astronomy facilities include a 2.3 m diameter radio telescope tuned on the HI line, 6 antennas (JOVE receivers) detecting Jupiter and solar bursts at 20 MHz, a solar radio telescope (Callisto, 45 to 870 MHz) and three dipole arrays for interferometry.

*Malaysia*. The University of Malaya in Kuala Lumpur hosts a team of 16 radio astronomers working in collaboration with foreign teams. They operate a 2.4 m diameter dish tuned on the

HI line. They own a 7 m dish, which they have not commissioned yet and have plans for a 20 m dish to be operational in 2017.

### *2.6 Summary*

Four countries, China, Japan, Korea and Taiwan, operate installations of international standard and host large research and academic communities organized under national institutions. Taiwan, mostly because of its specific historical situation, is an exception in the sense that it does not operate installations at home but collaborates instead with western communities and invests in international facilities abroad. In that sense, China, Japan and Korea are better models for what Viet Nam could hope to become in the future. With NAOC, NAOJ and KASI, they have centralized the management of their science, human and financial resources, in the hands of strong national organizations keeping close contacts with universities at home as well as with international institutions and organizations with which they set up collaboration agreements. They enjoy sufficient wealth and competence to contribute important elements to such international collaborations, such as ALMA antennas, state of the art correlators, sub-millimetre receivers, etc. At home, they focus either on specialized instruments, such as lunar exploration in China, the solar observatory in Nobeyama or the Ulastai 21 cm array, or develop networks of antennas that can be used in very large baseline networks both at home and in collaboration with other countries. The recent foundation of the East Asian Observatory and the East Asia Very long baseline Network, bringing together China, Korea and Japan, are emblematic of this effort. They pay much attention to exclusively support competitive instruments at home, while devoting important resources to invest in international facilities, such as ALMA or Mauna Kea, which attract the majority of their research staff.

At variance with the above countries, other South-east and East Asian countries have not yet developed a significant research community in radio astronomy. Two of these, Thailand and Indonesia, host observatories equipped with optical telescopes largely dedicated to the training of undergraduate and graduate students. In radio astronomy, they are all at a level comparable with that of Viet Nam, with a national research community not exceeding a dozen members and no other instrument than small radio telescopes similar to ours. Thailand, however, stands out as having ambitions well above the others, with NARIT established as a powerful federating organization having a clearly stated determination to develop rapidly and spending significant resources to this aim.

## 3. IMPLICATIONS FOR VIET NAM

The present section is an attempt to learn from the experience of others, as reported above, in order to conceive a possible scenario that takes in proper consideration the specificity of the Vietnamese situation.

### *3.1 The time scale*

In order to evaluate how much resources and time are required to progress, it is useful to fix a milestone that can be used as a reference. We take as such a milestone the installation in Viet Nam of a 20 m diameter single dish telescope, operated between 5 and 30 GHz, which could be used in the EAVN network. This choice is somewhat arbitrary and does not at all commit the future: it is just a reasonable hypothesis used as an exercise aimed at considering a concrete scenario. In particular, it would be premature at this stage to discard an antenna operated at longer wavelengths, such as the Indian GMRT interferometer, but the ability to be part of a larger network will most likely be retained as an asset. An important remark is the possibility to use this kind of antennas for satellite communication, which usually leaves significant free time for other users.

A first issue to consider is the time it would take to the user community to be able to reach such a milestone successfully. A good comparison is with South Korea when it started construction of its first 14 m radio telescope (TRAO) in 1986. Since 1974, it had organized its astronomy community centrally under KASI (then called Korean National Astronomical Observatory, KNAO). At that time there were less than 60 members in the Korean astronomical society, about half of them active, of whom no radio astronomer. Up to 1986, the only national facility was a 60 cm diameter optical telescope. In 1986, the active members were less than hundred and when the TRAO project started, there was a single radio astronomer in the country, who had just obtained his PhD in the US. With TRAO, the number of radio astronomers trained at home increased quickly and soon exceeded the number of those who had got their PhD abroad and had returned to Korea. KNAO did support universities to promote radio astronomy but most Korean radio astronomers today are KASI staff members. An important factor of success has been the close collaboration with Korean industry, which was at that time in a state of development more advanced than the present Vietnamese electronics industry. From this point of view, an asset of the national facility project will be to give a boost to the electronics and radio industry in Viet Nam: radio antennas are basic elements in satellite communication and their inclusion in a very long base line interferometer network provides invaluable high tech experience. This implies that a major effort must be made to foster progress in such high-tech domains at both R&D and industrial levels in the country.

Learning from the Korean model, we should then aim at starting operation of the national radio telescope in 2025. Ten years are left to reach this goal. By then the community of active astrophysicists and engineers should have increased to fifty or so, large enough to include a small team of scientists and technicians to maintain and operate the telescope and organize and coordinate the user community and training activities. To obey such a tight schedule, steps need to be taken urgently, in particular defining clearly the scope of the project and making it known, as well as declaring the strong determination of relevant authorities to support it with adequate financial and human resources.

### *3.2 Making workforce and skills grow*

In order to reach the target of 2025, actions must be undertaken right away to let workforce and skills grow fast enough. The existence of VNSC/VAST, soon to become the Space Centre, is very fortunate in this respect as it provides a natural framework in which to manage such growth and centralize resources and coordination in an environment that brings together science and technology.

At the same time as one needs to help the growth of the three existing nuclei (TPHCM International University, Ha Noi IOP and DAP/VNSC), one also needs to attract students from universities across the country to space science and technology. The rate at which the three existing nuclei can grow is modest, typically they may at best double their size every five years or so. Today, the TPHCM and IOP nuclei do not host large teams and the students they train usually leave after having obtained their degree.

A necessary preliminary to attract young students, and possibly encourage Vietnamese astronomers working abroad to return to the country, is to advertise a project documented with a serious and realistic plan, giving confidence in its reliability and the seriousness of the time table.

Far from including exclusively astrophysicists, the necessary workforce will need a strong participation of technicians and engineers having the ability to maintain and operate a large radio telescope, but also to contribute state of the art components to international facilities in which the Vietnamese astrophysics community takes part. In this respect, the involvement of VNSC will be a precious asset.

Proper training of both the scientific and technical workforce will be greatly helped by encouraging short stays abroad, typically 6 months to 1 year, in teams having experience with the construction, maintenance, operation and exploitation of radio telescopes. The contacts which we are maintaining with KASI, NAOJ, ASIAA and NAOC make us confident that Vietnamese scientists, engineers and technicians would be welcome in such teams.

On a short term, the main actions to be undertaken in priority can therefore be summarized as follows:

- centralize resources and coordination at VNSC;
- establish close links with universities in a spirit of partnership;
- encourage the three existing nuclei to grow in size and competence;
- draw a clear and realistic plan of the project and advertise it properly;
- develop skills in radio detection techniques in the GHz to 100 GHz range.

### *3.3 Consolidating the presence of Vietnamese astrophysics research on the international scene*

As was said earlier, it would be unrealistic to think that the present Vietnamese astrophysics community could devote full time to the project. Not only unrealistic but also not desirable. The primary aim is not to acquire a national facility, but to conduct a research of quality having its place on the international scene. In this sense, the national facility is a means to achieve this goal as efficiently and rapidly as possible. At the same time as steps are taken toward the national facility project, sustainable effort is therefore mandatory to help the community progress in the quality of its research. In particular, access to data collected using international facilities on the frontline of today's radio astronomy research, such as ALMA, must be supported. Participation of Viet Nam in international organizations such as the International Astronomical Union (IAU) must be secured. Participation of the members of our community to attend conferences and schools must be given proper financial support. We must keep in mind that we better have a successful research community without national facility than the contrary. Yet, there is no doubt that having a national facility is a major asset and the case for it is obviously very strong. The point that we wish to make here is that it should not absorb the totality of the resources made available to astrophysics in the country. For it to succeed, it must be accompanied by a strong support to the progress of the community in general terms.

For what concerns the Department of Astrophysics of VNSC, our current main lines of research are the study of evolved stars, in collaboration with Observatoire de Paris, which will be pursued for two to three years at least, and the study of remote galaxies using ALMA observations, for which we are currently seeking Asian collaborators. In addition, we are also contemplating to use FAST, the giant radio antenna in construction in nearby China, in particular to study millisecond pulsars and/or evolved stars. Toward the end of 2016, it will be the biggest single-dish radio telescope in the world and will allow open access to scientists worldwide, which could present an excellent opportunity for Vietnamese astronomers to carry out world-class research using state-of-art facilities.

### *3.4 Sketch of a possible scenario*

At that point, on the basis of the preceding considerations, we may already attempt to draw a possible scenario.

A recruitment plan must very soon be drawn up to account for the required increase of the workforce at research institutions as well as universities and for scientists as well as engineers and technicians.

A first phase, of say three years or so, should be devoted to get prepared. A priority is to have a clear plan, have its main lines accepted in terms of time table and funding, have it broadly advertised. Contacts should be established with universities to make them aware of the project and encourage them to contribute as partners. Their involvement could be strengthened by VNSC supporting and coordinating the exploitation of small radio telescopes of the SRT type (see Appendix 1) in a small number of universities across the country, say half a dozen or so. The budget for such an initiative would be at the level of 60’000 USD or so over 3 years. The performance of such radio telescopes as training tools is remarkable and offers excellent opportunities for students to become familiar with the techniques and methods of radio astronomy. While giving access to detailed studies of strong radio sources, such as the Sun in the continuum or the disk of the Milky Way on the 21 cm line, their ability to detect sources of lesser strength is limited to a very few, such as the Moon, Cygnus X or the Crab. The VNSC SRT has produced two master theses and seven publications, of which two in international journals and five in Communications in Physics/Viet Nam. Its proper exploitation requires care and attention, however; while some SRTs, in particular in the US, have been used with remarkable success, others, both in developed and developing countries, have remained essentially unused by lack of competent staff for their operation and maintenance.

The nature of the instrument to be selected as national facility should be debated during this preparation phase, a decision being taken at the end of the three years. Too early a decision is not desirable: the landscape evolves rapidly and the risk to have a national facility that has become obsolete when it starts operation is not negligible. Examples of such events are common.

At the end of the first phase, a team dedicated to the construction and installation of the national facility should be set up and given six months or so to write down the specifications, the time table and the budget. At that time, the progress achieved during the first three years in enlarging the workforce, both in size and in skills, will be evaluated and the realism of the proposed time table properly assessed. If the growth has been faster than anticipated, a faster time table could be envisioned. Indeed, as soon as the staff necessary for the installation, maintenance, operation and exploitation of the telescope is sufficiently large and competent, its acquisition can proceed rapidly, say in two years or so to get it working. The workforce is, by far, the determinant factor that decides on the time table. On the contrary, if the progress has been slower than anticipated in the first three year phase, one would need to learn lessons from it and set as a priority the enforcement of more energetic actions.

### *3.5 Required resources*

We may at this stage attempt to guess how much resources, financial and human, will be required to cover the plan in the first ten years, with the telescope starting operation at the end of the period.

While it is true that the national facility requires the growth of the community, both in size and in skills, to make sense, the main goal is to increase the workforce and its skills, not to acquire a national facility, and it would be wrong to assign the resources necessary to increase the size and skills of the community to the budget of the national facility. The rationale is: priority 1 is to develop the astrophysics community in the country, which has its cost; priority 2 is, once this is secured, acquire a national facility. We shall therefore distinguish between the budget devoted to the growth of the astrophysics community and the budget specific to the national facility.

Increasing the workforce from ~10 today to ~50 in ten years means ~300 man-years; most of these will be paid on salaries from research institutions and universities. Moreover, only a small fraction of this workforce will be specifically assigned to the national facility. In this sense, we can estimate to ~50 man-years what should be assigned to it over ten years. The running budget necessary for the training of scientists, engineers and technicians, salaries excluded, can be estimated as ~4000 USD per man-year, covering essentially participation in schools and conferences and acquisition of small tools and instruments. But of the ~1’200’000 USD that this means over ten years, no more than 200’000 USD should be assigned to the national facility. We shall therefore be conscious that we are talking about a budget of over a million USD or so over ten years to let the size and skills grow to a reasonable level. Arguments to do so are many and strong, starting with the urgency to develop in the country one of the most dynamic branches of modern research in physics, a domain in which Viet Nam is well behind the level that it deserves to have. The close connection between radio astronomy and several branches of frontline technology, and the many examples of fruitful synergy with industry that other countries have experienced, are very convincing arguments to convince the Government that investing in this direction is a good deal for the country.

The SRT programme implying the participation of several universities across the country should not require more than ~ 60’000 USD over the first three years, most of it spent in acquiring the instruments. Indeed, each university should assign a radio engineer (rather than an astronomy teacher) as responsible for the maintenance and operation of the SRT, who must be paid by the university as being part of its training programme. Buying SRTs for universities is a gift and a service that are made to them to help them fulfilling better their training duties: the running costs implied should not be charged to the central budget. Similarly, small costs necessary for the coordination, with typically one annual meeting and a few specific events, should be part of the normal running budget of the institutions and universities involved in the project.

The main cost will therefore be for the acquisition of the telescope, which is at the scale of 10 million USDs. In addition one needs to equip laboratories involved in radio detection and support their developments, which we estimate at the level of 200’000 USD over ten years and participation to international facilities, also estimated at the level of 200’000 USD over ten years. Together with the 200’000 USD necessary for the human resources, this adds up to a total of ~600’000 USD over ten years in addition to the cost of the telescope itself and in parallel with an investment of over one million USD devoted to the growth of the field in the country.

Finally, while beyond the scope of the present report, the resources required for the operation of the telescope once it is in operation, will be at the scale of some five staff members and a few 100’000 USD per year.

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# APPENDIX

## A1. SMALL RADIO TELESCOPES

As a training tool at undergraduate and graduate level, a small radio telescope had been developed by Haystack Observatory and made commercially available by Cassi Corp. DAP/VNSC owns one of these that is now installed on top of the USTH building. As it is a potential instrument for introducing Vietnamese universities to radio astronomy, and as it has recently been the object of several developments, we briefly review the current situation.

### *A1.1 The original SRT*

Developed to serve as an educational tool for universities and colleges for teaching astronomy and radio technology, the original SRT was popular, with several hundred being built, and is still in use at many colleges and universities. It was available for slightly less than 10'000 USD but no longer is: advances in electronics have rendered the original design obsolete. The telescope is equipped with a mobile parabolic dish, 2.6 m in diameter, remotely adjustable in elevation and azimuth. The reflected power is collected at the focus, where it is locally pre-amplified, shifted to lower frequency using standard super-heterodyne, amplified and digitized. Standard data collection consists in a sequence of successive measurements of ~8 s duration each, digitized in the form of a frequency histogram covering ~1.2 MHz in 156 bins of ~7.8 kHz each. Other characteristics are: pointing accuracy of ($0.11^o \times 0.22^o$); beam width ($\sigma$) of $2.3^o$; frequency resolution of 7.8 kHz; non linearity of ~5 ppm/K of antenna temperature; antenna efficiency factor of ~65% and conversion factor of 1.25 K/kJy fluctuating with an rms deviation of 0.09 K/kJy (7%) with respect to the mean; limit sensitivity of ~300 Jy limited by human interferences rather than by noise.

### *A1.2 The new SRT*

Development of a new SRT was undertaken by Haystack in Summer 2012. The primary philosophy of the new design was that the users should build the telescope themselves from commercially available equipment, based on plans, instructions, and software provided by Haystack. It is designed to be assembled easily with minimal need for special tools or skills. This approach provides an educational opportunity to the users who build the telescope. Also, users of the SRT become more familiar with how it works if they assemble it themselves, allowing better in-house technical assistance.

Recently a low cost USB dongle for digital TV has become available. Linux-based software was developed to adapt the device to form a low cost digital spectrometer for the SRT by integrating open source code into the existing C code written for the SRT. Several tests/corrections have been made to make sure that the USB TV dongle would be suitable as a replacement for the previous SRT system. The test of frequency drifting shows that the device is relatively stable at room temperature once it has reached its operating temperature, which requires roughly ~10 minutes. The overall cost of the new dongle based SRT system is found to be ~700 USD, not including the antenna, antenna motor, antenna motor controller and the antenna pier. The same system, using the previous SRT design was costing ~4'000 USD, meaning that the new total cost does not exceed 7'000 USD.

Users of the new SRT have access to abundant documentation and communicate between each other via its web site.

### *A1.3 The VSRT*

As part of a National Science Foundation (NSF) funded initiative to bring concepts of radio interferometry into the undergraduate classroom, Haystack Observatory has developed an interferometer using two SRTs. An interferometer receiver that contains a GPS timing capability has been built and installed on a three element interferometer system. The development and testing of the other components that are needed to provide a complete 2-element interferometer, such as software and data processing capabilities have been done. Given the complexity of the receiver and the high cost of the components, no effort was made to make it commercially available. Instead, a low-cost system, the Very Small Radio Telescope (VSRT), which can be used to demonstrate interferometry concepts, has been developed. It uses 0.45 m diameter dishes with 12 GHz satellite TV electronics and other inexpensive consumer parts that can be purchased from retail outlets or over the web. The system can be used in the classroom to demonstrate the basics of interferometry and physical principles related to the propagation and polarization of the electromagnetic radiation. In the original design, the analog to digital (A/D) conversion, the Fast Fourier Transform (FFT) and spectrum accumulation were made in the receiver itself on dedicated microchips. Due to the speed at which the receiver could run the FFT, only a portion of the data could be used for the spectrum, reducing the effective integration time and therefore raising the noise level. With the new SRT, the FFT and spectrum accumulation all take place in the SRT software. This allows continuous, high resolution collection of data.

## REFERENCES

To be written